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Telescopes and Automation

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The progress of astronomical research is at present limited by the small number of large optical telescopes (*1*). Astronomers are well aware of this situation and have naturally explored methods by which the productivity of smaller telescopes, as well as the existing larger ones, may be increased. Two principal approaches (*2*) to this problem are the introduction of auxiliary instruments (cameras, spectrographs, and others) that incorporate detectors of higher quantum efficiency than those used in conventional equipment (*3*), and the automation of telescopes and associated apparatus. These two approaches were encouraged by the Whitford Committee, which recommended that funds amounting to roughly $10 million be allocated (over a 10-year period) to research and development in the automation of telescopes, plate measuring machines, and other tools of the astronomer and also proposed that an equal amount be spent on instrumental development (*4*). This article reviews present and future programs for the development of automatic telescopes.

The automation of astronomical telescopes makes it possible (depending on the specific application or observational program) to realize faster and more efficient use of the equipment, to collect data in a more systematic fashion, and to analyze the data as they are obtained, thereby providing rapid feed-back to facilitate optimum programming of the observations. Considerable efforts along these lines have already been made by space and radio astronomers and by specialists in missile tracking. Here we are concerned with optical telescopes for ground-based astronomy, an area in which the automation efforts are only just beginning. The gains that can be achieved in practice, over manual techniques, are still uncertain, since the work is in its infancy, but there are advantages in kind as well as in quantity. Some of the applications of automatic techniques, such as the discovery of supernovae before they attain maximum light, are hardly worth attempting by ordinary means. We first report on the 50-inch (127-cm) remotely controlled telescope (RCT) (Fig. 1) at Kitt Peak National Observatory, which is one of the more elaborate existing systems; then other present and future projects are described.

Automatic Telescope for Photoelectric Astronomy

The remotely controlled telescope was originally conceived as an engineering experiment, inspired by the long-range scientific objectives of the national space program. The purpose was to gain experience in the techniques involved in remote operation of a modern astronomical telescope and the associated observatory instrumentation. The relevance to future orbiting or lunar-based telescopes is clear. As important as the remote operation feature, however, is the fact that control is vested in a digital computer. In fact, a major objective of our work has been the development of the RCT as an automated telescope for ground-based astronomical research.

The RCT is situated atop Kitt Peak, near the small town of Sells, on the Papago Indian Reservation of southern Arizona. The control center from which it is operated is located in Tucson, approximately 90 kilometers distant by road. Communication between the mountain facility and the computer is carried out over a phase-controlled telephone line. Each second, a 512-bit command frame is transmitted to the mountain; simultaneously, 1024 bits of sensor data, some of them redundant, are sent to the computer. In normal operation, no one is present in the telescope dome. In Tucson, however, a student assistant feeds in an observing program at the beginning of each night, and then checks the computer about once per hour, taking corrective measures in case a "hang-up" occurs. At present, the observations consist of photoelectric measurements of the brightnesses of stars in three wavelength regions (UBV system). More complex instrumentation, now being constructed, will enable us to scan ten regions of the stellar spectrum simultaneously and to obtain useful data despite the presence of thin or scattered clouds.

In practice, an observation is taken as follows. The computer is supplied with a stellar position (right ascension and declination) by the observing program. It consults a sidereal clock and determines if the star is actually suitably placed for observation. It also checks the output of an "automatic weather station" (Fig. 2) that senses precipitation, humidity, wind speed, and sunlight. (Eventually, a cloud detector will be added. However when clouds are present, their effects are apparent in the observations, and the bad data are discarded.) If the star is suitably placed and the weather is acceptable, and if a check on the position of the telescope service platform indicates that the latter is safely parked (and if certain other safety monitors supply the proper signals), then the observation process begins. The telescope shafts are driven until absolute encoders mounted thereon read out the desired hour angle

