Optimum Location of a Photoelectric Observatory[1]

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ALTHOUGH IT HAS BEEN MORE THAN FIVE YEARS since Kron (*1*) at the Lick Observatory demonstrated the astronomical possibilities of the multiplier phototube, little attention has been paid to the unique observing needs for research with this instrument. It has been expedient to adapt existing telescopes and sites, far better suited to astrometry and spectroscopy, to photoelectric photometry. Recent results, however, have been so successful, and new techniques have developed so rapidly, that it is surely not unreasonable at this time to consider the establishment of an observatory with telescopic equipment designed, and at a site chosen expressly, for the peculiar needs of photoelectric astronomy.

The photoelectric cell had always been a precision device for those astronomical objects that were bright enough; the modern multiplier phototube extended the faint limit to such a point that measurements in two colors were possible—with fair precision—for stars that were just visible in the eyepiece of the telescope. The photoelectric results of the past five years have verged on the spectacular. One might mention the startling discovery of interstellar polarization (*2, 3*), the puzzling relationship between color and distance for extragalactic nebulae (*4*), and the extension of fundamental magnitude and color sequences to fainter than nineteenth photographic magnitude (*5*)—sequences that will help to form the fundamental basis for any new cosmology. Furthermore, Hiltner has just announced (*6*) an increase in accuracy of a factor of more than ten in the determination of the degree of polarization of the light of bright stars; his ingenious instrumentation undoubtedly has opened up a completely new field of photoelectric investigation.

It is not, however, the purpose of this paper to dwell either on past successes or to predict the probable course of photoelectric investigations and discoveries in the near future. Rather, it is to inquire into the observational needs of the photoelectric observer, in order that his investigations may be pursued with maximum efficiency both as to quality and quantity. The viewpoint here is somewhat different from that usually taken. In general, one does as best one can with the available telescopic equipment, even though the telescope in question may be partially unsuitable, too small, poorly driven, and located amid city lights and haze or in an unsuitable climate.

It is recognized that the observational needs differ in astrometry, spectroscopy, and photometry. The positional astronomer is primarily interested in good seeing; haze or very thin clouds, rather than being objectionable, may be indicative of a very steady atmosphere and, therefore, of a first-class night. City lights, in moderation, are only a secondary nuisance. The spectroscopist, on the other hand, can work to advantage on nights that would be hopeless from the point of view of the astrometrist; that is, on nights of poor seeing. The quality of a spectrogram, except in special cases such as Sirius B or Antares B, is affected only to a minor extent by poor seeing, occasional clouds, haze, or, in the case of moderate to high dispersion work, by moonlight. One who has watched the McDonald observers at work in a moonlit sky half full of cumulus clouds can only marvel at how their persistence pays off in useful results. And yet, despite these less rigid requirements, and with all due respect to much excellent spectroscopic work accomplished in the Middle West and East, there is no question but that the great bulk of our spectroscopic research has been—and is being—accomplished at the Texas and Pacific Coast observatories, where observing conditions are notably superior. Only one type of astronomical spectroscopy—namely, objective-prism spectroscopy—has been pursued with outstanding success in the otherwise unsuitable climates of the Harvard, Leander McCormick, and Warner and Swasey observatories. This is probably due to the fact that in this type of work little telescope time is required for rather extensive investigations.

The astronomical photometrist requires, above all else, a clear sky; this is especially true because his results may be discussed in terms of thousandths of a magnitude. One might ask: "How clear a sky?" The answer is: "Just as clear as possible—*the best is none too good.*" The photocell can "see" and respond to thin cirrus clouds long before they become apparent to the naked eye. Such clouds are worse than a nuisance; once they have intruded themselves into the observations their effects are subtly injurious to the scientific interpretation and are difficult to eradicate. At the Goethe Link Observatory we call such clouds "photoelectric poison." Another photoelectric requirement, one that is probably almost as important, is that the atmosphere be uniformly transparent

[1] Based on an address given before the Neighborhood Astronomers, Ohio University, Athens, October 13, 1951.

over the whole sky and over long periods of time. This is necessary especially in the case of the determination of fundamental colors and magnitudes, where zero points must be repeatedly transferred over large angular distances and where a knowledge of the extinction coefficient, and its possible variation, is of the utmost importance. Unlike spectroscopy, partial runs are not only frustrating to the observer, but are often practically useless in the case of variable stars. They may be even worse than useless with the probability of dubious observations at the beginning or end of such runs.

