7. CELESTIAL MECHANICS (MÉCANIQUE CÉLESTE)

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INTRODUCTION

The most exciting feature of contemporary celestial mechanics is the close interaction with three of the most dramatic engineering achievements of our time: the electronic computer, artificial celestial objects, and the precise measurement of distances in the solar system. The last two provide new information for and make new demands on celestial mechanics and the former provides an effective means of response. These developments have also stimulated people with backgrounds other than celestial mechanics to make contributions in the field.

Since the last meeting of the Union, the use of the computer for literal theoretical developments has become effective and widespread.

The creation of artificial celestial objects not only requires the services of celestial mechanics but provides the means of obtaining new measurements that may throw light on the physical laws that govern the motion of celestial objects. In other words, we can now perform experiments as well as observe.

Until the present decade celestial mechanics was based on the measurement of the directions of other objects from the observer, and distances were found by triangulation from the angular measures. Even in the case of the Moon there was a loss in accuracy of nearly two orders of magnitude in the distances. During the past few years important results have been obtained by radar and other electronic methods and the laser method, which promises an improvement in accuracy of several orders of magnitude over the best angular measurements for the Moon, has been started. We in celestial mechanics are looking forward to the availability of extensive series of uniform observations of distance made in the same spirit as the angular measurements on which we now rely.

At the last meeting of the Union, Commission 7 held a colloquium on the Use of Electronic Computers for Analytical Developments in Celestial Mechanics. For the coming meeting Professor Duboshin is now organizing a colloquium on Analytical Methods for the Orbits of Artificial Celestial Objects, and Professor Clemence is organizing a discussion of The Impact of Precise Measurements of Distances on Celestial Mechanics.

An important function of this report is to assist workers with different backgrounds to find in what areas of celestial mechanics various people are working and where they publish their results. This requirement has influenced the arrangement of the report and especially that of the bibliography.

The subject matter has been classified according to the scheme in Table A. This is a somewhat modified form of that used by Hagihara in the previous report. The discussion of the material in the ensuing text follows in general the order of Table A, and each reference in the biobligraphy carries classification designations for the article. Section N contains general questions as well as several specific topics.

The names of the publications to which reference is made in the bibliography are not printed in the bibliography but separately in Table B. The term "periodical" is used in the same sense as in page 76 of the *IAU Astronomer's Handbook* (vol. XIIC) and the periodicals marked with an asterisk are contained in the list starting on the same page of the Handbook. The bibliography is in alphabetical order by author and the references are in coded form, for example the reference

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indicates that the article was classified Fc and J according to Table A, and was published in 1968 in the journal listed as number 42 in Table B (*Astronomical Journal*), volume 72, page 382. For articles in press as of November 1969 the year is replaced by asterisks. In references by joint authors the year is followed by "a" for the first author and "b" for the others. Obvious variations of the code are used for publications such as reports and dissertations. This form of bibliography appears to be more convenient than the conventional ones and it occupies about 60 % of the space.

In writing the report and in compiling the bibliography, we have made no attempt at completeness nor strict consistency with a concise set of rules; we have tried to give a representative picture. The report was developed in the following manner. The author made a quick inspection of fourteen of the journals used most frequently in the previous report to prepare a preliminary bibliography, listed by author. Each author who was either a member of Commission 7 or who had at least three titles (aside from joint articles with members of the Commission) was requested to correct, enlarge, and classify his portion. A second bibliography incorporating these corrections was arranged by classification for review.

Sections of the material were reviewed by members of the Commission as follows: Clemence (sections E and K), Garfinkel (F and I), Herget (A and L), Kovalevsky (B and C), and Szebehely (G and H). The reviewers' reports have received only general editing. I am most grateful to these gentlemen for reviewing the material and doing it on very short notice. I am also indebted to Professor Duboshin for a report on work in the U.S.S.R. which facilitated the work of the reviewers. Jose Fortoul and Sara Bellesheim of the IBM Watson Laboratory were largely responsible for the preparation of the bibliography.

The following review of the subject matter is presented in the order indicated in Table A. References in the Bibliography are referred to in the text by the name of the author and the number of the reference as it appears in his list. For joint authors the number given is that of the first.

Table A. Classification scheme

A. Two-Body Problem and Orbital Improvement
B. Perturbation Theory and General Dynamics
C. Planetary and Satellite Theory
D. Lunar Theory
E. Relativity and Other Non-Newtonian Effects
F. Artificial Celestial Objects
  a. General
  b. Air Drag, Light Pressure, and Rotation
  c. Lunar Orbiters and Artificial Satellites of Planets
  d. Optimization Problem
G. Three-Body Problem
  a. Regularization
  b. Numerical Survey
  c. Analytical Theory
H. Periodicity, Ergodicity, Stability
I. Resonance
J. *N*-Body Problem and Galactic Structure
K. Astronomical Constants
L. Minor Planets, Comets, and Meteors
M. Computing Methods
N. Other Topics

A. TWO-BODY PROBLEM AND ORBITAL IMPROVEMENT

The review of many articles is confined to their listing in the Bibliography. Benima (1) *et al.*, have given polynomials to replace the tables formerly used in the Gauss-Marth method of finding the position in a nearly parabolic orbit. Izvekov (1) concludes that the integration of the Variational

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Equation is not necessary for the correction of minor planet orbits, except when they are subjected to extreme perturbations. Kustaanheimo (1) has prepared an introductory text which is developed in terms of vector and spinors, leading to relativity theory. Mulholland (2) attempts to ameliorate the differential correction of highly perturbed satellite orbits, where the integration of the Variational Equation is required to achieve a satisfactory result.

B. PERTURBATION THEORY AND GENERAL DYNAMICS

Hori (1) attacked the problem of general perturbations by the use of Lie-series in such a way that the new procedure is now valid for any set of canonical variables. The formulae are presented in the form of canonical invariance. The perturbations of the elements or coordinates are given in an explicit form and the theory is applicable whatever variables appear in the undisturbed part of the Hamiltonian. Deprit (13) extended the concept of these transforms in order to include cases when the generating function depends upon a small parameter and he gave a recursive algorithm for the solution. Canonical transformations are generated explicitly as well as their inverses as explicit chains of Poisson's brackets without inversions or substitutions.

Kevorkian (1) proposed a procedure, called the "two variable method" in which he introduces a fast variable and a slow variable whose ratio is of the order of the small parameter and the final series are derived as simultaneous functions of these two variables. This method was compared with Von Zeipel's method by Kevorkian (2). Applications of averaging methods to celestial mechanics were studied by Grebenikov (2) who evaluated the errors of these methods for intervals of time of the order of μ^{-1}.

