

# THE PROBLEMS OF MAPPING IRREGULARLY-SHAPED CELESTIAL BODIES

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## **Abstract**

*Today cartography extends far from terrestrial limits. It can be applied to the planets of the Solar System, their satellites, asteroids, and nuclei of comets. The mapping of bodies with irregular shapes will play an increasingly important role in different fields of planetary science. The irregularly – shaped bodies are those smaller than a few hundred kilometers in diameter. This class of bodies exists primarily in the main asteroid belt between Mars and Jupiter and the Kuiper belt beyond Pluto. Some are found as small satellites of the planets. Their orbits can intersect the orbits of planets, including Mars, Earth, Venus and even Mercury. The Near-Earth Asteroids are those which make close approaches to Earth. In the last two years the "NEAR-Shoemaker" spacecraft has transmitted images of asteroid 433 Eros to the Earth. The main goal was to obtain images covering the whole surface of the body, which gives us the opportunity of global mapping.*

*The use of a regular surface such as a sphere, ellipsoid or triaxial ellipsoid as a reference surface does not accurately depict the form and surface features of an irregularly – shaped celestial body. Each body has a unique form, a complex morphology which does not comply with ideal regular surfaces. For all these reasons we need to develop cartographic projections taking into account the complex surface form of irregular celestial bodies. There are a lot of cartographic and non-cartographical problems on this way.*

The mapping of real surfaces of celestial bodies depends on the following points:

1. Factors determining initial material for creation of cartographical products for celestial bodies. They depend on the type and format of available data.
2. Requirements for cartographical products. They depend on the desired final product. It can be a thematic map (with all requirements implied by the style of data representation), an Atlas, a cartographical image (which already loses one of the map requirements), or a cartographical model that visualizes a real surface.

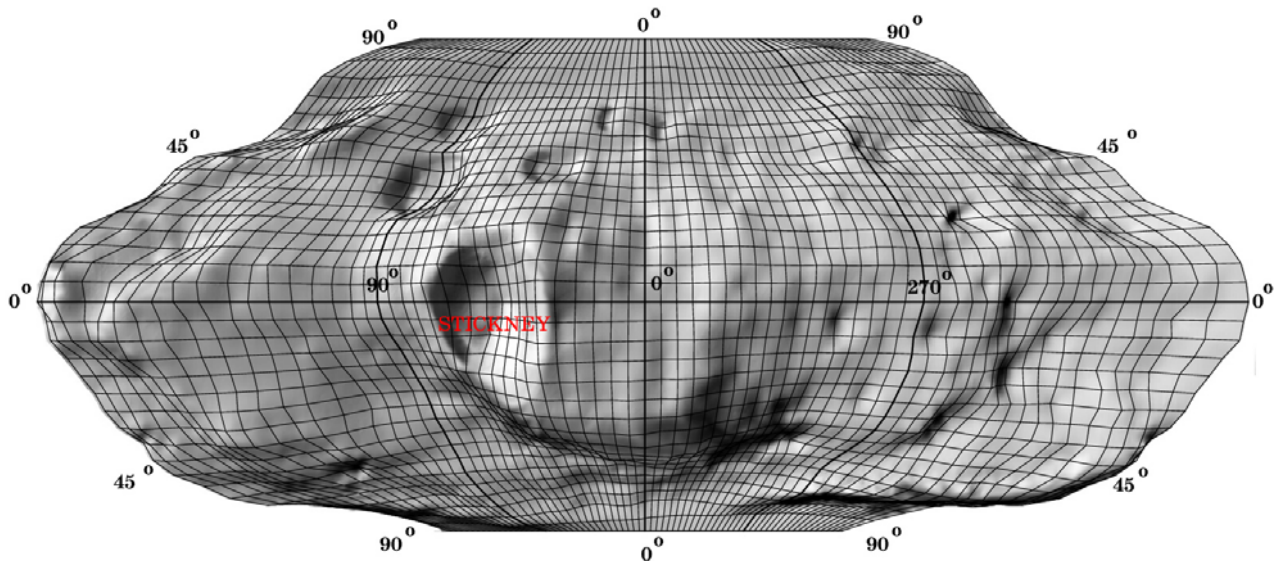
Let us consider the problems of mapping an irregularly – shaped celestial body. As an example we will consider creating a geographical map.

