SCIENCE

VOL. LVIII NOVEMBER 16, 1923 No. 1507

CONTENTS

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. McKeen Cattell and published every Friday by

THE SCIENCE PRESS

Lancaster, Pa. Garrison, N. Y.
New York City: Grand Central Terminal.

Annual Subscription, $6.00. Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

Entered as second-class matter July 18, 1923, at the Post Office at Lancaster, Pa., under the Act of March 3, 1879.

RECENT PROGRESS IN OUR KNOWLEDGE OF THE UNIVERSE[1]

IN his address at the dedication of the Yerkes Observatory in 1897, Simon Newcomb said, "If it be true that in nature nothing is great but man, in man nothing is great but mind, then may knowledge of the universe be regarded as the true measure of progress." Without discussing the validity of the premises which Newcomb himself casts in the conditional mood, let us boldly accept his conclusion and take time this evening to consider the progress we have made in the last thirty-five years by reviewing the increase of knowledge of the universe within that period. The time and the occasion are propitious for such an inquiry, for we are assembled to dedicate another great observatory; and this year, 1923, marks the 450th anniversary of the birth of Copernicus, whose book, "De Revolutionibus Orbium Coelestium," set the feet of men for the first time firmly on the road leading to knowledge of the universe and opened a new epoch in the development of the human mind.

The doctrine of Copernicus was more than epoch-making; it was revolutionary. The earth had been to men, in substance, the entire universe; the heavens a canopy drawn close about the earth; the sun, the moon, the planets and the stars merely greater or lesser lights set in that canopy for the comfort and delight of the dwellers upon the earth. Now they were asked to regard that earth as but a little planet, one of several revolving about a distant sun, and the stars, by implication, as vastly distant bodies that might rival with the sun in actual brilliance. No wonder that such heresy met with the most strenuous opposition; no wonder that only the boldest intellects became converts to it before Galileo, in 1609, turned the first small telescope upon the splendors of the sky and saw in the moons revolving about Jupiter a system, in miniature, resembling the one Copernicus had described.

I must resist the strong temptation to trace in detail the progress of astronomy through the centuries that followed. It is a brilliant story and one that has been told many times in prose and in verse. No one who has read it can have failed to note that advance in civilization closely paralleled the growth of man's knowledge of the universe, or to realize that this growing knowledge, by bringing man an ever-widening

[1] Address at the dedication of the Steward Observatory of the University of Arizona, April 16, 1923.

horizon, an ever greater freedom of thought, was a most potent factor in that advance.

Among the many conclusions that may be drawn from a thoughtful reading of this history, two are especially encouraging: First, that progress in astronomy has been continuous. From the days of Copernicus and Galileo the observations and generalizations made by any generation of astronomers have afforded the foundation upon which their successors could securely build. We have never had to go back and begin entirely anew, and even in our own times, observations of comets, of eclipses and of other objects and phenomena, made at dates preceding the invention of the telescope by many centuries, have been utilized to advance our knowledge. Secondly, that progress has been made at an ever accelerating velocity. At no period in history has the advance been so great as within the last few decades; and at no time has the promise for an increase of knowledge of the universe been as bright as it is to-day.

It was on June 1, 1888, almost precisely thirty-five years ago, that the newly completed Lick Observatory passed formally into the possession of the University of California and began its active work. Contrast the position of the astronomer at that date with his position to-day. The era of great telescopes was just opening; astronomical spectroscopy and photography were in their infancy; engineers were just beginning to develop practical methods of utilizing electricity as a motive power.

Since then four great observatories, besides the one at which we are gathered to-day, have been built on our own continent and several older ones have been rebuilt. If the advance in this respect has not been quite so great on other continents, still it has been remarkable everywhere and, in all, fully a score of powerful telescopes have been added to our equipment for exploring the universe. Particularly notable has been the development of the reflecting telescope since Keeler's work with the Crossley Reflector in 1898–1900 demonstrated the great efficiency of this type of instrument in many kinds of astronomical photography.

