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SOME PROBLEMS IN FUNDAMENTAL ASTRONOMY[1]

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IN presenting the subject of fundamental astronomy before this section it has seemed proper to consider in an elementary manner, and from an observational standpoint, some of the more important phases of the work, such as the general problem of determining positions in space, the progress of work on star places and some of the problems in the solar system.

There are possibly fifty observatories in this country where some form of astronomical observations are carried on at the present. By far the larger part of this work is in the line of astrophysics or the new astronomy. The advances in this line are remarkable. We are living in an era of creation of great reflecting telescopes. In this country alone there are eight or ten great mirrors with reflecting surfaces of from 20 to 200 square feet, now in use or under construction. Explorations into the space of the galaxies appeal to the imagination, and large sums of money are subscribed for such work. There is great interest and activity in, and remarkable increase in our knowledge through, the use of the spectroscope and photography. Our publications are full of interesting information as to what is going on in the stars and galaxies, and a different size of the universe is presented for our consideration every few years.

No such expansion is noticeable in positional astronomy. Mass production of routine observations and endless computations are prosaic and uninteresting to the uninitiated, and only exceptional men revel in celestial mechanics.

In this country fundamental observations for posi-

[1] Address of the retiring vice-president and chairman of the Section on Astronomy, American Association for the Advancement of Science, Atlantic City, N. J., December 31, 1936.

tion are continuous at one observatory only; at another photographic catalogues are being determined; at a third a general catalogue is being constructed; and a limited amount of positional work is done elsewhere. As the geometry of the universe depends basically upon positional astronomy it may be worth while for a few minutes to consider some of the processes and present needs of fundamental observations and the value of the base lines they furnish for measuring the heavens.

The way in which the size of the universe is deduced may not seem so complex, but the measurements are quite restricted in precision and complicated by many physical limitations.

Primitively we may say that the universe is measured with a foot rule. Geodesists with their standard tapes measure arcs of the earth's surface which astronomical observations show subtend certain angles at the earth's center, and from this the size of the earth is deduced. Then with two points on the earth as a base line astronomers triangulate to the planets or sun and obtain the sun's distance—the fundamental unit for all measurements of celestial distances. And finally using the sun's distance as a base line the distances of the nearer stars are found, also by triangulation. To obtain the distance of the stars the tape is multiplied a thousand million million times.

Accurate measures of distances are limited to the nearer stars. No direct measures of the distances of the great mass of stars are now possible. Precision measures furnish also positions and proper motions, and the spectroscope furnishes velocities in line of sight. There are now available positions for half a million stars; proper motions for 100,000; radial velocities for 7,000; and parallaxes for 4,000 stars.

With this precision data as a basis statistical studies furnish material for indirect or inductive methods of determining distances and motions of the stars in general. The dimensions of the universe of to-day rest largely upon these statistical methods, which give approximate rather than precise results, but which are the only methods available and are indispensable. The accuracy in such results depends upon the accuracy of the fundamental data as well as upon the statistical analysis and derived formulae.

The problem, however, is not simple; the determination of the positions and motions of the heavenly bodies is very complicated, and for a clearer understanding it is convenient to have in mind a few elementary ideas as to where the observer finds himself in space, and to realize how he must spend the larger part of his time in determining his own position and motion and the positions and motions of the coordinate planes to which the celestial objects are referred.

If now from some point, fixed in space with reference to any chosen group of stars, we should space out the stars at two different epochs we should have their directions and cross motions on the celestial sphere. The apparent direction of a star would differ from the true or real direction at any instant by the amount of cross motion in the interval of time it takes light to come from the star. Our catalogues define the directions in which we see the stars, not the true directions in which they are at that instant. Groombridge 1830 is really three minutes of arc away from the direction in which we see it. A double star may make several revolutions in the time its light is coming to us. We define the directions of the planets as they are to-day; of the stars and clusters as they were years and centuries ago; and of the spiral nebulae as they were ages in the past, when the solar system was far off in space from where it is now.