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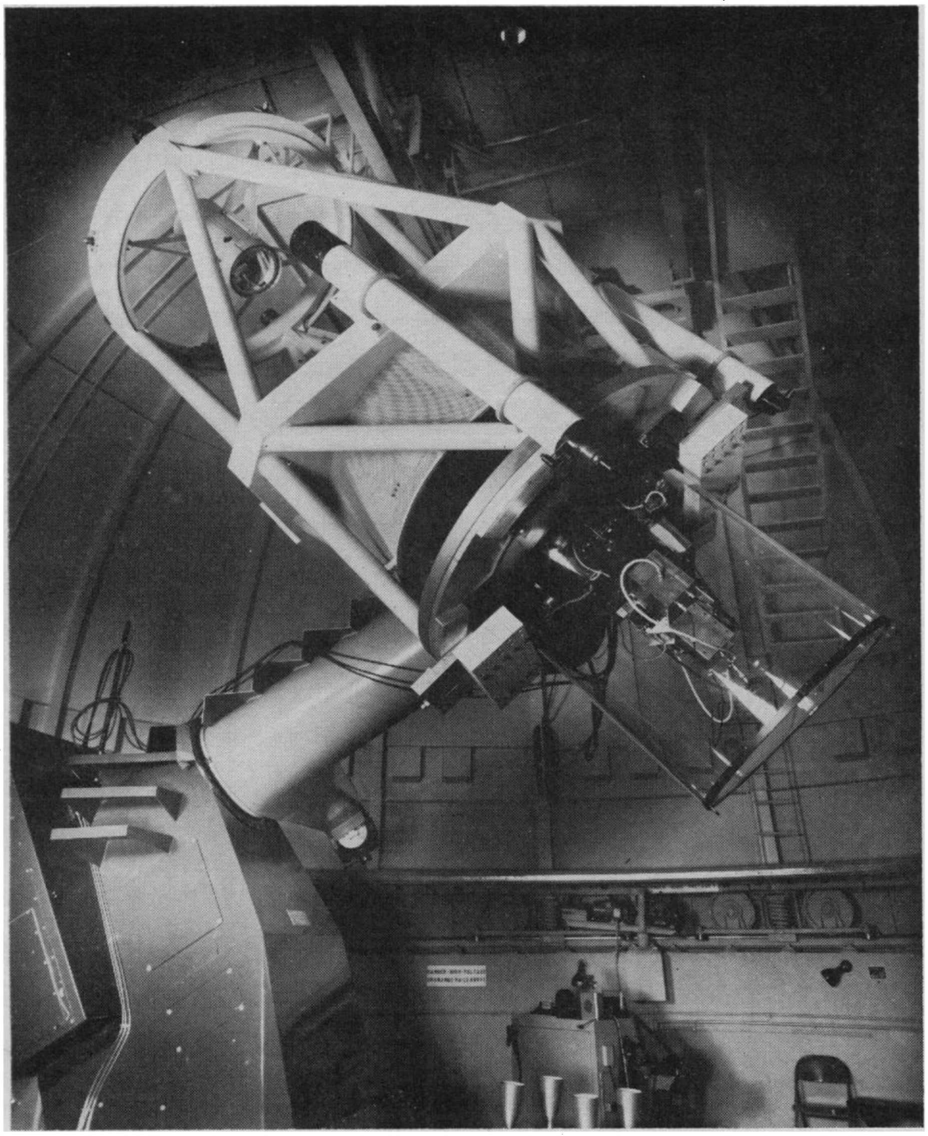


Fig. 1 (left top). The 50-inch (127-cm) remotely controlled telescope at Kitt Peak National Observatory.

and declination; as this position is approached, the motions are slowed, in order to reduce overshoot or oscillations. Meanwhile, the dome has rotated to the appropriate azimuth, and its shutter and windscreen have risen to suitable heights, under computer control. "Rough pointing" has now been accomplished, and the optical axis of the telescope is within one arc minute of the indicated position. A photoelectric star finder instrument (Fig. 3) is next used to perform the fine pointing, which can be done with an accuracy of better than one arc second. The fine pointing having been accomplished, the starlight is beam split, filtered, and measured (Fig. 4). On the average, the entire process described has taken roughly one minute of time.

