PART 3

COMPTES RENDUS DES SEANCES DES COMMISSIONS

REPORTS OF MEETINGS OF COMMISSIONS

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4. COMMISSION DES EPHEMERIDES

Compte-rendu de séance, 23 Août 1967

PRESIDENT: G. M. Clemence.
SECRETAIRE: J. Kovalevsky.

M. le Président ouvre la séance en rendant un dernier hommage aux membres de la commission décédés depuis le dernier congrès de l'U.A.I.

Prof. A. Danjon, ancien directeur de l'Observatoire de Paris, Membre du Bureau des Longitudes chargé de la Connaissance des Temps.

Dr. F. Fernandez de la Puente, Directeur du service des éphémérides de l'Instituto y Observatorio de Marina de San Fernando.

Dr. A. Tsukamoto, ancien directeur du service des Ephémérides du Japon (Hydrographic Division, Maritime Safety Board).

I. *Organisation de la Commission*

En plus des membres décédés, Dr. V. Planelles qui quitte le service des éphémérides espagnoles et Mme Gossner ne feront plus partie de la commission.

Par contre, les personnes suivantes sont proposées comme nouveaux membres: V. A. Abalakin, J. Arias de Greiff, R. Haupt, N. Owaki, M. Rodriguez, S. R. Trehan.

Enfin, Dr Freiesleben (Allemagne) est proposé comme membre consultant de la commission. En ce qui concerne la future organisation de la commission, il est proposé que le bureau soit constitué comme suit:

Président: G. A. Wilkins
Vice-président: J. Kovalevsky
Comité d'Organisation: G. A. Čebotarev, G. M. Clemence, R. L. Duncombe, W. Fricke.

La commission approuve ces propositions.

II. *Introduction of the IAU System of Astronomical Constants*

W. Fricke reported on the introduction of the new constants of aberration in the apparent places of fundamental stars starting from the volume for 1968.

D. H. Sadler supplemented the published report in respect of the content of the Astronomical Ephemeris (A.E.) for the years after 1968.

All appreciable changes will be introduced into the eclipses, the physical ephemerides of the Sun, Moon and planets and the ephemerides of the satellites, as from the *Astronomical Ephemeris* 1969. As from the A.E. 1970, it is proposed to incorporate the corrections to the lunar ephemerides in the tabulated values of ΔT.

The ephemerides of the Sun, Moon and planets will not be changed. Differential corrections to the lunar ephemeris together with the formulae from which differential corrections to the planetary ephemerides can be calculated will continue to be given in an appendix.

D. H. Sadler proposed that this procedure should be discontinued for the lunar ephemeris when there could be included W.J. Eckert's recalculation of solar perturbations. These would be therefore tabulated, without tables of corrections, in the A.E. 1972 and onwards.

However, since the corrections to the ephemerides of the Sun and planets from Mercury to Mars are smaller than the rounding errors, *D. H. Sadler* proposed that they continue to be given by means of formulae even after 1971. Not only are these corrections small, but they cannot, in any case, readily be computed for the change in the adopted value of the ratio of the masses of the Earth and Moon.

J. Kovalevsky supported this proposal and indicated that this problem arises even more acutely

for Le Verrier's theories tabulated in the *Connaissance des Temps*, and asked that this publication be authorised to continue to publish the ephemerides in the present form with the eventual addition of correction formulae.

The Commission agreed with these two proposals. On the other hand, for the ephemerides of the five outer planets being based on a smooth and consistent numerical integration, it was agreed that it would be worth while recalculating the apparent ephemerides with the revised values of the constants, including the revised value of the mass-ratio Earth/Moon (the change in the value of the combined mass of the Earth and Moon has negligible effect).

III. *Further Improvement of the System of Astronomical Constants*

W. Fricke recalled the achievements of the working group on astronomical constants in 1963–64 that proposed the subsequently adopted IAU system of astronomical constants. The task of this working group is finished and the working group was dissolved. However, though the new constants are satisfactory, some others have not been changed (constant of precession and planetary masses). Consequently, *Fricke* suggested that a group should be formed in order to study how to resume the discussions and prepare a procedure for an eventual change in those constants.

G. M. Clemence noted that the system of planetary masses is not satisfactory. Some remarkable progress was recently made for the masses of the nearest planets from discussions of the motion of space probes. As for the outer planets, nothing new is to be expected in the immediate future. The best prospects are now in the study of the motions of some minor planets in commensurable orbits with that of Jupiter.

After some discussion, it appeared that the most adequate group would be the organizing committee of the Commission, provided that some members of other commissions might be consulted. It was decided that this group should be chaired by G. Wilkins.

