of ancient communities whose existence had hardly been suspected in 1945. One can say almost the same thing for areas in Texas and California, except that in these localities there had probably been some knowledge of ancient communities prior to 1945. In the Southeast, additional crucial information has been added to that collected by TVA, by WPA, and by private institutions. Historic sites have been excavated and recorded, and new details added to our knowledge of the early fur-trading posts and army posts. On the whole, the record is a fine one, and much credit goes to the National Park Service, the Smithsonian Institution, and the numerous public and private cooperating agencies. The program is far from being at an end. In fact, it is expanding so rapidly that it is sometimes difficult to keep track of it. Water resources are still being developed, and there will be need for archeological salvage in reservoir areas for many years to come. We are faced with added problems due to the expansion of the population. The rebuilding of cities, the increase in the size of airports, the need for factories, real estate developments, and analogous operations threaten to destroy the evidence of the past upon which these works of the present are founded. It is not possible to relax, for there is an increasing amount of work to be done.

References and Notes

1. R. F. Lee, in "*Symposium on Salvage Archeology*, May 1955," J. Corbett, Ed. (U.S. Nat. Park Serv., Washington, D.C., 1961), mimeographed.
2. C. E. Guthe, *Science* **90**, 528 (1939).
3. F. Johnson, E. W. Haury, J. B. Griffin, *Amer. Antiquity* **11**, 142 (1945).
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The Training of an Astronomer

The dilemma of graduate schools in astronomy is best solved by establishing telescopes in good climates.

John B. Irwin

The topic "What's wrong with American astronomy and what to do about it" is one that has been helpful in years past to astronomers whiling away the long night hours in a cold dome, waiting for the clouds to go away. Such discussions are more than an idle parlor game, for out of them have been forged the knowledge, desires, and decisions that have led to larger telescopes, better instrumentation, new research ideas, and great discoveries. I suspect, however, that the average citizen in past years couldn't have cared less about this topic—this, despite the fact that news of new astronomical happenings arouses a public interest perhaps second only to that inspired by new medical discoveries.

But whatever else one may say now, this topic is no longer a matter of indifference to the federal government, with its deep concern for the future of all sciences. For example, the government space programs necessarily require hundreds of thousands of highly trained specialists of all kinds. Although Space is not completely synonymous with Astronomy, the link is a very close one, and a goodly number of these specialists are, will be, and should be Ph.D.-trained astronomers. If there are critical shortages of such specialists—and there are—three things will happen: (i) the already high costs of the space programs will go even higher; (ii) it will take longer to reach designated goals; and (iii) considerably less will be learned or discovered than would otherwise be the case. The stakes are very high indeed, and just as a matter of "insurance," therefore, it would seem desirable that an amount of money equal to only a few tenths of 1 percent of NASA's budget should be devoted to the training of new astronomers in all its many aspects.

Astronomers are greatly indebted to the Whitford report (*1*) for its repeated and carefully delineated emphasis of the value of ground-based observational astronomy, for its lengthy and thoughtful discussions concerning the shortage of astronomers and the severe lack of enough telescopes of all sizes in dark-sky locations, and especially for its pointing up of the incredible dilemma of the astronomy graduate school in 1964—and beyond. The report's total recommended 10-year budget is $224.1 million. In what follows I discuss a $3.2-million budgetary item which is connected with the training of graduate students in optical astronomy and suggest, for reasons given in part in the preceding paragraph, that the importance of this item is all out of proportion to the relative size of 3.2 to 224.1.

In 1957, the year of the first Sputnik, the top graduate schools in astronomy were, in order of numbers of graduate students, Harvard, Georgetown, California (Berkeley), California Institute of Technology, Michigan, Indiana, Colorado, Chicago, and Princeton, with Columbia, Ohio State, Stanford, and Yale (five students each) in a four-way tie for tenth place. These top 13 accounted for 150 of the 168 graduate-student total. The Whitford report's estimated top-ten ranking for 1966, in order of numbers expected, is: California (Berkeley), Harvard, Maryland, Colorado, Georgetown, Michigan, California (Los Angeles), Yale, Arizona, and California Institute of Technology (the last two being tied for ninth place). These ten would account for "only" 460 of an expected total of 793. In 1957 only six graduate schools had more than seven students; in 1966, 28 schools expect to have more than this number, and 12 of these expect to have at least 30 students or more—and this is only the

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beginning. Along with this increase in numbers there also has been an increase in quality because of selection effects. The expansion has been limited in most universities because of lack of facilities and of faculty and not because of lack of applicants.

