

Modern methodology for planetary mapping

Karachevtseva I.¹, Kokhanov A.¹, Rodionova Zh.^{1,2}, Zharkova A.¹

Zubarev A.¹, Garov A.¹, Matveev E.¹ and J. Oberst^{1,3,4}

- (1) MIIGAIK Extraterrestrial Laboratory (MExLab)
- (2) Sternberg Astronomical Institute (SAI MSU)
- (3) German Aerospace Center (DLR)
- (4) Technical University of Berlin (TUB)

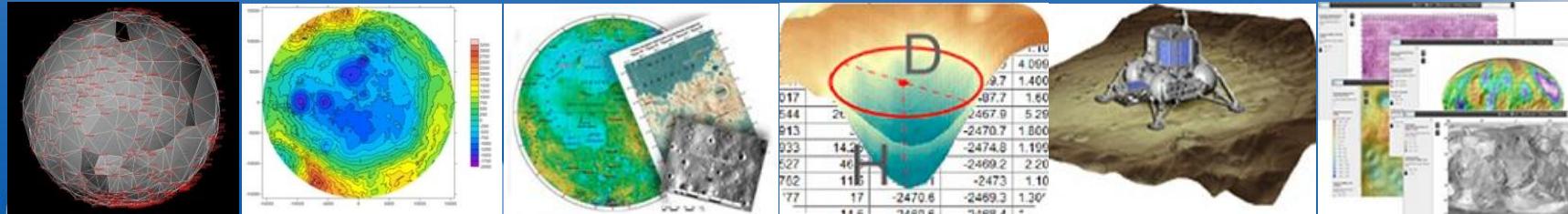
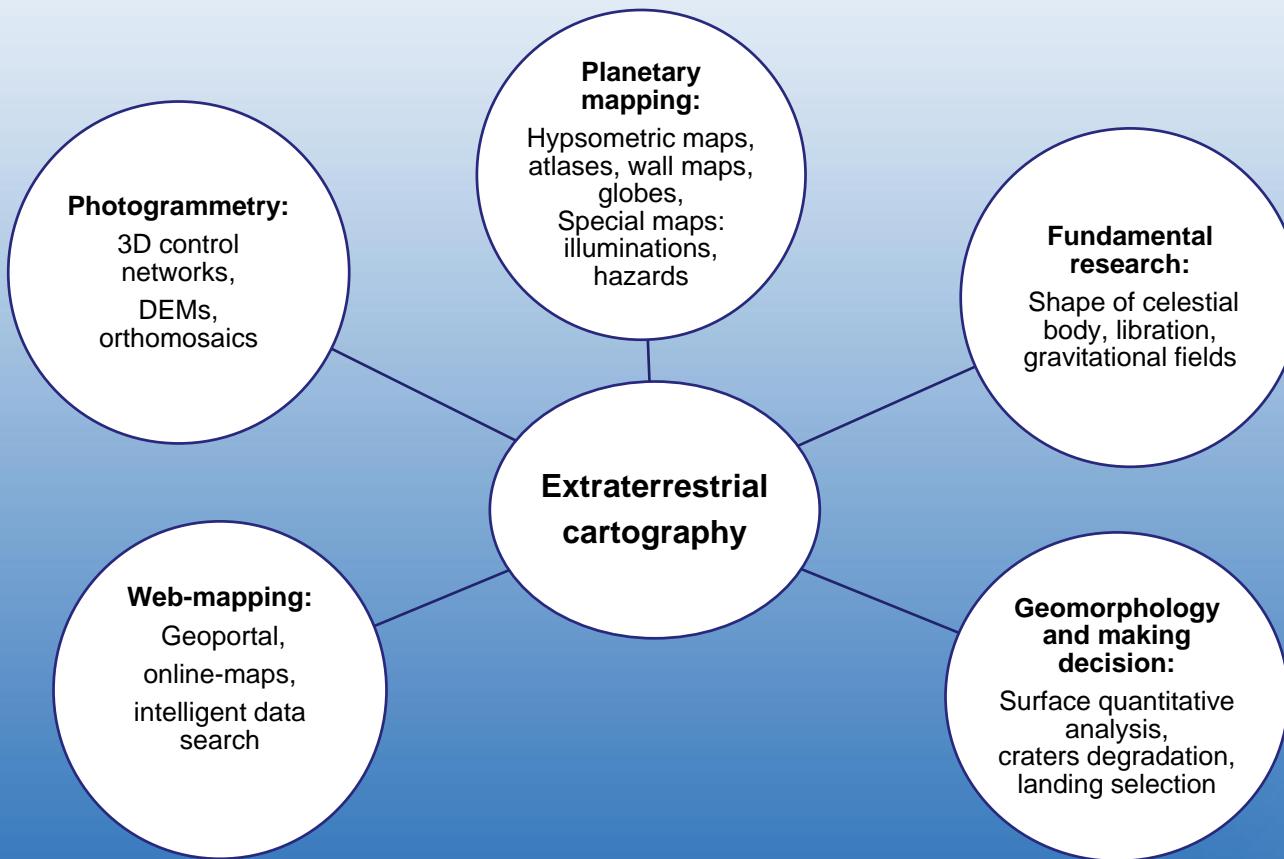
E-mail: i_karachevtseva@miigaik.ru

