## COMMISSION 7: CELESTIAL MECHANICS

### Report of Meetings, 18 and 21 August, 1979

PRESIDENT: V. Szebehely SECRETARY: J. Kovalevsky

### Business Meeting

OFFICERS OF THE COMMISSION

The President proposed the following names for officers during the next period of three years:

President: Y. Kozai, retiring Vice-President

Vice President: J. Kovalevsky

Organizing Committee: E.P. Aksenov, V.A. Brumberg, S. Ferraz-Mello, J.D. Hadjidemetriou, P.J. Message, F. Nahon, J. Schubart, P.K. Seidelman and V. Szebehely.

Recommendation for this list was moved and unanimously approved.

MEMBERSHIP OF THE COMMISSION

The following members of the IAU were proposed as new members of Commission 7: Drs. C.A. Altavista, C.J. Brookes, P. Cefola, S. Debarbat, B. Erdi, P. Farinella, G.M. Gaposchkin, R.J. Greenberg, P.M. Janiczek, H. Kinoshita, J.H. Lieske, C. Marchal, W. Markellos, W.G. Melbourne, V.F. Myachin, C. Oesterwinter, D.A. Pierce, I. Stellmacher, S.N. Vashkovlyak, R. Vilhena De Moraes, R.L. Wagner and K. Zare.

Their application for membership was unanimously approved (minus one abstention).

The following persons were proposed as consultants: R.R. Allan, V.R. Bond, J. Moser, J. Roels, and C. Simo.

The President sorrowfully announced that Drs. Y. Hagihara and E. Stiefel died during the last three years.

ASTROMETRY IN SPACE

After a short introduction by J. Kovalevsky, Commission 7 unanimously approved the recommendation of Commission 24 in support of ESA and NASA space astrometry programs on the grounds that they should provide an inertial reference frame for the mechanics of the Solar System.

### FIRST SCIENTIFIC SESSION

T.B. Omarov presented a generalization of the Lagrange-Jacobi equation for some non-classical n-body problems that represents an effective means of analysis of the motion. This can be applied to large scale systems, for instance to the gravitating systems in a Metagalaxy. One of the generalizations concerns the case of a system with a variable number of members, permitting the analysis of the disintegration of the system. Another case refers to gravitating systems with a variable length scale. The speaker showed that the kinetic energy of peculiar motions of galaxies is equal to one half of the module of the potential energy of the inhomogeneous part of the distribution of density in the system.

A.S. Sochilina has investigated the effects of resonant tesseral and sectorial harmonics of the gravitational field on the motion of a close-by satellite. In particular, she has studied the libration mode for NAVSTAR and MOLNYA type satellites (12-hour satellites with critical inclination). The first order perturbations due to the resonance harmonics were computed for several models of the

geopotential. The amplitude and the phase of the oscillations have been derived. Apart from the stable points, there are secular trends that limit the validity of the theory.

R. Meire presented a new property of systems of linear periodic ordinary differential equations for which the coefficient matrix has the so-called Hale's E-symmetry.

The monodromy matrix for such systems can be computed from the transition matrix after half a period. This decreases the computer time in the integration of such systems by 50%. As an application, the linear stability of the triangular points in the elliptic restricted three-body problem was investigated. The transition curves in the $(\mu,e)$ plane separating stable and non-stable regions were computed using the two independent second order systems due to TSCHAUNER. The new results are more accurate than the previous ones.

CELESTIAL MECHANICS IN CHINA

Dr. Yi Zhaohua reported on the work in Celestial Mechanics done in the Peoples Republic of China.

Before 1958, the main concern was in the motion of asteroids including numerical and analytical studies (Hansen-Bohlin method).

Later, the interest was extended to the following domains.

- The compilation and publication of the Chinese Astronomical Ephemeris (since 1964).
- The theory of motion of artificial satellites.
- Some basic theoretical problems including the improvement of the convergence of the development of the disturbing function and the theory of capture in the three body problem.

In the recent years, the main activities in Celestial Mechanics may be described as follows:

1) The perturbation theory of artifical satellites (Purple Mountain Observatory and Nanking University). A second order analytical theory with third order secular terms was derived including all effects due to the geopotential, air drag, solar radiation pressure, luni-solar perturbations, etc...(published in Acta Astronomica Sinica and Journal of Nanking University).

2) Qualitative investigations of the three body problem (Nanking University and the University of the Chinese Science and Technology). The topology of the $M_8$ manifold of the three body problem was investigated in more elementary and intuitive way than S. Smale or R.W. Easton.

- The Birkhoff conjecture that the topology of $M_8$ can vary only when the energy constant E passes through the admissible values of Lagrange particular solution, was strictly proved.
- The topologies of $M_8$ for the five corresponding intervals of E were given.
- The connectedness of $M_8$ has been proved (DONG JIN-ZHU, "Some problems of the regions of motion of the general three body problem") and ranges of change of the angles between the orbital planes have been investigated.

