PROCEEDINGS OF IAU COLLOQUIUM No. 9, THE IAU SYSTEM OF ASTRONOMICAL CONSTANTS, HEIDELBERG, 12–14 AUGUST 1970

B. EMERSON and G. A. WILKINS

1. General Introduction

The principal purpose of IAU Colloquium No. 9 on the IAU System of Astronomical Constants was to discuss whether further action should be taken to revise those fundamental constants (namely the constants of precession and nutation and the system of planetary masses) that were left unchanged when new values of the other constants were adopted at Hamburg in 1964. The opportunity to discuss other relevant matters was also taken.

The scientific programme was arranged by the Organising Committee of IAU Commission 4, namely: G. A. Wilkins (President), J. Kovalevsky (Vice-President), G. M. Clemence, G. A. Chebotarev, R. L. Duncombe and W. Fricke. The Local Organising Committee consisted of members of the staff of the Astronomisches Rechen-Institut, namely: W. Fricke (Director), S. Böhme, T. Lederle and J. Schubart. A complete list of the 30 participants is given on pp. 148–149.

The meetings were held, at the kind invitation of the University of Heidelberg, in the rooms of the Geological Institute. Generous financial assistance was given by the Federal Republic of Germany and by the Government of Baden-Württemberg, and some travel grants were given by the International Astronomical Union.

An informal gathering of the participants was held at the Astronomisches Rechen-Institut during the evening of Tuesday, 11 August. The Colloquium was formally opened at 1000 a.m. on Wednesday, 12 August by Dr S. Böhme on behalf of Professor W. Fricke, who was unable to attend owing to a recent car accident. (Many participants were, however, able to visit Professor Fricke in the nearby hospital during the course of the Colloquium.) The permanent Chairman of the Colloquium was G. A. Wilkins. The principal topics discussed at each session were as follows:

Wednesday, 12 August	
1015–1210	The determination of the constant of precession.
1500–1800	The secular variation of the obliquity of the ecliptic, and the series and constants for the nutation.
Thursday, 13 August	
0900–1220	The system of planetary masses.
1500–1730	The arguments for and against changing the precessional constants.

Celestial Mechanics **4** (1971) 128–149. *All Rights Reserved*

Friday, 14 August

0900–1200	Various topics including: the standard equinox of 2000.0, the *E*-terms of aberration, the definition of the astronomical unit, geodetic constants for the Earth, ephemeris time and the specification of the IAU system of astronomical constants.
1500–1800	A detailed consideration of the draft resolutions, leading to the final resolutions given on page 147.

Papers formally presented at the Colloquium are given in full on pages 150–280. A large part of the Colloquium was, however, spent in general discussion and no attempt has been made in the following report to minute the proceedings in detail. The material has been summarised and re-arranged, and some additional explanatory material has been inserted, in an endeavour to present an account that will be suitable for non-specialists. The resolutions that were finally adopted were discussed by Commission 4 at the following General Assembly at Brighton and a report of those proceedings, and of the action taken, will be found in *Trans. IAU* **14B**, 1971, pp. 79–85.

2. Background to the Colloquium

The Chairman opened the scientific proceedings by giving a summary of the background to the Colloquium. The use of standard values of the principal astronomical constants originated at conferences held in 1896 and 1911, and was confirmed at an IAU symposium held in Paris in 1950, when it was also recommended that ephemeris time should be introduced. (See *Exp. Supp.* (1961), pp. 7–9 and 168–202, for further details and references.) The subsequent developments in radar astronomy and space research led to the determination of, and requirement for, more accurate values of some of the constants, and so at IAU Symposium No. 21, which was held in Paris in 1963, it was recommended that new values should be introduced (*Bull. Astron.* **25**, 1–324, 1965). A working group was set up, and its report was adopted at the IAU General Assembly in Hamburg in 1964 (*Trans. IAU* **12B**, 593–625, 1966). No change was made in the constants defining the relative positions of the equator and ecliptic, or in the system of planetary masses, since sufficiently accurate values were not then available to justify any change.

As a result of discussions at the IAU meeting in Prague in 1967, and of subsequent correspondence, it was agreed by the Organising Committee of Commission 4 that a Colloquium should be arranged in order:

(a) to review the evidence for considering improved values;

(b) to review the arguments for and against making further changes in the system, and;

(c) to recommend to Commission 4 what further action, if any, should be taken to prepare for a formal decision by the IAU General Assembly in 1973.

The number of participants, and the number of formal papers, were kept small in order to provide suitable conditions for full and free discussion of the issues involved. The aim of having representatives of all relevant interests at the Colloquium was not fully achieved; in particular, the Organising Committee was disappointed that no astronomer from the Soviet Union was able to attend.

3. Determination of the Constants of Precession

A summary of the invited review paper by Fricke (p. 150) on the determination of the constant of precession was presented by Schubart. The previous survey by Böhme and Fricke (1965) at IAU Symposium No. 21 in 1963 had concluded that the value of the correction Δp_1 to the adopted value of the luni-solar precession lies in the interval $+0''.65$ to $+1''.50$ per century. Subsequent determinations based on the use of fundamental proper motions are compatible with a correction of $+1''.10 \pm 0''.15$ per century. The error in Newcomb's determination appears to be a consequence of systematic errors in the proper motions in declination of the Bradley stars used. While one of the two determinations from proper motions measured with respect to galaxies is in agreement with the above value, the other one deviates by an amount of the order of its error. A satisfactory determination from planetary observations has not yet been made, nor is one expected.

In a later contribution Clube claimed that the derivation of the constant of precession from fundamental proper motions is very sensitive to the model of the stellar motion that is adopted. In fact, the discrepancies between the separate solutions in R.A. and Dec. obtained by Newcomb (1897) were shown by Hough and Halm (1910) to be largely removed when account is taken of the distribution over the sky of the two stellar drifts postulated by Kapteyn. Current procedures, which rely on an asymmetric distribution of stars ($\delta > -20°$), are based on the determination from proper motions of a linear vector component, arising from the solar motion, and a small rotation vector. Although the near-perpendicularity of these vectors could be significant, the rotation vector is normally considered to be partly composed of a rotation in the plane of the Galaxy and a residual precessional rotation. Any real departure from such a simple kinematic model could seriously falsify the solution; Mineur (1929), for example, has suggested that there is evidence for a shear in the stellar-velocity field at right-angles to that which would result from differential galactic rotation. Although none of the suggested variations in the stellar-velocity field can be regarded as well-established, their possibility or plausibility cannot be denied, and Clube concluded that in these circumstances it would seem premature to adopt any correction to the precession constant arising from any method using a very simplified model of stellar kinematics.

Sinzi (p. 273) reported that he had determined from the proper motions of Cepheid variables corrections that were very similar to those obtained by Fricke.

