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A GREAT TELESCOPE AND ITS POSSIBILITIES[1]

VERY rarely has a project of scientific interest made a greater appeal to the imagination of those interested in the advance of knowledge than has the recent announcement of the action of the International Education Board in making provision for the construction of a 200-inch telescope and an astrophysical observatory for the California Institute of Technology. The plan for this great undertaking is unique in many respects. Involved in it are not only the design, construction and operation of a telescope nearly seventeen feet in diameter, but most essential of all, the active cooperation in all these questions of the group of scientific men in the laboratories of the California Institute, and of the astronomers and physicists of the Mount Wilson Observatory of the Carnegie Institution of Washington. The gift was made in the belief that the combined experience of the investigators at these two institutions in the design and use of large telescopes and accessory instruments, and their intimate knowledge of the important astronomical and physical problems to which such an instrument should be applied, provide an unusual opportunity for notable additions to our knowledge of the organization of the stars and universes of space, and the behavior of matter in the great celestial laboratories afforded by the stars and nebulae.

It seems especially appropriate at a meeting of the American Association for the Advancement of Science, which brings together men interested in all branches of research, to consider some of the questions involved in the design of a great telescope, the selection of its site, the character of its accessory instruments and the results which may be expected from its use. Some of the problems are those of the mechanical engineer, others are of an optical nature, while the meteorologist, the chemist, the physicist and the astronomer each finds abundant opportunity to apply the results of his own training and experience. The necessity for technical advice of the most diversified character has been recognized from the very beginning in connection with this undertaking, and the active and cordial support promised by eminent men of a wide variety of interests is one of the best assurances of its successful accomplishment.

[1] Address of the vice-president, and chairman of Section D—astronomy, American Association for the Advancement of Science, New York City, December 28, 1928.

In every field of science the investigator sooner or later finds himself confronted with the limitations of his apparatus, but there is none in which these limitations are felt more keenly and directly than in astronomy. For the astronomer is subject to two serious handicaps from which other scientists are free. In the first place, he has to work upon his material at fixed and enormous distances: he can not bring the sun or a star into his laboratory. In the second place, he is obliged to work through the veil of the earth's atmosphere, which reduces the light of the star which he wishes to photograph to nearly one half of its original amount and affects its quality in many serious respects. To meet these difficulties and advance the present limits of his knowledge, the only resource of the astronomer is to gather more light, that is, to build larger and larger telescopes. He can not bring a star into his laboratory, but if he can collect sufficient light with his telescope he can apply to the star the powerful laboratory methods of analysis which are beginning to prove so extraordinarily fruitful in increasing our knowledge of the nature of stars and the physical processes occurring within them. Similarly, for nearly every other research which one can name the pressing need is for more light. Greater light-gathering power means the possibility of photographing fainter stars and fainter nebulae, thus adding, on the one hand, to our knowledge of the extent and form of our own universe of stars, and on the other, bringing into view new universes separated from us by the enormous distances of space. A larger telescope also means a great advance in the difficult problem of measuring the heat of stars, in mapping the surface temperatures of the planets, in deriving the motions, distances and physical constitution of stars, in studying the processes of their evolution, and finally, in passing outward from our own universe to the investigation of the structure and development of the millions of island universes which are seen as the merest glimmers of light in the largest of existing telescopes.

The first great problem relating to a very large telescope is its design. It is clear at the outset that it must be of the reflecting type since the effective limit of refractors designed for photographic work seems to have been nearly reached at apertures of three or four feet, unless radical improvements in the absorptive power of glass are developed. The telescope should be designed to give great space-penetrating power, to reach as large a portion of the sky as possible, to be capable of adaptation to a variety of different forms, to be of massive and stable construction and simple and convenient in operation. Although no definite decision has as yet been reached with reference to the design of the 200-inch telescope, the results of experience with the 100-inch reflector on Mount Wilson lead to conclusions which can not fail to have a direct bearing upon the new undertaking.