But we are not at a fixed position but are moving among the stars in our local system with the motion of translation of the solar system of some 390,000,000 miles a year. At the apex of this motion the stars are apparently separating, while at 90° from it they are drifting past us by amounts depending upon their distances. As the distances of the stars have been unknown in general, the apparent motion of the star due to the sun's motion and the real motion of the star itself have not been separable. All proper motion catalogues of to-day give the sum of these two motions. The catalogues of the future must separate them. So far the value of the solar motion has varied with each group of stars chosen for a reference system.

Not only does the sun's motion affect the proper motions, but the secular aberration due to this motion changes the direction in which we see the stars by amounts varying from zero at the apex to 13″ at 90° from it, and this affects all stars alike independent of their distances. By convention, and for convenience, this anomaly also adheres to our catalogues, which give the directions in which we see the stars rather than the directions they would have if we were not moving.

For a more complete picture of the sun's motions there should be mentioned also its motion, with the local system of stars, of 200 miles a second towards an apex among the globular clusters, or around the center of the galaxy, with corresponding aberrations of 200″ or more.

We are not only moving with the sun, however, but with the earth in its annual motion of 585,000,000 miles around the sun, giving rise to annual parallax and aberration. And here again as the distances of the stars have been unknown, catalogue positions up to the present have not been corrected for annual parallaxes, though these are small.

The most noticeable change in a star's position due to the earth's motion around the sun is the annual aberration which may change its place by as much as 41″. This has been understood since accurate observations began, and they have been corrected for it. To know its true value at any instant it is necessary to know the direction and amount of the earth's motion at that time. This requires a knowledge of the size and shape of the orbit, such as the solar parallax, the eccentricity and perihelion, and the position of its plane, the ecliptic and the equinox, and also the constant of aberration. It is also necessary to know the directions, distances and masses of disturbing planets, in order to take into account their perturbations. The velocity of the earth varies with perturbations, with its motion around the center of gravity of the earth-moon system, and in its eccentric orbit.

It is realized, therefore, that before the true direction of a star at any time may be determined it is necessary to know the motions of the earth and other objects in the solar system.

The motion of the earth with the sun in space, and its variable motion around the sun, both enter into the determination of velocities in the line of sight, hence accurate tables of motion of the earth are necessary for all radial velocity results.

The most pronounced motion of which we are aware is the daily rotation of the earth, and this has determined another fundamental plane of reference, namely, the equator. But observations show that this plane is changing position among the stars with progressive and oscillating motions known as precession and nutation, which depend upon the shape, size and mass of the earth, moon and sun, and upon the elements of their orbits. For reduction of our observations it is necessary to determine the motions of these reference planes among the stars together with such constants as precession, nutation, obliquity and position of the equinox.

Besides the various motions of the observer with the earth as a whole of which we have been speaking, observations show small variations in periods of 12 and 14 months due to the variation of latitude or change of axis of rotation within the earth. Star places of the last century were uncorrected for this variation. It can be accurately determined only by observation, and is a continuing problem in position work.

Until recent years the rotation of the earth was believed to be uniform, and the earth has been used as a great clock to time the motions of the planets and stars. The evidence now is that this rotation varies and that astronomical time may vary as much as 70^s a century on uniform time. Nature furnishes other timekeepers, however. The most uniform time is determined for subdivisions of a day, by the oscillations of a crystal or a pendulum; for intervals of a year, by the rotation of the earth; and for parts of a century, by the revolutions of the moon and planets.

And finally our instruments are at the bottom of an ocean of air having refraction effects on rays of light traversing it, constantly varying with temperature, pressure, humidity and other changing conditions, the laws of which are not fully understood.

There is then no invariable point, line or plane in space to which we may tie the coordinates of the stars. We have therefore to set up a coordinate system with respect to the moving bodies in the solar system and determine its motion with reference to the stars. Professor E. W. Brown speaks of this as a moving frame of reference. Professor Lewis Boss considered that the problem of finding an invariable line of reference or direction in space is philosophically one of the most interesting problems which has been attempted in the whole range of science. Any system of reference planes and reduction constants becomes determinate only as the general motions in the solar system and the complex motions of the earth in particular become determinate.

