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STATEMENT OF THE PROBLEM OF STUDYING THE SMOOTHED STRUCTURE OF THE GALAXY AND THE RESULTING TASKS OF INVESTIGATING THE GALACTOVERTICAL COLUMN

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The following is envisaged to serve as guiding-marks for planning observational investigation of the smoothed structure of the Galaxy perpendicular to its equatorial plane. Underlying the deliberations is the thesis stating that, besides the tasks of stellar dynamics, the study of the smoothed structure of the Galaxy serves the task of improving the inertial system of reference.

1. Statement ot the scientific problem

Basic observational data on the structure of the Galaxy are used above all to improve the gravitodynamical model of the Galaxy. The model of the smoothed or regular structure of the Galaxy plays the role of a frame describing the fine structure and the evolution of the Galaxy itself. The model also serves as a practical background for describing various movements and physical phenomena occurring in the whole universe. The reference system determined by the totality of the stars in the Galaxy forms the bridge between the metagalactic inertial frame of reference and various reference systems within the solar system. The actual use of the stellar background is rendered possible by the spatio-kinematical models of the Galaxy, which enable us to reduce systematic movements of stars in different regions or macroelements of space to a common system. The identity of the background in different directions along the line of sight is secured by the model. Due to the complexity of modeling the Galaxy practical accomplishment of the galactic reference system is done in a synthetic way by superposing the models constructed separa-

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tely for those components of the galactic frame which have, been singled out for the purpose from among the field stars by their spectral types. Therefore we can say that the galactic descriptive background is formed by choosing and modeling one or several fundamental stellar populations or fundamental natural groups, each of which determines a specific reference system. This thesis was put forward by Dneprovsky and Gerasimovič /1/ and emphasized by Jõeveer and Eelsalu /2/.

Observational data are treated on the basis of the model of the smoothed quasisteady Galaxy, i.e. of its slowly evolving regular frame. The model is characterized by the galactic parameters (i.e. by the parameters of the galactic gravitational potential) and the spatio-kinematical parameters of the natural groups, as well as by the parameters of specific reference systems for observational data, related to the Earth and the Solar system. In general all these parameters are subject to adjustment from observational data covering the entire sky (the respective theses have been put forward by Einasto /3/ and Kutuzov /4/). However, observational data in the galactopolar caps and in the galactoequatorial belt carry the greatest weight for estimating the values of various galactic parameters, because, correspondingly, the galactovertical column and the galactoequatorial layer describe the main features of the model of the Galaxy. On the contrary, to improve values of the parameters of specific reference systems for observational data it is advantageous to obtain uniform distribution of data over the entire sky. These distinctions show that it is useful for practical work to divide the main subject of investigation into separate specific tasks.

The study of the vertical structure of the Galaxy at galactocentric distances close to that of the Sun as a specific investigation of the galactovertical column consists mainly in gathering observational data in one or both galactopolar caps together with their interpretation on the basis of the quasisteady model of the Galaxy. At the same time the question arises whether the quasisteady model is suitable at all. This means that the simplest effects of non-steadyness of the spatio-kinematical structure of particular stellar groups are to be investigated and results compared with our knowledge on the physical evolution of stars. What we know of the evolution of the stellar system as a whole is also to be allowed for. The statement of the problem of investigating the galactoequatorial layer can be formulated in the same manner.

The task of studying the galactovertical column cannot be entirely isolated from the task of studying the galactoequatorial layer. Already when formulating the theoretical problem we must bear in mind that both these tasks serve after all the task of modeling the Galaxy as a whole and are to be considered to be mutually supplementary. First of all, they both should play a practical role in modeling the spatio-kinematical structure of fundamental natural stellar groups to help to introduce into practice the results of observational programmes for improving the galactic reference system. As known, there are two such programmes, that of Poulkovo /5/ and of Lick /6, 7, 8/. By the way, the thesis on the need for deepening the statement of problems of galactic astronomy along these lines has been formulated by Schwarzschild /9/.