The results of recent analyses at the Lick Observatory of the proper motions of 1898 AGK3 stars measured with respect to galaxies were described by Vasilevskis (p. 163). Corrections to the precessional constants are determined by analysing the differences between the Lick proper motions and those in the AGK3 catalogue. The aim was to look for a rotation of the equatorial frame of AGK3 with respect to the fixed frame of the galaxies; the three components of such a rotation are denoted by ΔD (about the direction of the equinox), Δn (about the direction of R.A. = 90°, Dec. = 0°), and Δk (about the direction of the celestial pole). The results were generally in the region of $\Delta n = +0''.3 \pm 0''.1$ and $\Delta k = -0''.5 \pm 0''.1$ per century; the reality of the solutions for ΔD is doubted. The results correspond to a correction $\Delta p_1 = 0''.8 \pm 0''.3$ per century. It is, however, not yet clear whether the difference between this and Fricke's value is significant since only the fainter AGK3 stars could be used. (The proper motions were based on first-epoch Lick plates taken with a blue-corrected lens and the precision of measurement of the bright stars is lower than expected. On the other hand, the proper motions of the fainter AGK3 stars are less well-determined than those of the bright stars.) Until plates taken with the yellow-corrected lens are available for two epochs it is possible that the Lick program will not give directly a precise determination of the correction to the precession, but the results obtained on solar motion and galactic rotation should contribute indirectly to studies based on proper motions of a fundamental system.

Shapiro put forward the view that the new techniques of long baseline radio interferometry (e.g. see Cohen *et al.*, 1968) could be used to determine the precessional motion of the Earth with much greater precision than conventional techniques, since by using objects (quasars) at cosmological distances the method does not depend on any adopted model of stellar motions. Although there are only about 50 to 100 suitable quasars available, they are distributed over the whole sky and it is hoped to achieve eventually the same accuracy in the determination of their angular separations as has recently been achieved in angular resolution, namely $0''.0002$. It will be necessary to estimate the effects of the Earth's neutral atmosphere, but it should be possible to test the accuracy of the results by examining their reproducibility under different conditions. Observations over a period of 3 to 5 yr will be required for an adequate determination of precession.

4. Secular Variation of the Obliquity of the Ecliptic

The statement of the IAU system of astronomical constants that was adopted in 1964 does not explicitly include a complete expression for the obliquity of the ecliptic, although this is an essential part of the precise definition of the fundamental reference system based on the equator and the ecliptic. It is therefore desirable to establish the causes of the reported discrepancies between the theoretical values of the rate of change of the obliquity and the values deduced from observations of the planets, especially as any discrepancies due to an unsuspected motion of the equator would imply (as Aoki has previously pointed out) a correction to Oort's constant B of galactic dynamics.

The discussion was opened by Aoki who presented a paper by himself and Kakuta (p. 171). He was of the opinion that it is still worthwhile to examine the possibility that a secular change in the core-mantle coupling could give rise to a motion of the equator, and this is developed in the paper. He also considered that the motion of the ecliptic should be determined from an analysis of the observations of Jupiter since its orbit departs only slightly from the invariable plane of the solar system.

Lieske drew attention to the results of his recent work (1970). Numerical integration of the orbital angular momentum of the Earth–Moon barycentre indicated that Newcomb's rate of change of the obliquity is essentially correct. A re-examination, made on the suggestion of Fricke, of his previous analysis of the observations of Eros has shown that the discrepancy in obliquity is not significantly different from zero after all. Other determinations should be similarly re-examined.

Duncombe presented some results obtained by himself and Van Flandern. He summarized the previous planetary determinations of the secular variation of the obliquity and drew attention to a new determination by Laubscher from observations of Mars. The mean correction to Newcomb's value was $-0\overset{''}{.}257$ per century, and the discrepancy was increased when more accurate values of the masses of the planets were used. It had been possible to show, however, that some of the anomalous results were due to incomplete allowances for the systematic errors in the reference-star catalogues. Further, a new determination of the variation from an analysis of lunar occultations is not significantly different from zero.

Shapiro suggested that the combination of observations of pulsars via long baseline radio interferometry (which is sensitive to the orientation of the Earth's equator) and via the timing of pulse arrivals (which is sensitive to the orientation of the ecliptic) could be used to determine the obliquity, but he was not sure whether the accuracy would be sufficient to determine secular changes on the time scale of 5 to 10 yr.

Vasilevskis drew attention to the fact that Lick analysis of the residual proper motions did not give any support to the supposed rotation of the equatorial plane about the direction of the equinox. He also considered that independent knowledge of the structure of the Galaxy was not consistent with a large change in Oort's constant *B*, but Clube felt that this view should not be allowed to prejudice the interpretation of the solar system determinations of the obliquity.

5. Equinox Corrections

During the discussions on precession, Van Flandern (p. 182) and Aoki, in particular, emphasised the importance of taking into account the equinox errors of fundamental catalogues. An equinox error is the difference between the origin, or equinox, of a catalogue (i.e. the direction of zero R.A. and Dec.) and the position of the actual mean equinox (i.e. the direction of the line of intersection of the mean planes of the Earth's equator and orbit) at any given time. (The difference in Dec. is usually referred to as the equator-point error.) The equinox error of a catalogue may vary with time and so gives rise to an effect that is sometimes referred to as the 'non-precessional motion of the equinox' to distinguish this effect from the motion along the ecliptic due to the luni-solar precession of the equator and from the motion along the equator due to the planetary precession of the ecliptic. The analysis of stellar observations alone gives

https://doi.org/10.1017/S0252921100028256 Published online by Cambridge University Press

only the total correction ($\Delta\lambda + \Delta e$) to the motion of the equinox of the catalogue along the equator. The position of the ecliptic and hence of the actual equinox can only be determined from observations of bodies of the solar system. Correspondingly, the determinations of the elements of orbits and of universal and ephemeris time are affected by the equinox errors of the catalogues of the reference stars used in reducing the observations. Aoki briefly presented a paper by Yasuda (1971) which discusses the effect of systematic errors in the fundamental catalogue on the determination, from meridian observations of the Moon, of corrections to the elements of the lunar orbit and of the fundamental constants.

6. Consequences of Changing the Constants of Precession

It was generally agreed that before any changes are made in the adopted values of the constants of precession it is essential that a full statement of the consequences of such changes should be prepared and published in time for detailed scrutiny and evaluation. The following points were mentioned during a preliminary discussion of these consequences which was opened by Miss Bec (p. 277).

(a) The values of the proper motions of stars depend on the assumed values of the precessional constants, and so the published values in new catalogues will differ from those based on the current set of constants.

(b) The total variations (due to precession and proper motion) in the positions of stars will not be changed to the first order, so that the apparent places of fundamental stars will essentially be continuous, except for any equinox correction (which will be the same for all stars) and second-order effects (especially near the poles).