The necessary and longer task of determining absolute or independent positions of the stars includes, therefore, that of determining the positions and motions of the sun and planets, the positions of the planes of reference and the fundamental constants of astronomy. As planetary motions may be determined only by reference to positions of the stars, continuous observations are required both of the planets and of the stars. The observations must be so planned and reduced as to define the coordinate planes in continuous motion among the stars and to furnish sufficient material for determining the planetary motions.

The process is one of successive approximation, first for the planetary motions, then for the star places. This is illustrated in history. The observations of Tycho Brahe in the sixteenth century permitted a solution of planetary motions by Kepler and his followers in the seventeenth century, which in turn made possible the accurate star observation results of Bradley and Bessel and their followers. From these came the tables and constants of Struve, Leverrier, Hansen and others, in the middle of the last century, forming the basis of observational work for the later part of the century, and resulting in the great fundamental catalogues of stars by Newcomb, Auwers and Boss. With these new positions of the standard stars the planetary observations of the last century were reconstructed into a great system of planetary and lunar tables and coordinated constants, by Newcomb, Hill and Brown. These new tables and constants, all marvels of analysis, have in turn made possible still more accurate star places, as exemplified by two recent fundamental catalogues, the revisions of Auwers and Boss. These are both of great accuracy, and upon them another solution of the solar system will doubtless depend.

The observations are tedious and the reductions exacting, but the published results are milestones of progress in the unfolding of our own system, and they form a record of the sun's long journey among the stars.

Copernicus, in replacing the earth by the sun as center of the solar system, abolished the epicycle theories of Ptolemy and the ancients and demanded new theories and new orbits for the planets. Kepler and his followers lived with great anticipation as the new laws became understood. The aim of the observers 200 years ago was a new solution of planetary motions. The positions of the stars were of secondary consideration, and were used primarily for reference points. The sidereal motions as a whole received little attention. To-day the planetary motions are still of prime importance in themselves, but take on added importance in furnishing the coordinate planes and constants necessary to define accurate positions and motions in the great stellar universe revealed to modern astronomers.

Planetary and lunar theories are marvels of mathematical expression of gravitational laws. It is astonishing how complete a solution of the complicated motions in the solar system the mathematical astronomers have developed in the last 300 years, especially in view of the fact that they had remained an unsolved riddle for thousands of years. Accurate observations are less than 200 years old, yet positions of the planets are predicted within a few seconds of arc. All the larger perturbations in our system are known. New comets and asteroids, or even new planets may be expected, but their masses are feeble, giving less concern, for instance, than the uncertainty in the mass of Venus. There are still many interesting dynamical problems to be solved, and changes in theories are expected, but we look for no large deviation from theory, and certainly no dynamical upheaval such as seen in the novae. On the other hand, the streaming of the stars and the staggering dimensions and velocities of the galaxies, indicated by statistical studies, are absorbing attention, and call for expansion and increased accuracy in precision methods. The systematic errors in observed star places and motions must be distinguished from the real motions of the stars. Heretofore systematic errors in standard proper motions have amounted to $1\overset{''}{.}0$ a century in several parts of the sky, and individual motions have been uncertain by similar amounts. A considerable part of this is due to errors in early catalogues, which can not be changed, but the influence of which may be reduced as new places are added in the solutions. A few thousand motions are now known within $0\overset{''}{.}5$, and from existing data, 100,000 may be determined within $1\overset{''}{.}0$ a century. These are quantities of the same order as some of those found for galactic rotation and for group motions. There is a need, therefore, for greater accuracy in our observations both for position and for proper motion.

The older national observatories were founded by various governments mainly to promote the interests of navigation. And the needs of navigation both for the Navy and for commerce in general are still important considerations at such observatories. Observations of the sun, moon and planets and the brighter stars are required for this purpose, and as such observations form the basis of fundamental astronomy, the government observatories have become largely the fundamental observatories. And this appears necessary. The continuous observation of these objects with the necessary exacting reductions are so time-consuming and laborious that only government, or heavily endowed institutions, can assure the required continuity and permanency.