IV. *Epoch of Ephemeris Time*

D. H. Sadler commented on the effects produced on the definition of the epoch of ephemeris time by the change in the adopted value of the constant of aberration χ. He proposed that in spite of this fact, no discontinuity should be introduced in the geometrical ephemerides of the Sun and planets and in the lunar ephemeris. This implies that the epoch of Ephemeris time should not be changed. A discontinuity in the apparent ephemerides of the Sun and planets will therefore arise but no effect will be introduced into the definition and actual determination of E.T. The actual effect on the theory of the motion of the Earth that would arise if the observations were reduced with $\chi = 20''.496$ instead of $20''.47$ is not straightforward and it is therefore better not to try to introduce this change.

D. H. Sadler also proposed that the observed Ephemeris Time as deduced from observations, should be distinguished by a reference number according to the particular ephemeris that is used to reduce the lunar observations. This would provide a natural extension to the already existing E.T.O. as defined at the IAU meeting of 1961 in Berkeley. Already two such reference numbers may be assigned in the near future.

He then read the proposed resolution (see below) which was supported by *G. M. Clemence* who stated that it was the result of a considerable correspondence and discussion between himself and some of the directors of the National Ephemerides. It was agreed that this resolution should be discussed informally before the next meeting of the commission.

Séance du 28 Août 1967

IV. *Epoch of Ephemeris Time* (*suite*)

No further comment was made on the solution proposed by *D. H. Sadler* and which further was supported by *R. Duncombe* and *J. Kovalevsky*.

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The Commission unanimously approved this resolution (10 votes in favour, no abstention) which reads as follows:

Commission 4 recommends:

(1) That, consequent on the change, from 20″.47 to 20″.496, in the adopted value of the constant of aberration, and in spite of any effect that this change may have on the epoch from which Ephemeris Time is measured according to its adopted definition:

(*a*) no discontinuity be introduced into the lunar ephemeris;

(*b*) no discontinuity be introduced into the geometric ephemerides of the Sun and planets;

(*c*) a discontinuity be introduced into the apparent ephemerides of the Sun and planets, but the compilers of the international ephemerides be given discretion to decide whether these changes, arising solely from the changed aberration corrections, be formally incorporated into the ephemerides, or given as differential corrections.

(2) That (a) the time-arguments of the ephemerides of the Sun, Moon and planets be designated in the international ephemerides as Ephemeris Time (E.T.), without qualification;

(b) to each distinguishable lunar ephemeris (as recognised and designated by Commission 4) there be allocated a reference number j with the corresponding designations E.T.j and ΔT_j = E.T.j — U.T.;

(c) the first three such distinguishable lunar ephemerides be:

$j = 0$: the Improved Lunar Ephemeris (I.L.E.); (this ephemeris is that tabulated in the international ephemerides in the years 1960–1967);

$j = 1$: the I.L.E. corrected for

(i) the introduction of the IAU System of Astronomical Constants;

(ii) the error in the coefficient of term No. 182; (this ephemeris is that obtained by applying the corrections given in A.E. 1968 to the I.L.E. itself);

$j = 2$: the I.L.E. corrected for (i) and (ii), as for $j = 1$, for

(iii) the substitution of W. J. Eckert's (*Astr. J.*, **71**, 314, 1966) re-calculation of the solar perturbations instead of those used in I.L.E.

(d) the lunar ephemeris, specified above by $j = 2$, be used in the international ephemerides from 1972 onwards;

(e) the planetary ephemerides, as specified by resolutions 1 (b) and 1 (c), be used in the international ephemerides from 1968 onwards.

(3) That, pending a rediscussion of the observational data, the definition of the epoch of Ephemeris Time, as adopted by the tenth General Assembly (Moscow, 1958; *Trans. IAU*, **10**, 72, 1960) remain unchanged.

(4) That note be taken that:

(a) although the ephemerides of the Sun and Moon designated above are strictly in accord with the observational relationship between their mean longitudes as obtained by Spencer Jones (*Mon. Not. R. astr. Soc.*, **99**, 541, 1939), this relationship depends on the value (20″.47) of the constant of aberration used by Spencer Jones in his discussion;

(b) a discontinuity (new–old) of —0″.026 has been introduced into the apparent longitude of the Sun.

V. *The Introduction of a Modified Julian Day number*

G. Wilkins proposed a resolution against the official introduction of a modified Julian day in the form proposed during the joint meeting of commissions 4 and 31 (see p. 182). He argued that the chosen system is not a convenient one and that sufficient consideration had not been given to the proposition. *J. Kovalevsky* feared that the rejection of such a modified day count would prevent the IAU from improving the existing situation. The proposal was supported by *R.L. Duncombe*, *W. Fricke* and *D.H. Sadler*. It was agreed by 10 against 1.