Coincident with the growth in the size and number of our telescopes has been the invention and improvement of auxiliary apparatus to utilize their great light-gathering powers in new ways and to increase the accuracy of our observations. The modern spectrograph, the spectro-heliograph, the precision photometers of various types, the bolometer, the pyrheliometer, the interferometer, the periodograph, have all come to use within the period I have named. Electric power and light are to-day as indispensable in our domes as in our most progressive industrial plants, and photographic observations have virtually displaced visual observations in all but a few lines of astronomical research.

Such greatly increased facilities, together with the remarkable progress in physics, in chemistry and in the methods of mathematical analysis, have put it within the power of astronomers to enter upon the study of a whole series of questions relating to the stars as organisms which earlier investigators had left practically untouched; not because they took no interest in them or failed to appreciate their importance, but simply because to them it seemed hopelessly beyond the power of the human mind to devise means of securing the data needed for their solution. It is in investigations along these lines that some of the most striking advances have recently been made, but the increase in our knowledge of stellar motions and of stellar distances is fully as great and as important.

The analysis of stellar radiations with the aid of our powerful spectrographs has enabled us not only to classify the stars according to the quality of their light but also to measure with high precision the velocities of the stars in the line of sight, and to discover, and even to compute the orbits of binary star systems that must forever remain invisible[2] to us, no matter how greatly our telescopes may be increased in size. We have made at least a beginning in the measurement of the temperatures, the masses, the densities, the angular and linear dimensions of the stars. We recognize "giant stars" and "dwarf stars"; stars intensely hot as compared with our sun and stars that are relatively cool; "young stars" just emerging, it may be, from an antecedent nebular stage, and "old stars," nearing the end of their history as luminous bodies. It would be easy to continue this catalogue until it filled many pages and to draw up one equally long of the achievements in researches relating to the structure of the stellar system. But it will be of greater interest, I think, to select one of them for more detailed presentation to illustrate modern methods and results.

Let us then consider a problem that has a history dating back to the days of Copernicus, the problem of determining the distances of the stars. The fact that the stars did not change their apparent position or direction from the earth in different seasons of the year, as they should do because of the earth's revolution about the sun, was regarded by the opponents of the Copernican doctrine as one of their strongest arguments against it and was the chief reason why so great an astronomer as Tycho Brahe rejected the doctrine. The proponents of the theory could only reply that the stars must be very far away, but all their efforts to find out how far did not yield a single stellar distance until nearly 300 years had elapsed. Their

[2] That is, no telescope can show both components of the closer spectroscopic binary stars, especially if they are unequal in their brightness. One component, or the unresolved image of the pair, must, of course, be visible.

work was by no means all in vain, for though it did not achieve the end for which it was undertaken it did lead to the discovery, by Bradley, of the phenomena of aberration and nutation and to the discovery, by Herschel, of the existence of the binary star systems. Moreover, it served to set a minimum limit to stellar distances, a limit that receded ever farther as instruments and observing methods improved. Even before the telescope was invented it was clear that the limit must be about 200 times the distance from the earth to the sun, for a lesser distance would cause displacements that could be detected by the unaided eye; by the middle of the 17th century it grew to 4000, early in the 18th century, to 20,000 or 30,000 times that distance. By the 19th century astronomers had become convinced that the nearest stars must be at least 200,000 times as far away as the sun, or, in technical terms, that the largest stellar parallax could not much exceed a second of arc. This term, parallax, is a convenient one and I shall use it in what follows. It signifies the angle at the star between lines drawn from the star to the sun and to the earth, respectively; the farther away the star, the smaller the angle. Having this angle, we readily determine the distance, for in the triangle, earth, sun, star, we know one side, namely, the distance from the earth to the sun, and all the angles.