2. The state of the theory of the vertical structure of the Galaxy

In separating the study of the galactovertical column from the study of the galactoequatorial layer we move away to a considerable extent from the complex treatment of gravitodynamical theory of the structure of the Galaxy. In such case we can single out the following individual items of investigating the galactovertical column: 1) the run of the gravitational potential in the vertical direction near the galactic plane, 2) the interrelation between galactovertical and galactoradial attraction, 3) the run of the potential in the vertical direction far off the galactic plane, 4) effects of non-steadiness, incompatible with of the quasisteady Galaxy.

The first three items mentioned above are linked immediately to the theory of the third integral, which, entering the expression for the phase density of the objects, characterizes the relations between the spatial coordinate distribution of the stars and their velocity distribution in the case of quasisteady fundamental natural groups of stars. As to item 1, the well-known theory of the Lindblad-Oort quasi-integral has been elaborated. Gravitational acceleration near the galactoequatorial plane, entering the integral, is expressed by Kusmin's constant C /10/.

For item 2 theory has been also provided except for the extreme vertical heights. This is Kusmin's /11/ and van Albada's /12/ quasi-integral theory or the theory of the first terms of Contopoulos's /13/ and Kusmin's /14/ development of the third integral (explained in a simple manner by Ollongren /15/). The theory reduces the relation between the galactovertical and galactoradial component of the gravitational field to the tilt of the velocity body to the Galactic plane, which grows with vertical height. Several characteristics of the potential enter the cofficient of the tilt. Supposing grossly that the vertex of the velocity body points to the centre of the Galaxy, we get a significant tilt beginning with vertical heights about 1 kpc. To apply the theory of the third integral to practical stellar statistics further theoretical studies are needed.

Item 3 has two aspects, both insufficiently elaborated. The first of these is concerned with dynamical theory since there is a need for the theory of a third integral for the more or less spherical components of the Galaxy. The treatment of this question is still far from practical applicability.

The other aspect is concerned with gross theoretical modeling of the distribution of gravitating masses within the Galaxy in order to get an idea about to what extent the vertical potential at great heights could be affected by the parameters to be estimated later. The greater the heights above the equatorial plane of the Galaxy, the more difficult it is to separate the investigation of the galactovertical column from that of the galactoequatorial layer. The tilt of the velocity body could yield a direct criterion for the purpose.

As for the theoretical prediction of effects of non-steadiness, the latter can be done on fhe basis on the hydrodynamical theory. Above all, these effects include possible systematic vertical motion of centroids outside the galactic plane. Attention to this has been drawn by Kutuzov /16/. This set of problems borders to the dynamical theory on how groups of young stars and aggregates behave after evolving from interstellar matter, the properties and evolution of which they still directly reflect.

In addition to the four aforementioned categories of questions during the investigation of the galactovertical column it is useful to pay attention to the theory of stellar evolutionary paths and to the theory of the evolution of the Galaxy as a whole in order to secure a rational basis for grouping the stars into populations (cf., e.g, Iwanowska /17/ or Blaauw /18/). This plays a major part especially when great vertical heights are considered.

3. Statement of the problem of gathering observational data

Initial presumptions for studying the galactovertical column are simpler than those for the galactoequatorial layer. The latter probably requires simultaneous consideration of the smoothed and spiral structure of the Galaxy. Nevertheless, to allow for the interstellar extinction of light in the galactovertical column one meets with the problem of modeling the distribution of dust at medium and high galactic latitudes and, consenquently, with the problem of modeling the distribution of extragalactic objects at the same latitudes. However, the tasks of a differential nature depend only slightly on the estimates of interstellar extinction of light.