Nearly all reflecting telescopes which are planned for photographic investigations are of comparatively short focal length. The 60-inch and 100-inch reflectors on Mount Wilson both have a ratio of aperture to focal length of one to five, and there are few large instruments of this type in which the ratio is less than one to six. For most large refractors, on the other hand, the length is some fifteen times the aperture. The short focal ratio of the reflectors results in a great concentration of light in a small image, and so makes it possible to photograph very faint stars and nebulae at immense distances. This power to penetrate space is secured at the sacrifice of the field in good definition, the extent of field falling off as the ratio of aperture to focal length increases. But since the study of individual stars, of small areas in nebulae, and of planetary and lunar details will probably form the most important part of the program of the 200-inch telescope, the loss in size of field should not prove vitally serious. The possibility of constructing a lens to be placed in the convergent beam of light and increase the extent of field is now under investigation by a skilful designer of lenses, and a successful outcome would almost certainly lead to the decision for a very short focal ratio of about 3.3 times the aperture of the large mirror. The fundamental argument that a short focal length will result in very great space-penetrating power, while the possible loss of field can always be partially compensated by successive overlapping photographs on the object under investigation, is of great and perhaps decisive importance.

We may assume, accordingly, that the telescope with a mirror slightly less than seventeen feet in diameter will have a primary focal length of about fifty-five feet. The efficiency of such an instrument in rendering visible faint stars will be extraordinary. The mirror will collect about one million times as much light as the human eye, and with all allowance made for losses in the telescope a factor of 700,000 should be conservative. As compared with the 100-inch telescope on Mount Wilson, the new telescope will have four times the surface, and an additional factor of advantage in its relatively short focal length as compared with aperture. It seems probable, accordingly, that it will show stars at least five to ten times fainter, and the gain may be even greater. With the 100-inch telescope stars of the twenty-second magnitude have been photographed, so that the 200-inch instrument may be expected to reach stars of nearly the twenty-fifth magnitude. In other words, stars may be observed whose apparent brightness as compared with Sirius is less than that of Sirius as compared with our sun. The brightness of a twenty-fifth magnitude star is about equal to that of a standard candle flame of the same color seen at a distance of 41,000 miles, or one sixth of the distance from the earth to the moon.

The experience of all observers with large reflectors has shown the great advantage of the use of secondary mirrors in conjunction with the principal mirror to give longer equivalent focal lengths. For most spectroscopic work, for direct photography of the moon, planets, nebulae or star-fields where high magnification is desirable, and for all observations in which large accessory apparatus under laboratory conditions is to be used, the Cassegrainian or coudé form of the telescope is essential. In both of these modifications of the instrument the usual plane mirror of the Newtonian mounting at the upper end of the tube is replaced by a convex mirror of hyperboloidal shape. The convergent beam of light from the large mirror after reflection from the convex mirror converges much more gradually, and the equivalent focal length may be made as great as desired. In the coudé form of telescope the light is reflected a third time by a plane mirror placed at the center of rotation, and passes through the hollow polar axis into a laboratory where all kinds of powerful apparatus may be used to analyze and study the image formed in the focal plane. Both of the large reflectors on Mount Wilson are provided with combinations of mirrors of these types, which have proved of immense value. The recent work of Dr. Abbot, of the Smithsonian Institution, in measuring the radiation from stars throughout a wide range of spectrum, and the application of a spectroscope fifteen feet long to the analysis of the light of the brighter stars, would have been quite impossible without the use of fixed instruments under laboratory conditions. In the case of the 200-inch telescope a Cassegrainian combination is planned which will give an equivalent focal length of ten times the aperture of the mirror, or about 167 feet. The corresponding coudé arrangement will give double this length, or 333 feet. The importance of the use of the telescope in the coudé form will be recognized by making provision for two laboratories, one north and the other south of the instrument, so that stars in all parts of the sky may be observed equally well.