Boigey (1) studied parametric Lagrangian systems and applied her results to the reduction of equations, regularization and separation of variables. Gustavson (1) constructed formal integrals of a Hamiltonian system near an equilibrium point while Kikuchi (2) worked on the complete system of integrals in celestial mechanics. The ultimate behaviour of orbits with respect to an unstable critical point was investigated by Conley (2).

Losco (2) investigated relationship existing between integrals and invariant curves or surfaces of a dynamical system and properties of solutions associated with an invariant surface in equations in involution (3). Henon (5), Contopoulos (7) and Hadjidemetriou, and Roels (2) and Henon made systematic studies of invariant curves in various area conserving mappings.

Practical methods in obtaining formal solutions of various perturbation problems with computers were given by Deprit (8, 9) and Rom. Grebenikov (1) investigated the effects of small variations of initial conditions on the respective magnitudes of secular and long-periodic perturbations, while Kholshevnikov (2) studied the speed of formal convergence of the solution of a Hamiltonian system by means of successive approximations. Much effort was directed towards the description of the motion of a particle in various gravitational fields.

The problem of the motion of a point attracted by two fixed masses has been further investigated because it provides a good intermediate orbit for an artificial satellite and even, as proposed by Lukashevich (1) for natural satellites. Most results obtained up to now in this field are presented in the book by Demin (see Table B). Aksenov (3) and Marchal (1) derived general theories of the motion in such a field and Aksenov (2) put this problem in a canonicalform. Kiryushenkov (1) expanded solutions around circular orbits in small parameters. Degtjarow (1) and Evdokimova studied the stability of these orbits. Timoshkova (1) investigated elliptic orbits in the problem and Chepurova (1) analyzed the hyperbolic case. A. H. Cook (1) showed that the exact solution of this problem obtained in spheroidal coordinates cannot be extended to ellipsoidal coordinates.

A generalized axisymmetrical Earth-like field depending upon J_2 alone provides a simple example of a dynamical system with two degrees of freedom. This is why Danby (2) studied numerically the phase space in the regions where non-integrability very probably occurs and where the orbits become *wild*. Mangeney-Ghertzman (1) made a more restricted study using osculating elements and found a critical value of J_2 after which, the osculating perigee circulates while the mean anomaly oscillates. Separable potentials in triaxial ellipsoidal coordinates were studied by Madden (1) and A. H. Cook (1). Kholshevnikov (1) studied the potential of a body of an arbitrary shape.

Less 'normal' force fields are often studied because of their evident applications to the motion of stars in clusters. As Kovalevsky (1) has shown, some problems in stellar dynamics can be solved by methods pertaining to celestial mechanics. So, Hori (3) computed orbits in the plane of symmetry of the Galaxy while Woolley (1) and Candy studied the perturbations of such orbits by the local field irregularities. Barbanis (2) and Prendergast represented the gravitational field of a disc galaxy by Legendre functions multiplied by Fourier series and Barbanis (4) gave orbits and integrals of motion in a spiral field.

A similar type of problem arises in the study of the motion of planets or satellites, when the perturbation methods do not apply, as shown by Morando (3). A general investigation on such strongly perturbed systems was made by Jefferys (6). It is the case of long range behavior of satellites of high inclinations and large eccentricity studied analytically by Kozai (4) and R. S. Harrington (1) or numerically by Chebotarev (1, 2). It is also the case of a close approach of a planetoid to a planet examined by Stellmacher-Amilhat (1). Numerical methods are often used in these investigations. They can be improved by regularizing the equations as shown by Stiefel (2) and Scheifele. Leimanis (1) applied Sonneschein summation methods to get the analytical continuation of the solution.

Kyner (1, 2) and Bennett improved the numerical Encke's method in introducing part of the first-order perturbations in the reference orbit. Stiefel (3) and Bettis investigated the stability of Cowell's method of numerical integration.

Radar measurements of the rotation of Mercury and Venus and photometric observations of artificial satellites raised considerable interest in investigations of the rotational motion of celestial bodies.

Goldreich (2, 5) and Peale studied the spin-orbit coupling in the solar system and applied their theory to the resonant rotation of Venus (3). More generally, Blitzer (2) considered the rotational resonances of a rigid body in a Keplerian orbit. Vinti (1, 3) discussed the various types of Liapounov stability in the case of a free rotation as function of the ratio of the moments of inertia. Brumberg (4) wrote the equations for the rotational motion of the planets when corrections for general relativity are introduced.

Colombo (1) showed that the second and third laws of Cassini are independent from the first and could be satisfied if the Moon's inertial ellipsoids were rotationally symmetric. Peale (4) generalized these laws; he computed relations between the moments of inertia for stable commensurabilities between the orbital mean motion and the spin-angular velocity. Habibulin (1) solved the equations for the physical libration of the Moon for the non-linear terms, using Krylov-Bogolioubov method.

A complete review of the rotational motion of an artificial satellite was given by the book by Beletzky (see Table B), who also (1) gave the recent advances in this field. Recently, Holland (1) and Sperling derived a first order theory for a triaxial rigid body orbiting an oblate planet.

The general dynamical problem of the motion of two finite rigid bodies also includes cross-terms giving the effect of the rotation on the motion of the center of mass. This effect was studied in particular by Schinkarik (1) in a central Newtonian field, Osipov (1) in a generalized Hill problem and Johnson (1) and Kane in a special case of the relative motion of two rigid ellipsoids of revolution. The equilibrium of a rotating non-homogeneous fluid body was investigated by Marchal (2) and Volkov (2) who introduced a spherical core in the model, while Miyamoto (1) considered a possible influence of an extended halo and Aizenman (1) studied this problem in a system of two bodies. Yabushita (1) investigated the stability of the rotation of Saturn's rings in function of the density distribution and the total mass.

C. PLANETARY AND SATELLITE THEORY

The planetary disturbing function was constructed by Meffroy (5) and by Brumberg (3) who gave an iterative formulation while Petrovskaya (1, 3) investigated the accuracy with which it can be represented by trigonometric polynomials.

Musen (2) has investigated Hansen's planetary theory and improved the convergence by introducing a new method of computing the function dw/dt. Seidelmann (1) has programmed an iterative procedure for determining a planetary theory based on Hansen's method and continues doing research on the technique. Nacozy (2) has tested Hansen's method of partial anomalies and applied it to the motion of Comet Encke.

Meffroy investigated the applicability of Von Zeipel methods to a planetary theory in order to eliminate short period terms of the first and second order (1, 2, 3, 8).