3) The stability of the Cowell's method for numerical integration was studied.

4) Investigations in the field of analytical solutions for some particular cases of the three body problem are in progress. Hill's problem and the circular restricted problem are being studied.

## Second Scientific Session

This session was devoted to seven reviews concerning some of the most active domains of Celestial Mechanics.

PLANETARY THEORIES

P.J. Message, after a short reference to the important topic of comparison of theories with observations, reviewed the recent developments of analytical theories of planetary perturbations. Such theories have usually been constructed by "Poisson's method", "order by order theories" or "théories à variations séculaires".

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Nowadays, computer manipulations of multiple Fourier series are used. The expressions obtained give acceptable accuracies after time intervals of the order of 1000 years. The appearance of time in the coefficients leaves open the question of the possible instability of the planetary system. However, it is known that "general theories", generalizing Laplace's and Lagrange's theory of secular variations are able to represent the actual motions for an interval of half a million years and very likely very much longer. However, reaching a similar accuracy as the classical theory would lead to series much larger than those that can be handled by present day computers. Examples were mentioned of theories of each type recently constructed in France.

RESONANCE

B. Garfinkel spoke about the ideal resonance problem that he has formulated and solved in a series of papers. This problem furnishes a reference orbit for an attack on a variety of resonance problems in the solar system. The formulation epitomizes the methodology developed by Laplace, Bohlin and Poincaré. Successful applications have been made to the following problems:

1) Critical inclination in the motion of an artifical Earth satellite including $J_2$ and $J_4$.

2) Synchronous satellite with $J_{22}$ and $e = 0$.

3) The motion of Trojan asteroids treated as the case of 1 : 1 resonance in the restricted three-body problem.

The problem of double resonance has continued to evade a global solution, thus remaining an outstanding unsolved problem of celestial mechanics.

SATELLITE THEORY

Y. Kozai described what are the important problems in satellite motion theories by classifying the satellites into inner, outer and intermediary ones. There are many resonant pairs in the inner satellite systems. Analytical theories for outer satellites are difficult to derive when the ratio $n'/n$ is not small. For intermediary satellites, it was noted that the motion of their orbital planes are complicated. Therefore, complete analytical theories are also difficult to derive.

POSSIBLE EXPERIMENTS ON THEORY OF GRAVITATION

C.A. Lundquist presented two possible fundamental experiments in gravitational physics that could be carried out by a space mission. This mission would begin with a near-Earth, highly eccentric orbit to test the gravitational redshift. Later, the spacecraft would be placed into a heliocentric orbit to provide a long Earth to spacecraft baseline to perform the most sensitive search thus far proposed for bursts of low-frequency gravitational waves from extragalactic sources. Both goals are natural outgrowths of previous missions to study gravitational physics. In particular, the 1976 suborbital gravity probe A (SAO and NASA) showed that using masers on spacecrafts could provide a test of equivalence principle at the $10^{-4}$ level. The main improvement of the proposed experiment is the use of four simultaneous sources of Doppler tracking phase data between clocks on the Earth and the probe.

PERIODIC ORBITS

J.D. Hadjidemetriou presented recent results in this field, showing that periodic orbits are useful in the study of stellar and planetary systems. There exist stable triple stellar systems even for close approaches of the three components. Also stable triple systems exist with nearly zero value of the angular momentum. For planetary systems, a global view is presented of periodic orbits of the planetary type. It is clarified which configurations are stable and what factors affect stability. Provided that the masses of the planets are small and that they are not close to a $(2n - 1)/(2n + 1)$ resonance, nearly circular direct planetary systems are stable. If the orbits are elliptic, the system is generally unstable.

USE OF COMPUTERS IN CELESTIAL MECHANICS

M.S. Davis gave a report on this subject. Very little of a pioneering nature has been accomplished in the last three years in numerical or non-numerical uses of computers in Celestial Mechanics. The direction of modern computer science research was briefly touched upon, indicating the concentration on parallel processing on both the hardware and software levels. Then, the author gave a review of a large variety of numerical experiments in Celestial Mechanics and a survey of new or adapted analytical systems and their application to specific problems in Celestial Mechanics. Finally, attention was called to the publication by the Institute for Theoretical Astronomy in Leningrad: "Algoritmy Nebesnoj Mekhaniki", the only known publication devoted to the application of computers to Celestial Mechanics.

STABILITY IN CELESTIAL MECHANICS

A.E. Roy made a short review of this domain that is closely related to problems concerning the origin and evolution of various bodies in the solar system, multiple stars, etc... He gave a short review of the historical evolution of various concepts of stability that were originated by Laplace, Poincaré, Hill, Kolmogorov, Szebehely and others, including linear, non-linear and statistical methods. Several approaches to solve the problem were considered: local or general integrals, general perturbation methods, numerical studies, periodic orbits and topological analysis. In particular, a discussion of the relationship between resonance and stability was offered. It seems that deep resonance may be necessary for stability, but no relation seems to exist in other cases.