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THE DEVELOPMENT OF A NEW OBSERVATORY.

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The editor of the *Popular Science Monthly*, in the last issue of that journal, questions the wisdom of the Carnegie Institution in transferring a portion of the staff of the Yerkes Observatory to California for the purpose of establishing a new observatory. He believes that observatories should be situated where the seeing is best, and that good results may be obtained on Mt. Wilson, but doubts the necessity of providing for more astronomical work in a region already so well represented by the Lick Observatory.

The criticism, which is made in perfect fairness, is doubtless one that will independently present itself to others. It deserves an answer, which I shall endeavor in this paper to supply.

Let me say at the very outset that we yield to no one in our admiration for the splendidly effective work of our good friends on Mt. Hamilton. If it had been a question of duplicating the work of the Lick Observatory, or of occupying a similar field, the Solar Observatory would not have been founded.

It is easy to believe that one who has but recently closed a long period of preparation, which involved not only the ordinary discomforts of building, but also the details of construction of an extensive instrumental equipment, would not lightly embark upon another similar enterprise. A mountain summit, reached only by a narrow trail, and with no immediate prospect of better means of approach, does not appear to one engaged in quiet research as an ideal place for building operations. Furthermore, the great Yerkes telescope, thoroughly tested by investigations in many fields, appeals more and more strongly to the imagination as one's acquaintance with its capabilities increases. The possibilities of research which this instrument affords are unlimited. In some departments they are almost unique. Certain solar phenomena, for example, which it is one of the principal purposes of the new Solar Observatory to study, have hitherto been recorded only with the Yerkes telescope. The atmospheric conditions at Lake Geneva are not of the best, but with reasonable patience the astronomer finds enough good days in the year to crowd his cabinet with negatives that will repay much careful measurement and study. With these opportunities within his grasp, the attraction must indeed be a powerful one that will lead a reasonable man into new and uncertain fields.

But there is another side to the shield—a side so bright with promise that a few more years of preparation, even though they may temporarily deny the opportunity for research, may be considered as a slight obstacle. A man of science must so direct his efforts as to secure the largest results not within a single month or a single year, but within the entire period of his activities. He can thus afford to devote much time and effort to details of construction, if these promise sufficient advantage in the end. He must work for years, if need be, to secure such means of investigation as appear to him needful.

The purpose of the Solar Observatory should now be stated. It is not intended, in any important feature, to duplicate the work of the Lick or the Yerkes observatories. The aim of the Solar Observatory will be to apply new methods of research, under remarkably favorable atmospheric conditions, in a study of the constitution of the Sun and the problem of stellar evolution. The apparatus and methods, for the most part, will differ decidedly from those employed elsewhere. With its large shop, equipped for the construction of both the mechanical and the optical parts of instruments, the Solar Observatory will be in a position to develop new apparatus as fast as the need for it appears.

The proposed methods of research will cause the new institution to resemble a physical laboratory more closely than an observatory. For years astronomers have recognized some of the advantages that must result from a realization of laboratory conditions in observatory practice. Indeed, telescopes have been constructed that might seem on casual examination to accomplish the very purpose here in view. But an acquaintance with the facts would show that these telescopes, though they in some cases form stellar or solar images within laboratories, are suited for only a small part of the investigations now contemplated. Some of these, like the great equatorial *coudé* of the Paris Observatory, have splendidly demonstrated their worth in other fields of research. But even this instrument would be unsuited for our needs.

What we must have, if the full possibilities of solar research with the spectrograph and spectroheliograph are to be realized in practice, is a telescope of such mechanical and optical design, linear dimensions, and geographical position as to permit the formation of a sharply defined solar image, from fifteen to twenty inches in diameter, within a suitably equipped laboratory, on a large number of days in the year. These conditions have never been attained or even approached in practice, and no existing observatory is in a position to provide them.