Brouwer's method in rectangular coordinates was analyzed and programmed by Hamid (1) who gave the solution to the first order, and more recently, some second order terms. Musen (1) proposed some improvements to the original Brouwer's formulation. Broucke (2) gave an iterative procedure for the computation of planetary rectangular coordinates.

General methods of literal developments on a computer described by Kovalevsky (2) were applied by Chapront (3) who applied a first order term and all second order terms factored by the square of the external mass of a purely literal "LeVerrier type" planetary theory. The coefficients are literal functions of the ratio of the semi-major axes put under special explicit forms involving polynomials and more complicated divisors valid for any value of the ratio between zero and 0.7. Ferraz-Mello (1) has introduced a new approach to the study of the motion of quasi-circular and quasi-resonant orbits in Hill's normalized coordinates, and extended this method to second order terms (3) and to the case when the mutual inclination is not negligible (4). Along a somewhat similar line, Brumberg (6) combined Hill's method with the principle of elimination of short period variables, gave a solution of the variational equations obtained and presented a method to obtain a general solution of the equations of planetary motion.

Morando (2) has completed a generalized semi-numerical theory of the motion of Vesta giving a first approximation orbit in terms of trigonometric functions of four independent arguments. The same method is now being applied to the Jupiter-Saturn system, some of the long periodic arguments being computed in a purely literal form and compared with results obtained using Krylov-Bogoliubov method.

Musen (5) proposed the use of Hill's method of secular perturbations in obtaining the zero order perturbations. Skripnichenko (1) applied Weil's method to study secular perturbations of some planets of the solar system.

A long-range study of the elements of the Earth motion over 30 million years was made by Sharaf (2) and Boudnikova. A long-range numerical integration of the motions of Pluto, Neptune, and Uranus was made by C. J. Cohen (1, 2) *et al.* and the orbits of these planets were investigated also by Duncombe (1) *et al.* and Seidelmann (3) *et al.*

Duncombe (3) *et al.* derived new numerical theories of the motion of Ceres, Pallas, Juno, and Vesta, based on a series of observations collected by E. S. Jackson. Clemence's theory of Mars was studied by Böhme (1) and is currently compared with observations by Laubscher.

The disturbing function of the motion of a satellite was studied and iterative formulations were given by Brumberg (1) and by Challe (1) and Laclaverie.

Giacaglia (3, 8) applied to the solution of Hill's equation a method of transformation of generalized Mathieu equations. Elmabsout (1) gave a semi-numerical method of solving equations in the Hill-Brown method and applied it to the motion of Phoebe. Various determinations of luni-solar perturbations of an artificial satellite, as those by Kozai (1, 2) pertain as well to the study of the motion of a natural satellite.

Wilkins (1) obtained a new satsfactory representation of the orbits of Phobos and Deimos free of acceleration, while Vashkovyak (1), and Liakh constructed two other independent theories of the motion of these satellites. Sudbury (1) worked on Jupiter's fifth satellite while Charnow (1) *et al.* applied Hansen's method to the tenth satellite of Jupiter. Gill (1) and Gault redetermined a new orbit of Triton.

Ferraz-Mello (1) derived a theory of the motion of the Galilean satellites of Jupiter that includes most of the second order terms. This task is being continued by Sagnier for other higher order terms and terms depending upon the inclination while D. T. Vu is applying Sampson's method to the same problem.

D. LUNAR THEORY

The dramatic interaction between celestial mechanics and engineering mentioned in the Introduction is most striking in the case of the Moon. The motion of the Moon has always been a most effective means of testing the laws governing the motions in the solar system and now, in a comparatively few years, we are achieving a new overall order of accuracy. This increase in accuracy cannot fail to have important consequences.

The comparison of the theory of the motion of the Moon with observation requires not only the measurement of the direction or distance of the Moon, but also of the many other quantities necessary to refer the position of the observer to the center of gravity of the Earth and of the point observed to the center of gravity of the Moon, and the distribution of mass in the Earth and in the Moon. For many years the effects of several of the components on the overall accuracy of the comparison have been roughly of the same order of magnitude [W. J. Eckert (1)]. Fortunately the new technology is advancing in all these areas by means of earth satellites, lunar orbiters [Mulholland (1) and Sjogren], and lasers.

The most dramatic of the new observing techniques is of course the use of the laser in conjunction with the reflector array placed on the Moon by the Apollo astronauts. This method not only gives direct measures of distances with a new order of accuracy but it uses a sharp point on the lunar surface. A long series of observations from several stations on the Earth and hopefully with one or two additional reflectors should give excellent resolution of the necessary parameters. The following communication concerning the experiment has been received from Mulholland.

Present plans of the experimenters (Alley, Bender, Dicke, Faller, Kaula, MacDonald, Mulholland, Plotkin), approved by NASA, call for an observing program to be carried on for at least 9 years from the primary observatory (McDonald Obs., Ft. Davis, Texas). The experimenters are encouraging other observatories to establish observing programs, providing widespread coverage. The data, which are expected to yield a 1-nanosecond (15 cm) resolution, will be used to investigate a variety of minute effects, as well as providing for significant improvement to our knowledge of lunar motion. The phenomena upon which information will be obtained include the polar motion of Earth, the physical librations of Moon, a test of relativistic concepts, and several matters of geophysical interest.

In the meantime progress is being made in improving the angular measures (see Commission 8); this includes improved reductions of old observations and new techniques for observing occultations.

There is not yet a complete lunar theory covering all phases of the problem with the precision demanded for the near future, but results already achieved and work in progress indicate that no observational accuracy will be compromised for lack of accuracy in the theory. Parts of the problem are being attacked by several independent methods and this should not only assure precision for practical purposes but should throw light on mathematical developments when pushed to a dozen significant figures.

The electronic computer can now be applied to all the traditional methods of celestial mechanics including numerical integration and development in harmonic series. The series development for the main problem includes Delaunay's method where all the parameters m, e, e', γ, α are literal, that of Hill-Brown where m is numerical, and that of Airy where all are numerical. Brown's theory had a precision of 2×10^{-8} for most of the main problem and about an order of magnitude less precision in the perturbations.

During the past three years much progress has been made. The solution of the main problem by the method of Airy (precision of 1×10^{-12} in most terms) was completed by Eckert (4) and Smith in 1967. The solution was made both with and without the effect of the factor $(E+M)/m'$. Since then a great deal of effort has been devoted to the detailed publication to facilitate critical

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analysis of the work. The stimulating paper "Lunar Disturbing Function" by Barton (1) has been followed by Barton (2). A new formalism has been devised and checked by Chapront (2) and Mangeney-Ghertzman and is now being programmed for computation up to high orders of the parameters as well as to permit a study of the planetary perturbations.