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Vienna, 11, November

Content

1. Extraterrestrial cartography research areas.
2. Methods and technologies:
 - Establish coordinate systems;
 - Planetary surface analysis and planning future space missions;
 - Web-mapping and geoportal;
3. Published maps: wall maps and atlases.
4. Heritage and innovation.

Conception: interdisciplinary approach



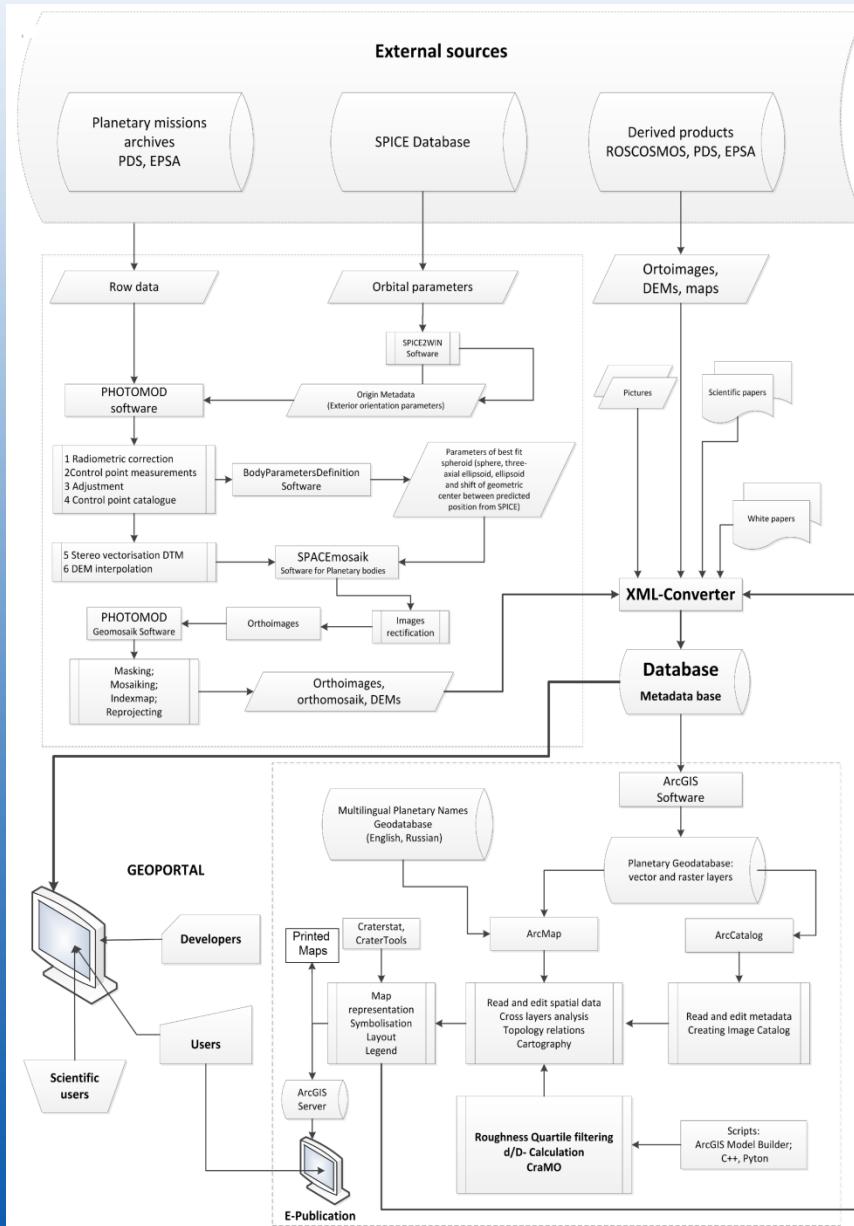
Flowchart of extraterrestrial cartography

