Problems of Fundamental Astronomy.¹

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THE science of astronomy has, in the past twenty or thirty years, developed most remarkably. The marvellous applications of photography and spectroscopy on one hand, and the sudden growth of statistical stellar astronomy consequent upon the discovery of the two star-streams on the other, have led to so many unforeseen results and so many new points of view, that it almost appears as if the whole science were born anew and the astronomy of to-day had only very slight connexions with that of the last century: we are apt to think that the great problems of the past have lost all their interest to us. This, however, is not so. On the contrary, I think the central problems of fundamental astronomy have gained an enhanced importance even by the newest developments of the science.

Astronomy is essentially the science of space and time. It is not my intention, in thus assigning to astronomy this wide field, to annex to it the whole of physical science. On the contrary, I am quite content to consider astronomy only as a special branch of physics, but, having at its disposal the largest spaces and the longest times, it has generally had the last word in all important questions. To mention only a few cases at random: the discovery of gravitation, of the finite velocity of light, and of aberration, all these are astronomical discoveries, and the three crucial tests of Einstein's theory are all three astronomical.

In our exploration of space and time we are compelled to make all our measures from this earth, to which we are tied, as a starting-point. The problems of fundamental astronomy are those which arise from this fact, that all our observations are necessarily referred to a moving origin. These problems are, from their nature, not very liable to change of aspect with time or fashion; they are essentially the same to-day as they were in the time of Hipparchus, the founder of astronomy, and they will remain the same so long as science lasts, and will require ever more accurate and more complete solutions, as we penetrate more deeply into the constitution of the universe. Fundamental astronomy thus consists essentially of a scrutiny of the last decimal place. This striving after extreme accuracy, this fidgeting over small quantities, may appear uninteresting, or even pedantic. But we must not forget that great problems always turn about the measurement of small quantities.

The problems of fundamental astronomy are, of course, all interconnected with each other, but, for the sake of clearness, they may be classified under three heads. There are, first, the problems connected with the system of constants. The motion of the earth, and the system of measurement based on it, are defined by several numbers, such as the solar parallax, the constants of precession and nutation, the ellipticity, the mean radius and the mass of the earth, etc. Between these several constants there exist relations, connecting two or more of them with each other and with other universal constants such as the velocity of light and the constant of gravitation. The problem here is essentially one of adjustment, so as to get a consistent set of constants satisfying all the connecting relations. The set of constants in actual use in the national ephemerides is not consistent. The discordances are, however, not very large, and changes should not be introduced unless by general international agreement.

¹ Synopsis of a lecture delivered at the Imperial College of Science and Technology, South Kensington, on May 7.

Another set of problems are those connected with the rotation of the earth. The paramount practical value of this rotation is that it is used as our standard measure of time.

Time is measured by observing the changes occurring in some physical system—*i.e.* in the relative positions of some material bodies, which positions at any time are determined by our theories, so that from the observed positions we can infer the time. Such a mechanism—by preference periodic—that is used to measure time may conveniently be called a "clock." But there is no absolute measure of time, nor an absolute test of the accuracy of any clock; we can only test one clock by another. If the two do not give the same time, then one or both must be wrong, *i.e.* our theories of the mechanism of one or both must be incomplete. The standard clock to which all others are generally referred is the rotating earth. Is this standard absolutely trustworthy? Do all observatories give the same time, and if so, is this a truly uniform time? In other words: does the earth rotate as a rigid body, and if so, is this rotation strictly uniform?

It has long been suspected that the earth's rotation is very gradually slowing down, owing to the friction of the tidal wave.² But lately other doubts have arisen as to the trustworthiness of our universal standard. As a matter of fact, it is not the rotation of the earth, but the rotation of a definite point on the earth—Greenwich Observatory or any other observatory—that is used as our standard, and now that the wireless distribution of time signals has made comparisons so easy, occasional discrepancies between the times of different observatories, amounting sometimes to several tenths of a second, have come to light.³

It appears probable that these are due to errors in one or more of the parts of the mechanism used to determine the time at some or all of the observatories—the transit instruments, the clocks, the astronomers—but it also may be that they are due to real differences in the rotation of the different observatories, which would mean that the earth does not rotate as a rigid body, but some parts of its surface are moving relatively to other parts.⁴ Here evidently is a most important problem, the solution of which must be found sooner or later.

Besides the rotating earth, we have other "clocks," of which the moon must be mentioned in the first place. It is well known that in the motion of the moon there are irregularities of a much longer period, called "fluctuations" by Newcomb, for which no explanation has yet been found. Brown⁵ and Glauert⁶ have pointed out similar irregularities in the motions of the sun, Venus, and Mercury. If this were confirmed, and if also other bodies—especially Jupiter's satellites—should show the same thing, then it would become very probable that the true origin of these fluctuations is in the rotation of the earth, or at least of the outer crust of the earth.

Other problems connected with the rotation of the earth, and the question whether it rotates as a rigid body, are those involved in the variation of latitude.

² Taylor, Mon. Not. R.A.S. lxxx. 308; Jeffreys, *ibid.* 309.

³ Sampson, Mon. Not. R.A.S. lxxxii. 215; Dyson and Bowyer, *ibid.* lxxxii. 193.

⁴ Dr. Innes (Johannesburg Circular 55) has recently directed attention to irregularities in the moon's motion of the same character as the discordances between the times of different observatories referred to above. But these are derived from several observatories, giving concurrent results, so that it would appear that the error is in the moon, and not in the time.

⁵ Brit. Assoc. Report, Australia, 1914.

⁶ Mon. Not. R.A.S. lxxv. 489.