The increase of power and speed in navigation and commerce has increased the importance of the time element, and to-day an important function of such an observatory is the determination and dissemination of accurate time. This requires the most perfect clocks and clock vaults, precision instruments and accurate star places. Free pendulum clocks carry time so uniformly that they detect minute nutations in the earth's motion amounting to $\overset{s}{.}02$ every two weeks. Such clocks at the Naval Observatory are now rated by photographic observations of transits of zenith stars each 24 hours. The zenith telescope used for this purpose gives results somewhat more accurate than those from transit instruments. The time signals are sent out under control of crystal oscillator clocks. While in the past poor clock systems produced considerable errors in observations, to-day the best clocks kept under constant temperature and pressure are appreciably more accurate than the observations.

The first substantial fundamental work was done by Bradley about 1750, using a mural quadrant and a transit instrument. The work has been continued at Greenwich since that time, a mural circle replacing the quadrant in 1812, and the transit and circle combined into a transit circle in 1850. Observations were begun at Paris about 1800; a little later at Königsberg by Bessel, using a transit circle; at Pulkowa by Struve, using the transit and a vertical circle as separate instruments; and at Washington by Newcomb, using a transit circle. And there were shorter series. These men, and their successors, endeavored to establish positions of the brighter stars with great accuracy and to accumulate material for construction of the planetary and lunar tables.

At the beginning of the last century, however, the desire for positions of more stars and of the faint stars diverted observational facilities, to a considerable extent, into mass production of less accurate positions, as illustrated by the great zone works of Lalande, Bessel, Argelander and others. And soon after the middle of the century cooperative work was started to determine fairly accurate positions of all stars to the ninth magnitude and fainter. This was begun some 70 years ago and the last southern zones are just now being observed. Twenty observatories or more have cooperated in the program. This work is now being repeated, using photographic plates, the transit circles furnishing positions of the 25,000 reference stars required for plate reduction. One half the program has been carried out this way in ten years. Additional instruments have been devoted to the plan of the astrographic catalogue for positions of all stars to the eleventh magnitude, started some years later and still far from completion. It has been impossible to carry out much of the meridian work planned for this undertaking. Thus the meridian instruments have been absorbed in mass production of only fairly accurate positions of something like a third of a million stars, and to some extent this has been with a sacrifice of fundamental observations.

The possibilities of the photographic plate furnishing positions of the fainter stars, suggested by the astrographic work, has, however, proven to be a turning point in positional astronomy. Very valuable work by Professor Schlesinger has shown that it is now possible to cover an area of 100 square degrees or more on one large plate. This reduces the number of reference stars required for photographing the sky to less than 50,000, and it reduces the task of the transit circle to one tenth that contemplated for it 50 years ago. Meridian observers welcome heartily the advent of photographic positions with the prospect that the great mass of faint star work may be cared for in this way and with the hope that more time may now be spent on fundamental work.

The recommendations of the International Astronomical Union at all its sessions have been more and more to encourage meridian work of greater precision on a well-spaced system of the brighter stars, and to carry to completion the great photographic surveys for positions of fainter stars. Dr. Kopff recently emphasized the need of series of meridian observations of absolute character and of the highest accuracy possible. He also expressed the view, emphatically, that long series of fundamental observations on the same instruments are a work of the highest value that astronomers can offer their science.

The change from the old to the new general plan for meridian work has been modifying observing programs of leading instruments for some years, and the new field is well established.

The new plan calls for a fundamental system of 2,000 or 3,000 stars to be kept under constant observation together with the sun, moon and planets.

Based upon this system, positions of some 40,000 or 50,000 standard stars, well spaced in the sky and including most of the stars brighter than the eighth magnitude, will be determined by meridian observations.

Based upon these standard stars, large photographic plates will give positions of all stars to ninth or tenth magnitude, and these in turn will furnish positions for all other photographic work.

In this way star places will become far more uniform and accurate by being based upon the same system and upon a standard system. This will do away with some of the accidental and systematic errors now attaching to zone catalogues based upon reference stars observed on individual instruments. By proper cooperation transit circles will be able to keep the standard stars under observation.

The great value of the photographic plate is in its economical and accurate differential spacing of large numbers of unknown stars among those whose positions are already known. At present photographic methods contribute little to absolute positions. The plate has neither divided circle nor uniform clock for independent spacing from pole to pole or from equinox to equinox. Meridian observers are aware of the fact that the plates must reproduce only too faithfully the systematic errors in their standard systems. Recently there is promise of using photographic plates, not for absolute spacing, but in determining the motions of minor planets relative to stars along their path. A difficulty here is to properly refer these stars to standard systems and coordinates. This is a difficulty in all differential work, where the zero points of the clock and circle or of the plate are determined from observations of reference stars only.