- Planetary Data System (PDS): storage, format and metadata.

- Workflow: integration technologic chains.

- Produce basic data: DEM and orthoimages.

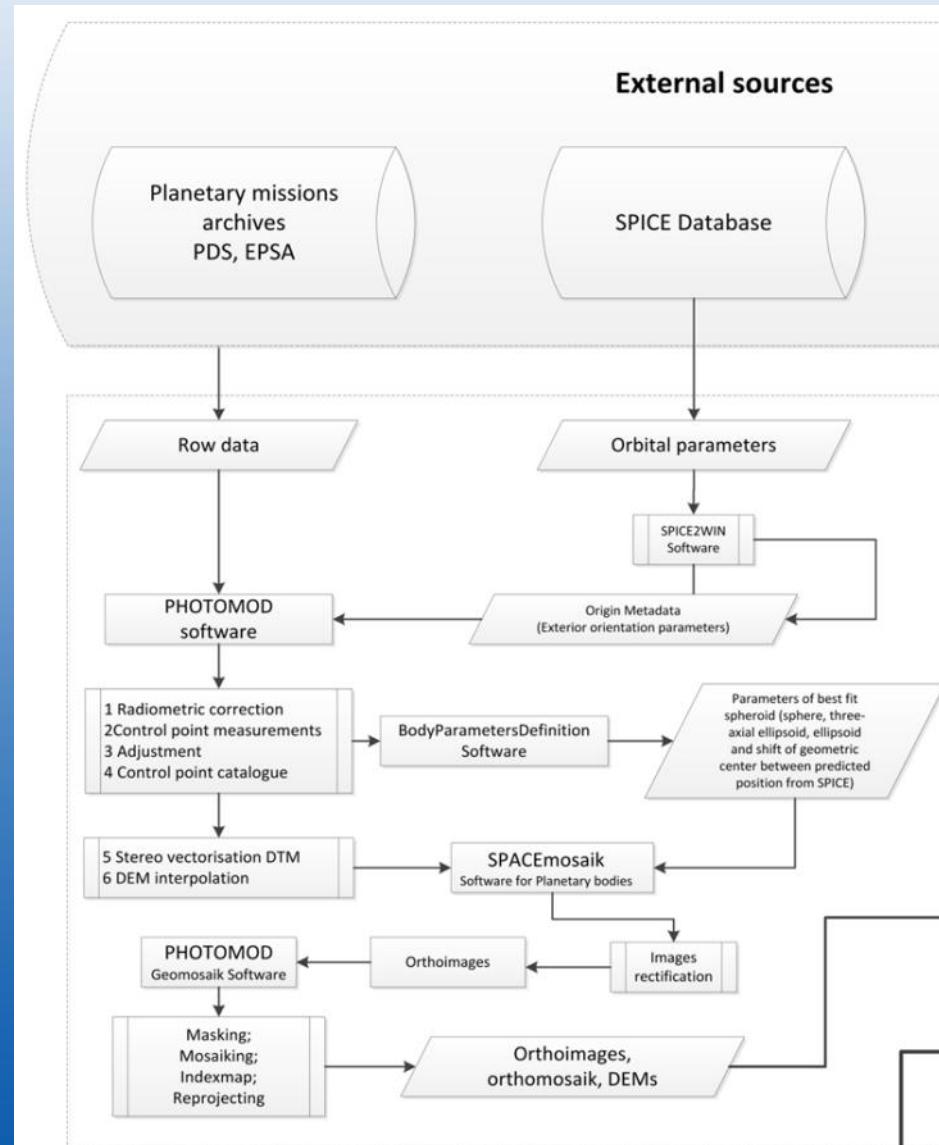
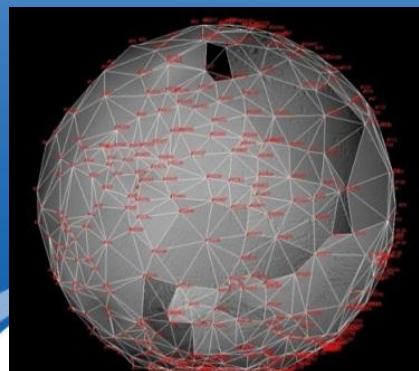
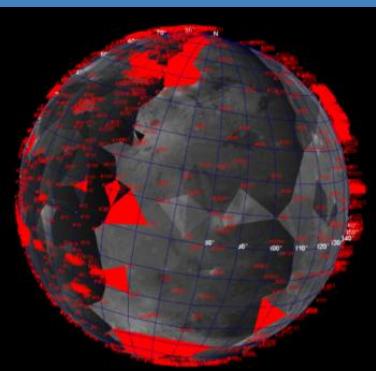
- Studied various celestial bodies: terrestrial planets and satellites (Mercury, Moon, Mars, Phobos), satellites of outer planets (Ganymede, Io, Callisto, Europa, Enceladus)..