Finally, in the years 1838–39, three astronomers, working in different places, with instruments of different types, announced almost simultaneously the parallaxes of three different stars; Bessel, the parallax of 61 *Cygni,* measured with the heliometer, Henderson, the parallax of Alpha *Centaur* determined from meridian circle observations, Struve, the parallax of Alpha *Lyrae,* from micrometer measures with his equatorial telescope. Success being thus achieved, after nearly three centuries of unavailing endeavor, it might have been anticipated that knowledge of stellar distances would grow rapidly, particularly in view of the constant improvement in instruments and the ever better understanding of the requirements of the problem. Actually, however, progress was slow. By 1880, it is fair to say, we had approximate values of the distance of but a score of stars; by 1900, of some threescore, only, and the prospects for rapid or great increase in number by visual observations were by no means encouraging.

But by this time methods of photographing the stars and of measuring their positions on the resulting plates had been developed to such a degree that it seemed feasible to attack the extremely difficult problem by the photographic method. Pritchard, at Oxford, indeed, had taken a large number of photographs for this purpose as early as the years 1887–1889, and these had led to the parallaxes of 28 stars. His work deserves high praise, even though it has since been found that his results are affected by systematic errors of considerable size. Early in the present century, however, when Kapteyn had definitely enunciated the "reasonable precautions" that must be taken by the observer, first at the telescope and then at the measuring microscope; when Turner and others had developed the exceedingly accurate modern methods of plate measurements; when Schlesinger had shown how to eliminate in large degree the very troublesome "guiding error"; then it became possible to enter hopefully upon a greatly extended program of parallax work.

In the meantime astronomers had been learning the lesson so thoroughly drilled into the heads of baseball and football men by their coaches—that good teamwork is fully as essential to the winning of games as brilliant individual play. Cooperation in astronomical research was by no means a novelty in the latter half of the 19th century, but in the 20th century it has become one of the distinctive features of our work. The photographic determination of parallaxes affords an excellent illustration. While each individual guards and preserves his right of initiative, astronomers at seven observatories, six in America and one in England, have formulated a cooperative program that ensures the elimination of useless duplication of labor and as great a degree of homogeneity in the results as differences in instrumental equipment and observing conditions will permit. Now they are engaged in that most generous form of rivalry in which each one gives all the others the benefit of any improvement in methods of manipulation or of computation he has devised, applauds every success the others achieve, and strives for even greater success himself. It is, therefore, not surprising, though extremely gratifying, that by 1915 we had the parallaxes of at least 200 stars and that now the number is well past the thousand mark and is growing at the rate of perhaps 150 to 200 a year.

At the same time we must face the fact that the number of stars whose parallax can be measured directly with the best of modern telescopes and with the most scrupulous attention to every detail of observation and measurement is strictly limited and pitiably small in comparison with the total number even of the brighter telescopic stars. In 1915, Sir Frank Dyson considered $0''.02$ the smallest parallax that could be measured with any reasonable degree of accuracy. Translated into other terms, this means that if a star is more than ten million times as far away from us as the sun is, we can hardly hope to measure its distance. To-day, eight years later, this may perhaps be regarded as a rather conservative statement, but even to-day no responsible astronomer would care to set a limit very much greater. It is true that by any terrestrial standard of distance 10 million times that to the sun is enormous, and that no human intelligence can comprehend it. Yet we have every reason to believe that the stars within a sphere of space of this radius do not number more than 20,000 to 25,000 (half of them probably too faint for photographic parallax measurements), whereas the number in our stellar universe is of the order of 1,000 million.

We now open a new chapter of our story. There is an obvious relation between the apparent brightness of a luminous object, its intrinsic or true brightness and its distance from the observer. Two lights may appear to be of equal brightness, because they really are equally bright and are at the same distance from us, or because the one of greater intrinsic brightness is farther away, the law of variation of brightness with changing distance being the well-known law of the inverse square; double the distance and the light is diminished to one fourth its former brightness; halve it and the light is increased fourfold.

