THE ROLE OF THE RESEARCHES OF E.I. KAZIMIRCHAK-POLONSKAYA ON THE DYNAMICAL EVOLUTION OF SHORT-PERIOD COMETS

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In 1961 Kazimirchak-Polonskaya (1961a, 1961b) published comprehensive reviews of all investigations on the dynamics of cometary orbits as well as on close approaches of the short-period comets with Jupiter for the time span covering 1770-1960 and for the first time put forward the basic problems of cometary astronomy from the standpoint of celestial mechanics. Chebotarev (1971) pointed out that "these reviews, supplemented with extensive references, can serve as a valuable manual for all researchers of cometary motions". In 1967 Kazimirchak-Polonskaya (1967a) developed the advanced problems in a definitive form. The corresponding member of the USSR Academy of Science M.F. Subbotin (at that time the Head of the Institute) characterized the above mentioned works as "the general plan for cometary studies in the important branch of cometary astronomy".

This plan incorporated, in particular, construction of computer program complexes and the development of highly accurate numerical theories of cometary motion for the entire period of observations taking account of all planetary perturbations and non-gravitational effects as well as a study of the secular evolution of cometary orbits including the large transformations of these which take place in the spheres of action of Jupiter and the other outer planets.

The first comprehensive study on the evolution of cometary orbits of numerous group of real comets, taking account of all planetary perturbations over a time span of 400 yr (1660-2060), containing also both the development of the capture theory from a completely new perspective and the presentation of a new hypothesis of cometary origin, was published by Kazimirchak-Polonskaya in 1967 (1967b).

Pages 453-457 of the above mentioned work are devoted to a critical review of the classical theories of capture by Jupiter, carried out by Laplace, H. Newton, Callandreau,

A. Carusi and G. B. Valsecchi (eds.), Dynamics of Comets: Their Origin and Evolution, 237–241.

Tisserand. The author evaluates their achievements and reveals the methodological shortcomings which inevitably resulted in discrepancies between the conclusions of these authors and the observational data. Overcoming these difficulties by her accurate research technique, Kazimirchak-Polonskaya has shown that owing to a new presentation and solution of the problem, contradictions of the theory with observations can be completely eliminated.

In short, the essence of this work is as follows. Kazimirchak-Polonskaya selected a large series of real comets either belonging to various planetary families or having transplutonian orbits: P/Lexell (1770 I), P/Herschel-Rigollet (1788 II), P/Olbers (1815), P/de Vico-Swift (1844 I), P/d'Arrest (1851 II), P/Stephan-Oterma (1867 I), P/Neujmin 3 (1929 III), P/whipple (1933 IV), P/Oterma (1942 VII), P/Kearns-Kwee (1963 VIII), etc. The detailed comprehensive studies of the motion of these comets taking account of perturbations, as a rule, from eight planets (Venus-Pluto) over the time span of 400 yr (1660-2060) illustrated by numerous tables, led the author to the following conclusions:

1. "The outer planets (Jupiter-Neptune) with their vast spheres of action are the powerful transformers of cometary orbits, essentially determining their evolution, changing their spatial orientation, shape and dimensions, transferring comets from one family into another, and in some cases either removing comets to the periphery of the planetary system and even outside its boundaries or capturing them from the nearly parabolic orbits" (p.453). Strong perturbations by Jupiter, particulary following close approaches, are very often favourable either for discovery of new comets or rediscovery of the lost ones; sometimes on the contrary they may be a cause for the loss of comets both temporary and permanent (1967b, pp.453 and 459).

2. The suggested hypothesis of cometary origin represents a combination of a diffusion theory of K.A. Shtejns (Shtejns, 1960, 1961, 1962, 1964) with the capture theory of Kazimirchak-Polonskaya.

Integrating the equations of diffusion with due consideration of cometary disintegration as a function of perihelion distance Shtejns arrives at a formulation of the laws of diffusion, two of these being essential for our purposes: (a) comets with smaller values of the semi-major axes have also smaller inclinations; (b) greater perihelion distances correspond to smaller eccentricities.

At this point Shtejns' investigations, which he carried out employing statistical methods for nearly parabolic and long period comets with semi-major axes $a > 40$ a. u., are completed.

The fourth stage of the comets' orbital evolution at

a < 50 a.u. - the capture by the major planets - represents the principal subject matter of Kazimirchak-Polonskaya's studies, performed by the precise numerical methods of celestial mechanics.

Thus, in accordance with her scheme (1967b, pp.458-460), due to diffusion at the periphery of the planetary system, there arises a concentration of perihelia of numerous comets, invisible from the Earth with quasi-circular orbits having small inclinations. The slow motion of these comets at great heliocentric distances and the vast spheres of activity of the outer planets (particularly of Neptune with radius 0.580 a.u.), favour rather prolonged encounters of comets with these planets as well as great transformations of their orbits. In this way favourable conditions are created for capture of these invisible comets into the region of the Solar system planets.