Future RCT Programs

Astronomical programs underway or planned for the RCT include studies of small amplitude, short period variable stars, patrol observations of 3C 273 (the brightest quasar), and a detailed photoelectric survey of the Andromeda galaxy. The last project, in which J. C. Brandt, K. I. Moyd, and the author are collaborating, is a particularly good example of the type of investigation that is becoming feasible with automatic telescopes. It is intended to measure the energy received through a diaphragm of known size at each of some 8×10^3 positions in the galaxy. Among the many problems involved is the necessity of locating each position accurately and reproducibly, and of correcting the data for the presence of foreground stars.

Specialized Telescopes

The problems encountered in developing an automatic telescope are reduced if the design is optimized for a particular sort of observational program. Although a number of such

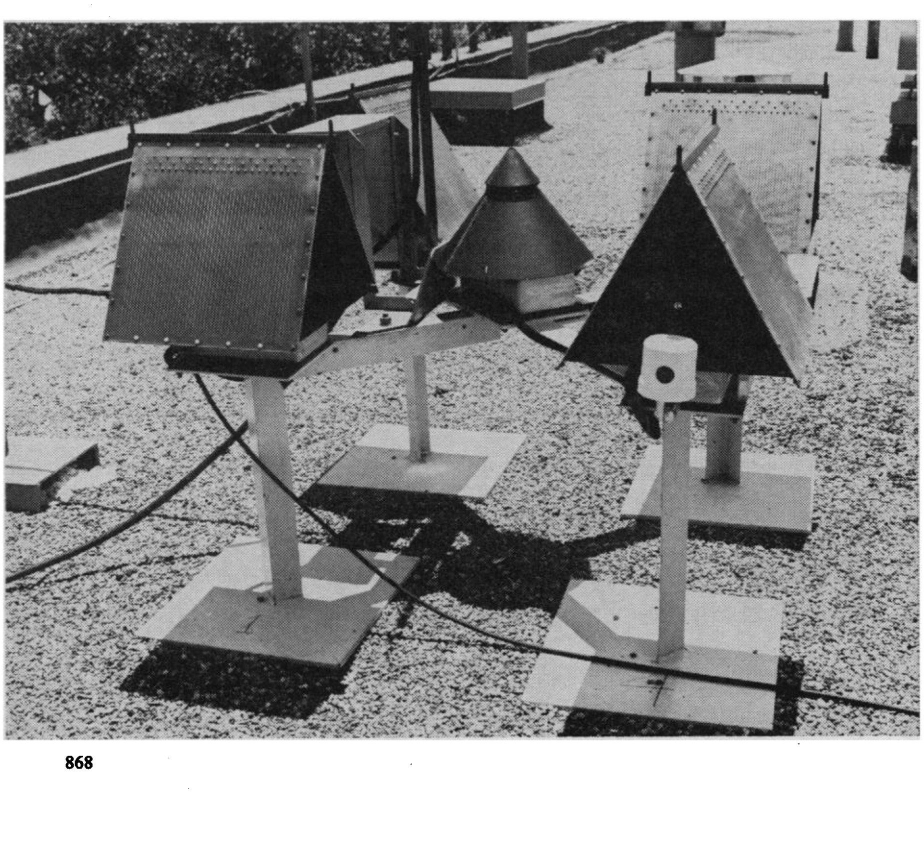


Fig. 2 (left bottom). Automatic weather station on Kitt Peak includes detectors sensitive to rain (large, wedge-shaped objects), humidity (central cone), daylight (white cylinder at right), and wind speed (not shown).

specialized projects are under way, they all involve fairly small telescopes, since the great investment in a major instrument requires that it must be suitable for use in a wide variety of research.

At the Royal Observatory, Edinburgh, a pair of remotely operated telescopes (*5*) has been developed for use in a particular observational program that arises naturally from the regular work of the observatory. An existing Schmidt camera is used there to photograph 4° × 4° regions of the sky; thousands of stellar images appear on a typical plate. The purpose of the new twin 16-inch (41-cm) telescopes is to calibrate such plates by obtaining accurate photoelectric magnitudes for about 100 selected stars in each region. The two telescopes are mounted together; one is used to acquire and track a star that is used as a reference source for both position and sky transparency. The second telescope is offset to each of the 100 program stars, and used to measure their brightnesses. The project is being approached in two stages: at present the instruments are operated by an astronomer in an adjoining room; his task will be eliminated by the installation of an Elliot 4100 computer.