So far, reference has been made only to the type of telescope required for solar investigations. The telescope is usually regarded as the principal instrument of the astronomer, and it is of course absolutely indispensable. Nevertheless, it may fairly be said that in the present state of solar research the spectroscopes and other instruments used in conjunction with the telescope are no less important than the telescope itself. The equatorial refracting telescope, hitherto employed almost exclusively in solar and stellar spectroscopy, has, through the nature of its construction, hindered the free development of the astronomical spectroscope. The serious effect of the changing temperature in an open dome, especially on the optical properties of prisms, has been recognized in recent stellar spectrographic work, and effective devices have been employed to maintain the temperature of the prisms constant throughout an exposure. But the limitation of size, imposed by the necessity of attaching spectroscopes to a moving telescope-tube, cannot so easily be overcome. This has precluded the use of long-focus grating spectroscopes, such as ROWLAND employed in his researches on the solar spectrum. Spectroscopes of this type are common enough in physical laboratories, and the classic results of ROWLAND, to speak of no other work, show how successfully they have been applied in investigations of the Sun. But whereas the astrophysicist has almost invariably been confined to the employment of small spectroscopes, which could easily be adapted to moving telescopes, the physicist has used powerful spectroscopes, properly mounted on piers, but provided with no adequate means of forming the image of a celestial body upon the slit. For this reason ROWLAND'S work was confined to the study of a very small solar image, produced with the aid of an ordinary laboratory heliostat. He was thus unable to investigate various minute phenomena of the Sun's surface, which can be observed only in large solar images produced by powerful telescopes. On the other hand, the users of such telescopes have had at their disposal no spectroscopic apparatus adequate for solar and stellar researches equivalent in precision to ROWLAND'S investigations.

In making these remarks I do not wish to be understood as in any way criticising the magnificent work hitherto accomplished by investigators in solar and stellar spectroscopy. Nothing could be more successful, for example, than the epoch-making determinations of stellar velocities in the line of sight perfected by CAMPBELL at the Lick Observatory, and it will be many years before a degree of precision in the measurement of the solar spectrum appreciably higher than that attained by ROWLAND and JEWELL at the Johns Hopkins University will be realized elsewhere. In both lines of investigation the available means of research have been utilized with extraordinary success. It is only through the lack of proper instruments that such special researches as we desire to undertake at the new Solar Observatory have not been carried out. In stellar spectroscopy these special studies will not in any way compete with the work now being accomplished by CAMPBELL, FROST, and others. They will simply permit the use of much higher dispersion for the minute investigation of the spectra of some of the brighter stars. In solar spectroscopy, on the other hand, while the degree of precision attained in previous investigations will hardly be exceeded, it is hoped that these investigations may be extended from the general light of the Sun to the details of solar phenomena.

To accomplish such results should be a comparatively easy matter as soon as a large and well-defined solar image or a brilliant and sharply defined stellar image can be produced within a laboratory. Spectroscopes may then be rigidly attached to immovable piers; the temperature conditions, when this is desirable, may be controlled more perfectly than is possible within an open dome; and the limitations of size, which are so evident in the case of an equatorial telescope, will no longer exist. In other words, the spectroscope, instead of occupying the position of an attachment to a telescope, may take its place as an instrument of still greater power and possibilities. From this point of view, it would hardly be unreasonable to define a telescope as an instrument for forming the image of a heavenly body on the slit of a spectroscope.

The importance of such an advance has been constantly before my mind for years. In the earliest work of the Kenwood Observatory, before the development of the spectroheliograph had been undertaken, this plan had already presented itself to me, as it doubtless had to others. Constant use of a long-focus concave grating in the study of the solar spectrum had strongly impressed me with the beauty and power of this instrument and the immense possibilities it would offer if, in modified form, it could be applied to the study of a large solar image. Subsequently, when engaged in the investigation of stellar spectra with a three-prism spectrograph, the dispersion of such an instrument seemed small and unsatisfactory when compared with that of a powerful grating spectroscope. Indeed, in passing from one instrument to the other it seemed almost like returning from the era of spectroscopy inaugurated by ROWLAND to the period of KIRCHHOFF and BUNSEN. I do not mean that the great possibilities of the prism spectrograph were underrated. Such an instrument to-day is by no means to be compared with the apparatus of the earlier investigators, particularly in view of the great extension of its power rendered possible by the application of photography. Spectrographs of this character will occupy an important place in the equipment of the Solar Observatory, and I do not believe that they can be materially improved in design as compared with the Mills spectrograph of the Lick Observatory or the Bruce spectrograph of the Yerkes Observatory. But the recognition of these facts cannot prevent one whose work has been largely dependent upon the use of long-focus grating spectroscopes from feeling that the realization of similar resolving powers in stellar spectroscopic research is a desideratum of the highest importance. In the Solar Observatory it is hoped to accomplish this result, at least for a few of the brightest stars, through the provision of a *coudé* mounting for a five-foot reflecting telescope, and the use of a large-grating spectrograph, mounted on a massive pier in a constant-temperature laboratory, where exposures long enough to record the feeble light of the star when highly dispersed can be given without fear of disturbance arising from flexure or temperature change.