To fix ideas, let us consider possible photoelectric observations of an eclipsing star with a period of five days. Satisfactory observations of primary minimum can be made only at minima occurring, say, within three hours of meridian passage—that is, only one out of four such minima on the average. If the star is too faint at such times to "put up" with a moonlit sky, this reduces to one out of eight minima; if the climate is such that the odds are two to one against the observer having clear skies, then he may expect, on the average, a satisfactory run every one hundred and twenty days; that is, once in an observing season, or year! And yet, it is this type of observation, repeated year after year, that affords the only direct approach to the knowledge of the internal density distribution of stars—one of the most important problems in stellar structure.

It is becoming increasingly clear that a sustained attack on this problem must be made photoelectrically, rather than photographically. Variation of period as determined from primary minima alone is complicated by effects due to the possible presence of a third or fourth component, by little-understood irregular changes in period, and so on. The phenomenon one seeks to evaluate is the rotation of the line of apsides, which only betrays itself unmistakably by the changing position of shallow secondary minima with respect to primary minima. This may seem like a dull and long-winded program—yet such may not be the case. The greatest known variation of period of any eclipsing star is that of SV Centauri (*7, 8*); nonetheless this variation is completely unexplainable under any reasonable set of assumptions. Eggen's results for Algol (*9*), derived from the complicated variation of period combined with six-color photometry of this famous eclipsing star, are also rather strange and unsatisfactory. Perhaps we are faced with some completely new astrophysical phenomenon. In any event, little or nothing is known of possible rapid changes of period of eclipsing stars.

It might be supposed that good seeing would be of primary importance in the best photoelectric work; this is probably not so, except for those observations where the amount of night-sky light (admitted with the starlight through a small diaphragm) must be kept to a minimum. This would be the case for measurements made on the very faintest objects, moderately faint objects in a moonlit sky, visual binaries, and very rich star fields. My own experience in South Africa (*10*), where the seeing at times was extraordinarily poor, indicated rather strongly that excellent results could be obtained at such times by merely increasing the size of the diaphragm by a factor of two. This might not be the case for small-aperture telescopes, inasmuch as Stebbins (*11*) has shown that photoelectric seeing varies markedly with the size of the objective.

If one is willing to admit that seeing is of secondary importance, then the whole problem of seeking the ideal photoelectric site in this country becomes very much simpler: One needs, at first, only to look for moderately high mountains located in a region of minimum cloudiness. Such a region in this country is apparent at the first glance at the appropriate Department of Agriculture map (*12*). A modification of this map is given in Fig. 1. The region in question is centered almost exactly on Yuma, Arizona, and is roughly elliptical in shape, extending about 80 miles north-northwest of Yuma and about 40 miles to the east and to the west of that city. Within this region there are more than 300 clear days a year; outside this region and the surrounding area there is no spot in the country where there are as many as 240 clear days a year on the average (these data are based on 20-year statistics). Unfortunately, there are no peaks as high as 5000 feet in this area, the highest being Black Butte (alt, 4505 ft), 42 miles west of Blythe, California. Other mountains include Castle Dome Peak (alt, 3793 ft), 38 miles northeast of Yuma, and Sheep Mountain (alt, 3150 ft), 26 miles east-southeast of Yuma. There are other peaks within this region just over 3000 feet in altitude. In general, one would not like to locate a photoelectric station at an altitude much under 4500 feet, although Castle Dome Peak and Sheep Mountain might be seriously investigated in more detail. It is a question not so much of getting above as much of the earth's atmosphere as possible, inasmuch as every 1000 feet gained in elevation means a reduction of only 3 per cent in the value of the atmospheric extinction coefficient, but rather of getting above the haze and dust level that might be seriously high during the critical summer months.