The fundamental catalogues which have been the standards since 1900 are now to be superseded by the Third Fundamental Catalogue of the Berliner Jahrbuch containing 1,500 stars and the new Albany General Catalogue of the Carnegie Institution with 32,000 stars. These two catalogues agree closely, and together will serve as bases of reference for positional astronomy for years to come. Inherently such catalogues are old before they appear, and these are already a third of a century old. They are most accurate at their mean epoch, about 1900. The FK3 system is being used as a basis of photographic reobservation of all stars to the ninth magnitude, and it will be used in all national almanacs after 1939.

The fundamental catalogues have had from 1,000 to 1,500 of the historical bright stars, whose motions are now well known. In order to meet the needs of photographic work for more stars, and fainter stars, the Paris Conference, 25 years ago, increased the standard list to 3,000 by adding well-spaced stars from fifth to seventh magnitude. This was a matter of mature consideration by eminent astronomers in the conference. These stars have been well observed since that time and should be kept in the standard list. There is now another proposal to add 3,000 stars from the sixth to the ninth magnitude. Comparisons of observational catalogues with standard catalogues containing but 1,500 stars—one to each 27 square degrees—give very unsatisfactory systematic corrections. Moreover, it is very hard to get a sufficiently rigid reduction of an observational program with so few standard stars among the program stars. This has been shown by the discontinuities from zone to zone in the A. G. Catalogues and elsewhere. More fundamental stars are needed. The conclusions of the Paris Conference were that observations of the historical stars must be carried on with those of any new list. And this is still the opinion, and it is important. Dynamically the solar system is referred to them, and must continue to be. The motions of the bright stars are the best known, and they alone can be observed in the daytime—a necessity in this work.

A considerable portion of the information concerning the general structure of the universe comes from statistical studies of the fainter stars. The relation of the brighter stars to the fainter stars or of the local system to the more distant stars, clusters and nebulae is not at all well understood. The general motions in the solar system, such for example as the motion of the equinox, have been with reference to the nearer stars. If these are rotating or streaming with reference to distant objects the constants of our system may not be applicable to cosmic problems at large. And again a motion of the equinox referred to stars with large proper motions and in rotation will not represent the true dynamical precession of the earth. In the past all determinations of the precession constant have been made assuming a random motion amongst the stars used. Recent researches indicate the motion in the local system are not random, and that the local system has a high velocity as compared with more distant objects. The sun or the nearer stars may in time be found to have accelerations. Doubtless the spiral nebulae would afford a better reference system, but this would be possible only through comparison stars. Such observations, however, are now being made. The solar motion relative to the spirals is probably unappreciable with present measurements, and a true precession would result from such a solution. We can not, therefore, establish the absolute motion of the sun in space, but only its movement with respect to selected groups of stars. The growth of stellar dynamics has thus greatly enlarged the demand on fundamental observations, which now become concerned also with precision measures relating to objects in all parts of space.

With more recent instrumental methods for eliminating personal equation or care in determining it, observations are giving positions of the fainter stars quite correctly spaced as regards the bright stars. This was not realized in the past nor have corrections for it been satisfactory, the result being that the proper motions of the bright and faint stars differ, as though the bright stars were rotating or streaming on the faint background. It seems desirable for this reason also to have faint stars in the standard system in order to properly redetermine the systematic corrections to old catalogues and thus determine better motions for faint stars in large numbers. Such standard stars should be selected by magnitude, type and small proper motion so as to represent a distant and stable system.

The practical astronomer must spend considerable time in care, improvement and investigation of his instruments, notwithstanding that they are among the most highly developed instruments in the world.

The transit instrument and a vertical circle, used separately or combined into a transit circle, are the standard instruments for fundamental observations, though other types of instruments are being tried. The errors of all divisions on the graduated circles are carefully measured, and the irregularities in the pivots and micrometer screws are investigated. The spider webs used to follow a star across the meridian in the instruments at the Naval Observatory are driven by tiny synchronous motors built into the micrometers. This, together with the use of reversing prisms and screens, eliminates a very large part of the personal equation of the observers, and that remaining is determined from moving artificial images.