The Whitford panel derives a 19-percent-a-year growth rate in Ph.D.'s in astronomy, starting with a Ph.D output of 30 in 1962. There may be reasons why this growth rate will taper off, but there are even stronger reasons for believing that it should increase a bit as the orbiting observatories go into action, as the ground-based facilities are multiplied, and as the wave of war babies reaches the graduate schools 3 years hence; in any event, we can confidently expect that, in just a few years, a dozen or more of our graduate astronomy schools will each have more than 100 students. A too conservative extrapolation predicts a doubling of astronomers in the next 10 years, but growth by a factor of only 2 will not match the growth in other sciences. It will mean "too little, too late" insofar as the astronomy-personnel needs of the universities, the government, and the space industries are concerned.

There are two problems involved here: (i) How can so few institutions, most of them with inadequate and obsolete instrumental equipment, give this necessarily expensive training to so many graduate students? (ii) Even more important, how can these would-be astronomers be given an excellent, modern, space-age type training? These two problems are interrelated in a manner that is not obvious at first glance. The *best* training can best be given with telescopes in good climates, and it is obviously difficult and most inefficient to train *large numbers* of students in observational astronomy with telescopes at cloudy sites.

The Whitford panel recognizes that graduate students must be trained with modern research instruments. They also recognize the contribution and advantages of Kitt Peak National Observatory in graduate student training, but point out some disadvantages, not the least of which is that Kitt Peak can satisfy only 25 percent of the total demand expected in the *near* future. Although Kitt Peak has other disadvantages, such as cloudy skies in July and August (just the wrong time for students) and a lack of close faculty supervision during the critical early stages of an observational thesis, nevertheless it might well have been appropriate for the panel to recommend strongly more telescopes at Kitt Peak for graduate training. But, more to the point, the time has long since come when other "Kitt Peaks" should be established. Cloud statistics indicate two maxima of clear daylight skies in the United States, one centered on Yuma, Arizona, where there are few high peaks, and the other centered on the Telescope Peak area of southeastern California. In both areas summer cloudiness is at a minimum. There are mountains appropriate for observatory sites a mere 100 miles (160 kilometers) east of both Palomar and Mount Wilson with substantially clearer skies in the winter and spring. These peaks need to be studied and exploited.

The other alternative to the Kitt Peak solution which the panel puts forward very strongly is a recommendation that eight, and possibly 12, *research* telescopes of 36- to 48-inch (90- to 120-centimeter) aperture, costing some $400,000 apiece, be "located at dark-sky sites near universities with active graduate departments. Climatic conditions need be given little weight." The panel stresses the advantages of such a "solution"; the many disadvantages are practically ignored. Before considering these disadvantages, let us consider a third solution of this very serious dilemma of the graduate schools, one not discussed by the Whitford panel but one that has a long history of outstanding success.

A moderate-size telescope (or two or more) is operated by a university at a good mountaintop site by a permanent staff of research astronomers. The graduate student finishes his required courses in 2 or 3 years at the university and then travels to the observatory for a year's research for his thesis. This briefly stated formula is a most successful one and has been followed by graduate students at the University of California and, with some modification, at California Institute of Technology. Graduate students from these two institutions alone have later been awarded eight of the 12 Helen B. Warner prizes given annually by the American Astronomical Society to the best young North American astronomer under 35. The other four awards have gone to graduates of Michigan, Massachusetts Institute of Technology, and two overseas universities.

Now, clearly, the above statistics are "thin," and one cannot use them to rate, for example, in order of quality such good graduate schools of astronomy as can be found at Case, Chicago, Harvard, Princeton, Yale, or even Michigan. Nevertheless, one finds these statistics suggestive, in somewhat the same way that a mathematician would find a value of 3.14159265, obtained for an unknown constant in his complex equations through much electronic calculation, suggestive. He hasn't proved that this constant is π, but there seems reason to think it is.

I now make a line-by-line comparison between the Whitford panel's preferred solution (in quotes, below) and the advantages of what I call the California solution.

"It is abundantly clear from results obtained, for example, at the Case Institute of Technology, the University of Wisconsin, and the University of Michigan that telescopes of 24- to 40-inch size can and have contributed enormously to the progress of observational astronomy. The research of both faculty and students at these institutions is of high caliber, and exemplifies what can be done under relatively poor sky conditions." I agree with the panel that the three best examples of observatories in cloudy sites are those they have named; they may, however, have stretched things a bit in using the word *enormously*. In a situation of this kind, where one would like to make a critical evaluation, it is necessary to make detailed comparisons. I leave it to the interested reader to make his own comparisons between the astronomy faculty and the Ph.D.'s produced at these three universities, on the one hand, and at California and California Institute of Technology on the other. The comparison can be made in a number of ways—on the basis of the number of significant research papers published by the faculty or by the graduate students, National Academy membership, number of Warner prize winners, later scientific accomplishments of graduates, and so on.