(c) It will be necessary to apply special corrections to the published mean positions of stars when comparing them with new positions if the published position includes a reduction from the reference frame of the epoch of observation to that of some standard epoch.

(d) The corresponding values of Oort's constants may be changed slightly, although the values in current use do not correspond to the currently adopted value of the constant of precession.

(e) The eventual availability of new catalogues and ephemerides based on an improved system of precessional constants would mean that for some investigations in stellar and solar system dynamics it would no longer be necessary to apply corrections to refer motions to an inertial frame. There will, however, still be some applications where the highest possible precision is required and for these the reduction in the size of the corrections would probably not be a significant advantage.

(f) The adopted values of the elements of the orbits of the members of the solar system with respect to the reference frame of a standard epoch will have to be changed, although elements referred to the mean equinox of date would not be changed. The principal change will be in the mean motions, and hence in the mean distances, of the planets, but there will be small changes in other elements. The changes in the mean distances will imply a change in the adopted ratios of the astronomical unit to the metre

https://doi.org/10.1017/S0252921100028256 Published online by Cambridge University Press

and light-second by about 5 parts *in* 10^7. To the first order, however, the apparent ephemerides of the planets will be unaffected, except for the effects of equinox corrections.

(g) Discontinuities will be introduced into both the universal-time scale and the ephemeris-time scale; these discontinuities will probably occur in both epoch and rate, but the exact effects will depend on the actual nature of the changes made and will require careful investigation – the effect of the change in the constant of aberration on the epoch of the ephemeris-time scale has yet to be resolved.

7. Form of Changes in the Precessional Constants

It was realized that new precessional constants could be introduced in a number of ways, and that further consideration would be required before a particular method is adopted. The following possibilities were noted:

(a) To change explicitly only the values of the general precession in longitude and the obliquity of the ecliptic at 1900.0, which are the quantities included in the current IAU system of astronomical constants. As a variation on this approach it would be possible to adopt a value of the constant of precession, in the sense used by Newcomb (1895, see *Exp. Supp.* p. 170), rather than the general precession in longitude.

(b) To adopt expressions for the angles ζ_0, z, θ, and ε as functions of time (see Newcomb, 1897, or *Exp. Supp.* pp. 30 and 98), in order to specify precisely the position of the mean equator and ecliptic at any epoch relative to their positions at any other epoch.

(c) To develop new theories of luni-solar precession and nutation, and of planetary precession and the other contributions to the total precession, such as the so-called geodesic precession. These theories to be based on an adopted model of the Earth and on standard lunar and planetary theories, with the minimum number of additional arbitrary constants to be determined by comparison with observation.

The first approach leaves unspecified the values of other precessional quantities at the epoch as well as their changes with time. The second largely ignores the possible relationships between the precessional constants and the other constants of the system. The third approach is the ideal, but it is probably not realistic to expect such a comprehensive system to be developed in the next few years.

It was also suggested that the value of the equinox correction to be applied to the system of FK4 in the published version of a new fundamental catalogue should also be explicitly stated.

8. Constants of Nutation

Vicente presented his invited review paper (p. 186) on the observed and theoretical values of the nutations in longitude and obliquity. The series adopted for use in ephemerides is based on Woolard's theory (1953) of the forced nutation of a rigid and homogeneous Earth, but with the substitution of Newcomb's value (1895) of the constant of nutation. This constant ($9\overset{''}{.}210$) is the value of the coefficient at 1900.0 of

https://doi.org/10.1017/S0252921100028256 Published online by Cambridge University Press

the principal term (period 18.6 yr) in the series for the nutation in obliquity. The observational determination of the coefficients of the series is difficult, and the results are quite discordant. This is partly due to the lack of homogeneity in the 70 yr of published observational data of the International Latitude Service owing to differences in the methods of reduction used. The theory of nutation should be based on an internationally adopted model of the Earth and should be related to the theory of body tides. He concluded that it would be premature to adopt new values until a new theory had been satisfactorily compared with observations.

In his paper Melchior (p. 190) discusses the relationships between the developments of the tidal potential and of the nutation, and shows the relationships between the tidal series due to Doodson and the nutation series due to Woolard. The comparison between the corresponding astronomical and geophysical phenomena would be easier if the nutation series was arranged and coded according to the systematic classification scheme introduced by Doodson (1922). The discrepancies between the theoretical and observed values of the coefficients appear to be due to the neglect of the dynamical effects of the Earth's liquid core; it will be necessary to introduce a resonance parameter in addition to the mechanical ellipticity into the model used for any new theory of the nutation. The introduction of the following new coefficients would significantly reduce the residuals in time and latitude observations, spectral analysis of which reveals the presence of the corresponding periods:

Period of term in nutation	Doodson code	Astronomical argument	Proposed value $\sin\varepsilon\Delta\psi$	Proposed value $\Delta\varepsilon$	Adopted value $\sin\varepsilon\Delta\psi$	Adopted value $\Delta\varepsilon$
6798 solar days	55.565	$+\Omega$	-6.8408	$+9.2014$	-6.8584	$+9.2100$
365 solar days	56.554	l'	$+0.0579$	$+0.0056$	$+0.0502$	
183 solar days	57.555	$2F-2D+2\Omega$	-0.5230	$+0.5724$	-0.5066	$+0.5522$
13.7 solar days	75.555	$2F+2\Omega$	-0.0828	$+0.0906$	-0.0811	$+0.0884$

Yumi briefly presented a paper by Wako (1970) in which it is suggested that the so-called annual z-term in apparent latitude variations may be explained by an error of 0″.02 in the semi-annual term of nutation.

Atkinson stated that he was carrying out a re-analysis of the observations made on the Cookson floating zenith-tube at Greenwich during the 25-yr period, 1911–1936. He had had much more difficulty than expected in finding out what had been done previously, and he had been forced to go back to the original notebooks. He was using the new value of the constant of aberration in his reductions and hoped to obtain satisfactory determinations of some of the coefficients.

There followed a lengthy and wide-ranging discussion, during which the following points were made.

A change in the series for the nutation only has small periodic effects and so causes much less difficulty than, say, a change in the constant of precession (Clemence).

For the investigation of geophysical effects, the reduction for nutation should be as complete as possible, and so the best available theory and constants should be used (Melchior).

The long series of observations of the International Latitude Service should be made available in machine-readable form, with the minimum amount of reduction required to achieve a common standard (Vicente).

The ever-increasing availability of computers means that published observations should only be corrected for instrumental and local effects, since it is then easier to reduce observations made at different places and times by a single procedure. Observational data should be published in machine-readable form as well as, or instead of, in printed form (Shapiro).