Another program in which the tasks of a remote observer will be reduced in stages and finally eliminated by complete automation is that of J. A. Hynek and J. Dunlap. At the Corralitos, New Mexico field station of Northwestern University, they have begun work on a system intended to monitor external galaxies with the aim of detecting supernovae in "real time." (Most supernovae are now found on photographic records, sometimes long after the event has occurred.) The objective is to alert astronomers as rapidly as possible when an event occurs, so that photoelectric and spectroscopic data can be obtained during the early stages of the supernova outburst. Initially, a galaxy image obtained with a 12-inch (30-cm) telescope and image orthicon camera will be displayed on the observer's TV monitor, next to a projected "control" image of the galaxy, obtained at a previous time.

Another approach to the supernova detection problem has been adopted by S. A. Colgate's group at the New

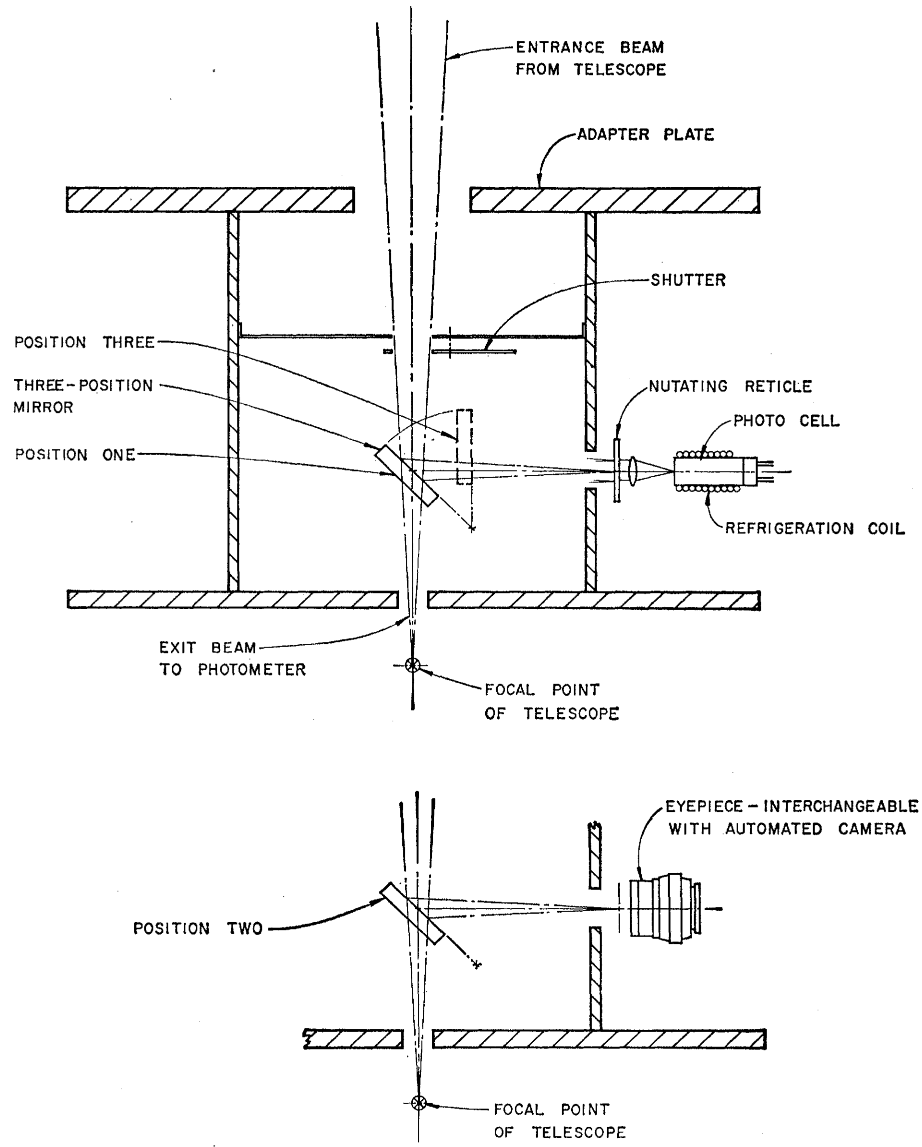


Fig. 3. Optical plan for a photoelectric star finder, designed by F. E. Stuart. Starlight is modulated by the nutating reticle; the resultant photo-cell signal is decoded by a computer, which supplies appropriate error signals to the telescope drive system.

