COMMISSION 7 : CELESTIAL MECHANICS (MECANIQUE CELESTE)

Reports of meetings on November 22 and 25

PRESIDENT: J. Kovalevsky SECRETARY: J. Henrard

BUSINESS SESSION (November 22)

The President opened the session by paying tribute to the memory of two deceased members of the Commission: Professor C.L. Siegel and Doctor J. Meffroy. He also greeted Prof. B. Garfinkel who has just celebrated his 81-st birthday.

OFFICERS AND MEMBERSHIP OF THE COMMISSION

After discussion and some proposals from the floor, the following list was moved and unanimously approved :

- President : V.A. Brumberg, the retiring Vice-President.
- Vice-President : J. Henrard.
- Organizing Committee :Ju.V. Batrakov, K.B. Bhatnagar, J. Chapront, A. Deprit, S. Ferraz-Mello, J.D. Hadjidemetriou, H. Kinoshita, J. Kovalevsky, H. Scholl, P.K. Seidelmann, A. Sinclair and Z.H. Yi.

Three members of the IAU were appointed members of the commission between the general assemblies: M.F. He (China), G.A. Krasinsky (USSR) and A.M. Nobili (Italy). The following members of the IAU were proposed to become members of Commission 7 and were approved: B.D. Jovalovic (Yugoslavia), J. Osorio (Portugal), A. Pal (Romania), M.J. Valtonen (Finland) and M. Yuasa (Japan).

The following new members of the IAU have requested to become members of Commission 7 and were approved after a short presentation: M. Ahmed (Egypt), B. Barberis (Italy), F. Boigey (France), N. Caranicolas (Greece), Z. Chen (China), K.H. Choi (Korea Rep.), C.F. Cui (China), H. Din (China), A. Drozyner (Poland), A. Elipe-Sanchez (Spain), S.M. Fernandez (Argentina), S. Ferrer Martinez (Spain), C.G. Fong (China), D. Galletto (Italy), A. Gonzalez Camacho (Spain), A. Hanslmeier (Austria) T.Y. Huang (China), A. Journet (France), A. Lemaitre (Belgium), B.K. Lu (China),S. Mikkola (Finland), C.D. Murray (U.K.), Y.S. Sun (China), C. Veillet (France), J-J. Walch (France), I.W. Walker (U.K.), E. Wnuk (Poland) L.D. Wu (China), P.X. Xu (China), H. Yoshida (Japan), S.P. Zhang (China), J.Q. Zheng (China), X.T. Zheng (China), H.N. Zhou (China) and W.Y. Zhu (China).

The 1982-85 list of consultants was reviewed. For the new term, eight consultants were presented and approved. They are: V.R. Bond (USA), P.P. Hallan (India), J. Moser (Switzerland), D. Saari (USA), S.K. Shrivastava (India), C. Simo (Spain), M. Soffel (Fed.rep. of Germany) and J. Waldvogel (Switzerland).

IAU COLLOQUIUM

The IAU executive committee has approved a colloquium by Commission 7 together with commissions 20, 26, 33 and 37. The title will be "The few body problem". It will be organized in June 1987 in Turku (Finland) by P. Valtonen. The chairman of the scientific committee is V.A. Brumberg.

RESOLUTIONS

The joint discussion on reference frames has voted two resolutions. The first resolution sets up a working group on reference frames. As it is of the interest of Commission 7 to be represented in such a working group, V.A. Brumberg and J. Kovalevsky were proposed to become members. The second resolution calls for a wor-

https://doi.org/10.1017/S0251107X00026110 Published online by Cambridge University Press

king group on the best current values of various constants. Commission 7 nominated P.K. Seidelman to be its representative in the working group. In addition, it is remarked that the working group should not concern itself about physical and geophysical constants, but only on astronomical and geodetic constants.

REPORTS ON MEETINGS

V.A. Brumberg reported on the IAU Symposium 114 "Relativity in Celestial Mechanics and Astrometry" held in Leningrad on May 28-31, 1985. It was the first IAU meeting devoted exclusively to relativistic problems of Celestial Mechanics and Astrometry, even if some such problems were partly treated in other meetings. Since the relativistic treatment of the motion of celestial bodies is useful only if the related Newtonian contributions are discussed with the necessary high-level accuracy, high precision dynamical theories were also included in the program.