The type of mounting to be adopted for this great instrument is still quite free for consideration. If feasible, the type of open fork, similar to that used for the 60-inch reflector on Mount Wilson, is highly desirable, since this makes it possible to reach stars near the north pole, and insures compactness and stability in the structural features of the telescope. Especial attention will be given to the rigidity of the tube in order that it may be equal to any demands made upon it by massive instruments, such as a forty or fifty-foot interferometer, or a large spectrograph placed at the primary focus. The comparatively short length of the tube, which will be about twenty feet in diameter, will assist greatly in its rigid construction, and the advances of recent years in the manufacture of very large roller and ball bearings should make the support of the tube and polar axis an engineering problem of no serious difficulty.

The question of greatest interest and importance in connection with the project of the 200-inch telescope is that of the material of which the large mirror should be made. All existing reflectors of any considerable size which are in active use have glass mirrors, silvered, of course, on the front surface. Such mirrors have certain great advantages. Glass may be figured easily and takes a high polish; it is permanent in character and not unduly heavy, and the silver film may be removed readily and replaced whenever tarnish affects its reflecting power. Glass, however, has two very serious drawbacks. It is a poor conductor of heat, and its expansion or contraction with change of temperature, although not great, is very appreciable.

Now, the degree of accuracy necessary in the surface of a mirror intended to give the finest astronomical images is very high. No area can be much more than one 500,000th of an inch higher or lower than other portions of the mirror without affecting the quality of its definition. In other words, it must have a perfect figure of revolution to within this limit. As a result, the final stages of polishing a large mirror in the optical shop are slow and difficult, requiring great care and very nearly constant conditions of temperature. Troublesome as this process is, it is quite possible to carry it out successfully under conditions which may be controlled. But when the mirror is in use in the telescope the situation is very different. The front surface must of necessity be exposed directly to the night air, and since glass conducts heat very slowly the result under ordinary conditions is that a thin film of glass at the surface and edges of the mirror becomes chilled, while the interior remains at a higher temperature. As a consequence the mirror is very likely to become slightly distorted and to give images which are no longer round, but elongated or unsymmetrical. If the change in temperature to which the mirror is subjected is not large this effect disappears within a few hours, but if the temperature between two successive nights shows a considerable difference a very large mirror may show a distorted figure throughout an entire night. The effect of the range of temperature between night and day may be largely eliminated by keeping the mirror tightly closed during the daytime in a well-insulated cover, as is done in the case of the 100-inch reflector on Mount Wilson, but there is no means of guarding against the effect of an abrupt change in temperature between successive nights. It is evident that this difficulty becomes more serious the larger the mirror, since the mass of glass to be equalized in temperature is then greater.

The ideal solution of the problem is clearly one of finding a material which expands or contracts very little with changes of temperature. Such a material is fused silica or quartz, for which the amount of expansion with a change of one degree is about six ten millionths of its length, or one fifteenth that of glass. As a result a rod of fused quartz may be heated red-hot and plunged into water without breaking. A quartz mirror, accordingly, shows practically no change of figure under any ordinary range of temperature, and retains its shape even when exposed to the heat of the sun. Although harder than glass, quartz presents no serious difficulties to the optician, and excellent mirrors of small size are in use at many observatories and laboratories.

The problem of making very large disks of fused quartz is now under investigation by the General Electric Company, which has given much attention to the development of methods for the manufacture of this material for commercial purposes. The chief difficulty which is encountered arises from the high temperature necessary to melt quartz sand, about 1,450° C., and the viscosity of the material even at this high temperature. For these reasons it would be extremely difficult, if not impossible, to cast large disks of uniform transparent quartz in molds as is done in the case of glass. Since it is not at all necessary, however, that the greater part of the mirror be homogeneous or free from air bubbles or other defects, a method of casting a rough disk to serve as the body of the mirror and coating the front surface with a thin layer of fine transparent quartz which may be figured optically, is being developed with excellent prospects of success. The method has so far been used only for disks two feet or less in diameter, but there appears to be no serious obstacle in the way of applying it to disks of any size. The telescope will require two auxiliary convex mirrors sixty inches in diameter, and the construction of these disks will afford an excellent opportunity to test the method fully before work is commenced on the 200-inch disk itself.