The development of the spectroheliograph furnished another strong incentive toward the accomplishment of such changes in telescope design as are here in view. When the Rumford spectroheliograph was first undertaken, the unsuitability of such a telescope as the 40-inch Yerkes refractor for work with so heavy an attachment was strongly realized. A spectroheliograph of these dimensions should be capable of motion as a whole across the focal plane of the telescope. In spite of the great strength and rigidity of the steel tube of the telescope, which is sixty-four feet in length, the motion of such a mass, weighing about seven hundred pounds, would set the tube into vibration and destroy the possibility of obtaining a sharply defined image. I was accordingly compelled to adopt a type of construction which did not appeal to me from a mechanical standpoint, though it subsequently yielded good results. The motion of the solar image across the first slit of the spectroheliograph was produced by means of an electric motor, which caused the entire telescope-tube to move slowly in declination. The corresponding motion of the photographic plate across the second slit was produced by the same motor, through a shaft led down from the center of the telescope-tube to the eye-end. Such an arrangement, it is obvious enough, is crude and unsatisfactory as compared with a device permitting the motion of the spectroheliograph as a whole, the solar image and photographic plate being fixed in position. On Mt. Wilson a spectroheliograph similar to the Rumford spectroheliograph, but much larger and more powerful, will be mounted on steel balls, so as to move as a whole across the solar image, the friction being relieved to any desired degree by floating the entire instrument in a bath of mercury.

Later developments of spectroheliograph design made it appear necessary to give the instrument much greater focal lengths, in order to secure sufficient linear dispersion. It is essential, if the instrument is to be used successfully in photographing the Sun's disk through the narrow dark lines of the solar spectrum, that these lines should be sufficiently widened by dispersion to cover completely the second slit. For this reason a spectroheliograph thirty-five feet long is to be used on Mt. Wilson. It is obvious that such an instrument could not be attached to an equatorial telescope, for even if its weight could be carried, the flexure of the parts would prove an insuperable obstacle. With a cœlostat reflecting telescope a spectroheliograph of this kind can be mounted rigidly on piers in a horizontal or nearly horizontal position. On account of its great length it will not be moved as a whole, but the motion of the solar image will be produced by the slow rotation of the concave mirror of the cœlostat telescope about a vertical axis.

The optical needs which have become apparent in the development of the spectroheliograph are not confined to that instrument alone. They involve the production of a solar image of a diameter so great that the details of sun-spots and other phenomena may become of appreciable size upon the photographic plate. It is my hope that sun-spots may be photographed with the aid of the widened lines, in such a way as to give a picture showing the distribution within the spot itself of the elements which give rise to these lines. A telescope 145 feet in length is thus rendered desirable. Obviously, even if an equatorial telescope could be made to carry a spectroheliograph thirty-five feet long, it could hardly be given a focal length of 145 feet.

These are some of the considerations that have for years been forcing upon me the immense importance of some form of horizontal telescope. They led me to include a long heliostat room in the design of the Yerkes Observatory, and to prepare, in the first years of the observatory's existence, for the construction of a large heliostat and cœlostat for work there. But the necessity of building in the observatory shop the entire instrumental equipment required for use with the Yerkes refractor, together with other instruments for the observatory, delayed the construction of the apparatus. The heliostat used by Professor NICHOLS in 1898 for his beautiful investigation on the heat radiation of the stars was an old one borrowed from the Allegheny Observatory. Two years later, when Professor NICHOLS returned to the Yerkes Observatory to continue this work, a 15-inch cœlostat, constructed in our shops, for use at the eclipse of 1900, was employed in the heliostat room and gave very satisfactory results. The original plan of building a larger cœlostat was then taken up, and after some vicissitudes, which included the destruction of the first horizontal telescope by fire, the Snow cœlostat reflector was finally completed with the aid of a gift from Miss SNOW of Chicago. This apparatus proved satisfactory in the tests made at Lake Geneva, but the atmospheric conditions there were not sufficiently favorable to permit it to be used to good advantage. It was taken to Mt. Wilson by the expedition for solar research sent out by the University of Chicago a year ago. This expedition has now been replaced by the Solar Observatory of the Carnegie Institution, but through the courtesy of the University of Chicago the Snow telescope will be retained for use on Mt. Wilson during some time to come.[1]