The solution of the main problem by the Hill-Brown method with 18 decimals and for several values of m and of $(E+M)/m'$ (including zero) is under way; the terms of zero order in e, e', k, α have been published [W. J. Eckert (1) and D. A. Eckert], and the first and second order terms have been completed. Deprit is engaged on a literal solution of the Main Problem. Musen (3) has re-examined Hansen's theory and Thiry (1) discussed action variables and Delaunay's theory.

Mulholland (3, 5) and his associates are using a combination of numerical integration and analytic techniques to prepare precise ephemerides for comparison with observations.

E. RELATIVITY AND OTHER NON-NEWTONIAN EFFECTS

Probably the most important development in this field has been the measurement of the oblateness of the photosphere of the Sun by R. H. Dicke and his collaborators, from which they deduce a motion of the perihelion of Mercury of some 3″ per century, which destroys the previously supposed excellent agreement with Einstein's prediction, and if substantiated, may require profound modifications in the theory of relativity. Dicke postulates the existence of a scalar field superimposed on Einstein's tensor field. Those results have appeared in the literature of physics rather than astronomy, chiefly the *Physical Review* and *Physical Review Letters*; e.g., Dicke (1, 4), Dicke (2, 3) and Goldenberg.

Several papers, including Carstoiu (2, 3) and Dăngvu (1), have appeared on the propagation of gravitational waves, which still awaits definite observational confirmation.

At least two papers, Eisenstaedt (1) and Kurmakaev (1), purport to give solutions of the relativistic two-body problem, which, according to the textbooks, is impossible.

F. ARTIFICIAL CELESTIAL OBJECTS

(a) *General.* The use of intermediate orbits for artificial earth's satellites has been the subject of numerous papers. A novel spherical-coordinate intermediary, introduced by Aksnes (2) has drastically simplified the calculation of perturbations. The author used this intermediary to construct a first- (1) and then a second-order theory (4). The latter paper is the first complete second-order theory for a geopotential including the J_2, J_3, and J_4 spherical harmonics. The work is noteworthy for its use of the method of Lie-series as formulated by Hori, and for the use of Hill variables to preclude the appearance of mixed secular terms. The Aksnes intermediary and its close relation to that of Garfinkel (1958) are discussed in Garfinkel (3) and Aksnes. The troublesome question of mixed-secular terms and their elimination by the use of action-angle variables is investigated in Garfinkel (5), Hori, and Aksnes.

The Vinti intermediary, separable in spheroidal coordinates has been adapted to the calculation of nearly polar orbits [Vinti (2)]. Practical applications of the Vinti potential have been investigated by Getchel (1) and O'Mathuna (2). An extension of the Vinti-type potential to *triaxial* ellipsoid has been studied by Madden (1). A closely related intermediary, corresponding to the solution of the problem of two fixed centers, has been used by Marchal (1).

The use of electronic machines to construct a formal artificial satellite theory is illustrated by the work of Deprit (19) and Rom. There the author solves the Main Problem, extending the Brouwer solution to the third order in J_2. The paper is noteworthy for the programming of the Lie-series method. However, not being in closed form, the solution is restricted to small eccentricities.

The luni-solar perturbations of an artificial earth's satellite have been studied by Kopal (1) and Roy (3). The effect of these perturbations on the 24-h satellite has been investigated by Martynenko (1) and Morando (1).

The problem of orbit determination was studied by Senjalow (1), Bazhenow (1), and Lundquist (1);

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the problem of position determination from simultaneous angular observations was treated by Zhongolovitch (1).

That the critical inclination is, indeed, real was reiterated by Garfinkel (2) in his comment on a controversial paper by Lubowe (1).

(b) *Air Drag, Light Pressure, and Rotation.* Second-order perturbations in a and i, due to the combined effect of drag and oblateness, were calculated by Fominov (1). The lifetime of satellites of large eccentricity was investigated by G. E. Cook (2) and Scott. The drag effects on a cone-shaped satellite were studied by Po (1). Sehnal (1) and Mills discussed the short-periodic drag perturbations. Further studies of contraction of satellite orbits due to drag were carried out by G. E. Cook (3) and King-Hele. The "shadow equation", governing the radiation pressure of a satellite, was solved by Batrakov (1) for the case of small eccentricity.

(c) *Lunar Orbiters and Artificial Satellites of Planets.* The theory of a lunar orbiter was studied by Giacaglia (9), Oesterwinter (1), Forga (1), Roy (1, 2), Evdokimova (2), and Kirpichnikov (1). The latter included the effects of lunar and solar radiation pressure. Classification of orbits was discussed by Felsentreger.

(d) *Optimization Problem.* Hiller (1) considered impulsive transfer between non-coplanar elliptic orbits having collinear major axes. Tapley (1, 2) *et al.* investigated the advantages of regularization in optimal trajectories. J. Breedlove is using the Lie-series method to obtain a first-order solution of the Lawden Problem for the case of low thrust.

G. THE PROBLEM OF THREE BODIES

The restricted problem of three bodies dominates the field. The main areas of interest are periodic orbits, regularization, motion around the libration points and stability. The general problem of three bodies received less attention. The principal approaches are analytic and numerical.

Various aspects of periodic orbits and their stability in the restricted problem are discussed by Bozis (3, 4, 5), L. H. Carpenter (2) and Stumpff, Colombo (2) *et al.*, Conley (1, 2), Deprit (3) and Henrard, Giacaglia (1), Guillaume (2), Henon, (2, 3, 4) and Guyot, Jefferys (2, 4) and Standish, Kevorkian (5), Kozai (6), Lanzano (2), Meffroy (6), and Szebehely (6, 9) and Nazocy. In the general problem of three bodies periodic and quasi-periodic orbits are treated by Duboshin, Jefferys (3) and Moser, Moser (1, 4, 5), and Szebehely (16, 22) and Peters. Motion and stability around the equilibrium points of the restricted problem have been studied in considerable detail by Deprit (1, 5, 7, 12, 15, 16, 17, 20, 22) *et al.*, França (1, 3), Giacaglia (12) and França, Hadjidemetriou (3), Henrard (11), Katsis (1), Junqueira (1), Rabe (1, 2, 5), Roels (1), Schanzle (1), and Szebehely (1, 8, 11, 21) *et al.*

The elliptic restricted problem received attention from Choudhry (1), Contopoulos (3), Guillaume (1), Lanzano (1), Lukjanow (1), Rabe (7, 8), and Szebehely (2).

The regularization of the three dimensional problem was discussed by Deprit (10), Kustaanheimo (4), Peters (3, 4), Stiefel (1) *et al.*, and Waldvogel (1). Perturbation studies using regularized variables were performed by Pierce (1, 2), Szebehely (5), and C. Williams (1). General comments on and applications of regularization were made by Broucke (1), Giacaglia (6), and Szebehely (3, 10) and Pierce.