It will perhaps be of interest at this point to summarize our discussion and attempt to visualize the type of instrument which, provisionally at least, we are designing. The large fused quartz mirror, nearly seventeen feet in diameter and weighing between twenty-five and thirty tons, will be placed in a tube about sixty feet long, which will itself be hung in an open fork of massive steel construction. Provision will be made for observations at the primary focus at a distance of fifty-five feet from the large mirror, both in the center of the tube with but a single reflection, and at the side of the tube in the usual Newtonian form with an additional reflection from a plane mirror. Much of the direct photography, most of the measurements of the heat of stars and planets, and spectroscopic observations in ultra-violet light or on very faint stars will be carried on at this focus.

In the Cassegrainian form of the telescope the light will be returned by a convex mirror, which replaces the Newtonian plane mirror at the upper end of the tube, through an opening in the center of the large mirror to a focus just below its rear surface. At this point, at which the telescope has an equivalent focal length of 167 feet, and an angular convergence of the beam of light of one in ten, a large part of the spectroscopic work will be carried on, as well as lunar and planetary photography which requires high magnification. The image of the moon at this focus will be nearly eighteen inches in diameter.

The telescope when used in the coudé form will have an equivalent focal length of 333 feet. In this case the beam of light coming from a convex mirror at the upper end of the tube will be reflected by a plane mirror placed at the center of rotation of the telescope, and directed in either a north or south direction into suitable laboratory rooms. Large accessory instruments, such as powerful long-focus spectrographs, and apparatus which must be used in a fixed position, such as radiometers and instruments of similar type, will be mounted in these laboratories. The possibility of controlling the temperature accurately over long intervals of time and the absence of flexure in the apparatus make this form of the telescope especially desirable for detailed studies of the spectral characteristics and the spectral radiation of the brighter stars. The very long focal length should also prove of great value at times of the finest observing conditions, in studies of close double stars or details of the surface of the moon or planets.

The entire telescope will be enclosed in a steel building with double walls to reduce the daily range of temperature. The rotating portion may be either a hemispherical dome of the usual type, or cylindrical in shape, forming a continuation of the fixed part of the building. The latter would afford considerable advantages in connection with the powerful cranes necessary for adapting the telescope from one to another of its three different forms. The building will be of the order of 150 feet in diameter, and not far from 150 feet high, with the telescope mounted on a pier some fifty feet above the ground.

A most fundamental question in connection with the entire project of the 200-inch telescope is its location. If we disregard for the moment the underlying principle of the entire plan, that it be within convenient access of the group of scientific men at the California

Institute and the Mount Wilson Observatory, and reason in a general way on the most favorable site we encounter some interesting considerations. The astronomer working outward through the ocean of the earth's atmosphere finds three serious difficulties. The first, to which reference has already been made, is the loss of light due to absorption and scattering in the atmosphere. The second is the definite limit set by it to ultra-violet radiation, the air absorbing completely all light of wave-length shorter than a fixed amount. Third, and most serious of all, the atmosphere introduces a blurring and lack of definition into his telescopic images which impairs the accuracy of measurement, conceals the finer details of the surface of the sun or planets, and by spreading out the light reduces greatly the limiting brightness of the faintest star he can see with his eye or photograph on his plate. This quality of the images of celestial objects as affected by the earth's atmosphere, which astronomers for brevity call "seeing," is the most important consideration in the location of any large observatory. Good seeing is far more vital than transparency of the air, or, within reasonable limits, even than clearness of the sky. Except in one or two special lines of work, few astronomical results of value can be obtained when the images given by the telescope are poor and ill-defined.

