Astronomy: TV Cameras Are Replacing Photographic Plates

Sophisticated television systems are being used at some of the world's largest telescopes to record the details of planetary atmospheres, faint galaxies, and quasi-stellar objects. Extremely faint objects can be recorded with these systems, even objects fainter than the background of light reflected from the atmosphere at night. The present systems are the culmination of more than a decade of research in many laboratories for many purposes. Although none of the sensors were originally developed for astronomy, the new technology represents—says one eminent astronomer at least half-seriously—"the greatest advance since the invention of the telescope."

For almost 100 years photographic plates have been the standard means for recording images at the focal point of a telescope. Plates are simple to use, but they have several limitations. For recording very faint objects, plates have the disadvantage of a very small quantum efficiency; quantum efficiency is the probability that one photon will liberate an electron, and thus be detected. Another disadvantage of photographic plates is that light and dark objects cannot be photographed on the same plate if the intensity of the bright object is more than 20 or 30 times that of the dark one. Photographic plates do not respond in a linear fashion to the amount of incident light, and it is difficult to calibrate exposures in absolute terms. Measurements with plates are not directly available in a numerical form; an intermediate step is necessary to convert the intensity pattern on the plate into numerical data.

Several instruments are now being used to convert optical images directly into electrical signals that can be recorded in a numerical format compatible with a computer, thus eliminating the intermediate step. No single electronic device is yet suitable for all observations, and it is likely that instrumentation will continue to change as technology improves and as astronomers change their interests. However, the routine use of television camera systems among the community of astronomers is growing, as measured by the amount of time allotted at major telescopes.

Two types of devices predate the television camera systems. One type (the image intensifier tube) that has been used since the mid 1950's simply brightens an image. The image intensifiers used in astronomy (such as the Carnegie image tube) are direct offshoots of night vision devices developed by the military. Another, older type of device (the photomultiplier tube) produces an electrical signal that is a measure of light intensity. A photomultiplier tube registers light from a single, undifferentiated element but cannot map an entire image.

The television camera system with which astronomers have had the most experience was designed by Joseph Wampler and Lloyd Robinson of the Lick Observatory, University of California, Santa Cruz. This device (called an image dissector) has been installed on the 120-inch telescope at the output of a small spectrograph that is located behind the primary mirror (Fig. 1). Spectra of objects as faint as 22nd magnitude have been measured with this device at moderately high resolution (about 10 Å). Even faint objects, for example those emitting light equivalent to 1/10 the light of the night sky as seen through the telescope, can be recorded by the technique of subtracting spectra obtained from two entrance apertures, one viewing the star plus the sky and a second viewing the sky alone. The system has been used 4 or 5 nights per month during the past year; when it is made available for routine use in the next few months, as many as 10 to 15 nights per month will be reserved for studies with the system.

The television camera device at the Lick Observatories functions like a single photomultiplier tube with directional capabilities. By a changing magnetic field, an image can be scanned in successive elements. Three consecutive image intensifiers are used to brighten the original image before conversion to an electrical signal. Data is stored in the memory of a small computer.

The system at Lick has been used for a variety of studies. One example that is relevant to the current question of the interpretation of red shifts as evidence for the distance of quasi-stellar objects is the measurement of the spectra of two faint galaxies (about 20th magnitude) apparently associated with the quasi-stellar object (QSO), PKS 2251+11. The measurement of Robinson and Wampler (*1*) indicated that the red shifts of all three objects are the same within an uncertainty of about 1 part in 1000, confirming an earlier suggestion of James Gunn of the California Institute of Technology that the QSO may be related to nearby galaxies. One of these two galaxies was described by Gunn as prohibitively faint for study when conventional equipment is used. Other studies with the system at Lick have investigated the strong emission lines of compact galaxies, spectra of M type stars, and the metal content of *RR Lyrae* stars.

Although the device at the Lick Observatories appears to be quite popular among University of California astronomers, many scientists think that, eventually, specialized television cameras (often called vidicons) will prove to be even more suitable for the requirements of astronomy. The principal difference between the image dissector and vidicons is that the vidicons have what is effectively a memory. Images can be built up on the target during an exposure as long as 6 hours. The long storage capability is important because it allows as many as 10^6 elements to be scanned (the Lick device is limited to 10^3 or 10^4 elements).

Vidicons work by converting a visible image into an induced charge pattern on the target. By the process of replenishing the charge deficiencies in the target with electrons from a beam that scans the target, the light pattern is converted into a time-sequence of electrical pulses. Vidicons for astronomy are designed for much slower scan rates than those for commercial television (1/30 second), and are designed with target materials that are different from those of the standard vidicon (antimony trisufide) in order to achieve better sensitivity to all wavelengths of light, especially the infrared and ultraviolet.

Several vidicons are now operative and many more are being prepared for use in astronomy. John Lowrance and associates at Princeton University, Princeton, New Jersey, have used one particular type of vidicon [called a secondary electron conductivity (SEC) vidicon] to obtain a very high resolution spectrum (0.75 Å) from a relatively faint object, PHL 957, that appears to be one of the most distant quasi-stellar objects (*2*). The Princeton device, which has been used in conjunction with a spectrograph at the 200-inch telescope of the Hale Observatories, records the image at the focal plane of the spectograph on a grid of 1000 by 1000 elements. Even though the light intensity was very low (the object is so faint—magnitude 16½—that each picture element receives one photoelectron only about every 2 minutes), a spectrum of the absorption lines of the QSO was obtained with sufficient detail that the shapes of the individual lines can be analyzed to learn something about the velocity distributions of absorbing clouds between the QSO and the earth.