Applications to orbits of interest in space explorations have been made by Giacaglia (7), Grebenikov, Jarov-Jarovi, Kirpichnikov, Noroselov, Petrovskaya (U.S.S.R), Kevorkian (6) and Brachet, Lancaster (1), Shi (1, 3) and Eckstein, and Szebehely (7, 4).

Asymptotic orbits were investigated by Danby (1) and Deprit (14) and Henrard. Capture in the restricted and general problems of three bodies was discussed by Sung (1) and by Kotsakis (2) *et al.* who also discussed drag effects in the restricted problem (3).

Orbits in the general problem of three bodies were treated by Agekyan (1, 2) and Anosova, Alekseev (1), Sconzo (2), and Szebehely (12, 14, 19) and Peters.

Integrals of motion in the restricted problem have been investigated by Bozis (1, 2) and Contopoulos (2, 3).

A book containing the major accomplishments and listing references on the restricted problem up to 1967 is *Theory of Orbits* by Szebehely (see Table B).

H. PERIODICITY, ERGODICITY, STABILITY

The articles which discuss the above subjects with applications to the problem of three bodies have been reviewed under Class G. The main trends in this category are quasi-periodic orbits, stability, and the study of integrals of motion. This last subject is discussed by Contopoulos (1, 5, 6, 7) *et al.*, and Deprit (21) and Henrard, in addition to Bozis (see Section G). Stability questions are treated by Contopoulos (9), Losco (1), Moustakhichev (1), Nahon (2), and Pius (1). Normalization is treated by Deprit (18) *et al.* and Krassinsky (1). Quasi-periodic orbits are discussed by Moser (1, 3, 4, 5), see also under G.

I. RESONANCE

The many papers on the subject of resonance dealt with general theories of resonance and with a variety of special problems found in the solar system. The first group includes Lectures on Hamiltonian Systems, Moser (5); spin-orbit coupling and dynamics of planetary rotations, Goldreich (2, 3) *et al.*; resonant structure of the solar system, Molchanov (1), comment by Henon (6); the relation of the third integral to resonance, Barbanis (1), Contopoulos (1), Hori (2); evolution of commensurabilities, Dermott (1, 2); and the ideal resonance problem, Garfinkel (4), Jupp (1). The group of special problems is illustrated by the tesseral harmonics resonance, Allan (1, 2), Blitzer (1); rotational resonance in a Kepler orbit, Blitzer (2); resonance in the restricted three-body, L. H. Carpenter (2) and Stumpff, Colombo (2), Giacaglia (11); and in the restricted four-body problem, Kolenkiewicz (1) *et al.*; resonance in the neighborhood of the Lagrange points, Roels (3, 4); asteroids commensurable with Jupiter, Sinclair (1); periodic Trojans, Deprit (15) and Rabe; Kirkwood gaps, W. H. Jefferys (1), Schweizer (1); Cassini laws, S. J. Peale (4); the Hilda-type asteroids, Schubart (1); periodic orbits emanating from resonant equilibrium, Henrard (10); and the Mimas-Thetys commensurability, R. R. Allan (3).

A novel method of treating resonance problems was proposed by Shi (2) *et al.* In a class by itself is the paper on the radar determination of the rotation of Venus and Mercury, Dyce (2), Pettengill and Shapiro, which furnished observational data for much of the subsequent theorizing.

J. N-BODY PROBLEM AND GALACTIC STRUCTURE

Many papers in this area of importance to celestial mechanics are reviewed in the report of Commission 33 and others in Section B of this report.

The proceedings of the IAU Colloquium on the Gravitational and *N*-Body Problem, held in Paris, in 1967 were published in *Bulletin Astronomique* (many of the references marked J68 7,... were presented at the Colloquium). A new IAU Colloquium on the Gravitational *N*-Body Problem will take place, in August 1970 at the Institute of Theoretical Astronomy, Cambridge, England.

K. ASTRONOMICAL CONSTANTS

The application of radar to the direct measurement of lunar and interplanetary distances has provided a new dimension in celestial mechanics (at least for the terrestrial planets), and has already resulted in several important contributions to the system of astronomical constants, and to the values of the masses of the planets. Indeed, the work of the past five years has added as much to our knowledge of these subjects as that of the fifty years preceding. Observations of the planets by means of radar include Dyce (3) *et al.*, Evans (1, 2) *et al.*, Goldstein (1) Pettengill (1) *et al.* Determinations of masses and other astronomical constants include Ash (1) *et al.*, Bec (1), Duncombe (1) *et al.*, Klepczynski (2), Lieske (2, 4), Lieske (3) and Null, Null (1), O'Handley (1), Rabe (3), Rabe (4) and Francis, Seidelmann (3) *et al.*, and Zielenbach (1).

In addition, with the aid of radar the gravitational field of the near side of the Moon has been mapped for the first time [Bray (2) *et al.*, Chuikova (1), Derr (1), Goudas (3), Koziel (1), Safranov (1), Volkov (3) and Schober], and our knowledge of the gravitational field of the Earth has been greatly increased with the aid of artificial satellites [Bivas (1), Kaula (1), King-Hele (2, 5) *et al.*, Kozai (3, 5), Murphy (1)].

Coherent light pulses have been sent to, and reflected from, the Moon. A systematic series of such observations, continued over a number of years, would provide a direct test of the Theory of the Motion of the Moon, which can be obtained in no other way (see Section D).

L. MINOR PLANETS, COMETS, AND METEORS

Everhart (1, 2) has made a very interesting statistical study of energy changes and captures of comets in a hypothetical solar system. His results are not in agreement with the known short-period comets. Herget (2) derived satisfactory orbits for J-VIII to J-XII, including the integration of the Variational Equation. The mass of Jupiter is not well determined, in contradiction to the results of Miss A. Bec (1). Hunter (1, 2) has made a statistical study of carefully selected hypothetical satellites of Jupiter and minor planets, to find their evolution and stability. His supposed region of minor planets between Jupiter and Saturn is not substantiated by the Palomar-Leiden survey, which reached magnitude 20·5 and discovered 15 new Trojans. Marsden (4, 7) has varying degrees of success in representing short-period comet observations in three or more oppositions by including an unspecified non-gravitational term in the equations of motion. The effect is mainly an outward radial force, in agreement with Whipple's comet model. Polozova has computed the first order general perturbations of (11) Parthenope by Venus to Neptune, using Hill's method. The residuals reach 300″ at dates 60 years from the epoch. Schubart (2) used the observations from five oppositions of (1221) Amor (1932–1964) to derive improved elements, but he found it necessary to adjust the mass of Earth + Moon (in agreement with the radar value for the astronomical unit) and he encountered the difficulties usually associated with the correction of highly perturbed orbits. The detailed study of the motions of comets in the solar system by Kazimirchak-Polonskaya (1, 3, 4, 5, 6) has been completed.