It was stated that future nutation theories should consider the motion of the angular momentum vector rather than the motion of the axis of figure or the axis of rotation (Melchior, Vicente).

9. Determination of Planetary Masses

In introducing his invited review paper (p. 213) on the system of planetary masses, Kovalevsky first of all drew attention to the extensive review of determinations made between 1826 and 1961 that had been prepared by Kozlovskaya (1963). (This paper also includes determinations of planetary diameters and satellite data.) His own tables are therefore restricted to a few representative early determinations and recent determinations. He had found difficulty in comparing different determinations as many authors did not state the type and basis of the error limits given. His principal conclusions were that the adopted values for Mercury, Jupiter, Uranus and Neptune should be retained, but new values should be adopted for Venus, Mars, Saturn and Pluto; the derived value of the mass of the Earth–Moon system given in the 1964 system of astronomical constants should be retained, even though it was no longer the most likely value.

Another review of determinations of the planetary masses was presented later in the Colloquium by Seidelmann (p. 253) and the final weighted means were shown to be in substantial agreement with those given by Kovalevsky. Further details of recent determinations of planetary masses were presented after Kovalevsky's introduction by a number of participants as follows.

Duncombe drew attention to new determinations that had been made at the U.S. Naval Observatory of the masses of the five outer planets (p. 224). The new value for Jupiter is based on individual determinations from seven minor planets, while the others are based on fitting numerical integrations to observations over extended periods of time, including an accumulation of 30 yr of precise meridian-circle observations beyond those utilised by Eckert *et al.* (1951).

Melbourne reviewed the determination of planetary masses from radio-tracking data of spacecraft, especially of the Venus probes, Mariner 2 and 5 and of the Mars probes, Mariner 4, 6 and 7. The mass determinations for Venus and Mars are based on the close-encounter phase and the quantity determined is the product GM (light-seconds)^3/second^2; the derived values of the reciprocal masses (m^{-1}) depend on the value adopted for the length of the astronomical unit in light-seconds. Some early determinations use different values and were corrupted by errors in the planetary ephemerides used. For Mariner 5 and 6, two independent types of data are available – time-delay measurements giving distance, and doppler-shift measurements giving the rate of change of distance. A new solution for the reciprocal mass of Venus gives $408\,523.8 \pm 1$ from both types of data for Mariner 5. The determinations of the mass of Mars from Mariner 6 (and 7) are not so accurate as those from Mariner 4, owing to the presence of non-gravitational forces, but a re-analysis of the Mariner 4 data gave a value of $3\,098\,708 \pm 6$ for the reciprocal mass and a value of $(1.88 \pm 0.07) \times \times 10^{-3}$ for the coefficient J_2, compared with the value $(1.97 \pm 0.02) \times 10^{-3}$ given by the analysis of the orbits of the natural satellites, using the same radius for Mars. The mid-course tracking data can be used to give the Earth–Moon mass ratio and the product *GE*. A typical result for the mass ratio is 81.3005 ± 0.0005 from Mariner 6, compared with 81.3007 ± 0.0002 from Lunar Orbiter 4A and the adopted value of 81.30. A recent value for *GE*, based on data from many different types of spacecraft is $(398\ 601.2 \pm 0.4) \times 10^9\ \mathrm{m}^3\ \mathrm{s}^{-2}$ (using $c = 299\ 792.5 \times 10^3\ \mathrm{m\ s}^{-1}$), compared with the adopted value of 398 603.

Lieske (p. 233) described an attempt to improve the ephemerides of the major planets and of the associated astronomical constants by comparing a gravitationally-consistent numerical integration of the orbits with an observational data set of over 37600 positions covering the period 1910 to 1969. The bulk of the data were transit-circle measurements, but the inclusion of radar time-delay measurements for 1964 to 1969, and of spacecraft radio-tracking data resulted in significant changes in some of the estimates and considerable reductions in their standard deviations. The comparison between solutions made with different sets of data and parameters (between 64 and 77 in each solution) suggested that the computed standard deviations of the estimates are optimistic, and that further investigations should be made of the many factors that could influence the results.

An even more extensive analysis of radar and optical observations was briefly described by Shapiro, who stated that the results obtained had not been commensurate with the amount of effort involved. Some 400 000 positions of the Sun, Moon and planets (including Icarus and Eros) during the period 1750 to 1970 had been collected. The preliminary fit was considered to be sufficiently good to justify the use of a single complete numerical integration and determination of the partial derivatives with respect to several hundred parameters. Many solutions were then made for different data and parameter sets to see the sensitivity of results to the choice of data and to modelling errors. Again the formal standard errors given by the individual solutions appeared to be optimistic and the results in general were not significantly different from the summary values given by Kovalevsky and Seidelmann. The mass of Pluto was found to be very sensitive to the variations in the model used and it was concluded that the mass could not be estimated reliably from existing data. A value of $3\,500\,000 \pm 2\,000\,000$, based partly on the measured diameter and partly on *a priori* estimates of the density, was proposed as an indication of the present state of knowledge of Pluto's reciprocal mass. This result contrasts with the estimate of 1800000 for Pluto's reciprocal mass recently obtained by Duncombe *et al.* (1968). Shapiro's analysis also showed that transit-circle observations made during this century at the U.S. Naval Observatory had a much higher precision than any other set of optical observations, and represented an improvement by a factor of five over earlier observations.

Schubart referred to numerical tests (p. 246) which had shown that the neglect of the mutual perturbations of the four principal minor planets could give rise to errors in their ephemerides that are comparable with those arising from the uncertainties in the masses of the major planets. He had been able to make a first determination of the mass of Ceres by examining its influence on the orbit of Pallas and obtained a mass ($m^{-1} = (1.5 \pm 0.1) \times 10^9$) which was about six times larger than that obtained by Hertz for Vesta (1968). He considered that adopted values of the masses of Ceres, Vesta and Pallas should be included in the system of planetary masses.

Scholl presented his paper (p. 250) on the determination of a correction to the mass of Jupiter from a study of the motions of three minor planets.

The major part of the general discussion of the determination of the masses of the planets was concerned with the problem of how to assign realistic error bounds to the various determinations. There was also a difference of opinion as to the relative values of making global solutions, such as those described by Lieske and Shapiro, and of combining the results of individual determinations based on the detailed examination of the motions of only a few bodies. Shapiro pointed out that by varying the model he was able to reproduce the various results obtained by individual analyses of the Eros data; he considered that most of the differences between solutions were due to the presence of systematic errors. Duncombe felt that the possibility of plotting the residuals before and after varying a parameter provides a valuable check on the solution. Seidelmann considered that it is necessary to make several iterations since successive solutions often did not converge in the expected manner. Duncombe also drew attention to the need for using long-data arcs when studying the motions of the outer planets.

