Structural analysis of the comet 45P/Honda based on isophote modeling

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Abstract. The work focuses on using the isophote method to construct a 45P/Honda comet model. At the same time, important problems were solved for modeling the physical surface of a comet and studying the structure of the cometary nucleus. This is due to the fact that, on the basis of modern studies of meteoroids, complex internal processes and dynamic phenomena on their surface have been discovered. The study of comet nuclei is of great importance, since, according to the theory of their formation, they were formed from the matter of the protoplanetary disk. Thus, modeling and analysis of the structure of various comets make it possible to create a more accurate theory of their evolution. This made it possible to evaluate the structural parameters more accurately and reliably. This allowed for the evaluation of the structural parameters more accurately and reliably. Isophotes of the nucleus, coma and tail of comet 45P / Honda were determined. Depending on the point where the comet is located on the trajectory of its orbit, one can see structural changes in the comet’s brightness from the nucleus to the peripheral region. Near the cometary nucleus, the isophotes are circular in shape. If in the center of the model the isophotes have a shape close to narrow rings, then elongations in the direction of the cometary tail and thickening of their structure appear towards the peripheral regions. Large and small tail rays can be distinguished, and the nucleus is well marked. In the future, the author’s method for modeling isophotes, developed in this work, will allow studying the structure of various cometary objects, and, based on the results, determine the degree of comet activity. On the other hand, about the development of the theory of dynamic processes and the evolution of the Solar system, one can use the data on changes in cometary activity in the process of its movement around the Sun.

1. Introduction

The study of physical characteristics and structural parameters of comets is an integral part of the theory of the evolution of the solar system [1]. However, most of the studies of cometary atmospheres, the structure of comets and planetary physics are carried out using observations of bright near-Earth comets [2]. However, it is necessary to note two evolutionary problems of cometary astronomy. The first one is that modern data on the comparison of the parameters of near-Earth and long-heliocentric comets have shown a different degree of their activity [3]. The second problem is that the major part of the cometary matter is concentrated in two different regions of space, one being the source of long-period comets (Oort Cloud), and the other – of short-period comets (Kuiper Belt) [4]. Therefore, to solve these problems, the study of long-period comets is very important.
45P/Honda is one of the long-term meteoroids, the study of which is a very important task, since the observation of such objects can be attributed to unique events. The isophotic model of the comet constructed in this work made it possible to study the relationship of its structure with the dynamic processes occurring during the movement of the comet along the trajectory, and the structure of the model itself turned out to be more accurate than in [4, 5].

Since the comet’s nucleus is an element of dynamic evolution and processes in the Solar System [6], the study of the 45P/Honda model will clarify the theory of its formation and evolution.

When performing works on the study of comets, one must take into account the fact that certain comets are interstellar objects [7].

2. The method for analyzing isophotes
Currently, Structural Isophote Analysis (SIA) is the main method for studying complex space objects [8]. SIA is based on the Sabatier effect (SE) [9]. SE is about transforming the negative into a positive image. Conducting SIA implies the use of SE to simulate darkening of brighter areas of the observed image and lightening more black areas on the negative. Such areas are called the Mackie line. By imitating the exposure time by a computer method (similar to the process of developing astronomical photographic plates), it is possible to perform a complete transformation of a negative into a positive. To construct a separate isophote, the corresponding interval of the brightness density of the image is determined. Thus, each isophote is a derivative of the selected brightness density. A software package (Automated Software Package for Isophot Modeling – ASPIM) was developed for the construction of isophotes. Using the software capabilities of graphic image processing systems, it is possible to build an SE simulation model by selecting brightness parameters for monochrome brightness curves. The methods and steps for building an SE simulation model for comet 45P/Honda are as follows:

1) The digital brightness parameters of comet 45P/Honda were obtained from astronomical images using an A3 Microtek ScanMaker 1000XL Plus scanner. This machine has a resolution of the scanned image of 2400×4800 dpi and an optical density of 3.8D.

2) To isolate isophotes (structural zones of the same density) with given initial parameters, the SE Simulation Computer Complex (SESCC) was used. With SESCC, a positive image was created from the original negative image and the graphics systems. As a result of using ASPIM, the final isophote model was built.

3) Next, we analyzed the constructed isophote model of comet 45P/Honda and obtained the results described in the next section.