Planetary coordinate system

- 3D-control point networks: the base data for planetary mapping.
- Fundamental parameters: libration, rotation.
- New software to provide coordinate support using various images with different illumination, resolutions, ect.

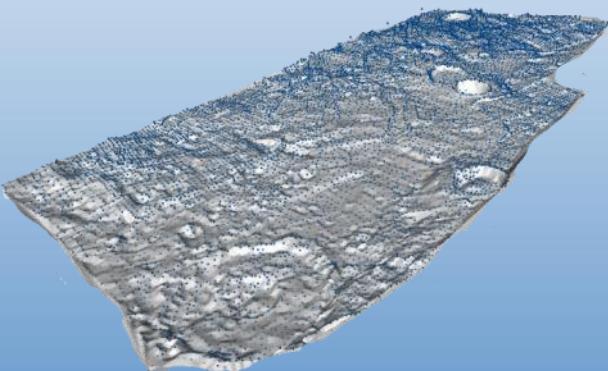
The new 3D control point networks of Ganymede (left) and Enceladus (right)



Results of photogrammetry image processing

- 3D visualization;
- Image orthorectification;
- Hypsometric mapping;
- Geomorphological analysis.

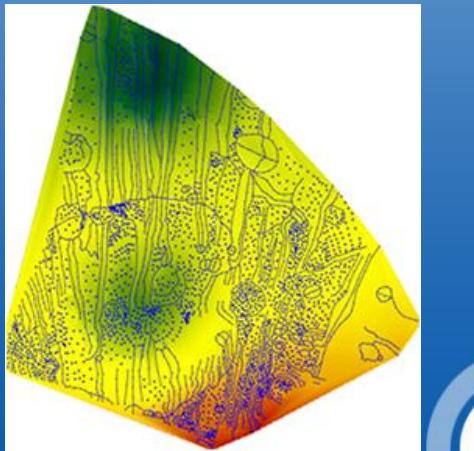
Producing local DEMs for Ganymede
(Voyager-2, resolution ~100 m)