Twelve-hour circumpolar observations define the pole point of the instrumental meridian independent of star place, and stable meridian marks are used for determining very accurately the variation of azimuth.

In all absolute declination work the pole point of the graduated circle is determined from circumpolar observations. While with adopted flexures and refraction two standard instruments agree closely at the pole, they sometimes differ as much as 2″ in going 90° from the pole. This is attributed largely to flexure, the determination of which has always been unsatisfactory. Some instruments are provided for interchange of object glass and eye end, but observations show that in most cases such interchange fails to eliminate the flexure. Reflection observations have never been conclusive as to flexure. New instruments show no improvement over old ones as to this error.

The best determinations of refraction are possible for observatories at high latitude such as Pulkowa, where stars south of the zenith may be observed also below pole. The Pulkowa refraction tables are now generally used and require little correction. The small deviations from them given by solutions of circumpolar observations represent mostly local conditions such as refraction around or in the building, location of thermometers, and daily and annual variations in such conditions. Such a solution represents the best value for reduction of work on the instrument used and possibly need not apply to other instruments with different local conditions. Modern buildings are constructed to allow free circulation of air and a wide exposure of the instruments to the open sky. Comparisons of observations in northern and southern hemispheres furnish additional information as to refraction, especially that towards the equator. In some locations the refraction seems to be different north and south of the zenith. Refraction solutions are frequently unsatisfactory, and both flexure and refraction require a careful investigation for each instrument.

For many instruments the pole point is the only zero point of the circle determined independently. Where the sun and planets are observed, however, a much stronger method of reducing declinations is possible, in that an additional point 90° from the pole and on the opposite side of the zenith is available. This principle was used by Newcomb in establishing his equatorial declinations, and these have held good for 70 years. It has been used in the new catalogue by Dr. Kopff, who expresses the opinion that Newcomb's method of using the sun and planets seems to be the best way of finding the errors of an instrumental system in declination at present. The determinations of the position of the equator and equinox are now made to depend upon day observations of the sun and inner planets, and also upon night observations of the moon and outer planets which are observed under the same conditions as the surrounding stars. The asteroids may also be used for this purpose. The differences between the day and night observations are determined from observations of bright stars, both day and night. Declination observations with different instruments reduced with solutions for both the pole and the equator agree within $0''.25$ throughout the meridian.

For elimination of periodic errors and day terms observations extend over 12 to 24 hours each day, and include observations of the sun, Mercury and Venus, and bright stars during the day; observations of clock and azimuth stars, evening and morning 12 hours apart; and observations of the moon, planets and standard stars throughout the night.

It requires five to ten years to observe a catalogue of stars, and several years more to complete the reductions. The planetary observations continue with each catalogue. The final reductions of such work furnish corrections to the tabular positions of the planets and stars adopted for comparison, and corrections to reduction constants. From the circumpolar observations values of the constants of aberration and nutation may be determined. Newcomb's values of these constants are closely upheld by modern observations. Investigations of results from recent sun and planet observations uphold also Newcomb's position of the equator among the stars and his motion of the equinox. The right ascensions of his standard stars, however, must be decreased by $^{s}.04$ or $^{s}.05$ to satisfy observations with traveling threads.

The comparisons of such independent catalogues of stars taken at widely different epochs furnish the proper motions of the stars, and the combination of such catalogues forms a fundamental catalogue. In the recent fundamental catalogue FK3 the system has been based on the more accurate independent observations since 1845, and Newcomb's value of the precession is used. There are now possibly 3,000 stars whose positions are known within $0''.1$, and, with application of systematic corrections, 300,000 within $0''.4$ or $0''.5$.

There is, however, a need for observations with smaller systematic errors. For this it is necessary to have more information as to day terms and refraction effects; better determinations of and greater elimination of personal and instrumental errors; improvements in instrumental equipment; and rigid observing programs. Work in astrophysical lines and with large reflectors, with its speedy output and interesting results, is very tempting. The tendency in this direction at fundamental observatories should, however, not be allowed to interfere with their already limited programs of fundamental work. The problems of astronomy are now so diverse and complex that the greatest success may be attained by concentrating the energies of each institution upon its major program and its supporting activities.