There were 80 soviet and 58 foreign participants including astronomers engaged in relativistic problems of Celestial Mechanics and Astrometry, specialists of classical but very high precision approaches to these sciences and physicists interested in applying their methods to practical problems. The proceedings will be published by D. Reidel Company in the IAU Symposium series. They will appear in February 1986.

V.G. Szebehely reported on the first meeting dealing with Celestial Mechanics held in India: the workshop was held in Delhi just before the IAU General Assembly. There were 130 indian and 27 foreign participants; 48 papers were presented during 8 sessions. A great variety of topics were addressed ranging from qualitative to quantitative problems and from artifical satellite mission analysis to regularization. The proceedings will be published by D. Reidel Company.

REPORT ON CELESTIAL MECHANICS IN CHINA

Yi Zhao-Hua reported on the contribution of chinese astronomers in Celestial Mechanics during the last four years.

1. Numerical studies of dynamical systems. Sun Yi-Sui continued his studies in this field and obtained a series of results on dynamical systems with even and odd dimensions. In particular new results were obtained in the case of odd dimensions.
2. General and restricted three body problem. Sun Yi-Sui together with C. Marchal and J. Yoshida obtained a new test for escape in the general three body problem. Huang Tian-Yi and his collaborators dealt with stability region of the planar three body problem and applied the results to the solar system. Yi Zhaohuc and J.H. Jefferys used the Liapounoff characteristic numbers to study the region of stability of the restricted three body problem. Ding Hua and Tong Fu found periodic orbits of the first kind for the restricted three body problem with an ellipsoid.
3. Perturbation and resonance theory. Liu Lin, Zhang Sheng-pan and Zhao De-Zhi presented an interesting method to study high order perturbations that can be used for artificial satellites. Recently, together with F.A. Inanen, he established a new theory of resonance different from those of Garfinkel and Schubart and applied it in the case of the solar system.
4. Dynamics of the solar system. Tong Fu derived analytically the precise post-Newtonian terms for all major planets. Zhang Jia-xiang and Li Gang-yui gave the secular perturbations of many asteroids. Liu Lin studied the resonance phenomena of asteroids and of satellites of Neptune.
5. Other subjects. Huang Tian-yi, K.L. Innanen and Zhou Qing-lin obtained some interesting results by using integral invariants to check numerical computations. Zhan Hong-nan et al. used numerical methods to study the evolution of galaxies and close binaries, while Zheng Xue-tang et al. studied the velocity dispersion of galaxies.

https://doi.org/10.1017/S0251107X00026110 Published online by Cambridge University Press

SCIENTIFIC SESSION (November 22, chaired by J. Kovalevsky)

V.G. Szebehely presented a paper on binary asteroids. Several theorerical and observational approaches have been reported in the literature since 1966 to the present time. One of the best references is F. Whipple's paper presented in 1982 at the IAU meeting in Patras.

The theoretical models are the restricted problem of three and many bodies. The actual dynamical system consists of the Sun, Jupiter, Asteroid and its Satellite. If the effect of Jupiter is neglected the limiting distance between the asteroid and its satellite is given by :

$$d = (\mu/81)^{1/3}$$

where μ=(Mass)asteroid/(Mass)Sun and d is in nondimensional units to be multiplied by the distance of the asteroid from the Sun. The above equation for the limiting distance for stability may also be written as :

$$d < 30 R l$$

where R is the radius of the asteroid in km and l is the distance of the asteroid to the Sun in a.u. The many assumptions made in the derivation of the above equation restrict seriously its applicability, therefore, better models are presently being developed. These models are known as the restricted problem of many bodies. Analytical solutions are not known but the generalization and the extension of the Jacobian integral has been established. Regarding the questionable observational results, we mention Lucina and Herculina which might have satellites inside the stability limit given by the above equation.

- A. Deprit presented a paper entitled "The critical inclination in artificial satellite theory" co-authored with S.L. Coffey and B.R. Miller.