10. System of Planetary Masses and Ephemerides

A general discussion on the desirability of adopting revised values of the planetary masses was introduced by Clemence. He first of all pointed out that it is not difficult to carry out a numerical integration or to evaluate a general theory with new masses, but that it is not a trivial task to make a new comparison with observations in order to determine new constants of the orbit; this step is absolutely essential in both cases as otherwise the change in the masses would not be justifiable. All available observations should be examined, especially because of the high costs of making observations – a single transit-circle observation probably costs $15 to make. In making changes it is important to remember that the mass of the Earth–Moon system and the solar parallax are connected so that if one is changed, so must the other. In view of the current high level of activity in the studies of planetary motions it is inopportune to change the system now – in fact, changes are best made when there is little work in progress.

https://doi.org/10.1017/S0252921100028256 Published online by Cambridge University Press

Better values should be available in 4 or 5 yrs' time, and so he considered the question should be deferred at least until 1973.

The Chairman pointed out that even if the meeting decided that changes were required, it would not be possible to adopt them until 1973 because of the necessity for adequate consultation within the Union and with other interested organisations, such as COSPAR (Committee on Space Research) and IUGG (International Union of Geodesy and Geophysics). At this point Shapiro questioned the value of having an adopted set of masses since for current research it is always desirable to use the best available set of constants. In reply, Clemence pointed out that the national and international ephemerides (which are based by agreement on adopted constants and theories) are not primarily intended for the use of specialists in celestial mechanics, but rather for the general scientific community; the accuracy required is then usually less than that given. The printed ephemerides would also serve as a standard of reference and represent a compromise between the requirements of high accuracy and long-term continuity. The Chairman pointed out that the ephemerides that are printed in the first half of the Astronomical Ephemeris are specially distributed 4 or 5 yr in advance of the year to which they refer since they are used as the basis for derived ephemerides for astronomy and navigation; it would therefore not be practicable to introduce into the almanacs a new generation of ephemerides until 1980.

Kovalevsky expressed the view that the second generation of ephemerides in the almanacs should not only be based on new masses and constants, but should also be based on new theories that were designed to allow the ready evaluation of the effects of changes in the elements and masses. Duncombe stated that he was interested in the development of a new set of general theories to be used as the basis of the ephemerides in the almanacs.

Melbourne drew attention to the need to supply ephemerides for the prediction and reduction of pulsar observations; these required higher accuracy than that given in the almanacs. Shapiro expressed the opinion that the ephemerides printed in the almanacs were no longer precise enough to meet the needs in many areas of astronomy and that an alternative system of publication which allowed frequent up-dating was required. Seidelmann considered that the use of undocumented ephemerides should be avoided; it would therefore be necessary to up-date the documentation as well as the ephemerides. Duncombe emphasised that even if machine-readable ephemerides were available it would still be desirable to print ephemerides of high precision to meet the needs of those who did not have ready access to computers; there would be no significant saving if only ephemerides of low precision were to be printed.

Lieske expressed concern at the present inconsistency between the two adopted values and the mass of the Earth-Moon system, but the Chairman stated that it had previously been decided that the correction of the present ephemerides would not be made in view of the other deficiencies of the theories used in their construction. Morando gave details of an investigation that he had made of the effects of changing the masses of the inner planets by the amounts now suggested, and he concluded that the corrections involved would also be smaller than the other errors now present in the ephemerides.

Van Flandern stated that the only significant amendment to Brown's lunar theory following from any likely changes in the planetary masses would be a correction to the great Venus term in longitude of about $-0''.02$ in amplitude. This term has a period of 270 yr, and there would be a corresponding correction of $+0^{s}.03$ to the current value of ΔT.

There was clearly a wide measure of sympathy for the view that, in addition to the ephemerides printed in the almanacs, there was the need for more accurate ephemerides for special purposes, and that these should be up-dated when necessary; but every ephemeris should be clearly identifiable and its basis should be published in some suitable way. On the other hand, as Clemence pointed out, a general agreement to adopt a system of constants and a particular set of theories did not in any way restrict the freedom of an individual to use whatever ephemerides he considered would be best suited to his particular investigation.

11. Introduction of the Standard Equinox of 2000.0

Kovalevsky opened a brief discussion on the question of the most opportune time to introduce the use of the standard equinox of 2000.0 into the almanacs. He considered that it would be appropriate to wait until a new fundamental catalogue is available and until other changes are introduced in, say, 1980. Vasilevskis stated that Commission 24 would like a decision to be reached soon, since a proposal to base the 'names' of faint stars on their positions for some standard epoch was under consideration. Sinzi suggested that it would be better to wait until the year 2000 and then introduce the standard equinox of 2050.0 to serve for the whole of the 21st century; others, however, agreed that for many purposes the span of 50 yr of precession would be inconvenient. Lederle pointed out that at least one catalogue already gives positions for 2000.0 and that it would be necessary to give precession tables for both equinoxes for several years. Herrick referred to the similar differences between the points of view of L. J. Comrie and E. C. Bower when the introduction of the equinox of 1950.0 was under consideration.

12. *E*-terms of Aberration

For computational convenience the correction for annual aberration used to be based on the assumption that the Earth moves around the Sun in a circle. This procedure neglects the so-called *E*-terms of aberration, which depend on the eccentricity of the Earth's orbit, as well as small periodic terms. The *E*-terms are of the order of about $0''.34$ but, since they are constant throughout the year for any particular star, their omission was not considered to be significant. As from 1960 aberration corrections have been based on the actual motion of the Earth, but in the computation of apparent places from catalogue mean places, the effects of the *E*-terms are subtracted from the aberration corrections, since it can be considered that their effects are already included in the catalogue mean places; equivalent procedures are followed in the computation of day numbers and planetary positions, and in the computation of mean places from apparent places. Guinot expressed the view that this procedure was illogical and had been a source of considerable confusion in both practice and teaching, especially as the effects varied slowly with time. In the future it would be better to apply the full aberration correction in the reduction between mean and apparent places. Since continuity in the apparent places is to be preserved, it will be necessary to change the catalogue mean places. This can easily be done in all future catalogues and the new procedure should be introduced into the almanacs at the same time as the other changes in the bases of the ephemerides. This view was supported by Shapiro, who considered that the current practice had led to a great deal of wasted time by new astronomers, and by Herrick, who pointed out that the procedure implied that the x- and y-axes of current star catalogues are not perpendicular. Lederle considered that the early astronomers, working to a lower precision without modern aids to calculation, were justified in omitting these terms, and he emphasised that any change must be specified very clearly, as he considered that the resolutions concerning the change in 1960 were ambiguous and misleading. Van Flandern was concerned that the astronomers of 2100 should know what changes had taken place. Herrick drew a parallel with the confusion still caused by the change in 1925 of the beginning of the astronomical day from noon to midnight. The Chairman suggested that the *Explanatory Supplement* could continue to provide a record of such changes.