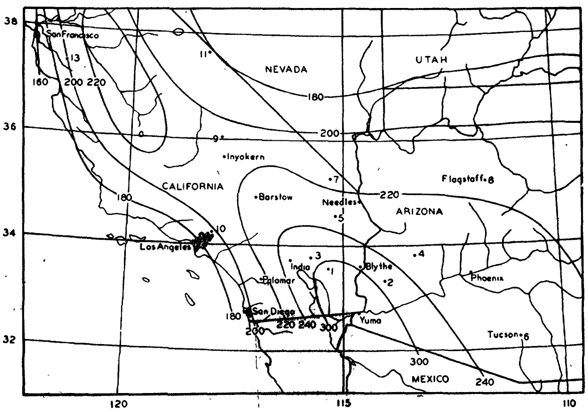

FIG. 1. Average number of clear days a year, adapted from USDA data. Numbered sites refer to stations listed in Table 1.

Two higher peaks are to be found just outside the optimum region. Signal Peak (alt, 4828 ft) is 55 miles northeast of Yuma; Eagle Mountain (alt, 5347 ft) is 25 miles east of Indio, California. Other desert peaks that might be considered include Harquahala Peak (alt, 5672 ft), 72 miles east-northeast of Blythe; Old Woman Mountain (alt, 5300 ft), 40 miles southwest of Needles, California; New York Peak (alt, 7445 ft), 50 miles northwest of Needles; Cactus Peak (alt, 5415 ft), 25 miles north of Inyokern, California; and White Mountain Peak (alt, 14,256 ft), 10 miles west of the California-Nevada border and about 10 miles south of the latitude of San Francisco. Clear day (per year) data and percentage sunshine data (for each season and measured in terms of the ratio of total sunshine to total possible sunshine) for these peaks and for certain other observatory locations have been interpolated from the appropriate Department of Agriculture maps (*12, 13*) and are given in Table 1. One can think of reasons why these data may be systematically wrong by small amounts, especially for the tops of mountain peaks, inasmuch as they have been "smoothed," and local irregularities have probably been ignored; furthermore, the original observations, for the most part, were taken at lower altitudes.

TABLE 1*

Station	Av no. clear days	Percentage sunshine of possible total					Estimated photoelectric nights (%)
		Winter	Spring	Summer	Fall	Av	
Black Butte	310	82	92	95	90	89.8	79
Signal Peak	280	83	91	94	96	91.0	75
Eagle Mountain	285	80	90	92	90	88.0	73
Harquahala Peak	235	79	87	91	91	87.0	63
Old Woman Mountain	230	80	86	93	91	87.5	63
Tucson, Ariz.	230	78	88	88	91	86.2	61
New York Peak	215	74	81	90	84	82.2	55
Flagstaff, Ariz.	215	73	77	86	84	80.0	52
Cactus Peak	205	68	79	93	84	81.0	52
Mount Wilson	195	65	70	79	80	73.5	42
White Mountain Peak	180	60	76	87	78	75.2	41
McDonald Observatory	175	61	70	76	78	71.2	36
Lick Observatory	200	46	70	74	70	65.0	34
Goethe Link Observatory	120	42	58	70	61	57.8	12
Boston, Mass.	120	48	62	62	52	56.0	10

* Stations should be numbered in sequence from 1 to 15 to correspond with numbers in Fig. 1.

The *relative* cloudiness of the different sites should be approximately correct. In terms of "photoelectric" nights—entire nights without a trace of a cloud—the numbers and percentages are both almost certainly too optimistic—by different amounts. Somewhat arbitrary corrections must, therefore, be applied to the data. A mean for each station was computed as follows: the number of nonclear days for each station was multiplied by a factor of 1.3, and the product subtracted from 365. This result, when divided by 365 and expressed as percentage, was given equal weight with the result obtained by multiplying the nonsunshine percentage by a factor of 2.1 and subtracting the product from 100 per cent. These mean percentages are given in the last column of Table 1 and are the estimated percentages of "photoelectric" nights that might be expected at each station. They were computed in such a way as to agree with various independent estimates of photoelectric conditions at the McDonald and Goethe Link observatories. The main result of this analysis is to show that the desert peaks in southeastern California and southwestern Arizona near Yuma *are probably almost a factor of two better for photoelectric research* than other large existing American observatory sites. This is in terms of quantity; in terms of percentage of satisfactorily completed programs—especially observational programs by guest investigators—the factor would almost certainly be somewhat larger.