In one particular the astronomer is at a disadvantage as compared with investigators in some other departments of research. In working with the microscope, for example, the only limitation to the use of high powers is imposed by the nature of light itself. In astronomy, as is well known, the condition of the atmosphere is an all-important consideration. Constant disturbances of the atmosphere ordinarily transform the images of celestial bodies into more or less confused objects, in which the delicate details of the original are completely lost. Many expeditions have been sent out for the purpose of discovering suitable observatory sites, but in almost every case conditions favorable for night observations have been the principal object sought. But sites that are admirably suited for night work are frequently wholly unsuited for observations by day. A mountain summit, for example, though it has the advantage of elevating the observer above the lower and more disturbed strata of the atmosphere, is usually a source of air-currents due to the heating of the mountain-slopes, which

[1] See "The Solar Observatory of the Carnegie Institution of Washington," *Astrophysical Journal*, March, 1905.

seriously disturb the image in solar observations. Tests made on several mountain-tops, including Pike's Peak and Mt. Etna, had not led me to a very optimistic view of the possibilities of such sites for day observations. It was therefore with no small degree of pleasure that I learned of Professor HUSSEY'S success, when examining various mountains and high plateaux at the request of a committee appointed by the Carnegie Institution, in finding a station which in all respects seemed to be ideally adapted for both solar and stellar research. Mt. Wilson lies within a region of remarkable atmospheric calm, broken, it is true, by occasional violent storms in the rainy season, but offering through a large part of the year conditions, both by night and by day, which no records within my acquaintance show to be surpassed elsewhere. Mt. Hamilton, I am told, is no better adapted for solar work than many sites in the eastern part of the United States. This is a matter of comparatively small importance from the standpoint of the Lick Observatory, since the extensive observational programme of this institution is designed with special reference to the admirable night conditions which obtain at Mt. Hamilton, and includes no solar research. It is evident, therefore, that in providing for extensive work on the Sun at Mt. Wilson, the Carnegie Institution by no means proposes to encroach upon the field of the Lick Observatory. Mt. Wilson and Mt. Hamilton, though within the limits of the same State, enjoy atmospheric conditions which differ in a considerable degree. It is with the purpose of utilizing the fine atmospheric conditions at Mt. Wilson for the purposes already outlined in part that the new Solar Observatory is being established.

Up to this point my remarks have related principally to solar research, though I have also touched upon certain special investigations in stellar spectroscopy. The scope of the Solar Observatory is not to include all classes of astronomical and astrophysical observations: it is to be strictly limited to certain definite lines of inquiry which appear to be of special promise. The importance of studying the Sun, in view of the great advances that are so clearly within the reach of suitable apparatus, can hardly be gainsaid by one who is familiar with the present condition of solar research. Even if knowledge so gained were to serve merely for the better interpretation of solar phenomena, there would be reason enough for every effort put forth to acquire it. But such knowledge is capable of far wider use. Leaving aside the important question as to the relationship between solar and terrestrial phenomena, which is in itself worthy of great consideration, we may consider only the application of knowledge derived from a study of the Sun to the solution of the problem of stellar evolution. Within the wide boundaries of astrophysics there is no problem that appeals to the imagination more strongly than this. It should be obvious enough that if we are to form a correct estimate of the processes of stellar evolution, in which the successive steps in the development of stars from nebulæ are to be definitely stated and understood, we can do so only through an intimate acquaintance with the phenomena of a typical star. No star other than the Sun is sufficiently near the Earth to permit such knowledge to be gained. Reduced by distance to mere points of light, even in the most powerful telescopes, stars of the sidereal system appear to be wholly beyond the reach of detailed examination. We may analyze their light as a whole, but we can study their surface phenomena only by inference, and not by direct observation. The Sun, on the other hand, presents, under excellent atmospheric conditions, a large and sharply defined image for minute study. Here, if anywhere, we may seek with reasonable hope of success for a firm foundation upon which the superstructure of stellar evolution may be erected.