M. COMPUTING METHODS

A review of computing methods as such is not a part of this report, but many papers in celestial mechanics contain contributions to the subject. We have attached 'M' to a number of references and commented on a few of them.

The principal development has been in the use of computers for the manipulation of large harmonic series with literal coefficients. The exciting paper of Barton (1) has been followed by the sequel (2). The report of the colloquium on the Use of Computers for Analytical Developments in Celestial Mechanics held at the meeting in Prague has been published, Eckert (3), with papers by Davis (1), Kovalevsky (2), Deprit (8) and Rom, Chapront (1) and Mangeney Ghertzman, and LeShack (1) and Sconzo. Other papers include those by Deprit (2) and Rom, Chapront (2) and Mangeney-Ghertzman, and Glebova (1).

Section D of this report contains examples of large literal and numerical calculations. Many of the references marked B, Ga, and J involve extensive numerical work; the paper by Prendergast (2) and Miller is of particular interest. Propagation of errors in numerical methods is discussed by Kinoshita (1), by Miachine (1), and by Stiefel (3) and Bettis.

N. OTHER TOPICS

Minor changes were made in the classification scheme of Table A during the course of collecting the bibliography, and some references have retained classifications that were assigned before the scheme was in final form. This explains some of the anomalies of classification, particularly in this section.

General and historical questions were discussed by Duboshin (1), Levy (1) and Neugebauer (1). A conference on the general problems of celestial mechanics and of astrodynamics was held in Moscow in March 1967; a symposium, "The General Questions of Celestial Mechanics", in Leningrad in May 1969; and a conference on the qualitative methods of celestial mechanics in October 1969.

Discussions of the internal structure of the Earth, Moon and planets include Goldreich (4), Jeffreys (1), Khan (1), Kozlovskaya (1), Mikhailov (1), Sconzo (4), Shimazu (1), and Volkov (1, 2). A symposium, "The Theory of the Figures of the Earth and Moon", was held in Lvov in October 1968 and another. "The Figures and Rotation of Celestial Objects", in Tiraspol in October 1969.

Secular effects, cosmic dust, etc., were treated by Sharaf (3, 4), and Boudnikova, Divari (1), Gerstenkorn (1, 2), Giuli (1), Lebedinets (1) and Kashcheev, McCord (1, 2), Roosen (1) and Ruskol (1).

W. J. ECKERT
President of the Commission

PERIODICALS

35. *A. Rev. Astr. Astrophys.**
36. *Acta. astr.**
37. *Adv. Astr. Astrophys.**
38. *AIAA J.*
39. *Akad. Nauk., Arm. USSR., Astrophys.*
40. *An. Acad. brasil. Cienc.*
41. *Astr. Astrophys.*
42. *Astr. J.**
43. *Astr. Nachr.**
44. *Astr. Pap. Washington**
45. *Astr. Zu.**
46. *Astrophys. J.**
47. *Astrophys. Norw.**
48. *Astrophys. Space Sci.*
49. *Bjull. Inst. teor. Astr.**
50. *Bull. Am. astr. Soc.*
51. *Bull. astr., Paris**
52. *C. r. Acad. Sci. Paris**
53. *Cel. Mech.*
54. *Commun. Sternberg astr. Inst.*
55. Dissertation, ETH, Zurich
56. Dissertation, Yale Univ.
57. *Dokl. Akad. Nauk. SSSR**
58. ESRO Publ.
59. *Icarus**
60. *J. astronaut. Sci.**
61. *J. diff. Eq.*
62. *J. geophys. Res.**
63. JPL Publ. (Cal. Inst. Tech.)
64. *Math. Annln*
65. *Math. USSR Sbornik*
66. *Mem. Am. math. Soc.*
67. *Mem. Soc. astr. ital.**
68. *Mon. Not. R. astr. Soc.**
69. NASA Publ.
70. *Nature**
71. *Num. Math.*
72. *Observatory**
73. Ph.D. Thesis, Univ. Conn.
74. *Phys. Rev.**
75. *Phys. Rev. Lett.**
76. *Planet. Space Sci.**
77. *Proc. nat. Acad. Sci. Am.**
78. *Proc. R. Soc. London Ser. A**
79. *Publ. astr. Obs. Helsinki**
80. *Publ. astr. Soc. Japan**
81. *Publ. astr. Soc. Pacific**
82. *Q. appl. Math.*
83. *Res. cel. Mech. diff. Eq., Univ. Sao Paulo*
84. *Science**
85. *SIAM J. appl. Math*
86. *SIAM Rev.*
87. *Smithsonian Inst. Obs., Spec. Rep.**
88. *Tech. Ann.*
89. *Trudy Inst. teor. Astr.**
90. *Vest. Leningrad. gos. Univ.**
91. *Vest. Mosk. gos. Univ.**
92. *Vistas Astr.*
93. *Z. angew. Math. Phys.*
94. *Z. Astrophys.**

Table B. Publications

BOOKS

1. Abalakin, V. K., Aksenov, E. P., Grebenikov, E. A., Riabov, J. A. *Reference Book of Celestial Mechanics* (in Russian), Moscow, in press.
2. Baker, R. M. L. 1967, *Astrodynamics: Applications and Advanced Topics*, Academic Press, New York.

https://doi.org/10.1017/S0251107X00023476 Published online by Cambridge University Press