13. Astronomical Unit and Related Constants

A discussion on the system of constants adopted in 1964 was opened by Melbourne, who considered that the choice of the 'measure of 1 AU in metres' as a primary constant had proved to be mistaken; instead the 'light-time for unit distance' is to be preferred. The measure of the AU in metres is irrelevant to astronomy and so should be a derived constant. He was strongly supported by Shapiro, who had taken this view at the Paris Symposium in 1963. On the other hand, Kovalevsky and Herrick felt that the distinction between primary and derived constants was not important as their roles could be interchanged in appropriate circumstances. The form of the definition of the astronomical unit was also discussed but, although there was little support for a 'picturesque' definition in terms of the radius of an orbit of a stated period, no conclusion was reached.

In reply to a question by Atkinson, Shapiro stated that a recent estimate of the light-time for unit distance is $499.004\,780 \pm 2 \times 10^{-6}$ s, compared with the derived value of 499.012 in the IAU system. There was, however, no suggestion that the new values adopted in 1964 should be revised again. It was also agreed that only the actual list of values is regarded as significant and that there is no need to revise the accompanying explanatory notes.

14. Constants for the Earth

Kovalevsky (p. 279) reminded the Colloquium that the system adopted by the IAU in

1964 included the following primary constants to define the dimensions and gravitational field of the Earth:

equatorial radius	a	$= 6\,378\,160$ m,
dynamical form-factor	J_2	$= 0.001\,082\,7$,
geocentric gravitational constant	GE	$= 398\,603 \times 10^9$ m^3 s^{-2}

These values were discussed by IAG (International Association of Geodesy) in 1967, and were then adopted by IUGG as the basis of the 'Geodetic Reference System 1967'. Although at that time better values of these constants were available, IUGG decided to adopt the same values as the IAU in order not to introduce inconsistencies. This implies that, in turn, the IAU should accept the responsibilities that accompany this wider use of its system.

For geodetic purposes, the derived parameters for the standard reference ellipsoid defined by these three primary constants are required to a much higher precision than for astronomical purposes. The aim is that geodetic computations on the ellipsoid should be good to one-tenth of a millimetre and so the derived parameters have to be consistent to 12 significant figures. Such values have been calculated independently by several groups and are soon to be published in a special issue of *Bulletin Géodésique*, to be called 'Geodetic Reference System 1967'.

In order to compute these derived parameters, it was necessary to specify the mean angular velocity (ω) of the Earth to a high precision. The adopted expression and value refers to the epoch 1900.0 and is as follows:

$$\omega = \frac{2\pi}{86\,400} \cdot \frac{s + 86\,400 - \mu/1500}{s} = 7.292\,115\,146\,7 \times 10^{-5} \text{ rad s}^{-1}$$

where

s is the number of ephemeris seconds in 1 tropical year at 1900.0,

$\mu = p \cos\varepsilon - 12''.473 \sin^2\varepsilon$,

p general precession in longitude, in seconds of arc, per tropical century at 1900.0,

and

ε = obliquity of the ecliptic at 1900.0.

It is also assumed that the atmosphere is concentrated on the surface of the ellipsoid. The following results are obtained:

reciprocal flattening	$1/f$	$= 298.247\,167\,427$,
polar radius	b	$= 6\,356\,774.5161$ m,
normal gravity at equator	γ_e	$= 978.031\,845\,58$ gal,

and the gravity formula is

$$\gamma = \gamma_e\,(1 + k \sin^2\phi)\,(1 - e^2 \sin^2\phi)^{-1/2},$$

https://doi.org/10.1017/S0252921100028256 Published online by Cambridge University Press

where $k = 0.001\,931\,663\,383\,21$, $e^2 = 0.006\,694\,605\,328\,56$, and ϕ is the geodetic latitude.

IAG has requested that these precise values should be used in preference to any other similar values for use in computations for the international reference ellipsoid and Kovalevsky concluded by suggesting that the IAU should endorse the IAG values of the derived parameters. No objections were raised to this suggestion.

15. Ephemeris Time

The original definition of ephemeris time was adopted at the Symposium on Astronomical Constants held in Paris in 1950, but alternative definitions were later introduced in an attempt to make the scale more suitable for general use. The rapid development of atomic-time standards has, however, meant that ephemeris time is now only used in dynamical astronomy. It therefore seemed appropriate that the Colloquium should consider whether any further changes in the definitions of the unit and epoch of ET are necessary or desirable.

The discussion was opened by Van Flandern, who first mentioned that although the definition of ET was in terms of the motion of the Sun the primary determinations are of observations of the motion of the Moon, giving the difference ΔT between ET and UT. He then claimed that our present estimates of ΔT require drastic revision to allow for errors in the position of the equinox and its motion and for errors in the adopted value of the acceleration due to tidal forces. Even so, it would be better to redefine ET in terms of the motion of the Moon rather than the Sun or other bodies, but the epoch and unit should be related to that of the atomic-time scale (AT) at some convenient epoch.

Lederle said that there was a need for a detailed study of the relationship between ET and AT and of the effect on ET of the introduction of a new theory of the motion of the Earth around the Sun. He pointed out that Poland still used the ephemeris second as its legal unit and emphasised that any changes must not be adopted hastily because of the great risk of making new mistakes.

Shapiro described ET as being an approximation to Newtonian time which is theory dependent and is not observable. He felt that there was the need for a new definition that makes sense in terms of modern science. Clemence, on the other hand, felt that ET is observable and that it is of fundamental interest to see whether ET has an acceleration on AT.

Guinot considered that a new start is necessary and suggested that AT should be used as the time argument of the ephemerides. Discrepancies between observation and theory could be explained in a number of ways – for example, the constant of gravity may vary with respect to ephemeris time. The Chairman suggested that the name ephemeris time might be retained but that the unit should be defined to be equal to the atomic second, thus making the mean motion of the Earth a quantity to be determined from observation. Kovalevsky pointed out that this would allow a simplification of the system of astronomical constants, since there would be no justification

https://doi.org/10.1017/S0252921100028256 Published online by Cambridge University Press

for using the tropical century as a secondary time unit. Herrick emphasised the need for a proposal in simple terms and challenged Shapiro to produce a statement of a definition of an alternative time-scale so that it could be subjected to detailed examination.

16. Consideration of the Resolutions

At the end of the session on Thursday afternoon, a Resolutions Committee was appointed. The members were Kovalevsky, Lederle, Lieske, Vicente and Wilkins (Chairman). The drafts of the resolutions were distributed at the beginning of the session on Friday afternoon for individual study before they were discussed. After an unsuccessful attempt to dispose of the 'non-controversial' items, the resolutions were taken in the sequence of the draft. In this report the original draft form is given together with the principal arguments that led to the adoption of the final resolutions that are listed on page 147.