VI. *Automatic Printing of the Ephemerides*

J. Kovalevsky described the tape converter which is used in the *Bureau des Longitudes* in order to

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convert 7 channel paper tape punched by the computer into 31 channel Monotype tape used to control a hot metal setting machine. The main advantages of the system are:

(1) a sizeable reduction of the cost of the setting,

(2) a considerable reduction of the number of misprints, though proofreading is still necessary,

(3) no change in the quality of the printing.

More than half of the tables published for 1968 are set by this system which will be used for 90% of the tables published in the *Connaissance des Temps* and in the *Ephémérides Nautiques* for 1969.

R. Haupt described some of the work done in the U.S. Naval Observatory with a magnetic tape to Linotype 15 channel paper-tape. Many tables have been published by this photo-composition method which will probably soon be used for the Air Almanac. A new system, in which rules can also be programmed was also described by *R. Haupt*. It would be possible to set the American Ephemeris in the present format.

W. Fricke recalled the method used for the *Apparent places of Fundamental stars* since 1960: the tables are printed with a card controlled typewriter and then photographed. No proof reading is carried out.

G. A. Wilkins stated that it was the intention to use a similar system to that described by J. Kovalevsky for the setting of the first part of the *Astronomical Ephemeris*. The editing and coding programs had been written in Fortran and a Monophoto filmsetter would be used.

A short discussion followed these presentations.

VII. *Working Group on Ephemerides for Space Research*

G. Wilkins presented the report of this working group, set up at the Hamburg meeting of the I.A.U. (see the annex, p. 51). It appears from the comments obtained by the working group that most space research organizations have larger computing possibilities than the Ephemeris Offices. The latter are ready to supply in machine readable form the best ephemerides that are in their possession.

A letter just received from the Jet Propulsion Laboratory showed the interest of this organization in the work of the group and it appeared that a collaboration could be fruitful for both parties. The commission therefore decided unanimously to maintain the group in existence. In addition to the present members, T. Lederle was nominated as member of the Working Group, which is also allowed to coopt other members outside Commission 4.

VIII. *Future Form of the Ephemerides*

D. H. Sadler introduced the question of the future form of tabulation of the fundamental ephemerides. He mentioned that the present procedure required that they be calculated at least five years in advance, which makes difficult the rapid introduction of a new theory on the new constants. Moreover, he questioned whether their presentation in annual printed volumes was the most useful as compared with, for example, availability in special publications for each body, as machine listings or in machine readable form. In addition, there was the problem of making these ephemerides available well in advance of publication for the preparation of navigational and other ephemerides for practical use. New methods could introduce difficulties.

The Commission agreed that the ephemerides distributed for the latter purpose need not be 'fundamental'.

There was also the question as whether the published ephemerides in their present form provided users with the pertinent data they request and *D. H. Sadler* suggested that this problem should be considered objectively, preferably in consultation with users.

R. L. Duncombe remarked that, in spite of a large distribution there are no complaints on the form of the present ephemerides.

G. M. Clemence suggested that *D. H. Sadler* initiate correspondence on these problems.

IX. *Ephemerides of Ceres, Pallas, Juno and Vesta*

R. L. Duncombe reported on a work by Jackson and himself; they had analysed 40 years of meridian observations of minor planets (1), (2), (3) and (4) and made a numerical theory of their motion until the year 2000 (*Astronomical papers of the American Ephemeris*, **XX**, part I). Compared with Herget's numerical theory, the new theory gives a considerable reduction in the mean residuals for these meridian observations and for 8 years of homogeneous photographic observations.

After some discussion on the fact that in the construction of this theory, older observations were not used, and despite the fact that Newcomb's value of $S/E + M$ was used, the Commission unanimously agreed that the national ephemerides be authorised to use this numerical theory in their publication.

X. *Jupiter Galilean Satellites*

J. L. Sagnier reported on the present and future status of the publication of the ephemerides and phenomena of the Galilean satellites of Jupiter. They will be computed directly from the analytic expressions instead of the tables by Sampson and consequently the method of Andoyer for the computation of the phenomena should be changed. The following schedule is foreseen:

Until 1969: ephemerides computed from Sampson tables by Andoyer's method. Phenomena deduced by Andoyer's method.

1970 and perhaps 1971: ephemerides computed from the analytic expressions in true coordinates. Phenomena deduced from these ephemerides by a modification of Andoyer's method.

As from 1971 or 1972: ephemerides in rectangular coordinates from the analytic expressions. Phenomena deduced from these ephemerides by purely geometrical methods.

The Commission unanimously authorised the national ephemerides to publish coordinates and phenomena of the Galilean satellites of Jupiter computed from the analytical expressions of Sampson.