3. Baker, R. M. L., Makemson, M. M. 1967, *An Introduction to Astrodynamics*, 2nd. ed., Academic Press, New York.
4. Beletzky, V. V. 1965, *The Motion of an Artificial Satellite About Its Center of Mass* (in Russian), 'Nauka', Moscow.
5. Captuo, M. 1967, *Gravity Field of the Earth from Classical and Modern Methods*, Academic Press, New York.
6. Cherbotarev, G. A. 1967, *Analytical and Numerical Methods of Celestial Mechanics*, American Elsevier, New York.
7. Contopoulos, G. 1966, *The Theory of Orbits in the Solar System and Stellar Systems*, IAU.
8. Demin, V. G. 1968, *The Motion of an Artificial Satellite in a Non-Central Field of Gravitation* (in Russian), 'Nauka', Moscow.
9. Duboshin, G. N. 1968, *Celestial Mechanics, Fundamental Problems and Methods*, 2nd ed., *Manual* (in Russian), 'Nauka', Moscow.
10. Duncombe, R. L., Szbehely, V. G., Eds. 1966, *Methods in Astrodynamics and Celestial Mechanics*, Academic Press, New York.
11. El'yasberg, P. E. 1967, *Introduction to the Theory of Flight of Artificial Earth Satellites*, Israel Program Sci. Transl.
12. Escabol, P. R. 1968, *Methods of Astrodynamics*, Wiley, New York.
13. Giacaglia, G. E. O., Ed. 1969, *Proceedings of the Symposium on Periodic Orbits, Stability and Resonances*, University of São Paulo, Brazil, in press.
14. Grodzovskii, G. L., Ivanov, Y. N., Tokarev, V. V. 1969, *Mechanics of Low-Thrust Spaceflight*, Israel Program Sci. Transl.
15. Hagihara, Y. *Celestial Mechanics*, vols. I, II, MIT Press, in press, vols. III, IV, V, in preparation.
16. Herrick, S. *Astrodynamics*, vol. I, van Nostrand Reinhold, New York, in press, vol. II, in preparation.
17. Kaula, W. M. 1966, *Theory of Satellite Geodesy*, Blaisdell, Waltham, Mass.
18. Kovalevsky, J. 1967, *Introduction to Celestial Mechanics*, Reidel, Dordrecht, The Netherlands.
19. Kovalevsky, J. 1966, *Trajectories of Artificial Celestial Bodies as Determined by Observations*, Springer-Verlag, New York.
20. Markowitz, W., Guinot, B. 1968, *Continental Drift, Secular Motion of the Pole and Rotation of the Earth*, IAU.
21. Marsden, B. G., Cameron, A. G. W. 1966, *The Earth-Moon System*, Plenum Press, New York.
22. Melchior, P. J. 1966, *Earth Tides*, Pergamon Press, Elmsford, N.Y.
23. *Modern Questions of Celestial Mechanics*, Internazionale Matematico Estivo, Edizioni Cremonese, Roma 1967.
24. Morando, B., Ed. 1970, *Dynamics of Satellites*, Springer-Verlag, New York.
25. Mueller, I. 1969, *Introduction to Satellite Geodesy*, Ungar, New York.
26. Mueller, I., Rockie, J. D. 1966, *Gravimetric and Celestial Geodesy*, Ungar, New York.
27. Pollard, H. 1966, *Mathematical Introduction to Celestial Mechanics*, Prentice-Hall, Englewood Cliffs, N.J.
28. Rosser, J. B., Ed. 1966, *Lectures in Applied Mathematics*, vols. 5–7, Space Mathematics, Am. Math. Soc., Providence, R.I.
29. Runcorn, S. K., Ed. 1967, *Mantles of the Earth and Terrestrial Planets*, Interscience, London.
30. Sedov, L. I. 1968, *Analytical Mechanics, Stability of Motion, Celestial Ballistics*, Part I, Israel Program Sci. Transl.
31. Sternberg, Shlomo 1969, *Celestial Mechanics*, Part I and Part II, W. A. Benjamin, New York.
32. Stiefel, E., Ed. 1966, *Mathematische Methoden der Himmelsmechanik und Astronautik*, Bibliographisches Inst., Mannheim.
33. Subbotin, M. F. 1968, *Introduction to Theoretical Astronomy* (in Russian), 'Nauka', Moscow.
34. Szebehely, B. G. 1967, *Theory of Orbits*, Academic Press, New York.

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Abalakin, V. K.	K68a49,11,481	Aksenov, E. P.	B68 45,45,858
Abitt, M. W. Jr.	I69b53,1,31		C68 45,45,1284
Agekyan, T. A.	Gb67a45,44,1261		B68 54,no.155, p. 3
	Gc68a39,4,31	Aksnes, K.	Fa67 47,10,149

	Fa67 47,10,69
	L67b42,72,952
	Fa69 56
	Fa**b42
	Fa**b42
Alekseev, V. M.	Gc68 65,5,no.1
Allan, R. R.	I67 76,15,53
	FI67 76,15,1829
	IN69 42,74,497
Allen, W. A.	Fc69 38,7,890
Anand, S. P. S.	E68a59,8,492
Anosova, Z. P.	Gb67b45,44,1261
	Gc68b39,4,31
Aoki, S.	K67 80,19,585
	B69 42,74,284
Ash, M. E.	K67a42,72,338
Astapovich, I. S.	L67b45,44,614
Aver'yanova, T. V.	E66a45,43,1301
Baierlain, R.	E67 74,162,1275
Barbanis, B.	I66 42,71,415
	B67a42,72,215
	H68b48,2,134
	B68 42,73,784
Barton, D.	DM66 42,71,438
	DM67 42,72,1281
Batrakov, Y. V.	Fb67 49,11,14
Bazhenow, G. M.	Fa67 49,11,116
Bec, A.	K69 41,2,381
Beletzky, V. V.	B** 24
Belorizky, D.	Gc66 52,262,1133
Belous, L. M.	L66 49,10,543
Belyaev, N. A.	L67 45,44,461
	L67b45,44,614
Benima, B.	A69a81,81,121
Bennett, M. M.	B66b42,71,579
Bernstein, I. S.	H68b59,9,281
Bettis, D. G.	CM69b71,13,154
Betz, H. R.	Fa69b53,1,91
Bivas, R.	K68 51,3,517
Blitzer, L.	I66 62,71,3557
	IB67 42,72,988
	I68 62,73,2304
Böhme, S.	C68 43,290,249
	E** 43
Boigey, F.	B66 51,1,265
Boudnikova, N. A.	C66b89,11,89
	BC67b49,11,231
	CN68b57,182,291
	CN69b89,14,48
Bourke, R. D.	K67b62,72,1265
Bozis, G.	GbH66 42,71,404
	GcH67 42,72,380
	Gb68 42,73,616
	Gb69 72,89,75
	Gb** 13
Brachet, G.	Gc69b38,7,885
Brady, J. L.	L67a42,72,365
	L67 42,72,1184
Branham, R. L. Jr.	L68 42,73,97
Bray, T. A.	Gc67a42,72,202
	K67a59,7,76
Brockelman, R. A.	K66b42,71,897
Broucke, R.	Ga67 59,7,221
	C69 53,1,110
Brouwer, D.	I66a42,71,543
Brumberg, V. A.	C66 89,11,3
	C67 49,11,73
	C67 45,44,204
	EB68 45,45,828
	E68 45,45,1110
	C** 13
Burdet, C. A.	BGa67b69,N67-29387
Campbell, D. B.	KB67b42,72,330
Campbell, J. W.	J68b42,73,611
Candy, M. P.	B68b68,139,231
	J68b68,141,277
Carpenter, E.	L67b42,72,365
Carpenter, G. C.	M69b53,1,72
Carpenter, L. H.	I67b42,72,180
	GcI68a43,291,25
Carstoiu, J.	E68 52,266,754
	E69 52,268,201
	E69 52,268,261
Cary, C. N.	Fc68a84,160,875
Castaing, C.	H67 52,264,333
Challe, A.	DFaC69a41,3,15
Chandrasekhar, S.	J68a68,139,135
Chapront, J.	D68a42,73,214
	D69a41,2,425
	C** 41
Charnow, M.	DC68a60,15,303
Chebotarev, G. A.	B68 49,11,341
	B69 49,11,625
Chepurova, V. M.	B68 54,no.154,p.14
Cherniack, J. R.	A69b81,81,121
Choudhry, R. K.	Gc66 49,10,523
Chuikova, N. A.	K68 45,45,1293
Clemence, G. M.	E67a42,72,1324
Cochram, J. E.	Gc**b42
Cohen, C. J.	C67a42,72,973
	C68a42,73,290
Cohen, L.	J68a51,3,213
Colombo, G.	B66 42,71,891
	GcIL68a42,73,111
Conley, C.	Gc68 85,16,620
	B69 61,5,136
Contopoulos, G.	HI67 51,2,223
	GcH67 42,72,191
	GcH67 42,72,669
	HI68 46,153,83
	H68a48,2,134
	D68 70,220,1018
	BH68a42,73,86
	H** 42
	H** 42
Cook, A. H.	B66 68,134,253