After a Delaunay normalization to average the Hamiltonian over the mean anomaly, invariance with respect to the group of rotation about the polar axis is used to assimilate the flow on the manifold of constant L and constant H to a flow on a two-dimensional sphere in a three-dimensional space (ξ,η,ζ). Expressed in the averaged Delaunay elements (G,H,L,g,h,l) the coordinates are :

$$\xi = LGe \sin l \cos g, \quad \eta = LGe \sin l \sin g, \text{ and } \zeta = G^2 - \frac{1}{2}(L^2+H^2);$$

the sphere's equation is: $\xi^2 + \zeta^2 + \eta^2 = \frac{1}{4}(L^2-H^2)$.

At any point in the interval $0<H<L$ the flow on the sphere presents two isolated singularities: S_0 at the North pole ($\xi=\eta=0, \zeta>0$) corresponding to the circular orbits, and S_5 at the South pole ($\xi=\eta=0, \zeta<0$) corresponding to the equatorial orbits. *In addition, when only the terms in J_2 are retained, the flow admits*, as long as $0<H<L/\sqrt{5}$, a continuous manifold of equilibria lying on a small circle of latitude representing the orbits with stationary perigee at critical inclination.

However, the second order perturbation in the reduced Hamiltonian removes the degeneracy to leave only four isolated orbits with stationary perigees: two of them, say S_1 and S_3, such that the average perigee lies on the average line of nodes, the other two, S_2 and S_4, keeping their perigee at right angle with the line of nodes. The orbits S_1 and S_3 are stable whereas S_2 and S_4 are unstable.

A detailed analysis reveals that, as H approches $L/\sqrt{5}$ from below, all four equilibria S_1, S_2, S_3 and S_4 move toward S_0. A bifurcation occurs at a value $H=L/\sqrt{5}-O(J_2)$ when the merging of S_1 and S_3 with S_0 results in S_0 regaining its stability. Extensive numerical integrations of the differential equations including first and second terms in the perturbations fully confirm the mathematical deductions.

CELESTIAL MECHANICS IN INDIA (November 22, chaired by K.B. Bhatnagar)

Five papers, representative of the indian achievements in Celestial Mechanics were presented during this session prepared by K.B. Bhatnagar.

- "The effect of perturbations in Coriolis and centrifugal forces on the non-linear stability of equilibrium points in the restricted problem of three bodies" by K.B. Bhatnagar and P.P. Hallan.

The non-linear stability of the equilibrium points in the restricted problem has been studied when small perturbations ε and ε' are given to the Coriolis and the centrifugal forces respectively. It is found that the collinear points are unstable and the triangular points are stable for all mass ratios in the range of linear stability except for three mass ratios.

- "Stability of the particular solutions for the restricted as well as unrestricted problem of three bodies" by R.K. Choudhry.

Under the joint authorship with Smt. Nanju Kumari, we studied the stability of the triangular points of libration for the restricted problem of three bodies when the effect of solar radiation pressure is also taken into account. We have investigated the stability for all orders and all times. We took into consideration the resonance case also. For the unrestricted problem of three bodies we have taken the equations of motion in Whittaker's form and we have examined the stability of Lagrange's particular solutions in full detail taking into consideration the effect of light pressure as well. Under the joint authorship of Dr D.N. Singh, we have investigated the stability of the libration points for the generalized restricted problem of three bodies when the shape of the infinitesimal mass is an oblate spheroid. Here we have considered the stability only of the first order. We have also found the existence of such points of three bodies when one of the finite bodies is taken to be a radiating body. Here we have not considered the stability of libration points. In the latter problem we get coplanar libration points in addition to the triangular and the colinear libration points.

- "The existence and stability of the equilibrium points of a triaxial rigid body moving around another triaxial rigid body"by K.B. Bhatnagar and Mrs Usha Gupta.

The motion of two mutually attracting triaxial rigid bodies has been considered. Thirty six particular solutions corresponding to the libration points analogous to the points Spoke, Arrow and Float (Duboshin, 1959) have been found. The stability of these libration points has been discussed in two categories of cases. In the first category, different shapes of the bodies have been taken and in the second category, the mass and the linear dimensions of one of the bodies have been taken small in comparison to the other.

- "Influence of planets on the Sun" by S.D. Verma.