The cause of so-called "poor seeing" is easy to understand. Light in passing through the atmosphere is refracted or bent, and the amount of this bending varies with the temperature and density of the air. Consequently, when masses of air of different temperatures or densities pass rapidly in front of a telescope they refract the light of a star by different amounts, and the combined result is a quivering and blurring of the star's image and the obliteration of planetary or lunar details. The twinkling of stars when seen with the naked eye is a familiar illustration of this effect, and extreme cases may be seen on any summer day in the desert where the heated air rising from the sands produces grotesque distortions of distant objects. The length of these air-waves varies greatly, and their effect on the image in the telescope varies accordingly. When the waves are short, so that several are in front of the telescope at the same time, they produce a greatly enlarged blurred image. When the waves are long as compared with the aperture of the telescope, the result is a bodily displacement of the star's image without any great change in size. As a rule, however, both effects are present at the same time, and it is clear that the influence of these air-waves is greater the larger the aperture of the telescope.

Our knowledge of the conditions which produce the best definition of images in the telescope is very imperfect, and must necessarily remain so to some extent since we can know little of what takes place in the upper portions of the earth's atmosphere. At the same time, experience has shown that influences such as local weather conditions, wind and temperature range, and local topography are extremely important factors in affecting the seeing, and it seems probable that the lower levels of the atmosphere within a few miles of the earth's surface are those which are chiefly concerned with the effects we observe. From these considerations, and as a result of the experience of observers in many parts of the world, it is clear that the most favorable site for a telescope should be in a region in which the atmospheric conditions are very uniform, where abrupt changes of weather are infrequent and where the average wind-velocity is low. Such conditions are probably most nearly fulfilled in those portions of the zones of the earth's surface lying between latitudes 30° and 35°, within which the so-called "Mediterranean" type of climate prevails. This climate is characterized by wet and dry seasons, with a long, nearly uninterrupted period of clear skies followed by a shorter period of unsettled weather with moderate or low precipitation.

Speaking in general, therefore, the most advantageous location, so far as our present knowledge extends, would lie in a region having the Mediterranean type of climate, at an elevation sufficient to be above the fogs and haze of the lower strata of the atmosphere, but not so high as to be subject to the intense cold and strong winds of the loftiest mountains. A height of some 4,000 to 8,000 feet has been found to meet these conditions adequately. In the high veldt country of South Africa, in some of the countries bordering the Mediterranean Sea and in the extreme southwestern portion of the United States, including Central and Southern California and a part of Arizona, are probably the best locations which astronomers at present know for the most efficient operation of a large instrument. The long periods of continuous clear sky, the mountains and high plateaus with forests and other ground coverage sufficient to reduce radiation from the soil, the rare occurrence of high winds, freedom from extremes of temperature, and, finally, a latitude from which about three fourths of the entire sky may be observed satisfactorily, combine to give these areas advantages beyond those of any we know. Many years of experience on the part of the astronomers at the Lick, Mount Wilson and Lowell observatories, and at the Union and other observatories in South Africa, afford strong evidence for the accuracy of these conclusions.

In recognition of the extreme importance of the question of location, the California Institute and the Mount Wilson Observatory are carrying on extensive investigations in Southern California and Arizona, and the definite selection of a site may be postponed for as much as two or three years. During this time observers equipped with similar telescopes will carry on observations based on a quantitative scale of seeing at numerous points within a radius of some hundreds of miles of Pasadena. A great variety of stations will be tried at altitudes ranging upward from 4,000 feet, some in the mountain range near Mount Wilson, others on the edge of the Mojave Desert and still others on isolated mountains, or on the plateau area of northern Arizona. An especial attempt will be made to secure simultaneous observations at most of the stations, and all of the results will finally be compared with one another, and with the concurrent records available from the Lowell and Mount Wilson observatories. So little is known regarding many of the variables which enter into the question of night seeing, such as the effect of nearness to the desert or the ocean, the direction of the wind, the local configuration of the ground, the altitude of the station and the extent of the daily range of temperature, to mention but a few of the many conditions involved, that an investigation of this character would be well worth the labor and time required, even were the results not to find immediate application to the location of the 200-inch telescope.