Thanks to the efficiency of modern photometers and to the extensive and skillfully executed researches which have led to an accurate scale of visual and of photographic magnitudes, we can now determine with all desired accuracy the apparent brightness or magnitude of any star down to the faintest ones revealed by our telescopes. If then, by some means, we can also determine its *intrinsic* brightness or its "absolute magnitude" (the magnitude it would have at a definite distance from us) it is clear that its distance becomes known. But how is it possible to know anything about the actual luminosity of a star until we know how far away it is? As recently as the opening year of the present century the problem might well have been declared insoluble. Fifteen years later the answer was found in the correlation between the relative intensities of certain spectral lines and the intrinsic brightness of stars of the same spectral class.

This is not the place for a detailed explanation. It must suffice to say that we have ascertained from laboratory experiments and from solar observations that the character and intensity of certain spectral lines are strongly affected by changes in the physical conditions in the light source. Now, "if two stars which have closely the same type of spectrum differ greatly in luminosity it is probable that they also differ greatly in size, mass and in the depth of the atmospheres surrounding them. Accordingly, we might hope to find in these stars certain variations in the intensity and character of such spectrum lines as are peculiarly sensitive to the physical conditions of the gases in which they find their origin, in spite of the close correspondence of the two spectra in general." Adams, whom I have been quoting, was not the first to search for such lines, but it was he who first succeeded in using them to determine stellar parallax. His paper describing the method was published in 1916; five years later he and his collaborators were able to publish a list of the parallaxes of 1646 stars; and these values are of the same order of accuracy as the best photographic ones.

The method has not as yet been successfully applied to stars of all spectral classes, but we may look forward with confidence to its further extension. Thousands of stellar spectrograms, taken for other purposes, are also available at several of our great observatories, and it is certain that many of these will be utilized for parallax determinations by this new method. Great, therefore, as has been the recent advance in knowledge of the distances of individual stars, the prospects are bright for still more rapid progress in the coming years. For there is, practically, almost no limit to the number of the stars whose distances can be measured by the spectroscopic method. To determine uniquely the absolute magnitude of a star we need only spectrograms on a scale sufficiently large to record accurately the relative intensities of the spectrum lines, and as our instrumental equipment grows more powerful we may hope to get such spectrograms of ever fainter stars.

I have treated this problem of the determination of stellar distances at considerable length not only because of its intrinsic importance in our studies of the structure of the universe, but because it illustrates admirably many of the characteristics of modern astronomical research, and, in particular, the fact that advance in any one line is so closely correlated with and dependent upon advance in others which are seemingly entirely unrelated to it. Nothing, for example, could have been farther from the thoughts of those who were investigating the behavior of the spectra of gases under different physical conditions than that their results would be applied to the determination of the distances of the stars.

Let me now continue my story by reviewing more rapidly some of its other developments. The determination of the position of stars upon the surface of the celestial sphere is one of the oldest forms of astronomical observation, dating back to the days of Hipparchus. The first catalogue giving star places of sufficient accuracy for comparing with modern meridian observations is Bradley's, about the middle of the 18th century. Since then, by the patient, skilful labor of scores of able astronomers an enormous mass of data has been accumulated and made available for analysis by statistical methods. Comparison of the positions of stars observed at different dates shows that these are changing; slowly, indeed, but in many instances rapidly enough to make the change measurably great within a few years or decades or a century or two. Herschel utilized the scanty knowledge of such motions—proper motions, we call them—available in his day to prove that they were due in part to the actual motion through space of the solar system itself; and with the insight, and, may I add, the good fortune of genius, he was able to estimate the direction of this motion with amazing accuracy.