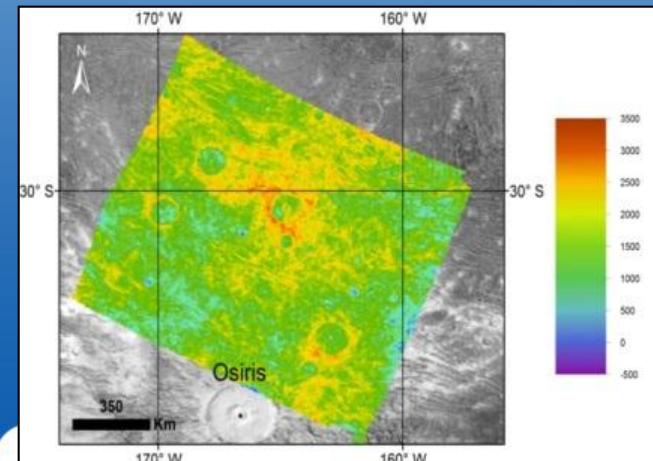
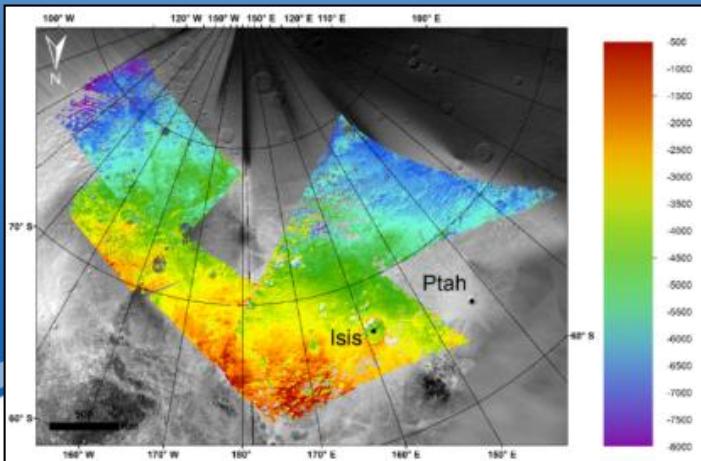
Orthomosaic of Phobos surface
(MIIGAiK, 2014),
resolution – 5 m/px



Detailed DEM
Phobos crater Drunlo
(resolution 10 m/px)



Local Hypsometric maps of Ganymede (DEM 250 m/pixel)