One half the observations used by Newcomb in his tables of the inner planets were made at two observatories only—Greenwich and Paris—and these show marked systematic differences. There are instances also where longitudes of the sun from two different instruments differ a second of arc for a number of years at a time—a quantity the size of fluctuation. There are small discordances between occultation and meridian observations of the moon. Much of the difference between theory and observation in the longitude of the moon is attributed to fluctuation in the earth's rotation. This follows no formula, and it can be determined only by continuous and uniform observation. Dr. Ross found a lack of observational material for his work on Mars. He also called attention to large systematic differences between mean results from different instruments, and expressed the opinion that more accurate positions than are now available are necessary for proper determination of fluctuation. Positions of the equator and the equinox from different series may differ a third of a second of arc.

Continuous observations of this nature are now being carried on at three observatories, Greenwich, Washington and the Cape, with shorter series at Pulkowa and elsewhere. There is clearly a need for another such series. For this the instrument should be in the southern hemisphere, south of 40° south latitude, so as to permit a satisfactory solution for the pole. To insure continuity and permanency it should be under government supervision. I believe it would be of great help to observational astronomy of to-day, and of lasting benefit to astronomy in the future, to establish another series of continuous observations of the sun, moon and planets and standard stars in the southern hemisphere.

And finally a word may be said as to future reductions and theory. The new fundamental catalogues will require new systematic corrections to all the 600 catalogues of the past, with corresponding changes, averaging 0″.2 or 0″.3, in all centennial proper motions. Present programs are furnishing large amounts of material for determination of proper motions, and these will need to be discussed for general motions in space and for a new value of the precession constant. Theoretically, Newtonian dynamics define precession, but the constants of the earth-moon-sun system entering into it are not sufficiently determined to give a complete solution. In fact, the best value of the ellipticity of the figure of the earth is determined from the observed precession. The precession is therefore determined by combination of theory and observation. The best determinations at present are based on the observed motions of some 6,000 of the brighter stars, but better material, and a much larger amount, will soon be available for discussion of this important constant. It is complicated by the motions of the comparison stars, including a possible galactic rotation of 1″, and by dynamical relations in the solar system, including also a relativity effect of 2″.

The present planetary and lunar tables are very accurate, and with minor corrections will be sufficient for a long time. They depend largely upon observations in the last century during which astronomical time gained continuously on uniform time. Planetary motions should represent uniform time if it is found possible to define such time. The knowledge of the geophysics of the earth is so limited that tidal retardation can not be accurately computed, nor can fluctuation be predicted. The fluctuations in the longitudes of the sun and moon are not well correlated. Observations in declination as well as in right ascension should be discussed for the longitudes. The difference between theory and observation of the moon is now 16″. The correlated residual for Mercury is 6″, but observations give 3″. There is a similar discrepancy about the year 1785.

Planetary tables include sufficient terms in adopted theoretical expansions to give tabular positions within 1″. Single observed positions approximate this, and normal positions are considerably more accurate. It may be possible, therefore, now to determine more exact coefficients in the expansions and to include higher terms. Residuals of 5″ in the longitude of Neptune, which has been observed but part way around its orbit, may be satisfied by simple changes in its elements. There are residuals in longitude for several of the other planets. Pluto suggests expansion in planetary theories, and the asteroids and satellites constantly furnish new and interesting problems. The mass of Mercury is uncertain, and the meridian observations of this planet need further discussion. The secular motion of the perihelion given by observation is uncertain by a number of seconds, the transits and the meridian results being discordant. The theoretical motion has been computed five times with a range of 3″, using the same masses of the disturbing planets. The mass of Venus is uncertain by one part in a hundred, and this leads to uncertainties in the periodic and secular terms in other planets depending upon this mass, such as the secular variation in the obliquity for which discordant results are obtained, and an uncertainty of 3″ in the motion of Mercury's perihelion. There are rather large residuals in the observations of Mercury and Venus near inferior conjunction.