Any consideration of the uses and possibilities of this great instrument must distinguish between the types of research in which important advances can readily be predicted, and new types which will develop as a result of its great size, massiveness and light-gathering power. When the 100-inch reflector on Mount Wilson was designed, no one could foresee that by means of a twenty-foot interferometer beam placed across the end of its tube the first measurement of the diameter of a star would be successfully carried out. In the case of the new telescope it seems reasonable to predict that the brightness of the stellar and planetary images formed by the 200-inch mirror will make it possible to apply methods and instruments of analysis which hitherto have been limited to the sun or to bright sources of light in the physical laboratory. The possibilities in such directions form a most interesting field of study, both for the physicist and the physical astronomer.

Of the numerous lines of investigation in which we can feel certain that the 200-inch telescope will extend our knowledge greatly, I shall speak in detail of only three. There are others quite as important to which but a mere reference can be made. For example, there can be little doubt that the new instrument will add some hundreds of millions to the number of stars within our own universe which can be photographed and measured for brightness. It is already known that the stars of our system, estimated at some thirty billion in number, are not equally scattered in space, but thin out with increasing distance, least rapidly in the direction of the Milky Way, and most rapidly at right angles to it. The increased light-gathering power of the 200-inch reflector will carry us much nearer to the boundaries of our system, and greatly improve and extend our knowledge of the character, extent and constitution of this island universe of which our sun forms an insignificant, but to us, all-important member.

The application of the new instrument to the analysis of the light of faint stars will prove of immense value. The spectrum of a star gives us information not only regarding its constitution and surface temperature, but also regarding its motion, its distance, its total luminosity and the physical state of the matter composing it. At present it is a difficult undertaking with existing instruments to photograph the spectrum of a star 1,000 times as bright as the limiting brightness of stars which may be seen on direct photographs of the sky. The great increase in light-gathering power of the new instrument will aid especially in the solution of the problem of the motion of our universe of stars as a whole, of the individual motions of stars and groups of stars within it, in the study of the great aggregations of stars seen in the globular clusters, and in furthering our knowledge of the faint stars which are among our nearest neighbors in the sky, and which probably represent suns nearing the final stages of their life.

It is in the field of nebular research that the 200-inch telescope will find perhaps its richest field of investigation, since the largest of existing instruments have been able to make only a beginning on the great problems involved in the study of the bright spiral nebulae outside of our galaxy of stars. These immense systems of stars form the most conspicuous examples of a sequence of structural forms, apparently genetic in character, which includes all the spiral, elliptical and globular nebulae. Their total number is enormous, a million or more being within reach of the 100-inch reflector, with the probability that the 200-inch will increase this number several fold. In some five or six of these objects Hubble has been able with the aid of the 100-inch telescope to resolve a part of the nebulosity into individual stars. Among these he has succeeded in identifying some as variable stars of the type known as Cepheids. The application of the method developed by Shapley for the determination of the luminosity of such stars then leads directly to values of the distances and dimensions of the nebulae in which they occur. In this way the distance of the Andromeda nebula has been found to be 870,000 light-years, or about 5×10^{18} miles, and its diameter approximately 45,000 light-years. The light which it gives out is about a billion and a half times the light of our sun, and its mass is probably five hundred million to a billion times as great. In other words, it is a huge universe of stars comparable to, but somewhat smaller than our own.