"The existence of modern telescopes at individual graduate schools has many advantages." Largish conventional reflectors at cloudy sites have a long history of relative nonproductivity, both in the United States and in Europe. Their average annual output of significant research is certainly not zero—only close to it. A realistic appraisal of their relative contributions to astrophysical progress, as compared, say, with contributions of the two Lick Observatory

36-inchers, is only somewhat better than John Nance Garner's pungent evaluation of his job as Vice President. A man who buys a Rolls Royce which has all but one or two of its spark plugs permanently missing should not be surprised if it performs wretchedly. I am referring here to conventional reflectors similar to those suggested by the panel, and not to special-purpose, wide-angle instruments which have given us such things as the Henry Draper Catalog, the Yale Zone Catalogs, the Shapley-Ames Catalog, and the Case infrared surveys.

"A healthy research atmosphere is almost automatically created among faculty and students alike." I have seen too many students and faculty members, frustrated too often by continuing cloudiness and wasted time, turn away to other problems and other fields. A mountaintop observatory in a good climate has a far stronger research atmosphere. Such an observatory, with its freedom from classroom lectures and textbooks and with its single-minded emphasis on the best possible research and associated problems of instrumentation and observation, is a real eye-opener to a graduate student. "Any problem requiring close surveillance . . . cannot be dealt with away from home because the need is for repeated observations at selected times." It is most difficult to make *repeate*d observations at *selecte*d times at a cloudy site —in fact, it is next to impossible. The California solution is markedly better in this regard because "home" is where the telescope is—at a good site.

"Most important is the fact that most university-connected astronomers are engaged in teaching and hence are on the campus for three quarters of the year." A college professor with a strictly limited time for research should do it under optimum conditions. "If maximum use is to be made of equipment, it must not be located hundreds of miles away, but must be easily accessible, not more than one hour's travel time away." If a professor or a graduate student travels half a day by jet to a distant mountaintop for 30 scheduled nights (or more) of observing, the telescope is markedly more accessible to him than if he is forced to make 30 2-hour round trips at all hours of the night; in addition, the single trip will be vastly more profitable scientifically.

The main disadvantage of the California solution is simply stated; although highly effective and efficient, it is expensive. Most universities, in the past, have not wanted to "go that deeply" into astronomy; now they cannot help themselves. Any department of astronomy which now has 20 to 25 graduate students or more can anticipate that, very soon, these numbers will be doubled and still heading upward, and that copious quantities of observing time *must* be made available to these students. This cannot be done in cloudy climates, nor can so many students be trained as guest investigators at some distant, unrelated institution. It seems to me that the California solution, whatever its difficulties—and there are many—is an approach that should be given thoughtful consideration. In the long run it will be cheaper, and—more to the point—the end product will be of substantially higher quality.

Any president of a college or dean of a great university in a poor climate who would like to build up a top-notch astronomy department—and what university can call itself great in this day and age unless it has one—and who is tempted to ask for one of these $400,000 gift telescopes to be set up *nearby* under the clouds should consider the following. He should realize that this "gift," which is costly to maintain and to operate, both in money and in astronomer-years, is at least three times as expensive to use per result obtained as a similar instrument at a site with three times the number of clear nights. It will not even perform as well on those infrequent occasions when the sky is clear, because the seeing is poorer, the skies are brighter and hazier, and, most of all, because there is substantially less incentive to develop continuously the auxiliary instrumentation so necessary for keeping pace with astronomical progress. He will find it increasingly difficult to hire the best astronomers, and he will have a continual evaporation of the best that he can hire. He should not be surprised if his Professor Cloudbound turns away, frustrated, from trying to be a Watcher of the Sky and becomes a Watcher of the Computer—a less profitable occupation. He must expect that his astronomers will soon ask him for another such costly telecope —and still another—because there are too many graduate students and too few clear nights. He should expect his smartest students to move elsewhere to sunnier climes, and the smarter they are the sooner they will move. He should expect to be surprised if any of those who do stick it out get the best research jobs later on.

To put it bluntly, the majority of today's graduate students in astronomy are getting shortchanged. Only a very small percentage of them can hope to get out in the front lines of observational research, using modern telescopes at good sites. Perhaps more to the point, NASA is getting shortchanged. The Space Administration has a continuous, urgent need for the best-trained observational astronomers—men who know what needs observing, who know what can be observed and when, and who are thoroughly familiar with just what instruments need to be used and developed. These are not easy things to learn, and, for the most part, they are not learned out of textbooks—nor at telescopes in cloudy locations.

What is needed is at least $10 million invested in modern, moderate-size telescopes to be put up at a few new, excellent sites; these telescopes to be the property of, and the sole responsibility of, those universities which wish to produce—by time-tested methods—large numbers of high-quality observational astronomers. The need is urgent, and the priority should be of the highest.

Reference and Note

1. *Ground-Based Astronomy, A Ten-Year Program* (National Academy of Sciences, Washington, D.C., 1964). Lengthy excerpts from this report were published in *Science* **146**, 1641 (1964)]; that condensation does not include, however, the sections dealing with the dilemma of the astronomy graduate school.