The SEC vidicon, developed by Westinghouse Laboratories in Elmyra, New York, is primarily distinguished from others by a potassium chloride target suggested in 1955 by Ernest Sternglass and associates at Westinghouse. In 1960-61, the National Aeronautics and Space Administration started development of the second orbiting astronomical observatory, which carried three early verisons of the present SEC vidicon. Shortly after that (about 1963) Westinghouse began receiving orders for tubes that were eventually used in Apollo flights (including the tube that burned out when pointed at the sun during the Apollo 12 mission). During the late 1960's the Air Force funded major improvements of the tube, developing it, as one scientist said, "from an Apollo gadget into a very sensitive device for nighttime navigation by starlight." Lowrance and his associates took the basic tube developed for the Air Force and made changes designed to reduce leakage current and to enable integration for a very long time.

A type of vidicon that is quite different from the SEC tube is a result of the commitment by the American Telephone & Telegraph Co. to build picture phones. Because most types of vidicons known in 1965 suffered severe burning when exposed to very bright light, and because the technology of fabricating silicon devices was very advanced, Eugene Gordon and Merton Crowell of the Bell Telephone Laboratories in Murray Hill, New Jersey,

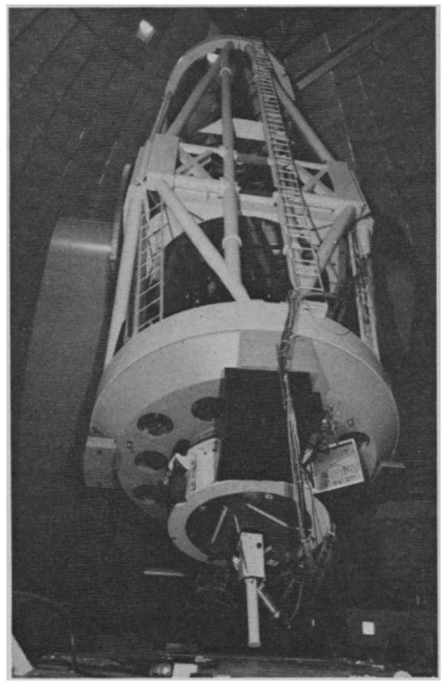

Fig. 1. The 120-inch telescope at the Lick Observatories. The white tube at the base of the telescope is a spectrograph. The shiny cylinder to the right of the spectrograph houses a television camera tube.

developed a vidicon target that was a small semiconductor chip consisting of approximately a million closely packed silicon diodes. This device, called the silicon vidicon, has proved to be durable enough to withstand bright light and sensitive enough to operate in very little light.

The silicon vidicon is particularly well suited for the study of planetary atmospheres, where many gases absorb light at infrared wavelengths, because it will detect light with wavelengths as long as 1.2 micrometers with a relatively large quantum efficiency (6 percent) compared to the quantum efficiency of a photographic plate (less than 1/10 percent). James Westphal of the California Institute of Technology, Pasadena, and Thomas McCord of the Massachusetts Institute of Technology, Cambridge, have used a portable system with a silicon vidicon tube at the primary focus of the 60-inch telescope at the Cerro Tololo Interamerican Observatory in Chile to measure the reflected light (albedo) of Mars and Jupiter in many narrow ranges of wavelengths with high spatial resolution (½ arc-second). Gerard Kuiper and associates at the University of Arizona, Tucson, have used a similar silicon vidicon system to measure albedos and spectra from Titan, one of the moons of Saturn.

The silicon vidicon has an extremely linear response to the number of photons absorbed, and the ratio of brightness that can be measured in one exposure (dynamic range) is approximately 1000 to 1, compared to approximately 25 to 1 for plates. Because of the commercial demand for TV cameras that produce a high quality picture with very little light (to survey parking garages, for instance) the silicon vidicon is available at a reasonably low cost in a complete system suitable for astronomy (*3*).

In addition to the primary use for sensing stars, QSO's, and planets, vidicon systems have been used to enable astronomers to steer large telescopes more efficiently. It is now possible to steer telescopes by stars fainter than those that can be seen by eye, with the result of a great saving, in many cases, of observing time that would be lost sighting and checking the telescope position. Furthermore, the astronomer can oversee all the details of the observation in a warm, lighted room, rather than—the traditional astronomer's lot—spending the night in a small cage suspended at the end of the telescope and exposed to the cold air on a mountaintop.

Astronomers have been criticized for being less receptive to new technologies than are other physical scientists. At a time when automation of many stages of data-taking is standard procedure for many research projects, automation of large telescopes is just becoming fashionable. On-line recording of data with minicomputers is also relatively new. According to Wampler, astronomers are learning the same lessons that particle physicists learned earlier: that efficiency is increased very significantly when immediate data-reduction and display are available. On the other hand, photographic plates will probably continue to be used when astronomers want a quick permanent record, or when they want to survey very large regions of the sky.

Not only have television camera systems made it easier to observe faint objects, but they have enabled astronomers to be more efficient (and more comfortable) while doing so.

—William D. Metz

References

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