"Considers that it would be premature to adopt in 1973 new conventional values for the precessional constants."

Even though many felt that this resolution was realistic as far as our present knowledge is concerned, it was rejected by a large majority on the grounds that new data may become available or fresh arguments may be put forward to justify making changes in 1973.

"Considers that any changes in the precessional constants and in the system of planetary masses should be introduced into the national almanacs together at a time that is closely linked to the production of the next fundamental star catalogue."

After minor amendments this resolution was adopted nem con (i.e. without any objection) and is given as resolution No. 1 on page 147.

"Recommends that a Working Group be set up to report in 1973 on the consequences of changes in the precessional constants and on the procedures for the introduction of new values at a later date."

This was amended to make it clear that the report of the Working Group should be published well before the General Assembly in 1973, so that the recommendations can be subjected to a wide and detailed examination before any decision is taken. The Colloquium also felt that the Group should not be inhibited from putting forward definite proposals for changes in constants. The amended resolution was then adopted nem con as resolution No. 2.

"Considers that no changes should be made in the series for the nutation until a decision is made about the precessional constants, but considers that a new theory of nutation, based upon a more realistic model of the Earth, should be developed."

On the suggestion of Melchior, this resolution was amended without objection so as to emphasise the desirability of connecting the astronomical theory of nutation and the geophysical study of body tides. The resolution was adopted nem con as resolution No. 3.

"Recommends that no changes in the bases of the ephemerides published in the nautical almanacs should be made before 1980."

The Chairman pointed out that this date was consistent with the earliest likely introduction of FK5 in 1978 as the almanacs are published one year in advance of the date to which they refer. The resolution was adopted nem con without amendment as resolution No. 4.

"Recognises the need for ephemerides of higher precision for use for certain specialised applications and recommends that Commission 4 should seek ways by which a standard set of such ephemerides may be made available with adequate documentation."

This resolution was amended on the suggestion of Shapiro, who considered that there is a greater need for high precision ephemerides than is implied in the original wording, and that the main requirement is ephemerides in a form suitable for use with computers. There was some division of opinion about the frequency with which it would be practicable or desirable to produce improved ephemerides but the amended resolution was carried by a large majority as resolution No. 5.

"Recommends that a Working Group should be set up to specify in time for consideration in 1973 the bases for the planetary ephemerides to be published in the almanacs for 1980 onwards, and suggests that ephemerides on this basis be made available in machine-readable form at the earliest opportunity."

This resolution was adopted with one verbal amendment as resolution No. 6.

"Considers that further changes in the values of the primary constants adopted in 1964 should not be made, and endorses the values of the secondary constants compiled by IAG in 'Geodetic Reference System 1967' (special publication of the Bulletin Géodésique, 1970)."

This resolution was amended to make it clear that the first clause refers only to the forthcoming IAU General Assembly at Brighton. It was then adopted without objection as resolution No. 7.

"Recommends that a Working Group should be set up to review the definition of ephemeris time, its relation to other time scales, and the possible effects of changes in the primary constants on its determination."

In view of the possibility that a change in the primary constants might affect the definition as well as the determination of ET, the resolution was agreed, and it was then adopted, with one objection, as resolution No. 8.

"Makes no recommendation about the time of introduction of the standard equinox of 2000.0."

During the discussion, it became clear that the Resolutions Committee had misjudged the feeling of the meeting, and so a positive recommendation was proposed and then adopted, with one objection, as resolution No. 9.

"Recommends that the Working Group on precessional constants should also consider the desirability of amending the mean places of stars by the effects of the *E*-terms of aberration when the next new fundamental catalogue is produced."

With one verbal amendment, the resolution was adopted nem con as resolution No. 10.

"Makes no recommendation on the specification of the IAU system of astronomical constants."

Although Herrick suggested that the distinction between primary and secondary constants be abolished, it was agreed that no resolution was required.

"Makes no recommendation about the form of presentation of the series for the nutation."

It was agreed that no resolution was required, although Melchior's point about the notation for, and sequence of, the nutation terms was pathetically noted.

"Considers that the observational data of the International Latitude Service should be made available on a uniform system and in machine-readable form as soon as is practicable."

This was amended to strengthen its tone and to indicate why the data are relevant to the system of astronomical constants. It was then adopted nem con as resolution No. 11.

"Considers that the promising techniques for long baseline radio interferometry should be developed for astrometric purposes and that the regular observation by radar of the positions of planets would help to resolve the present uncertainties in the masses and orbital elements of the system of planets."
"Urges that observational data obtained by radio and radar techniques should be made available to the scientific community."

These two resolutions were eventually combined and widened to give resolution No. 12, which was then adopted nem con.

Shapiro then proposed a further resolution recommending the preservation of raw observational data in machine-readable form. After discussion resolution No. 13 was adopted nem con.

Herrick made the suggestion that there should be a resolution recommending publication only of standard errors rather than of probable or mean errors. Although this was sympathetically received, it was agreed not to proceed to a formal resolution.

17. Concluding Remarks

There being no further business, Clemence proposed a vote of appreciation to the Local Organising Committee and helpers for the efficient and thoughtful way in which they had made all the arrangements for the Colloquium. He also congratulated the Chairman on bringing the Colloquium to a successful conclusion without the necessity for the additional meeting that had been contemplated in the provisional programme. Finally, it was unanimously agreed that best wishes for a full and speedy recovery should be sent to Professor Fricke, the absent host.

18. Resolutions Adopted at the IAU Colloquium No. 9 on the System of Astronomical Constants

IAU Colloquium No. 9:

(1) Considers that any changes in the precessional constants and in the system of planetary masses be introduced into the national and international almanacs together, at a time that is closely linked with the introduction of the next fundamental star catalogue.

(2) Recommends that a Working Group be set up to report, in time for consideration in 1973, on the consequences of changes in the precessional constants and on the procedure for the introduction of new values at a later date. The Group should feel free to discuss actual values, if it wishes.

(3) Considers that no changes be made in the series for nutation until a decision is made about the precessional constants, but considers that a new theory of nutation be developed, based upon a more realistic model of the Earth and consistent with recent developments of the tidal potential.

(4) Recommends that no changes in the basis of the ephemerides, published in the nautical almanacs, be made before 1980.

(5) Recognises the need for ephemerides of higher precision for use in many applications and recommends that Commission 4 seek ways by which a standard set of such ephemerides may be made available in machine-readable form as often as is practicable, together with adequate documentation.

(6) Recommends that a Working Group be set up to specify, in time for consideration in 1973, the basis for the planetary ephemerides to be published in the almanacs for 1980 onwards, and suggests that ephemerides on this basis be made available in machine-readable form at the earliest opportunity.