A fundamental and basic model is developed in which the influence of planets, mainly Jupiter, Venus, Earth and Mercury on the Sun is evaluated. There is observational support for the model, which spans from few months to hundred of years. The simplicity and the beauty of the model is a point to discuss together with the convincing experimental observations. In turn these effects on the "Sun", cause changes in the solar atmosphere which easily extend to the orbit of Earth. They produce an influence on the Earth's environment (ionized and neutral atmosphere) especially in the Northern and Southern polar regions of the Earth.

- "Attitude dynamics and control of artificial satellites" by Shashi K. Shrivastava.

The motion of a spacecraft presents two dynamical aspects of interest: the trajectory of its center of mass, and the rotational motion about its center of mass, commonly referred to as libration or attitude motion. There are numerous situations of practical importance such as communications, scanning of cloud coverage, Earth resources survey, astronomical observations, etc... where it is necessary to maintain a fixed orientation with respect to the Earth or a given direction in space. There are many sources of environmental and internal perturbations which tend to disturb the attitude of the satellites. To overcome these disturbances a wide range of attitude stabilization and control concepts has been proposed over the years and several concepts have found practical applications. Broadly these may be classified as active, passive and semi-passive procedures.

Over the past 30 years, several hundred papers have appeared which deal with various aspects of attitude dynamics and control of satellites. Currently most of the attention is focussed on dynamics and control of large flexible spacecrafts. This paper presents an overview of studies on attitude dynamics and control of satellites. Sources of environmental and internal disturbances and the concepts behind various methods of attitude control are discussed. The presentation also includes a brief discussion on dynamics and control of large flexible spacecrafts along with some results of the related studies by the author and his associates. A few important and challenging areas needing researcher's attention are identified.

UNSOLVED PROBLEMS IN CELESTIAL MECHANICS
(November 25, chaired by A. Deprit and U. Gupta)

The objective of this session was to list a certain number of problems in various aspects of Celestial Mechanics and related fields (such as reference frames and observations) that are not solved and to discuss their relative importance as an incentive to think about areas that really need attention.

- P.K. Seidelmann discussed the problems that are connected with the study of the solar system and grouped them in six general topics.

1. Discrepancies between observations and ephemerides. The present Uranus predicted ephemerides deviate from observations by about 0"5. A systematic difference exists also in Saturn declination and there exists a seasonal effect in solar right ascension. There still exist systematic errors in correcting planetary phases and satellite separations. For faint objects, a good reference catalogue of faint stars is badly needed. Finally, a possible error of 1" per century in the solar observations can have several causes (equinox motion, constant of precession, longitude of the Sun, etc.). It still remains an unsolved problem.
2. Formation and stability of the solar system. Many problems remain unsolved or the solutions proposed are not satisfactory. The history of the Earth-Moon system or of the Neptune-Pluto system and more generally the very long time period motions; the non-gravitational effects on comets, the interactions between minor bodies of the solar system and more generally the explanation of the distribution of these bodies; the problems connected with the existence, the evolution of planetary rings and their interactions with satellites. One may add to these problems, the relation between chaotic motion theory and the reality which may lead to a partial long term unpredictability of the motions.
3. Resonances. They are largely present in the solar system. Why these resonances exist, or do not exist? How they were built up. In connection with resonances are the problems of Kirkwood gaps, families of minor planets and rings of Saturn.
4. Theory. A number of types of representation of general theories (Fourier series, Chebyshev polynomials, rational functions, elliptic functions, etc..) exist but not all are sufficiently well studied to assess their usefulness.

Important problems are the construction of general theories to a designed accuracy, of compact very long period theories and of very accurate theories with the relativistic effects.

5. Reference systems. The present important problems refer to the practical realization of ideal systems and the relationship between such realizations (in particular the space fixed versus inertial references). Several definitions are to be clarified (equinox, obliquity, inertial, mean, proper versus dynamical time).
6. Artificial satellites. An accurate modelling of all forces acting on a satellite is still a problem. It governs the long time period accurate prediction and the determination of various physical parameters.

- J. Kovalevsky presented a paper co-authored with V.A. Brumberg. Every problem is considered under four different aspects: its physical bases, the mathematical aspects, the computational techniques and the astronomical objectives. Some of these aspects might be trivial and others might present major difficulties or different importance and oldness. Three main fields were considered.