It is obvious that the motion of the sun through space provides the astronomer with an ever-lengthening base line from the extremities of which he can observe the positions of the stars and hence their "parallactic" displacement. These observations do not lead to the distance of any particular star, because the star's own motion is a factor in its displacement; but, assuming as a first approximation that the stars are moving quite at random; that, in the average, in any given area of the sky as many stars are moving north as south, east as west, towards us as away from us, they do lead to a knowledge of the *average* parallactic displacement of the entire group and hence to the *average* distance of the stars in it. Within the past twenty-five years men like Kapteyn, Campbell, Boss, Dyson, Charlier, to name but five of an illustrious company, have been engaged in a series of brilliant researches on the motions of the stars. Campbell, it is true, has been concerned entirely with the motions of the stars in the line of sight, as determined with the spectrograph, but it will appear immediately that his measures have the greatest significance in the questions I am discussing. Remarkable, indeed, are some of the results obtained. Thus Boss demonstrated that a number of stars apparently unrelated and widely scattered in the region of the constellation *Taurus* are really moving together through space along practically parallel lines. The spectrograph supplied the radial velocities of a few of the brighter members of the group, and the combination of the data on simple geometrical principles led directly to an accurate knowledge of the distances of every star in the group. Several such "moving clusters" are now recognized and are the subjects of fruitful study.

Still more striking was the announcement by Kapteyn, in 1904, that the stars as a whole are divided into two great streams moving towards vertices at two diametrically opposite points in the plane of the Milky Way. The stars of the two streams are thoroughly intermingled and members of either stream are to be found in every part of the sky, being distinguishable only by their motions. This conclusion has been abundantly verified by later investigations and stands as one of the most important contributions yet made to our knowledge of the stellar system.

Again, Campbell and Boss, quite independently and almost simultaneously, announced that the stars of different spectral classes are moving through space with different velocities.[3] The stars of Class B, the blue white stars, at one end of the series of spectral classes, have the smallest average velocity; and the velocity increases, class by class, as we pass from the white stars through the yellow stars on to the red stars of Class M at the other end of the series. Each investigator gave values for the average velocity, and also for the average parallax of the stars in each group; Campbell from an analysis of the radial velocities of the stars after making correction for the sun's motion through space, the velocity of which his researches measured for the first time, Boss from a similar analysis of the proper motions; and the two sets of figures were in excellent accord.

Carrying his work still farther, Kapteyn was able to calculate the approximate *average parallax* or distance of stars of every order of magnitude and of every spectral class. Thus, these diverse researches on the distances of individual stars, on star positions and proper motions, on radial velocities, and on the quality of lines in stellar spectra are all made to focus upon the great fundamental problem of the form and structure of the stellar universe.

I have by no means enumerated all the investigations which bear upon this great problem. I have said nothing, for example, of the binary stars. I might show how they lead us to a knowledge of stellar masses and densities; and, conversely, since we find the range in mass to be relatively small, how we can compute the "hypothetical parallaxes" of the visual binaries (as Jackson and Furner have recently done for more than 550 pairs) by assuming an average value for the mass. Or I might ask you to consider the variable stars, and especially the Cepheid variables, and show how Miss Leavitt's discovery that in the Cepheids in the Smaller Magellanic Cloud a definite numerical relation exists between the magnitude of the star and its period, that is, the length of one complete cycle of light variation, enabled Hertzsprung to estimate the distance of the Cloud itself and put into the hands of Shapley a new gigantic "yard-stick" with which he has measured the distances of the globular star clusters and the dimensions of the stellar system.

The precise length of this yard-stick depends upon the absolute magnitude of the nearer Cepheid variables, and it may well be that further observations will modify to some degree the value adopted by Shapley; the *validity of its use* rests upon the assumption that the relation between magnitude and

[3] Kapteyn's independent investigations led him almost simultaneously to the same general conclusions. More recent investigations indicate that this apparent correlation between velocity and spectral class may prove to be, physically, a correlation between velocity and mass, the less massive stars having the greater space velocity.

period which holds for the Cepheids in the Magellanic Cloud is independent of the star's environment and characterizes these variables wherever they appear, whether in space comparatively near us or in the most distant star cluster. The assumption has been challenged and it is not impossible that it may prove to be invalid; but it is supported by so much corroborative evidence that it commands ever more respect and credence.