Observational tasks can be formulated above all only to the extent they are dictated by some specific theoretical problems related to certain details of the model of the smoothed structure of the Galaxy. Additional limits are set by the power and geographical position of observational instruments. A prominent role should have considerations about how to coordinate observations and integrate observational data accumulated during the execution of the programmes of investigating the galactovertical column, the galactoequatorial layer and the galactic reference system. This question has become especially acute because the photographing of the second epochs in the areas of the Poulkovo plan /5/ is being carried out. To form a concept of the macroelements of space corresponding to the observed stars in a certain area, and to reduce thereafter the mean motions in different areas to a common basis one needs reliable models for the smoothed structure of some fundamental stellar groups. Since the characteristics of the models should be determined from the programmes of investigating both the galactovertical column and the galactoequatorial layer, there must be a possibility of identifying the fundamental natural groups (populations or subsystems) when separate results are compared, as well as when observational data about the galactic reference system are subjected to treatment. It seems that the programmes of determining physical observational data about the stars designated for linking stellar movements to extragalactic objects must be guided by such considerations. Stars included into these plans dictate which groups are to certainly receive special treatment for modeling and identification.

There are also practical and technical links between observational tasks. E.g., for a given observatory programmes for observing a galactopolar cap and the galactoequatorial belt naturally supplement one another since observations are made during the opposite seasons. It is also useful not to forget that behind the stars in the galactopolar caps there is an extragalactic background, so that it is necessary to distinguish between faint stars and point-like extragalactic objects (according to Seyfert /19/ already at photographic magnitudes 10^m to 11^m galaxies amount to 1% of the total number of objects). On the other hand, in the northern galactopolar cap the cluster Coma Berenices is projected into the stellar background although, fortunately, not centrally. According to Artyuhina /20/ there is no reason to expect the number of its members to be considerable among apparently faint stars.

The usage of specific observational data as statistical samples is possible to the extent to which methods of stellar statistics and the adjoining gravitodynamical theory are applicable to them. The samples must be representative in a sense. It can be pointed out that selected areas of Kapteyn's plan and areas of the Poulkovo plan are not of the same value in the sense that the latter have been chosen not at random but in the directions where galaxies are visible. If one has reason to suspect that the matter absorbing light is so patchy that it changes the visibility conditions for galaxies at a given galactic latitude, then difficulties arise with the areas of the Poulkovo plan. Strictly speaking, deduction of the mean characteristics of the extinction of light from the areas of the latter need not to be acceptable and, the other way, the mean characteristics of extinction need not be applicable to the set of these areas.

4. The state of gathering observational data

Those theoretical tasks which were enumerated in Section 2 can be solved by resorting to optical observational data. The degree of representativeness and homogeneity required from observational data vary from one theoretical problem to another. Notably, determination of the tilt of the velocity ellipsoid (from the comparison of the galactoradial components of proper motion with radial velocities) and detection of the change of systematic vertical movements with vertical heights are tasks of a more differential kind than others. The following kinds of observational data can be considered as crucial: 1) data on dividing the stars into natural groups and populations, 2) data on stellar movements, 3) data on spatial distribution of the stars. Observational data about interstellar matter and about the extragalactic background are to be considered as secondary, as well as necessary observational data outside the galactopolar caps needed for the determination, e.g. the spatio-kinematical structure of fundamental groups near the galactoequatorial plane.

According to apparent magnitude observational data can be divided into belonging to 1) bright stars (brighter than, say, 7^m) used for studying the basis of the galacto-vertical column in combination with all data on bright stars in general, 2) moderate stars (approximately 8^m—12^m), forming the main target of investigation at present, 3) faint stars (fainter than, say 12^m). The availability of radial velocities and proper motions together with a precise classification suitable for singling out homogeneous groups of objects is of crucial importance. The border between moderate and faint stars is dictated above all by these considerations. The apparent magnitude behind which the halo stars begin to dominate would serve as the natural limit between them. This limit would probably be farther than 12^m (cf., e.g., /18/).

An important landmark in planning contemporary studies of the smoothed structure of the Galaxy are the documents of the IAU Symposium No. 7 /21/. Among other things they describe the state and plans of the investigation of the galactopolar caps in 1957. In particular Oort proposed a systematic survey of K-stars in the galactopolar caps up to the faintest limit.