1. Relativistic Celestial Mechanics. The application of the PPN formalism to all actual motions is the most important present problem. The tools have been developed by physicists, but their applications to the solar system are far from being completed. The main theoretically and practically unresolved problem is the general rotational-translational motion of a finite body. Two mathematical problems deserve attention: the problem of relativistic resonance (solution developed in fractional powers of the relativistic parameters) and building up perturbation theory in general relativity. Finally, an important astronomical aspect is the construction of reference frames in astronomy and geodynamics in a general relativistic context.
2. Newtonian Celestial Mechanics. The main problem is evidently the N-body problem. The qualitative behaviour is still unknown for N 3. Many questions are to be answered concerning the structure of the phase space, the ergodicity of some regions, stability, the existence of families of periodic orbits, the strange attractors, etc... A whole field of separating the predictable results in overall non deterministic long term trajectories is opening now. Many of these problems are to be dealt within simplified cases. At this point, the importance of the problem in Celestial Mechanics may be questionned and should rather refer to the study of dynamical system. Difficult numerical problems exist in long term integration, the construction of litteral solution and all the studies dealing with the dynamics of complex stellar systems.
3. Evolutionary problems. Very modern, difficult and unsufficiently studied problems concern the evolution of the solar system, of clusters and galaxies. Non-gravitational effects have to be introduced (tidal effects, interaction in planetary rings, cometary dynamics, mass loss and depletion in clusters). Even the physical background of these problems is still to be studied and the mathematical aspects are not satisfactorily dealt with. Problems like capture into resonance, very long term evolution of a planetary or satellite system or the escape and multiple star formation in clusters present a number of unsolved difficulties. Other problems like the evolution of double stars exchanging matter or with strong magnetic interaction or other wild force fields are studied only by astrophysicists: they could be the source of major and useful activities for celestial mechanicists - who have built up very powerful tools that are unsufficiently used on problems of astronomical interest.

During the discussion, A. Deprit suggested a few other fields of interest to Celestial Mechanics: autonomous navigation on satellites including real time reduction, and the use of the possibilities offered by the new generation computers.

- J. Henrard presented a paper on the Emerging Problems in Resonance Theory and concentrated on two specific problems.

1. Planetary rings. It is certainly an important problem in our understanding of the evolution of the solar system and its dynamical aspects are numerous and

https://doi.org/10.1017/S0251107X00026110 Published online by Cambridge University Press

varied. The main questions connected with resonance are at present: formation of the Cassini division, density waves, sharp edges and the theory of shepherd satellites. The first difficulty about dynamical aspects of planetary rings is that it is not clear how to model the various forces acting on them. A ring can be considered in a first approximation as a collection of particles or as a continuous medium leading to very different models. The theory of shepherd satellites leads to perturbations of a type quite unusual in Celestial Mechanics. Two mathematical models are presently proposed to deal with this aspect: Hill's problem (Henon, Waldvogel) and the stream-line (Borderies, Goldreich, Tremaine).

2. Chaotic motions and the double resonance problems. The fact that chaotic motions can be of importance in Celestial Mechanics was clearly revealed by the paper of Wisdom, Peale and Mignard about the rotation of Hyperion. Chaotic motions is also at the base of one of the possible explanation for the formation of Kirkwood gaps. Wisdom has shown numerically that the 3/1 resonance gap associates with chaotic motions and has proposed a mechanism explaining the appearance of such motion: the periodic crossing of the critical curve of the circular averaged restricted three body problems forced by the perturbation due to the eccentricity of Jupiter. Such motion was also described by Froeschlé and Scholl.

This problem is related to the two resonance problem which can be described by the Hamiltonian function :

$$H = H_0(P,Q) + \varepsilon H_1(P,Q,p) + \varepsilon' H_2(P,Q,p,q)$$

If we assume that $\partial H / \partial P$ vanishes along a curve $f(P,Q)=0$, we say that we have a resonance problem. When $\partial H_0 / \partial Q$ does not vanish the angular variable q can be averaged out and the problem is approximated by a one degree of freedom problem But when $\partial H_0 / \partial Q$ vanishes also in the domain of interest we say that we have a double resonance problem. This is the case in the elliptic restricted three body problems. When ε' is much smaller than ε, one may consider introducing action angle variables (J, ψ) for the $H_0 + \varepsilon H_1$ problem and the Hamiltonian H then reduces to :

$$K = K_0(J,Q) + \varepsilon' K_2(J,Q,\psi,q)$$

Of course the action angle variables are singular along the critical curves of the one degree of freedom $H_0 + \varepsilon H_1$ problem. This will lead to chaotic motion if the orbit of K crosses periodically one of these critical curves. If certain conditions are met, the Hamiltonian K can be studied by perturbation methods. Hopefully the approximations so obtained will describe meaningfully the very long time behaviour of the system.