There seems to be evidence⁷ of sudden as well as slow and continuous changes, which, if they are real, may be due either to shifting of parts of the crust of the earth relatively to each other, or to a slow sliding of the whole of the crust over the core.

All these problems, which evidently are of the greatest importance not for astronomy alone, depend for their solution on very small quantities which even now only begin to come within the reach of our most accurate measures and most refined discussions.

The third set of problems of fundamental astronomy concern questions relating to the positions and motions of the fixed stars. Bessel's great work called "*Fundamenta astronomiae*" consists of a careful discussion and synthesis of the observations made by James Bradley as Astronomer Royal at Greenwich upon the positions of the stars.

Indeed, the positions and motions of the "fixed" stars are the basis on which the whole structure of astronomy rests. The manner in which these positions are determined is forced upon us by our location on the moving earth. The accumulated labours of astronomers since the commencement of accurate observing by Bradley have resulted in a system (or rather three systems, differing by small, but not negligible, quantities) of positions and motions of the stars. These are referred to a frame of reference, which is defined by the motion of the earth, and consisting of the equator, and a zero point on it. Both the equator and the zero point are moving. It need scarcely be stated that the formation of such a system of positions and motions of stars is a most intricate and difficult problem, and we must confess that it has not, so far, been solved in a manner which satisfies the demands of statistical astronomy and cosmogony.

The system which is generally considered the best of those now in use, that of Boss, is by no means perfect: large errors in it are not at all improbable.⁸ These errors are errors of the system, not of the individual star-positions, and the question naturally arises: Is an "absolute" system at all necessary? Strictly absolute, of course, it is not: all systems of reference are relative. By "absolute" we mean relative to the inertial frame defined by the motion of the earth in the solar system. But is it necessary to base our system of star-positions on this motion of the earth? Would it not be much more natural, and much more simple as well, to have relative positions and motions of the stars with regard to one another, or to the general average of them?

Many astronomers are inclined to answer this question in the affirmative, and to consider the absolute system more as a time-honoured institution of our predecessors, a venerable relic from the pre-photographic days, than as a useful and necessary adjunct of modern stellar astronomy. In fact, by the application of photography, we can easily derive relative motions, or motions of individual stars relatively to the "background," with an accuracy which many times exceeds that attainable by fundamental methods.

By the blink-microscope we find, with comparatively very small labour, proper motions of very satisfactory accuracy referred to the background of faint stars in the area examined. Of course this "background" is a rather loosely defined frame of reference, and we have no guarantee that the motions of stars in different areas of the sky are really referred to the same frame. A more elaborate method of referring the relative motions determined photographically to a quasi-absolute system is proposed by

Kapteyn.⁹ This method, however, depends on the hypothesis that the sun's motion relative to faint stars is the same as that relative to bright stars. This is why I call it a "quasi-absolute" system. Are not the proper motions derived by these and similar methods quite as valuable as those found by fundamental methods?

My answer is decidedly in the negative. We cannot do without the "absolute" system of fundamental astronomy. The value of that system is not that it is attached to the earth, but that we know exactly what the frame of reference is and that it is a rigorous system, giving certainty that all motions are really referred to the *same* frame. To see the importance of this, I will put some questions, which cannot be answered until we have a fundamental system including the faint stars.

Is star-streaming a universal phenomenon, or is it local, and in the latter case, how far from the sun does it extend? Do the Orion-stars take part in the star-streaming or not? Is there a systematic motion of faint stars relatively to bright stars; or in other words, is the average motion in space of the stars independent of their brightness?¹⁰ Is there a rotation of the system of stars as a whole?

These and similar questions are again examples of great problems the solution of which depends on very small quantities. These small quantities, the proper motions of faint stars, cannot be profitably discussed unless we have the certainty that these motions are referred to a rigorous system.

The necessity of a fundamental system being granted, we must next ask: how are we to improve and extend our present system? Must we, in order to establish an absolute system, necessarily retain the old methods, or can we find other means? Is the meridian instrument to remain the only one by which star places are to be determined? To this question I wish, as emphatically as to the former one, to answer in the negative. We must look for other methods, if it be only to verify the results from the meridian work.

Here I think is the greatest problem, and the most urgent problem, of fundamental astronomy. It is twofold: the determination of the positions of the stars, and that of their motions. We must thus not only establish a rigorous and faultless system of star positions for the present day, but also strengthen as much as possible our knowledge of the positions in the past. These latter as now used depend practically exclusively on Bradley's observations. But there are other data available, though not yet, or not yet sufficiently, reduced. Among these the most important are the rich mine of material still lying unused in the observations made in the last quarter of the eighteenth century and the first quarter of the nineteenth by Hornsby and Robertson at Oxford.¹¹ I think the careful reduction of these observations, which are of the same excellent quality as those of Bradley, is one of the most urgent demands of fundamental astronomy.

As to the means by which the modern positions must be determined, I will not attempt now to enter into details regarding the methods which have been, or may be, proposed to supplement the classical meridian methods. All I wish is to convey an idea of the meaning and the importance of the problems of fundamental astronomy, and to show that far from being uninteresting remains of a past period, their solution has become even more urgent by the newest developments of several branches of modern astronomy.

⁹ Groningen Publications, 28.

⁷ Lambert, U.S. Coast and Geodetic Survey, Serial No. 183, giving many references to other papers.

⁸ See e.g. Kapteyn, B.A.N. 14.

¹⁰ A considerable difference in average velocity would arise if the percentage of high-velocity stars (cf. Oort, B.A.N. 23) were not the same for all magnitudes.

¹¹ See Rambaut, Mon. Not. R.A.S., lx. 265.