Capture according to a new interpretation of Kazimirchak-Polonskaya is a complex process, developing over centuries, millennia and even million of years*. It can start from the periphery of the planetary system, when Neptune is capturing a comet (with perihelion in the vicinity of its orbit) into its sphere of influence and represents an evolutionary process - a successive translational transfer from one planetary family into the other until it reaches that of Jupiter. But the capture can also proceed catastrophically either from nearly parabolic orbits or by means of transferring of a comet from one planetary family into another which is at a considerable distance from it. Sometimes a comet (as, for instance, P/Oterma) can be transferred due to perturbing force of Jupiter from one planetary family into the other and then returned back into the original family. More often the capture represents a complex many-staged process where all stages of an evolutionary and catastrophic development are either combined or interchanged. At the final stage (relative to a terrestrial observer) the cometary orbit approaches the Earth's orbit, contributing to the discovery of the comet.

In the case of a very deep penetration of the comet

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* Let it be briefly noted, that in the classic presentation of the problem the capture was considered:
1/ by Jupiter only,
2/ from a parabolic orbit (owing to the interstellar origin of comets),
3/ as a rule, in the problem of two bodies (outside the Jupiter sphere of activity: Sun-comet; inside the sphere: Jupiter-comet),
4/ as one single passage through the sphere of activity.
As a consequence of the four points indicated above the capture turned out to be an exceptionally rare occurence.

into the Jupiter's sphere of influence there arise in a heliocentric frame of reference, short-term, osculating, strongly elongated ellipses instantaneous parabolae, and hyperbolae (for instance, in P/Brooks 2 orbit's transformations in 1886). In exceptional cases, there appear even short-period osculating ellipses with retrograde motion and very small perihelion distances (see, for example, Table 18, illustrating the transformation of P/Lexell's orbit deep within the Jupiter's sphere of influence in 1779) but on leaving Jupiter's sphere of influence, these osculating conic sections are swiftly transformed into the short-period ellipses with direct motion.

Therefore, the short-period comets from Jupiter's family do not leave its sphere along elliptical orbits with retrograde motion. And if, in exceptional cases, hyperbolic orbits are preserved on leaving this sphere of influence, then their perihelia are situated either on the Jupiter's orbit or in its close vicinity, and that is why such comets can not be observed from the Earth. Thus, in Kazimirchak-Polonskaya's capture theory all contradictions of the classic theories with observational data have been overcome.

Such is, in brief, a general picture of the capture and origin of comets outlined by Kazimirchak-Polonskaya in her paper (1967b).

The results of this work were successfully reported at the meeting of the IAU Commission 20 during the General Assembly Session of the International Astronomical Union, in Prague (1967). After Dr.Kazimirchak-Polonskaya's report, President of the IAU Commission 20, Prof.G.A.Chebotarev (at that time the Head of the Institute of Theoretical Astronomy) proposed that a decision be taken to carry out a special symposium on the motion, evolution of orbits and origin of comets, in Leningrad. The proposal was unanimously approved and the Symposium was organized and carried out by the Institute of Theoretical Astronomy of the USSR Academy of Science (Leningrad) in 1970. Up to the present time it remains the only IAU Symposium on cometary problems.

A wide horizon and a profound knowledge of the history of evolution of cometary dynamics and cosmogony as well as her new results in 1967 on the secular evolution of cometary orbits and the capture of comets; her further investigations in this field (Kazimirchak-Polonskaya, 1971) along with the works dealing with motion and the secular evolution of meteor showers, accompanied by large transformations of their orbits while passing through the Jupiter sphere of influence; all this enabled Kazimirchak-Polonskaya to elaborate the entire program of IAU Symposium 45 and together with G.A. Chebotarev take an active part in its organization.

G.A. Chebotarev in (1972, p.4) evaluates the results of Kazimirchak-Polonskaya's works in the following way: "By studying the motions of a number of comets over the interval 1660-2060 Kazimirchak-Polonskaya has obtained for the first time a real picture of the evolution of cometary orbits". In his paper (1971, p.640) Chebotarev stresses that "Kazimirchak-Polonskaya's studies have for the first time provided a convincing basis for the hypothesis of capture of the short-period comets by the major planets and made necessary a critical revision of hypotheses of cometary origin. Her works represent an important contribution both into the modern theoretical astronomy and dynamic cosmogony. By a decree of the Presidium of the USSR Academy of Science of 1969, Jan. 24, E.I.Kazimirchak-Polonskaya was awarded a prize named after an outstanding comet's researcher A.F.Bredikhin for a series of her works concerned with the theory of short-period comet motions and the evolution of their orbits".

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