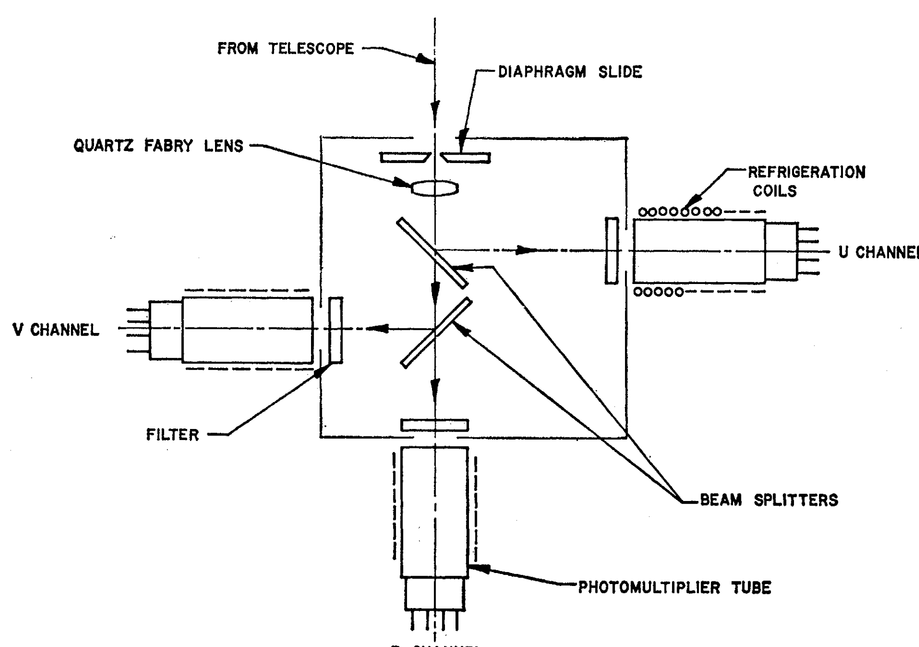


Fig. 4 (right). Optical plan of a three-channel photometer used to simultaneously measure the fluxes received from a star in three spectral regions. The beam splitters are dichroic mirrors.

Mexico Institute of Mining and Technology. Their automatic mountain observatory will be linked by microwave to the Institute's IBM 360/44 computer. The galaxy image, after electronic intensification, will be focused on an image orthicon tube. The digitized orthicon output is then compared with a control image stored in the computer. A typical observation will require only a few seconds. The purpose is to detect supernovae several hours *before* they reach maximum light, in order to test theoretical models for the initial development of a supernova explosion.

A major application for small automatic telescopes is illustrated by the operational 8-inch (20-cm) system at the University of Wisconsin (*6*). This telescope, under control of a PDP-8 computer, monitors standard stars and obtains data on the transparency of the atmosphere as a function of wavelength, sky position, and time. The information is used in the reduction of measurements collected with a nearby 36-inch (91-cm) telescope, and thereby enables the observer at the larger instrument to spend more time on program stars.

A significant approach to the elimination of systematic effects in astronomical measurements is described by Klock (*7*) of the U.S. Naval Observatory. He is developing an automatic transit circle for use in fundamental measurements of stellar positions. The design criteria include the capability of pointing to any spot on the local meridian with a repeatability of 5×10^{-2} second of arc. Among the improvements in measurement technique to be afforded by this instrument is the elimination of thermal effects attributable to an astronomer's body heat.