This analysis, of necessity, omits such important items as "smog" and city lights, currently available instruments, photoelectric "know-how," and past achievements in this field. More detailed investigations as to haze conditions might possibly change the above conclusion. My own experience at Cactus Peak during the summers of 1948 and 1949 indicated that the haze was negligible and that the atmospheric transparency could only be described as superb. Other preliminary investigations might include the analysis of airways meteorological statistics, the seeing and transparency, and questions of power, telephone, water, roads, availability of land, etc. The desert is not usually thought to be an ideal place to live and work; and yet, with the amenities of air-conditioned houses, water and electricity, good highways, refrigerators, and radios, it can be both comfortable and satisfying. The University of Chicago astronomers have shown how an observatory in a rather remote section of the country can be efficiently operated from a very considerable distance. There is no reason to think that their techniques cannot be duplicated.

A few remarks on possible equipment for our suggested photoelectric observatory might be in order. Inasmuch as the cost of a telescope goes up something as the cube of its size, and because the vast majority of the countless photoelectric problems can be attacked with instruments of small or moderate size, it would seem profitable to have a number of small reflectors, rather than a single large one. One 12-inch and two 36-inch reflectors might be one solution. The small instrument would be useful not only in keeping track of the atmospheric extinction, but also in a variety of programs dealing with the brighter stars. One of the larger instruments might be devoted to long-range programs, and the other could concentrate on numerous special investigations. The telescopes should be reflectors (because of their perfect achromatism) and should be of the "light-bucket" type—that is, a short focal length mirror in combination with a special

Cassegrain secondary mirror. This would minimize the size of the telescope—and hence the expense—as well as make it easier to handle. Such a design is already in existence. The optics, mounting, and driving mechanism should all be of the finest construction so that very small diaphragms might be safely used.

If such an observatory were to be established, there is no question but that it would make a very substantial contribution to our astrophysical knowledge at a fraction of the initial cost of a very large reflector. It would also provide a real opportunity for guest investigators from the Middle West and the East, who are seriously handicapped at present by their climate and often by city lights. "Home" researches in objective-prism spectroscopy and photographic photometry would be greatly strengthened by additional photoelectric observations. Serious photoelectric work is being accomplished or contemplated at many observatories in the eastern half of this country, including Harvard, Princeton, Pennsylvania, U. S. Naval Observatory, Virginia, Case, Ohio State, Michigan, Vanderbilt, Wisconsin, and Indiana. Such work is invaluable both in the training of graduate students and in the development of photoelectric equipment and experience. All these observatories—and others—should be intensely interested in the establishment of a permanent desert observatory devoted to photoelectric research. Here, then, is a superb opportunity which, if brought to fruition, would make possible an ever-continuing series of important investigations pursued under optimum conditions.

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Application of Echo-Ranging Techniques to the Determination of Structure of Biological Tissues[1]

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THE RESULTS OF PRELIMINARY STUDIES on the use of a narrow beam of 15 megacycle pulsed ultrasonic energy for the examination of the histological structure of tissues have been sufficiently encouraging to warrant the development of the apparatus that is the subject of this report.

Whereas the initial method of examination of tissues gave records of histological structure in one dimension analogous to a needle biopsy, the method to be described was designed to give a two-dimensional picture such as would be obtained by adding up the information from a series of needle biopsies taken in one plane across a given piece of tissue. Such differentiation of soft tissue structure is without precedent in the biological field. Theoretically it was thought possible to record soft tissue structure by tracing the information obtained from a sound beam sweeping through the tissues onto a fluorescent television screen. Thus, a tumor could be detected in soft tissues, provided the echoes returning from the tumor differed from the echoes returning from the tissue of origin of the tumor. Differences of sufficient magnitude obtained from the needle biopsy method of examination have already been demonstrated in the pilot studies reported elsewhere (*1–4*). The initial studies covered a variety of common tumors arising in the human stomach, brain, and breast. Work subsequent to these studies has confirmed the findings on a larger and wider scale.

Definition of terms. It is necessary to introduce some new words in order to make it possible to describe the

[1] This investigation was supported by a research grant from the National Cancer Institute of the National Institutes of Health, USPHS.

[2] We wish to thank Maurice B. Visscher, head of the Department of Physiology, and Henry E. Hartig, head of the Department of Electrical Engineering, University of Minnesota, for their help and suggestions in the preparation of this communication, particularly in regard to the section on terminology.

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