The Andromeda nebula is one of the two largest and presumably nearest of the spiral nebulae. Among the millions of other spirals only three or four more can be studied in a similar way with existing telescopes. The assumption, then, that the fainter, smaller nebulae are similar systems but more distant in proportion to their faintness, although partially justified on independent grounds, rests on a slender foundation—our knowledge of stars of known types in half a dozen of the nearest systems. The new reflector will add very greatly to these meager results. A conservative estimate is that it will furnish reliable distances for twenty-five or thirty nebulae, instead of the present five or six, and less accurate values, but sufficient for statistical purposes, for possibly two hundred more. Provided with representative material of this quality and extent the astronomer can venture upon the exploration of more distant space with a new order of confidence. From our present knowledge it seems probable that the 200-inch telescope will show nebulae of average size and brightness out to a distance of the order of 400,000,000 light-years, a minute but appreciable fraction of the finite universe postulated from the theory of generalized relativity.

The new reflector should contribute equally to the important question of the natural history of the stellar systems which we now recognize in the spiral nebulae. The stars observed in the nebulae will throw light on the physical conditions present in what, we have some reason to believe, is their place of origin; and we may thus find in the observed sequence of nebular forms the past history of our own stellar system.

When we pass to a consideration of the application of the 200-inch reflector to the analysis of the light of stars, we come to a field of remarkable possibilities. Spectrum analysis is no longer a subject of purely empirical investigation. The number, distribution and intensity of the spectral lines are a sure index of the physical conditions under which atoms exist in the laboratory or in a star, and the interpretation of observational results has acquired a sound and rational basis. We know, for example, why stars of different temperatures show different spectral lines, although the material composing the stars is the same; why in stars at the same temperature but of different densities many of the spectral lines behave very differently; how the relative intensities of certain lines may be used to determine the luminosities, and so the distances of stars; and how it is possible for matter to exist with densities several thousand times that of the heaviest element we know upon the earth, and, again, at the inconceivably low densities found in the planetary nebulae or the atmospheres of giant stars. The discovery by Bowen that the unidentified lines in the spectra of gaseous nebulae, long thought to be due to an unknown element, are produced by atoms of oxygen and nitrogen radiating under conditions we have been unable to duplicate in the laboratory, is a remarkable illustration of the value of physical theory as applied to the stars.

The messages contained in the spectra of stars can, however, be fully and adequately interpreted only if these are photographed on a very large scale, such that the thousands of individual lines in the more complicated spectra are completely separated. To do this requires a very bright image and hence a very large telescope. A few of the brighter stars have already been studied in this way with a powerful spectrograph and the 100-inch reflector on Mount Wilson, and the resulting spectra form a mine of the most valuable information. They have provided a new method for finding the temperatures of stars, for studying the distribution of atoms in their different states in stellar atmospheres and for sounding the levels of these atmospheres throughout their depths. Almost equally valuable is the possibility which such spectra afford of determining the motions of stars with a high degree of precision and of investigating the ebb and flow in the enormous atmospheres of the pulsating giant stars, some of which are hundreds of millions of miles in diameter. There is no field of investigation to which the great light-gathering power of the 200-inch telescope will make a more direct or vital contribution. It will multiply by at least five the number of stars whose spectra can be studied in this way, thus giving us material from nearly every spectral type and division, and in the case of the brightest stars it will enable us to apply spectrographs of a power never before used on any celestial objects except the sun.

A field of investigation of unusual interest both to the scientist and the layman is the measurement of the heat of stars and of the temperatures of the surfaces of the moon and planets. Heat-measuring devices have been developed by physicists to such an extraordinary standard of sensitiveness that changes of temperature amounting to a millionth of a degree can easily be recorded and accurately measured. With the aid of a large telescope they are capable of detecting the heat from a candle flame at a distance of 100 miles. Some of these devices depend on the fact that heat applied to the junction of two strips of different metals in contact with one another produces an electric current which may be measured with a delicate galvanometer; others make use of the change of resistance of fine platinum wire with temperature, so that the amount of current flowing through it is modified by the application of heat; in still others, a delicate radiometer vane is suspended by a fine quartz fiber, and the reaction of the molecules of gas in contact with the vane when it is warmed turn it about its axis away from the direction of the radiant source. All of these types of instruments have been used in recent years with great success by astronomers, especially at the Lowell and Mount Wilson observatories, and the amount of radiated heat has been measured for nearly 150 individual stars. These results are of fundamental importance to all theories of stellar constitution and radiation.