In recent years work has been started at some specific programmes:

Blaauw /22—23/ has initiated a programme of spatial studies (photometry and, thereafter, probably spectroscopy in Kapteyn's areas) and of stellar kinematics (proper motions in the McCormick fields). As to the radial velocities Blaauw /24/ remarks that above all it would be essential to begin from the types G8—K3 and carly A.

The programme initiated recently by Eggen /25/ with the aim of comparing several kinds of observational data can be described as heuristic, not tied to a particular theory and to systematic usage of methods of galactostatistics.

Some programmes such as Upgren's /26, 27/, Oja's /28/ and Davies, Philip's and Sanduleak's /29/ pose and solve a restricted question of how to improve the knowledge of the spatial distributions of stars of different kinds from gross spectral data and narrow-band photometry apart from kinematic and dynamic problems.

In contemporary works no direct attention is paid to specific problems of galactodynamics. This is understandable, since there are too few necessary data available on radial velocities. However, in works devoted specifically to radial velocities (Perry /30/, Woolley and Asaad /31/) the problem of the vertical potential is raised explicitly. Such works deal only with A-stars. Radial velocities of K-stars have been measured up to 11^m by Edmondson /32/, yet standards are available at present up to 9^m only /33/.

As for the stars of moderate magnitude, one can agree with Bok /34/, who states: "I consider future work on stellar distribution on high and intermediate galactic latitudes for A and F stars and for giant K stars among the most urgent for researches on models of the Galaxy. If at all possible, this work should be supplemented with radial velocity measurements. . .". It is to be added that among late-type stars it is especially advantageous to choose a group at the junction of types G and K because these stars are numerous and simple to classify.

As for bright stars, Irwin's plan /35/ (apparently its new version has been published in /36/, not accessible to us) is to be supported, because bright stars must yield homogeneous data to enable the tie-in of all data from every direction. As to faint stars, the area covered by Bok's and Basinski's photometry /37/ in the southern cap calls attention along with galactopolar areas of Kapteyn's plan and the Poulkovo plan. Unfortunately Bok's and Basinski's work does not have an analogue on the northern cap. The research programme of faint blue stars /38/ also deserves attention as well as spectrophotometric works /39/.

5. Conclusions

1. A complete plan for the investigation of smoothed structure of the Galaxy should consist of three components: a plan for improving galactic coordinate system,

a plan for studying the galactoequatorial layer, and a plan for studying the galactovertical column.

2. The study of the galactovertical column can be divided into partial problems. Their theoretical foundation and adequate formulation have not been sufficiently elaborated. At present the links between observational programmes and theory are inadequate.

3. Observational investigation of the galactopolar caps should in the first place yield spectral and photometric durchmusterungs, and, thereafter, proper motions and velocities for stars selected to form a sufficient sample for solving specific problems. Particularly promising is work on giant stars at the junction of types G and K.

4. Work can be planned in consecutive approximations to the extent progress is made at such particular problems which have caught the attention of a sufficient number of astronomers.

June, 1969.

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Постановка вопроса исследования сглаженного строения Галактики и вытекающие из нее задачи изучения галактовертикального столба. Ээлсалу Х. (англ.)
Академия наук Эстонской ССР, Институт физики и астрономии, Тарту, 1969.

Изложены некоторые соображения для планирования наблюдательного исследования сглаженного строения Галактики в галактовертикальном направлении исходя из тезиса о том, что такое исследование должно служить прежде всего задаче улучшения инерциальной системы отсчета. Библ. 39.

Х. ЭЭЛСАЛУ
ПОСТАНОВКА ВОПРОСА ИССЛЕДОВАНИЯ СГЛАЖЕННОГО СТРОЕНИЯ ГАЛАКТИКИ И ВЫТЕКАЮЩИЕ ИЗ НЕЕ ЗАДАЧИ ИЗУЧЕНИЯ ГАЛАКТОВЕРТИКАЛЬНОГО СТОЛБА
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