ANNEX

REPORT OF THE WORKING GROUP ON EPHEMERIDES FOR SPACE RESEARCH

Introduction

The Group was set up by I.A.U. Commission 4 at Hamburg (*I.A.U. Trans.*, **12B** (1964), p. 103) with the principal function of finding out the current and likely future requirements for astronomical ephemerides for space research. The Group has not met between the two General Assemblies of the Union and so this report has been prepared by correspondence between the members.

We have assumed that the group should only be concerned with the ephemerides of natural astronomical bodies, i.e. that the ephemerides of artificial satellites and space probes are not within our terms of reference. Cospar Working Group I has not been able to gather any specific information about the requirements of space research organisations, but the general comments obtained have been included in this Report. In fact, most of the requirements of space research are not essentially different from those of dynamical, optical and radio astronomers. The principal exception to this statement is that in the case of launching of a space probe to another planet the relevant planetary ephemerides are required to the highest possible accuracy; they should therefore be based on the best estimates of the astronomical constants and other parameters of the system.

There is now, however, in astronomy as well as in space research a much greater emphasis in requiring the data to be in machine-readable form, rather than in annual printed volumes. We have therefore concerned ourselves with the more general problems of specifying what ephemerides already exist or need to be computed and of indicating appropriate ways of making the data more

readily available. We hope that this Report will meet our terms of reference and be of value to Commission 4 in its considerations of future policy on the publications of ephemerides.

Review of Astronomical Ephemerides

(a) *The planets.* The first requirement is for heliocentric ephemerides of high precision (say, 10^{-8} a.u.); the most useful form is that of equatorial rectangular coordinates for a standard equinox, but such coordinates can be obtained from ecliptic longitude, latitude and radius vector by straightforward transformations. Ephemerides based on an analytic theory are most useful for theoretical purposes, since the theory can be used directly to determine the dependence of the coordinates on the fundamental parameters of the system. For many practical purposes, however, coordinates obtained by numerical integrations that have been fitted to existing, but less precise, theories are equally useful.

The second requirement is for geocentric ephemerides of the angular coordinates and of distance (range) and doppler velocity (range-rate) for radar astronomy. It is this latter requirement that demands a higher precision in distance than that previously thought necessary. At present the doppler velocities are calculated separately to meet special requirements, but for the convenience of radar astronomers consideration should be given to publishing them with the other coordinates. Consideration should be given in the construction of new analytical theories to the desirability of obtaining precise expressions for the derivatives. The precision of the geocentric ephemerides is, of course, dependent on the precision of the ephemeris of the Earth-Moon barycentre that is used; the further reduction to the centre of the Earth can be obtained directly to high precision from the lunar ephemeris.

Publication and Distribution of Ephemerides

It is clear that it is necessary, as well as desirable, that ephemerides should be made available in both printed form and in machine-readable-form, although the two forms need not be identical in content and arrangement. We consider the different requirements separately.

The Royal Greenwich Observatory is prepared to endeavour to meet requests for planetary and lunar ephemerides and for the smaller star catalogues. Its present computer is an ICT 1909, but it can handle a wide variety of codes, including many IBM codes. It is hoped that the R.G.O. will eventually have duplicate copies of the ephemerides in the U.S.N.O. list but at present the R.G.O.'s collection is incomplete.

The Astronomisches Rechen Institut will endeavour to meet requests for star catalogue data and the Bureau des Longitudes is prepared to act as a secondary data centre.

The only other known source of such data is NASA, but the extent to which the special ephemerides that have been produced in NASA establishments are available to other users is not known to us. Perhaps also other institutions, such as the European Space Data Centre, may be prepared to cooperate.

It should be made quite clear that organisations requesting data must be prepared to pay (directly or indirectly) for the costs of materials and postage. In some cases payment for computer time required for, say, copying magnetic tapes may be appropriate. Such matters are primarily for arrangement between the organisations concerned. The source of the data should, of course, be acknowledged in any report of work in which the data have been used.

Conclusions

We consider that there is no need for Commission 4 to initiate special action to provide ephemerides for space research, although we have drawn attention to the needs for further improvement for general astronomical purposes in the precision and scope of the published ephemerides and for a revised system of planetary masses.

We note that the organisations responsible for launching artificial earth satellites and space probes

have much more powerful computing facilities than the almanac producing agencies, but we consider that the latter may be able to assist, either directly or by giving advice, when the need for a new ephemeris becomes apparent. The responsibility for such special ephemerides must, however, rest with the launching organisations.

We recommend that the distribution of ephemerides in machine-readable form be coordinated through a limited number of data centres in the manner that we have indicated.

G. A. Čebotarev J. Kovalevsky
R. L. Duncombe G. A. Wilkins

Note—The report on the Joint Meeting of Commissions 4 and 31 appears with the report of Commission 31.

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