Cartographic support of future missions

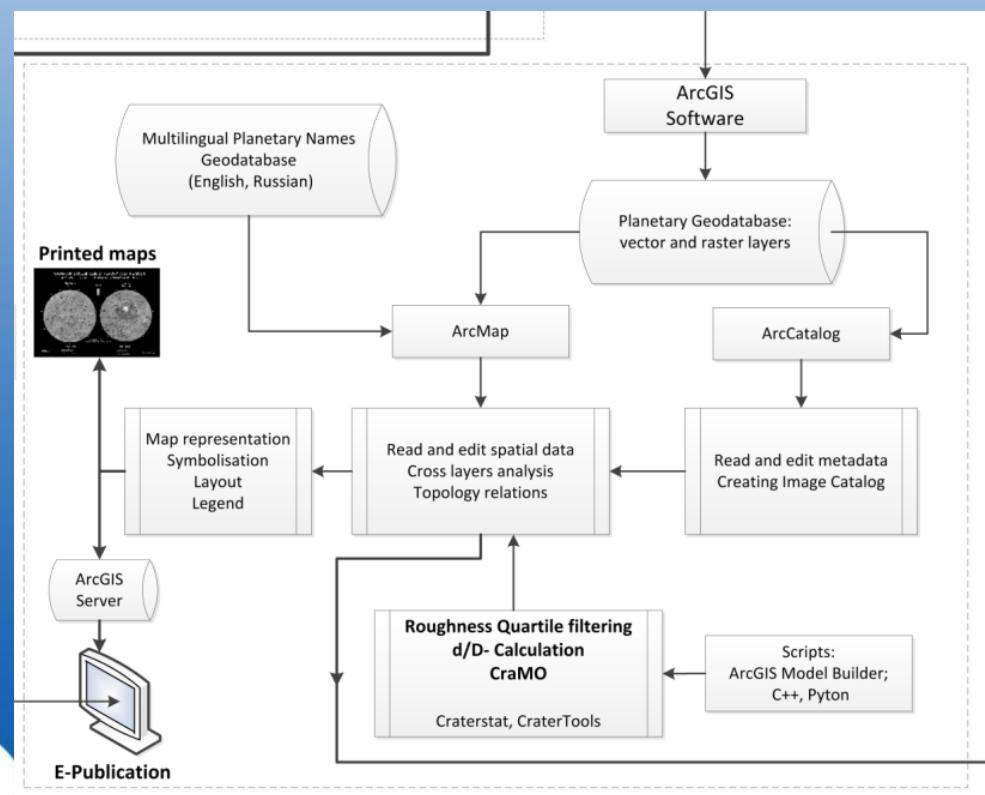
Future space missions

- Roscosmos: Landing on the Moon: Luna-25, 27.
- ESA: Flight to the Mercury: Bepi Colombo.
- ESA: JUICE mission (Jovian system, Ganymede).
- Roscosmos: Boomerang, sample return mission to Phobos.



For making decisions:

Special tools and maps: maps of hazards, illumination maps, slope, geological maps.



Surface analysis: crater measurements

Methods:

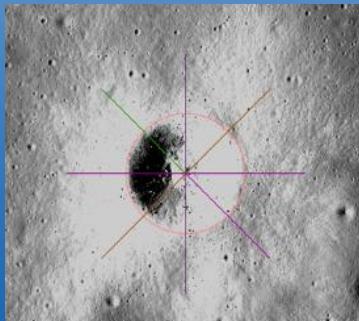
- Automatic measurements of crater arrays;
- Automatic profiles building.

Results:

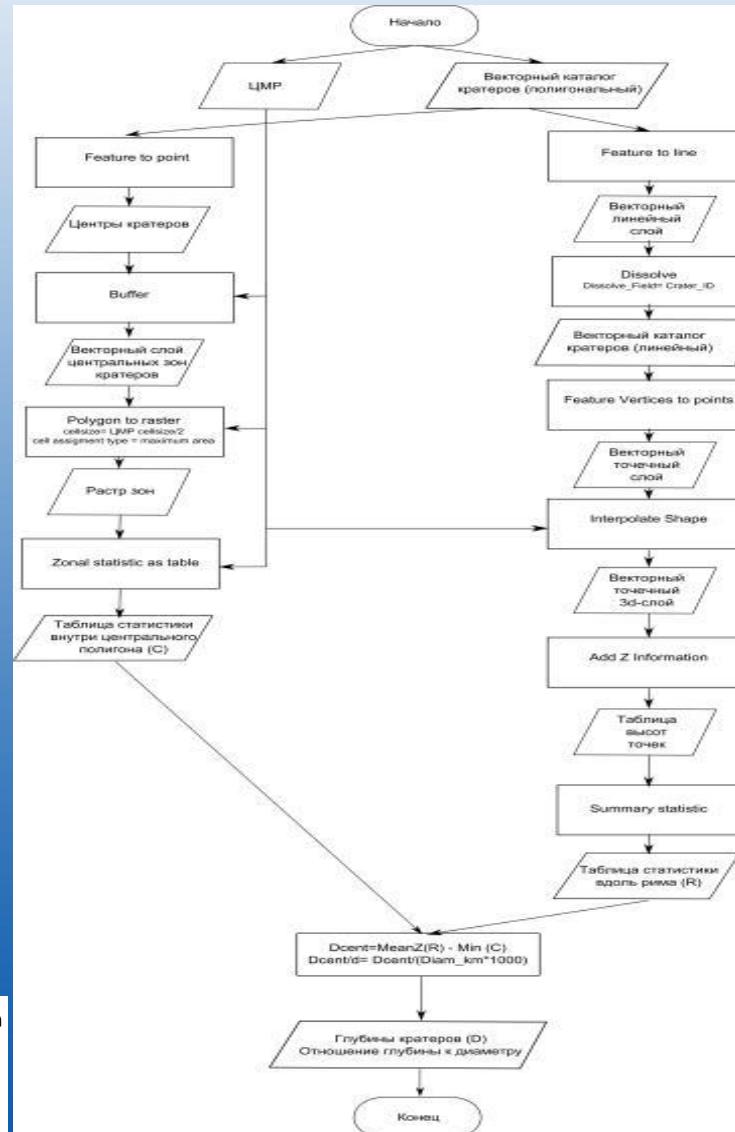
- Crater shape estimation;
- Study of crater degradation degree.