The observations of the moon need to be corrected for irregularities of the limbs, and the residuals in latitude and longitude require further study.

There is some question as to the value of the aberration deduced from latitude work. The visual and photographic zenith results give discordant values of this constant, but very accurate values of the constant of nutation. To avoid confusion it would seem best not to change the fundamental constants now in use, except the equinox, until a complete new adjustment can be made. These problems have been suggested by the observations, and there are many others awaiting investigation.

Some 40,000 observations of the sun, moon and planets have accumulated in the 40 years since the construction of the present tables. This great mass of observational material has nearly as much weight as that used in the tables. It is as yet largely undiscussed. There are also some older series needing rediscussion.

Modern calculating machines are becoming very valuable for carrying out the long numerical operations required in such computations, and with a minimum of labor and a maximum of efficiency.

Contributions to astronomy from endowment funds have been generous. The great Albany catalogue, just being completed by the Carnegie Institution of Washington, will be of great value to astronomers. The results from Mt. Wilson are inestimable. Many important investigations have been made possible by grants from various research funds, and much more support is desirable.

The present generation has had many men of outstanding ability in this work who are passing on a heritage to the younger men of to-day. It is an open and inviting field for investigation. In our classrooms and observatories there may be young men with special talent for such work. I know of no greater help to astronomy nor of any more profitable use of endowment funds than that those who are directing larger astronomical activities should make provision for men of marked ability to study with theoretical men and at fundamental observatories, and later, furnished with assistants and facilities, to make a complete discussion of all observations into a new and comprehensive solution of planetary motions.

I leave with you the suggestion that a more complete solution of the motions in the solar system is now an important problem in fundamental astronomy.

OBITUARY

JESSE EARL HYDE

JESSE EARL HYDE, professor of geology at Western Reserve University, Cleveland, Ohio, died on July 3, 1936. He was born on May 2, 1884, in Rushville, Ohio, the son of Eber and Flora (Johnson) Hyde. He passed his boyhood in Lancaster and attended Ohio State University, graduating in 1906. He held minor positions in Harvard and Columbia Universities and became assistant professor of geology in Queen's University, Kingston, Canada, in 1911. From this position he was called to Western Reserve University as associate professor in 1915, becoming professor after the death of Professor Cushing in 1921.

The father of Professor Hyde was a pharmacist by profession and a geologist by avocation. There was built an annex to the family home, a room devoted to collections and work in geology, and in this room Jesse spent most of his boyhood leisure. During those years and later there were collected thousands of specimens, and these are now in the possession of Western Reserve University.

A discussion of Hyde's work and influence during his Cleveland years falls somewhat naturally into certain categories. The first to be discussed is his interest as a teacher, one might say also, as a conversationalist. In all his personal contacts he promptly struck a responsive strain, and when he spoke, no one, in his class or outside, failed to give him attention. Probably his most stimulating teaching was in the course called "Evolution of the Earth and the Ascent of Man." These class lectures were so inspiring that a number of his colleagues joined themselves to his listeners. His fund of experience, his philosophical interpretations and his manner of approach were such that his auditors received a stimulus which was high above the ordinary classroom type.

In 1922 Professor Hyde became formally associated with the Cleveland Museum of Natural History, then in its early stages. He was curator of geology until his health in 1931 required the severance of the more formal connection. However, he continued in the capacity of adviser and volunteer curator after that date. The work of those years was three-fold. He left the entire geological collection completely labelled, catalogued and arranged as a study collection. He directed the collection of fossil fishes, and the Cleveland Museum now possesses the best collection in existence of Devonian fish in the Cleveland shales. He was justly proud of the J. H. Wade gem collection which he arranged, a laborious and rewarding piece of work. It has been called the best exhibited gem collection in America.

He worked many summers under the Ohio State Geological Survey. His work on the Waverly Formation is of considerable magnitude, but has not yet been published. The "Camp Sherman Quadrangle" (Geological Survey of Ohio) is a monograph of 185 pages. About fifteen other publications are of lesser size. He was on the Geological Society of America Exchange Committee, in charge of the exchange, distribution and deposition of geological publications from all over the world.

Professor Hyde often deplored the sacrifices he made in attending committee meetings in the adminis-