The contribution of the 200-inch telescope to progress in this field will undoubtedly be very great. The surface of the large mirror, nearly 240 square feet in area, will collect and bring within the range of measurement stars at least five to ten times fainter than can be studied at present, and so will multiply the total number many times. It will also make it possible in the case of the brighter stars to extend and make more accurate the skilful work of Abbot in measuring the radiation throughout all parts of the spectrum. Finally, it should enable us to gain a very accurate knowledge of the temperatures of different parts of the lunar and planetary surfaces, and the rate of change of temperature during the planet's day and night. In Russell's phrase, the 200-inch telescope should provide us with a "weather map of Mars," and it is probably on such records rather than on direct observations that speculations regarding the possibility of life on the planets must find a logical basis for discussion.

With all the far-reaching and definite advances in knowledge which we can foresee for this great instrument, the appeal which it makes to the imagination is still one of its most valuable indirect contributions. A few weeks ago a small spiral nebula near one of the poles of the Milky Way was observed with the 100-inch reflector on Mount Wilson. It is very faint and probably one of the most distant objects within the range of present telescopes. It was found to be moving away from the earth at the amazing rate of nearly 2,500 miles a second, nearly double the velocity of any cosmical object so far observed. The possibilities of what the new telescope may discover in these inconceivably remote regions of space, under what strange forms matter may exist in some of the stars it will reveal to us, what it will tell us of the development and motions of the outer universes, and of space and time and gravitation, are all speculations for the future. But they can not fail to stir the mind and imagination, and it is to the trained imagination of scientific men in every generation that science has owed her greatest advances.

Walter S. Adams

Mount Wilson Observatory

SCIENTIFIC EVENTS

MEDALLISTS OF THE ROYAL SOCIETY

At the anniversary meeting of the Royal Society on November 30, the medals were presented. There is here abridged from *Nature* the descriptions of the work of the medallists, as stated when the medals were conferred by the president of the society, Sir Ernest Rutherford.

The Copley Medal to Sir Charles Parsons

In the world of mechanical engineering the genius of Charles Parsons has opened up a new era. He has originated and developed a new type of thermal engine entirely flexible and adaptable, and capable of high efficiency combined with concentration of power never even imagined before. By continuous practical effort for the past forty-five years, aided by remarkable mathematical insight acquired in his university days, he has perfected the parallel-flow compound steam turbine, and has applied it successfully to electric generation and to marine propulsion, both attaining to an unprecedented scale. While the utilization of heat in the best triple-expansion reciprocating steam engine amounts to 17 per cent. of the whole, the Parsons' large central station turbines now convert 25 per cent. into mechanical power, and in still larger turbines 28 per cent. is anticipated. The first steam turbine of 4 kilowatts was used in 1885 for electric lighting; at present, turbines of 20,000 and 30,000 kilowatts are in operation. The application to marine propulsion was signalized in 1897 by the appearance of the *Turbinia,* a small experimental craft developing the extraordinary speed of 33 knots. Large turbine-driven destroyers for the Navy rapidly followed, and now all large high-speed liners are turbine driven.

The Rumford Medal to Professor Friedrich Paschen

Professor Paschen is especially distinguished for his practical and theoretical contributions to spectroscopy. He early acquired remarkable skill in the investigation of infra-red radiation and made valuable determinations of the distribution of energy in the spectrum of a black body, giving the first experimental proof of the law that the frequency of maximum energy is proportional to the absolute temperature. He afterwards made numerous observations of the infra-red emission spectra of various elements, which were of fundamental importance for the development of our knowledge of series in spectra, and afterwards for the theory of spectra in relation to atomic structure. He has also contributed in a notable degree to the precise measurement and series classification of spectrum lines in general; he has long been one of the foremost workers on the Zeeman effect, and the results which he has obtained, including the discovery of the