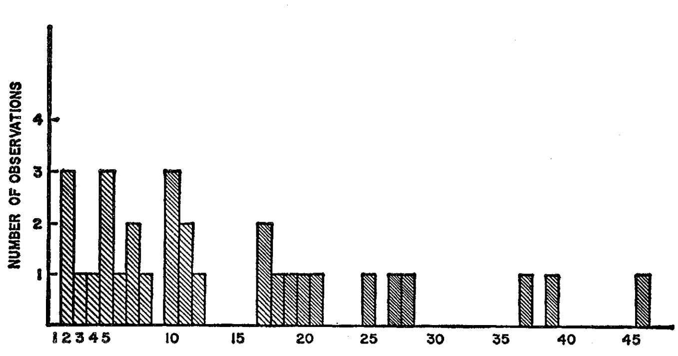
Automation and Solar Astronomy

Automation is likely to play a major role in the future development of solar astronomy. For some years now, small telescopes equipped with photoelectric sun trackers have been used to obtain photographic records of the changing appearance of the solar disk. At Kitt Peak, much of the instrumentation associated with the McMath Telescope (*8*) has been automated by the staff of the Observatory's Solar Division. The SDS 910 computer is used, for example, when observations of the solar magnetic field are made. Such a measurement is made at each of many thousand discrete locations on the solar disk, and the computer is invaluable as a data-collecting aid for this purpose. The ability to perform data processing during an observing run is especially valuable when one is trying to detect signals that are very weak with respect to the noise; the computer has accordingly played an important role in such programs as the search for faint molecular lines in planetary spectra (*9*) with the McMath telescope.

The study of chromospheric flares is a major field in contemporary astrophysics, and one in which a very great requirement exists for the introduction of automatic techniques (*10*). Of particular interest would be spectroscopic observations of major flares during the explosive phase, which takes place during the first few minutes of the event. It is then that flashes of x-ray emission occur and also certain microwave bursts that reveal the ejection of energetic particles. Unfortunately, however, the available spectroscopic material on the early development of flares is very poor. The reason is clear: in order to obtain a spectrum, the astronomer must adjust the telescope so that the position of the flare in the solar image falls on the entrance slit of the spectrograph. However, flares are rarely visible in the white light solar image available at the spectrograph head. Instead, a small telescope provided with a narrow pass-band filter centered on the Balmer-α of hydrogen is generally used to detect flares, and an observer estimates the locations of the flares and uses this information to set the main telescope. This process is obviously time-consuming, as can be seen from Fig. 5. The block diagram of an "Automatic Solar Observatory" that has been proposed to attack this problem is shown in Fig. 6. The left side of the figure concerns apparatus for the rapid location of a flare, which would then be analyzed spectroscopically by the apparatus represented on the right side. This hypothetical facility is discussed in greater detail elsewhere (*11*).

Summary

In stellar astronomy, the future of automation techniques lies in their application to the largest telescopes. In such a case, the cost of automation is small compared to that of the telescope project as a whole, and is well repaid in the savings in observing time. A "stand-alone" capability for manual operation in event of computer breakdown is usually provided for systems like this; an example is the 107-inch (272-cm) telescope under construction at the McDonald Observatory of the University of Texas, which will be as-



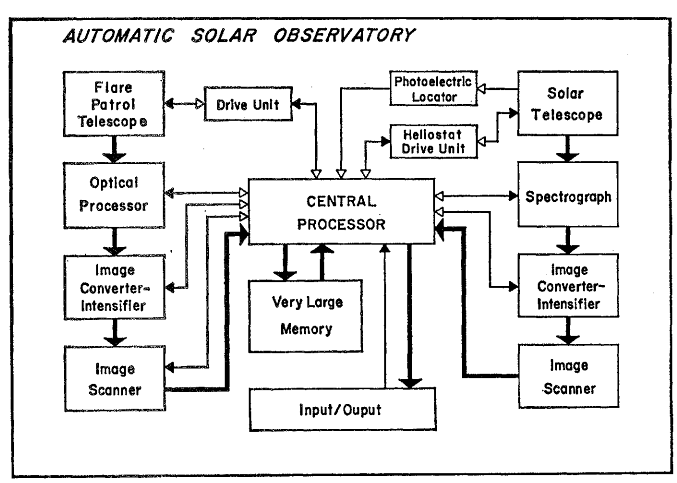


Fig. 5 (above). Histogram showing the number of solar flare spectra that have been published, as a function of the time elapsed between flare onset (observed at the earth) and start of the spectroscopic exposure. Omitted are observations with time differences greater than 50 minutes, or for which insufficient data on exposure times were reported. Fig. 6 (right). Block diagram of a proposed Automatic Solar Observatory. Heavy lines indicate the transmission of astronomical data. Thin lines represent the flow of commands (directions shown by solid arrowheads) and monitor signals (directions shown by open arrowheads).

sociated with an IBM 1800 computer.