Cook, G. E.	K67b76,15,741
	Fb67a76,15,1549
	Fb68a78,303,17
	K69b76,17,629
Cronin, J.	H68a59,9,281
Danby, J. M. A.	Gb67 42,72,198
	C68 42,73,1031
Dăngvu, H.	E69 52,268,297
Davies, R. D.	K68b68,140,537
Davis, M. S.	M68 42,73,195
DeBra, D. B.	K67b62,72,1265
Degtjarow, W. G.	BH66a49,10,516
Deprit, A.	Gb67a68,137,311
	M67a51,2,425
	Gc67a42,72,158
	Gc67a42,72,173
	Gb67a59,6,381
	A68a51,3,315
	Gb68a37,6,2
	BM68a42,73,210
	B68a38,6,1234
	Ga68 93,19,369
	Gb68a59,9,336
	Gb68 42,73,730
	B69 53,1,12
	Gc69a42,74,308
	GbI69a42,74,317
	Gb69a41,1,427
	Gb69a41,3,88
	H**a53
	Fa**a53
	Gb**a13
	H**a48
Deprit-Bartholomé, A.	Gc67b42,72,173
	A68b51,3,315
Dermott, S. F.	I68 68,141,349
	I68 68,141,363
Derr, J. S.	K67 59,7,261
Devine, C. J.	D68b84,160,874
Dicke, R. H.	E64 70,202,432
	E67a75,18,313
	E67a70,214,1294
	E67 84,157,960
Ditto, F. H.	N69 53,1,130
Divari, N. B.	N66 45,43,1273
Douglas, B. C.	FI69b76,17,1505
Duboshin, G. N.	N67 49,11,1
	J69a45,46,895
Duncombe, R. L.	CK68a42,73,830
	CK69b42,74,776
	C** 44
Dupont, E. N.	K66b42,71,897
Dyce, R. B.	KB67b42,72,330
	IK67a42,72,351
	K67a42,72,771
Eckert, D. A.	D67b42,72,1299
Eckert, W. J.	D65 42,70,787
	D67a42,72,1299
	M68 42,73,195
	D**a44
Eckstein, M. C.	GcJ67b42,72,685
	I68b42,73,275
	GcJ68b42,73,653
	I69a42,74,551
Eisenstaedt, J.	E66 52,263,149
Elmabsout, B.	C** 41
Evans, J. V.	K66a42,71,897
	K66a42,71,902
Evdokimova, L. S.	BH66b49,10,516
	Fc68 49,11,523
Everhart, E.	L68 42,73,1039
	L69 42,74,735
Fahlman, G. G.	E68b59,8,492
Feix, M. R.	J67b46,147,1164
	JM68a51,3,289
Felsentreger, T. L.	Fa68 76,16,285
Ferraz-Mello, S.	C66 51,1,287
	C68 40,40,447
	BC69 52,268,198
	BC69 52,268,985
	C** 13
Finzi, A.	K68 59,9,191
Fominov, A. M.	F68 49,11,507
Forga, R.	F69 41,2,75
Foursenko, M. A.	N67 49,11,127
	K68b49,11,481
França, L. N. F.	Gc68 83,1,42
	Gc**b13
	Gc** 83
Francis, M. P.	K67b42,72,856
Franklin, F. A.	GcIL68b42,73,111
Freeman, K. C.	J66 68,133,47
	J66 68,134,1
	J66 68,134,15
Freeman, K. G.	J68a51,3,269
Froeschlé, C.	N68 52,266,747
	N68 52,266,846
Gaposchkin, E. M.	E68a87,no.283
Garfinkel, B.	I66 42,71,657
	FaI69 53,1,11
	Fa**a42
	I** 13
	Fa**a42
Gault, B. L.	C68b42,73,95
Gehrels, T.	L67 42,72,929
Gerstenkorn, H.	N67 59,6,292
	N67 59,7,160
Getchell, B. C.	Fc** 38
Giacaglia, G. E. O.	Ga67 42,72,386
	GNJ67 42,72,674
	BC67 42,72,998
	J68 51,3,63
	I68 87,no.278
	GaB68 83,1,1
	Gc68 83,1,3
	BC68 42,73,379

	Fc69 69,N69-28050
	N** 53
	I** 42
	Gc**a13
	I** 13
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	E67b70,214,1294
Goldreich, P.	K66a59,5,375
	ICH66a42,71,425
	ICH67a42,72,662
	N67 62,72,3135
	ICH68a35,6,287
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Gonzalez, C.	J68a51,3,209
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	K67b59,7,76
	K67 42,72,955
Graham, R.	J67 68,137,25
Grebenikov, E. A.	B66 45,43,882
	B68 49,11,293
Guillaume, P.	Ga67 51,2,533
	GBGc69 41,3,57
Guinot, B.	N67 51,2,449
Gustavson, F. G.	B66 42,71,670
Guyot, M.	Gb69b13
Hadjidemetriou, J. D.	Gc67 42,72,865
	BH68b42,73,86
	Gb68 42,73,104
	A69 48,3,330
	A69 48,3,31
	GH69 42,74,789
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