A more general classification of double resonance classes of problems is needed to describe and predict the onset of chaotic motion. This kind of problem has already received much attention in the fields of dynamical systems, plasma physics and particle physics. Celestial Mechanics may yet trace a new path in the study of these phenomena.

SCIENTIFIC SESSION (November 25, chaired by J. Kovalevsky)

- P. Farinella "Numerical simulations of asteroid families", co-authored with Ch. Froeschlé, Cl. Froeschlé, R. Gonczi, M. Carpino, P. Paolicchi and V. Zappalà.

The accuracy and reliability of the proper orbital elements used to define asteroid families are investigated by a new method, that is by simulating numerically the dynamical evolution of families assumed to arise from the "explosion" of a single object. The equations of motion of the simulated family asteroids are integrated in the frame of the elliptic restricted three body problem Sun-Jupiter-asteroid, over times of the order of the circulation periods of perihelia and no-

https://doi.org/10.1017/S0251107X00026110 Published online by Cambridge University Press

des. By filtering out short-periodic perturbations, the behaviour of the proper eccentricities and inclinations is monitored. Significant long-period variations have been found especially for families having non-negligible eccentricities and (or) inclinations (like the Eos family), and strong disturbances due to the proximity of commensurabilities have been evidenced (e.g. the Themis family). We conclude that further dynamical studies on the collisional origin of families and on the properties of their parent bodies must probably await the development of more accurate and reliable secular perturbation theories.

- Yi Zhao-hua: "On the qualitative study of the N-body problem", co-authored with Wong Qiou-dong.

A transformation of the phase space in the N-body problem has been established. It is suited to study the cases when time tends to infinity or to any collision moment. The following results were obtained.

a) The existence of a global solution departing from any initial condition which corresponds to any ordinary point in the original space was proved. The solution is analytic in all axes.
b) An extension of McGehee's total collision manifold of the N-body problem was given, which includes all the cases of k-tuple collisions as well as the total collisions. We showed that in order to understand the character of motions near a collision is equivalent to understand the characters of motion in the case h=0 of the transformed system.
c) This transformation was used to discuss qualitative properties of the isoceles three body and trapezoidal four body problems. The singular manifold obtained is compact and contains all singular motions corresponding to escape, super hyperbolic or tending to a collision or a libration point.

- D. Galleto: "On the collapse of a homogeneous incoherent cloud of matter".

It is observed that if an isolated homogeneous incoherent cloud of matter is radially collapsing towards one of its elements and if the homogeneity is preserved during the collapse, the cloud is also radially collapsing towards any other element of the cloud. The shape of the cloud is necessarily spherical and the forces at distance are necessarily those expressed by the Newton's law of gravitation or those of an elastic type. Furthermore, a principle of impotence follows.

THE JOURNAL "CELESTIAL MECHANICS" (November 25, chaired by J. Kovalevsky)

M.S. Davis, the new executive editor of the journal "Celestial Mechanics" presented some of the problems related to the journal. They are: the length of time between submission and publication of a paper, the low rate of rejection which may be due to the fact that some editors feel compelled to help the authors rewrite their papers, the new typography, the editing of grammar and spelling for non english speaking authors, the need of an Index, a possible publications of letters.

Some of the problems may be alleviated soon. M.S. Davis talked with the publishers: the typography will be improved soon, Reidel is willing to take charge of the editing concerning the english grammar and spelling. The executive director will send a memorandum to editors and prepare instructions and a questionnaire for reviewers should be sufficient. As he is in the process of computerizing the files of Celestial Mechanics, an Index composed of key words provided by the authors should be forthcoming. The publication of letters does not seem to correspond to a real need.

https://doi.org/10.1017/S0251107X00026110 Published online by Cambridge University Press