3. Analysis of the model of comet 45P / Honda
Comet 45P/Honda is a topical object for study. Long-period comet 45P/Honda belongs to objects from the Jupiter family. The orbital planes of comets of the Jupiter family are located at a small angle to the plane of the ecliptic and are quite stable in their dynamics.

Figure 1 shows an isophote model of comet 45P/Honda. The accuracy of isophote deposition is 0.045 magnitudes. When studying the isophote model of comet 45P/Honda using the ASPIM software package, the following results were obtained. The quantitative characteristic of isophotes remains stationary with an increase in the values of the brightness parameters. However, the width of individual isophotes becomes smaller for these model parameters. This leads to an increase in the accuracy of the system model, which is important for the analysis of the heterogeneous complex structures of the 45P / Honda comet.

Figure 2 shows the evolutionary diagram of comet 45P/Honda. The temporal dynamics of the change in the structure of the comet shows the transformation of the region near the comet’s nucleus to the peripheral regions. In the center of the cometary model, isophotes are similar in shape to ring formations. Moreover, the closer to the nucleus, the narrower the isophote rings. If we move to the periphery of the model, the tail components are formed and the isophotes thicken. This process can be
observed in models 845, 849 and 851. The structures of the small and large tail rays can be found here as well.

![Figure 1. Structural isophote model of comet 45P/Honda](image)

![Figure 2. Evolutionary diagram of comet 45P/Honda](image)

The obtained images of isophotes showed the inhomogeneity of the formation processes of gas components by the comet’s nucleus under the influence of solar radiation. This can be explained by an effect similar to the Yarkovsky effect. Since the nucleus of the comet rotates during its movement in space, there is a different effect of solar radiation on different zones of the nucleus. The intensity of gas release for different regions of the comet's nucleus also changes accordingly. Thus, the formation of the comet’s head is of more complex nature than the general sublimation of gases from the cometary nucleus. Here, the redistribution of the gas emitted by the cometary nucleus due to the influence of the solar wind on it is of great importance. Each structural element of the 45P / Honda comet model is formed depending on the volume and vector of the gases emitted. In this case, the dynamics of the structure of isophotes characterizes the drift of the regions of the core emitting gases.
An analysis of Figure 2 has shown that some structural elements of the 45P/Honda comet model are elongated not in the opposite direction from the direction to the Sun, but under different angular vectors. This phenomenon can be explained by the ejection of particularly intense gas jets by some areas of the core. Moreover, such processes continue almost until the final stage of gas emission. The asymmetry of the selected isophote with respect to the geometric center of the 45P / Honda is related to the average rate of gas ejection from a specific area of the core. This analysis is expected to be performed in the next phases of the 45P/Honda study.

4. Summary and conclusions
The study of long-period comets is associated with the development of the theory of the Solar System evolution. Currently, modern hardware technologies are used for the reduction of astronomical photographs. The photographs contain images of unique celestial processes. Such photographic plates have been obtained for many decades, and the image of the celestial sphere on them cannot be repeated. The analysis of astronomical photographs is a modern and relevant task. In this work, a structural model of comet 45P/Honda was constructed. Comparison of the model constructed in our work with the similar systems built in other works [10, 11, 12] showed its superiority in the accuracy of the structural interpretation of the brightness characteristics. The isophote method made it possible to analyze comet 45P/Honda and assess the activity of the processes occurring during its movement in space. Moreover, long-period comets in many cases can be studied only with the use of archival astronomical plates and for the only passage of a comet through perihelion.

The developed isophote method can be used to study other astrophysical objects. For this purpose, a digital gradient model is formed, depending on the brightness of various regions of the celestial body, and then an isophotic system is built. This approach is relevant for the analysis of meteoroids of various nature [13, 14, 15, 16], selenodetic systems [17, 18, 19, 20, 21], galactic objects [22], planetary systems [23], studying the dynamics and kinematics of space bodies [24], as an addition to the regression [25] and fractal analysis, for the study of active formations on the surface of the Sun [26].

A relevant task is the creation of virtual observatories and the creation of unified electronic digital data systems. The combined digital libraries make it possible to use heterogeneous astronomical observations in the global scientific network. Digital bases of virtual observatories can be used for space missions and modern astronomical observations.

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