There are a number of other automatic telescopes under construction, including at least three in the Soviet Union, and also an elaborate installation on Mount Haleakala, Maui, which will be partially devoted to infrared astronomy. However, the purpose of the present paper is not to catalogue every scheme that has been advanced to automate the optical observatory. Rather, an attempt has been made to illustrate the methods adopted by several groups in their efforts to solve specific astrophysical problems and increase the productivity of optical telescopes through automation.

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12. I thank many of my colleagues, especially F. E. Stuart and P. R. Vokac at Kitt Peak, for numerous illuminating discussions on automation techniques in astronomy. This paper is Kitt Peak National Observatory contribution No. 267.

Pesticide Pollution Control

Suggestions are made for improving the quality of water subject to pollution by pesticides.

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The Water Quality Act of 1965 amended the Federal Water Pollution Control Act to provide, among other things, for the establishment of water quality standards for interstate waters. The purpose of the act is to enhance the quality and value of our water resources and to establish a national policy for the prevention, control, and abatement of water pollution. Various pesticides now are recognized to be water pollutants and, as such, they must eventually be considered in the establishment of water quality standards.

Pesticide Pollution History

Water pollution by pesticides began to occur about 22 years ago when the organic insecticides developed just before and during World War II reached the public market. There followed an almost explosive expansion of chemical pesticides; today there are more than 650 basic kinds, of which at least 200 are of first importance. The tonnage of pesticides sold in the United States increased by 84 percent in the decade 1955–1965. Production of basic pesticides in the United States in 1965 totaled 437,500 tons (396,900 metric tons) (*1*).

Fish kills associated with rainfall runoff following application of chlorinated hydrocarbon insecticides in agriculture were the first evidence that a new form of water pollution was occurring. Sporadic scattered kills were climaxed in 1950 by the almost simultaneous occurrence of kills in 15 streams tributary to the Tennessee River in Alabama (*2*). Subsequent investigation indicated that the kills were caused by insecticides washed from cotton fields following passage of a storm front with its attendant intense thunder showers.

The first recovery and identification of a water-polluting pesticide was made in 1953 by personnel at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio, who recovered DDT from the Detroit River and Lake St. Clair (*3*). The first quantitation was achieved in 1957, when DDT was detected in the Mississippi River at Quincy, Illinois, and at New Orleans, in the Missouri River at Kansas City, and in the Columbia River at Bonneville, Oregon, in concentrations ranging from 1 microgram to 20 micrograms per liter (*4*). The quantitation procedure involved passage of several thousand gallons of water through activated carbon, extraction of adsorbed residue, column cleanup, and analysis by infrared spectroscopy. The advent in 1959 of gas-liquid chromatography for pesticide identification (*5*), quickly followed by other developments in instrumental analysis, made possible the first detailed evaluation of water pollution, by pesticides, resulting from runoff (*6, 7*). These studies were undertaken in 1959 by the U.S. Public Health Service's Division of Water Supply and Pollution Control, Pesticide Pollution Studies Laboratory, in Atlanta, Georgia. (The work of this Division has since been taken over by the Federal Water Pollution Control Administration of the U.S. Department of the Interior.) This activity, considerably expanded, continues at the Administration's Southeast Water Laboratory at Athens, Georgia.

Present Status of Knowledge

The two principal sources of water pollution by pesticides today are runoff from the land and discharges of industrial waste, either from industries that manufacture or formulate pesticides or from those that use these compounds in their manufacturing processes. Less important causes of pollution are (i) activities designed to control undesirable aquatic life, (ii) careless use of pesticides, and (iii) occasional accidents in transportation. Instances of careless use have been decreasing as a result of intensive educational campaigns sponsored by agricultural, con-

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