A similar remark applies to many other generalizations as to the structure and dimensions of the universe. *Quantitatively,* they are admittedly approximations which are to be corrected and improved as additional data of observation are accumulated. They also involve *assumptions,* some of which can not be submitted to direct tests, but which are adjudged valid because they seem to be in harmony with accepted physical laws and give results which agree with observation. Some of them, no doubt, will have to be modified; some may have to be abandoned entirely. But it is certainly an inspiring fact that, imperfect and limited as our knowledge is, it is yet sufficient to have enabled Kapteyn, in the last paper published before his death last year, to formulate—with hesitation and some misgivings, it is true, but yet with confidence in the principles involved—"a tentative theory of the dynamical organization of the stellar universe."

The researches which I have been reviewing relate chiefly to one of the two fundamental problems of astronomy; the other is that of stellar evolution. This is distinctly a problem of our own times, one that could not be attacked until spectroscopy and photography had been successfully applied in stellar observations, until modern methods of solar research had been developed, and physicists and chemists had given us a better insight into the properties of matter and especially of matter in the gaseous state.

Observationally, stellar spectra provide the first and by far the most important data for the study of stellar evolution, and for the vast accumulation of such data now available astronomers gratefully acknowledge that they are indebted most of all to the late Professor Pickering and his colleagues at the Harvard College Observatory. The monumental "Henry Draper Catalogue of Stellar Spectra," of which seven volumes have already been distributed, contains the classified spectra of more than 200,000 stars. The first remarkable fact to be noticed is that fully 99 per cent. of all the stars whose spectra have been examined fall into one or the other of only six great groups, designated by the arbitrary letters B, A, F, G, K and M. The next is that these groups grade into each other in such a way as to form a continuous linear series, the color deepening from white through yellow and orange to red as we pass from B to M. The classification is on an empirical basis depending simply upon the characteristics of the spectral lines; but the continuity and particularly the linearity of the series is strong evidence, in Russell's words, "that the principal differences in stellar spectra, however they may originate, arise in the main from the variations in a single physical condition in the stellar atmosphere." All astronomers now agree that this dominant physical condition is temperature, a conclusion that has been abundantly confirmed. We have even been able to measure stellar temperatures directly by the use of extremely sensitive thermocouples in conjunction with some of our great reflecting telescopes, and thus have definite knowledge that the intensely white Class B stars are the hottest, the red Class M stars the coolest in our series. These facts point to a genetic or evolutionary relationship between the stars of successive spectral classes; the question is as to the direction in which the evolution proceeds.

Within the past decade data for the discussion of this question and the related question of the status of matter antecedent to the stellar stage have been offered in such abundance, in such variety and in such rapid succession as fairly to bewilder the conservative mind. The astronomer has been applying his telescope to the measurement of the radial velocities of the nebulae and has found not only that the planetary nebulae are moving at speeds greater than those of the most rapidly moving stars (on the average), but that the velocities of the spirals are so much greater still as to be of an entirely different order. He has found that the planetaries, with but few apparent exceptions, are rotating on their axes; he is adducing ever stronger evidence that the matter in the arms of spiral nebulae is moving outward along the curves of the arms. He has shown that the great diffuse gaseous nebulae have such low velocities as to be practically at rest with respect to the stellar system; and, further, that diffuse nebulous matter capable of obstructing rather than of radiating light is extraordinarily abundant. He has studied the distribution in the sky and especially with reference to the galactic plane, of stars of different spectral characteristics, of binary stars, of variable stars, of nebulae of the different types, and has found, for example, that the red stars of Class M, whether bright or faint, are distributed over the sky almost at random and that they exhibit no relationship of position to the diffuse nebulae, whereas the stars of Class B, among others, are strongly concentrated towards the plane of the Milky Way and show a marked apparent affinity for the diffuse nebulae.

While observatories and astronomers in all parts of the world have been making effective and valuable contributions in such researches, it is a matter of legitimate pride that the astronomers in our own country, using our great modern telescopes, and particularly those in our Pacific area, have been among the leaders in nearly all of them.