## **THEME, PURPOSE, LAYOUT, CARTOGRAPHICAL PROJECTION MAPPING A BODY ON PLANETARY SCALE**

For the first step of creating the map it is necessary to make decisions about the theme, purpose, layout and mathematical basis of the future cartographical product. Depending on initial materials and territorial scope we choose the layout. The next step is to determine cartographical projection. For traditional maps of the larger planets and their satellites, as for Earth, it is customary to divide the map of the body into sheets use a specially developed sheet line system and nomenclature. A surface of an investigated celestial body conditionally breaks into separate trapezoids with the appropriate labels. The problem of nomenclature for maps of irregularly – shaped celestial bodies is still a subject of consideration.

I propose the following sheet line system for the maps. The celestial body is mapped on a planetary scale, and in hemispheres and separate regions. Nowadays the available materials for celestial bodies with irregular form are sufficient to create maps primarily on a planetary scale and in hemispheres. For Eros, regional maps may be useful in future.

It is impossible to view a global (unbroken) scene of a celestial body in a single space image. Up to now maps of celestial bodies on a planetary scale were created in traditional cartographic projections (derived from spheres) not taking into account the real physical form. I developed the concept of deriving real surface projections displaying the irregular form of celestial body on a planetary scale (Fig. 1).



**Figure 1** Cartographical grid for Phobos real surface in planetary projection (the transformed Kavraysky sinusoidal pseudo – cylindrical projection).

Canadian scientists have proposed using maps of two opposite hemispheres to portray the whole surface. For this purpose a modified azimuthal conformal projection was recommended. American researchers have suggested a similar approach using the orthographic projection. Three mutually orthogonal pairs of views illustrate the morphology of the body completely. They are centred at the poles (north, south) and on the equator with axial meridians of  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ ,  $270^\circ$ . But these hemisphere views show only one side of the body at once and are insufficient to show the distribution of surface structures on a planetary scale and to determine their relationships. That demonstrates the necessity for developing new planetary map projections.

Most planetary map projections strongly distort the polar regions or omit them altogether. In the latter case it is necessary to add separate cartographical grids for mapping the polar regions. Thus I propose mapping of the whole body including cartographical grids at a planetary scale and separate maps of the north and south polar regions.

#### COORDINATE SYSTEM, INTERPRETATION OF SPACE IMAGES

It is also necessary to determine a coordinate system and a proper definition of latitude and longitude depending on the rotation of the body and the recommendations of the International Astronomical Union (IAU). Some celestial bodies are being mapped for the first time, for example, asteroid Eros. Initially many features of the body's surface are hard to interpret. It is quite difficult to attribute them to relief form. The detection of positive and negative relief forms requires certain skills for image interpretation and the use of indirect indications. Even more complicated situations occur when on small – scale images of a celestial body it is possible to observe only photometric differences, permitting us to show on a map only the tone of the surface. For the Earth after laboratory interpretation of images, field research may be used to confirm the interpretation, but for celestial bodies such as asteroids this opportunity does not yet exist! Only experience of image interpretation and some knowledge of physical and geographical conditions helps us to understand

surface details. As a result of new space missions our knowledge of the surfaces of planets, satellites, asteroids etc. is increasing; standards of interpretation, classification of topographical objects on celestial bodies, which should be shown on maps, are creating. Therefore all appropriate problems of modern cartographical production will be considered using the most current information.

#### **INITIAL DATA FOR A MAP CREATION. REQUIREMENTS FOR THE MAPS**

Initial data can include both direct and indirect materials. Direct materials are the materials of space images transmitted to the Earth. Further creation of the map will depend on their quality, resolution and other characteristics. Indirect materials are existing cartographical products that can be taken as initial data. It is necessary to take into account all requirements as for traditional maps:

- the analysis of the mathematical basis,
- estimation of completeness of contents, reliability of the information shown on a map,
- accuracy,
- up to date information,
- quality of design.