But if these remarks in any way illustrate the importance of the most searching investigation of the Sun, they can hardly fail to suggest the desirability of carrying on simultaneously an investigation of various questions relating to the constitution of the stars. The interdependence of solar and stellar phenomena render it exceedingly desirable that the same investigator should concern himself with both. A study of the various classes of stellar spectra affords the means of tracing out the past and future conditions of the Sun. Hitherto, as already remarked, such investigations have been confined to the use of spectrographs of comparatively small dispersion. Given sufficient light and a powerful grating spectrograph rigidly mounted within a constant temperature room, there is reason to hope that the spectra of some of the brighter stars may be photographed on a scale comparable with the scale of the solar spectrum in the largest modern spectroscopes. It is accordingly a matter of great satisfaction to state that the five-foot mirror, which was for some time under construction at the Yerkes Observatory by Professor RITCHEY, will be mounted at the Solar Observatory.[1] Funds for the mounting and dome required for this mirror never became available at the Yerkes Observatory, and for several years no work has been done upon it. It will now be finished and erected on Mt. Wilson as soon as possible.

In addition to its use in a study of stellar spectra under very high dispersion by Mr. ADAMS and myself, this instrument will be employed by Professor RITCHEY in photographing the minute details in the structure of the nebulæ, an investigation which he has had constantly in view for many years; by Professor NICHOLS in a continuation of his interesting work on the heat radiation of the stars with the radiometer; and for other similar researches bearing upon the problem of stellar evolution. The massive mounting which Professor RITCHEY has designed for the five-foot mirror, and the success he has already achieved in the photography of nebulæ with the two-foot reflector constructed at the Yerkes Observatory, give reason to hope that the five-foot reflector will accomplish important results in direct photography, especially as the fine night-seeing at Mt. Wilson is accompanied by but little wind.

It is not my intention to claim that the purpose of the Solar Observatory is to be accomplished at once or without difficulty. The cœlostat reflector, through the distortion of its mirrors by the Sun's heat and through other difficulties peculiar to this type of instrument, is hardly likely to give the best results without much study and experience. It is not improbable that some material other than glass must ultimately be used for the mirrors, and that special precautions, not yet worked out, will be necessary in other directions. The work has gone far enough, however, to lead me to hope that the principal objects in view may sooner or later be attained. That the five-foot reflector offers problems of its own may also be admitted, though

[1] See Professor RITCHEY's account of the construction of this mirror in *Smithsonian Contributions to Knowledge,* Vol. XXXIV.

without serious fear that they cannot be overcome. It is likely enough, for example, that the block of glass five feet in diameter and eight inches thick which forms the mirror of this telescope must be maintained throughout the day at the mean temperature of the night in case its full possibilities are to be realized in practice. But this is a simple matter, requiring only the application of processes commonly employed in commerce. As for the mechanical questions involved in the production of a mounting capable of carrying this mirror with precision, there seems to be no reason to doubt that they can be solved.

I trust it has been shown that the Carnegie Institution, in establishing a Solar Observatory on Mt. Wilson, is entering a new and promising field of research, in which equipment and conditions not now available are indispensable. I am not qualified to express an opinion whether the work to be undertaken is more or less important than possible researches in other departments of science.

MT. WILSON, March, 1905.

PLANETARY PHENOMENA FOR MAY AND JUNE, 1905.

BY MALCOLM MCNEILL.

PHASES OF THE MOON, PACIFIC TIME.

New Moon,	May	4,	$7^h\ 50^m$ A.M.	New Moon,	June	2,	$9^h\ 57^m$ P.M.
First Quarter,	"	11,	10 46 P.M.	First Quarter,	"	10,	5 5 A.M.
Full Moon,	"	18,	1 36 P.M.	Full Moon,	"	16,	9 51 P.M.
Last Quarter,	"	25,	6 50 P.M.	Last Quarter,	"	24,	11 46 A.M.

The Sun reaches the summer solstice and begins his southward motion at about 7 P.M. June 21st, Pacific time.

Mercury will not be in very good position for observation during May and June. It passed inferior conjunction and became a morning star on April 23d. It continues to be a morning star until June 24th, when it passes superior conjunction and becomes an evening star. It attains its maximum western distance from the Sun (25° 26′) on the morning of May 21st, at a time when it is near aphelion in its orbit; so