All this material and far more, including the ever-growing volume of data on the visual and spectroscopic binary stars, on variable stars and on solar phenomena, the astronomer is placing at the disposal of the student of stellar evolution; and it is only fair to say that the latter is availing himself of it all and of all the progress made by physicists and chemists in their researches on the properties of matter, eagerly and effectively. It would be interesting, did time permit, to follow in detail the development of evolutionary theory during the past thirty-five years, but, passing scores of valuable contributions by Schwarzschild, Eddington, Jeans and many others without a reference, I can only take time to present most summarily and imperfectly the theory which now, in its general features, commends itself strongly to the majority of astronomers. It was first proposed by Lockyer, so far as its fundamental principle goes, but it has been so expanded and enriched and in many features so radically modified by Russell and so brilliantly presented and defended by him that we commonly refer to it as Russell's theory.

Briefly, the theory assumes that in the beginning of their stellar stage all stars are of Class M. They are then bodies of gas of extraordinarily low density and of low temperature and surface brightness. As they contract they grow ever hotter and pass through the successive spectral classes towards B, but only the more massive stars can generate heat enough to reach the white-hot state required to produce spectra of Class B; the others reach their critical density at spectral Class A, F, G or even K. After this critical point in their contraction is reached the stars begin to fall off in temperature and in luminosity and gradually pass through the spectral classes in the reverse order until they again become red stars of Class M before they finally sink to invisibility. The stars on the ascending branch are, in the terminology introduced by Hertzsprung, chiefly "giants," those on the descending branch chiefly "dwarfs," the terms "giant" and "dwarf" referring to luminosity rather than to mass.

On this theory the very bright red stars of Class M must be giants of enormous volume to compensate for their low surface brightness. On the basis of observational and theoretical data Russell and Eddington, independently, calculated the "hypothetical" diameters of some of these stars, and it is one of the most cogent arguments in favor of the theory that the recent interferometer measures of Betelgeuse and of Antares at the Mount Wilson Observatory, which constitute one of the most brilliant achievements of modern observational astronomy, are in excellent agreement with these predicted values.

Innumerable difficulties remain to be overcome, innumerable questions to be answered; but in the investigation of stellar evolution as in the investigation of the form and dimensions of the stellar universe, we may at least feel that our feet are set firmly on the road to fuller knowledge.

What of the future? Prediction would be worse than vain. Who, thirty-five years ago, could foresee the discovery of star-streaming, of the correlation of stellar velocity with spectral class, of the applicability of stellar spectra to the measurement of stellar distances? One thing, and only one is certain. Never have the opportunity and the need for good work, well-planned, skilfully executed work, in observational astronomy been as great as they are to-day. In his able address to the American Astronomical Society, Schlesinger recently presented the urgent need of extensive observations of star positions to provide further data on proper motions. It would not be at all difficult to show at least equal need for measures of the radial velocities of stars and nebulae; for measures of stellar distances; for photographic investigations of nebulae and of star-clusters; for qualitative studies of stellar and nebular spectra; in brief, for extensive additions to every form of observational data on the motions and radiations of the nebulae and of the stars.

To secure these additions to our knowledge we must have observatories equipped with powerful modern telescopes and their accessory instruments, and we must have more trained observers. For material equipment and support we must look to a generous public and we shall not look in vain if we, who are learning a little about this great universe of ours, tell what we learn and make it part of the common knowledge of our time. For trained observers we must turn, first of all, to the students of our universities. I count it, therefore, a matter for special congratulation that this new observatory, the gift of a private citizen, a public spirited woman, equipped with the first powerful telescope whose *optical* as well as mechanical parts were all made in our own country, located in a most favorable climate, and directed by an able astronomer of wide experience, is so closely associated with a vigorous and rapidly developing university. It will be its high privilege not only to make significant contributions to our knowledge of the universe—knowledge that promotes the progress of which it is itself the true measure—but to inspire eager youth who, when we of the older generation one by one lay down the torch, will

> Take . . . the splendor, carry it out of sight
> Into the great new age (we) must not know
> Into the great new realm (we) must not tread.

ROBERT G. AITKEN

LICK OBSERVATORY