The design of symbols and of the key – legend to help read the map, and also transliteration of feature names on celestial bodies are two additional important tasks in the process of creating the map. The recommendations for classification of topographical objects and their names on planets and satellites are developed by the Working Group For Planetary System Nomenclature of the IAU. All names of topographical objects recommended by the IAU are given in Latin language. Maps produced in different countries using different languages must systematically transliterate those names.

#### **THE SINGULARITY OF CONTENTS OF A NON-SPHERICAL CELESTIAL BODY GEOGRAPHICAL MAP**

The fundamental role of a geographical map of a non-spherical celestial body is to show the physical surface and its numerical characteristics. The most typical topographical objects on planets and satellites are craters. At the same time it is important to take to account that every celestial body surface is unique. Therefore it is necessary to make decision about ways to show the map contents. The map can consist of space images transformed into cartographical projection (a photomap) or shaded relief made by various ways. If the relief is a basic unit of the map contents, let us consider how it is created.

On maps of irregularly – shaped celestial bodies the major role is played by the cartographical grid, which is distorted by the form of body. The amount of distortion (depending on the requirements of relief visualization) depends on the choice of a vertical map scale. During calculation of vertical scale, it is important to consider not only good visualization but also reliability of relief. High relief structures can be exaggerated too much, or flat relief can be shown by a hole. Therefore it is possible to use a variable vertical scale depending on character of relief. In some situations very high structures can conceal low structures, making them invisible on the map. These factors must be considered in designing the cartographical grid space. There is also a problem of relief generalization. The known factors and ways of generalization from terrestrial experience should be used in creating geographical maps of celestial bodies.

## **The factors:**

### **Direct factors:**

- purpose and theme of map,
- scale,
- singularity of mapping surface;

### **Indirect factors:**

- ways and conditions of map use (popular issue for a wide range of customers, for special use),
- method of depicting the cartographical image (shading relief, contours etc.),
- materials for compilation of a map (space images, catalogues of coordinates, map etc.),
- ways of compilation and reading of a map (using a map on digital or traditional presentation)

## **Ways:**

- formation of concepts and development of primary classifications and their generalization (craters, grooves, ridges etc.),
- generalization of qualitative indications and quantitative parameters (craters by depth up to 100 meters – holes, craters by depth up to 3000 meters etc.),
- detection and selection of objects (to show craters more than 20 mm<sup>2</sup> on a map of 1:1000000 scale),
- generalization of the form and structure of cartographical image,
- transition from individual to collective spatial-structural concepts.

The last two ways depend on transition in scales of map. The scale row of map of irregularly – shaped celestial bodies is a subject of consideration.

It is possible to use various kinds of shaded relief and other ways or their combination to show the relief on a map of celestial body except known ways of contours. It is recommended to show relief structures that is not expressing by contours by using symbols. This way is effective when there is a big difference of altitudes, for example, big slope of a crater wall. The method of illuminated contours is interesting too for high relief and monotone surfaces. If there is a desire to create an obvious cartographical image of the real surface of a body it is possible to use various 3D methods such as anaglyphs, raster stereoscopic views etc.

## **References**

- Bilich, U. S., Vasmut, A. S. (1984). Designing and compilation of maps, Nedra
- Nyrtsov, M.V., Bugaevsky, L.M., Shingareva K.B. (2000). Mathematical basis for non-spherical celestial bodies maps// Journal of Geospatial Science and Engineering, Hong Kong. Vol. 2, № 2, December 2000, pp. 45 – 50
- Nyrtsov, M.V., Bugaevsky, L.M. (1998). Theoretical aspects of cartographical projections for real surfaces of celestial bodies development. Izv. vuzov. A geodesy and air photography, № 3
- Saliszhev, K. A. (1990). Cartography, Moscow, MGU
- Stooke, P.J. and Keller, C.P. (1990). Map projections for Non-Spherical Worlds: The Variable – Radius Projections. Cartographica 27, pp. 82 – 200
- Tuflin, U. S. (1986). Space photogrammetry in study of planets and satellites, Moscow, Nedra