(7) Considers that further changes in the values of the primary constants adopted in 1964 should not be made at the Brighton meeting, and endorses the values of the secondary constants compiled by IAG in 'Geodetic Reference System 1967' (special publication of the Bulletin Géodésique, 1970).

(8) Recommends that a Working Group be set up to review the definition of ephemeris time, its relation to other time scales, and the possible effects of changes in the primary constants on its definition and determination.

(9) Recommends that the next standard equinox be that of 2000.0 and that it be introduced in the next fundamental catalogue.

(10) Recommends that the Working Group on precessional constants should also consider the desirability of changing the mean places of stars by the effects of the *E*-terms of aberration when the next new fundamental catalogue is produced.

(11) Urges that the observational data of the International Latitude Service be made available on a uniform system in machine-readable form as soon as is practicable, for use in the determination of nutations.

(12) Urges that the promising techniques of radio interferometry and laser ranging be developed for astrometric purposes, that regular observation by radar of the positions of planets be made to help resolve the uncertainties in the orbits and masses of the planets, and that the observational data be made available to the scientific community as soon as possible.

(13) Urges that all significant observational data be preserved in machine-readable form, in as raw a state as is practicable.

References

Böhme, S. and Fricke, W.: 1965, *Bull. Astron.* **25**, 269–93.
Cohen, M. H., Jauncey, D. L., Kellermann, K. I., and Clark, B. G.: 1968, *Science* **162**, 88–94.
Doodson, A. T.: 1922, *Proc. Roy. Soc. London* **100**, 305–29.
Duncombe, R. L., Klepczynski, W. J., and Seidelmann, P. K.: 1968, *Astron. J.* **73**, 830–5.
Eckert, W. J., Brouwer, D., and Clemence, G. M.: 1951, *Astron. Papers Am. Ephem. Naut. Alm.*, Vol. **12**.
Explanatory Supplement to the Astronomical Ephemeris: 1961, H.M. Stationery Office, London.
Fricke, W.: 1967, *Astron. J.* **72**, 1368–79.
Hertz, H. G.: 1968, *Science* **160**, 299–300.
Hough, S. S. and Halm, J.: 1910, *Monthly Notices Roy. Astron. Soc.* **70**, 568–88.
Koslovskaya, S. W.: 1963, *Byull. Inst. Teoret. Astron. Leningrad* **9**, 330–76.
Lieske, J. H.: 1970, *Astron. Astrophys.* **5**, 90–101.
Mineur, H.: 1929, *Compt. Rend. Acad. Sci. Paris* **188**, 1086–8.
Newcomb, S.: 1895, *Supplement to the American Ephemeris and Nautical Almanac for 1897*, Washington.
Newcomb, S.: 1897, *Astron. Papers Am. Ephem. Naut. Alm.*, Vol. **8**, Part 1.
Wako, Y.: 1970, *Publ. Astron. Soc. Japan* **22**, 525–30.
Woolard, E. W.: 1953, *Astron. Papers Am. Ephem. Naut. Alm.*, Vol. **15**, Part 1.
Yasuda, H.: 1971, *Ann. Tokyo Astron. Obs.*, Second Series, Vol. **12**, No. 3.

List of Participants

Aoki (Dr Sh.), Tokyo Astronomical Observatory, University of Tokyo, Mitaka, Tokyo, Japan.

Atkinson (Dr R. d'E.), Astronomy Department, Indiana University, Swain Hall West, Bloomington, Ind. 47405, U.S.A.

Bec (Miss A.), Bureau des Longitudes, 3, rue Mazarine, Paris-6e, France.

Böhme (Dr S.), Astronomisches Rechen-Institut, Mönchhofstrasse 12–14, 69 Heidelberg 1, G.F.R.

Clemence (Dr G. M.), Yale University Observatory, Box 2023, Yale Station, New Haven, Conn., U.S.A.

Clube (Dr S. V. M.), Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, Sussex, U.K.

Duncombe (Dr R. L.), Director, Nautical Almanac Office, U.S. Naval Observatory, Washington, D.C. 20390, U.S.A.

Emerson (Mr B.), H. M. Nautical Almanac Office, Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, Sussex, U.K.

Ferraz-Mello (Dr S.), Instituto Tecnológico de Aeronáutica, Observatório Astronômico, São José dos Campos, São Paulo, Brazil.

Gondolatsch (Prof. Dr F.), Astronomisches Rechen-Institut, Mönchhofstrasse 12–14, 69 Heidelberg 1, G.F.R.

Guinot (Dr B.), Observatoire de Paris, 61, avenue de l'Observatoire, Paris-14e, France.

Harris (Mr B. J.), Perth Observatory, Bickley, Western Australia.

Herrick (Dr S.), 4731 Boelter Hall, University of California, Los Angeles, Calif. 90024, U.S.A.

Kovalevsky (Dr J.), Bureau des Longitudes, 3, rue Mazarine, Paris-6e, France.

Lederle (Dr T.), Astronomisches Rechen-Institut, Mönchhofstrasse 12–14, 69 Heidelberg 1, G.F.R.

Lieske (Dr J. H.), Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif. 91103, U.S.A.

Melbourne (Dr W. G.), Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif. 91103, U.S.A.

Melchior (Prof. P. J.), Chef de Département à l'Observatoire Royal de Belgique, Avenue Circulaire, 3, 1180 Bruxelles, Belgium.

Morando (Dr B.), Bureau des Longitudes, 3, rue Mazarine, Paris-6e, France.

Sagnier (Dr J. L.), Bureau des Longitudes, 3, rue Mazarine, Paris-6e, France.

Schombert (Dr J. L.), U.S. Naval Observatory, Washington, D.C. 20390, U.S.A.

Schubart (Dr J.), Astronomisches Rechen-Institut, Mönchhofstrasse 12–14, 69 Heidelberg 1, G.F.R.

Seidelmann (Dr P. K.), U.S. Naval Observatory, Washington, D.C. 20390, U.S.A.

Shapiro (Dr I. I.), Building 54–622, Mass. Institute of Technology, Cambridge, Mass. 02139, U.S.A.

Sinzi (Dr A. M.), Chief of Astronomical Division, Hydrographic Department, Tsukiji-5, Chuo-ku, Tokyo, Japan.

Van Flandern (Dr T. C.), U.S. Naval Observatory, Washington, D.C. 20390, U.S.A.

Vasilevskis (Dr S.), Lick Observatory, University of California, Santa Cruz, Calif. 95060, U.S.A.

Vicente (Prof. Dr R. O.), R. Mestre Aviz, 30, R/c, Algés, Portugal.

Wilkins (Dr G. A.), H. M. Nautical Almanac Office, Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, Sussex, U.K.

Yumi (Dr S.), International Latitude Observatory of Mizusawa, Mizusawa-shi, Iwate-ken, Japan.