Fundamental study: evidence of water ice in Moon polar area

Automatic created rose of profiles for maximum slope estimation

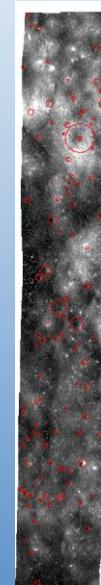


Algorithm of the relative depth calculation

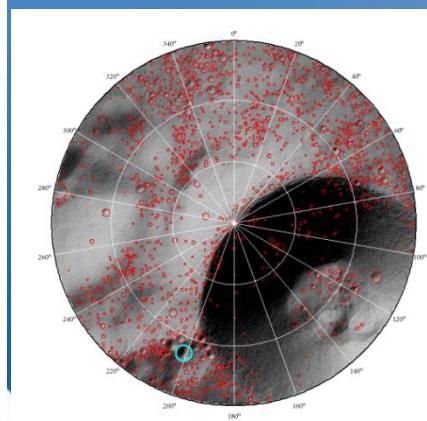


Crater catalogues of areas

Luna 20, 3.8° N 56.6° E

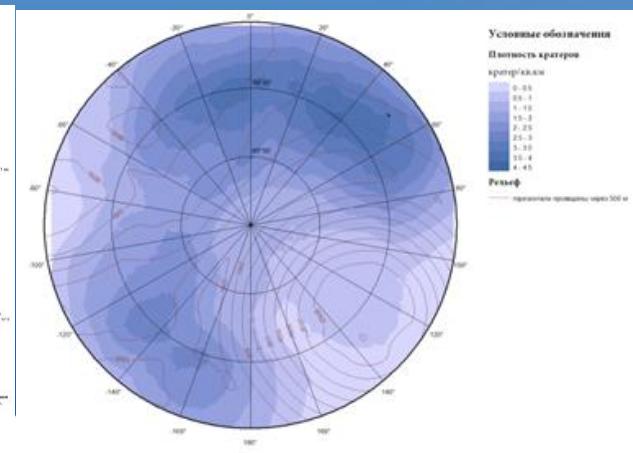
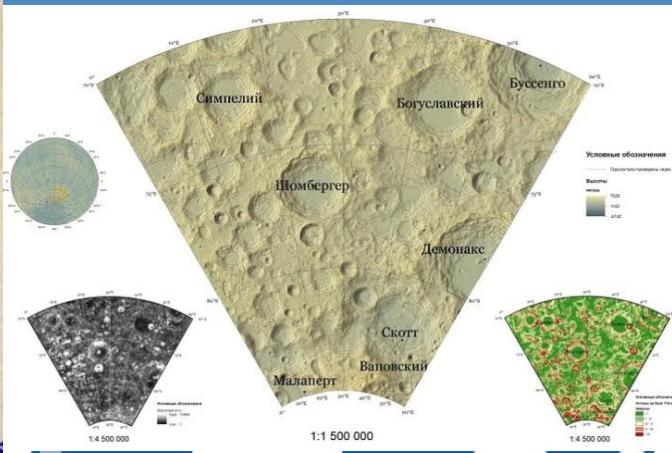
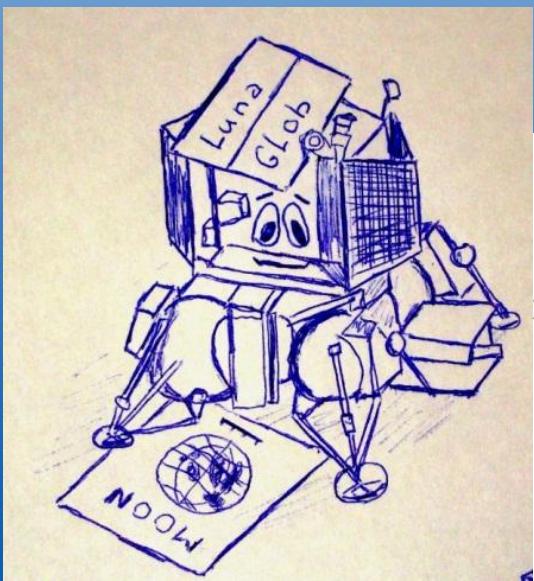
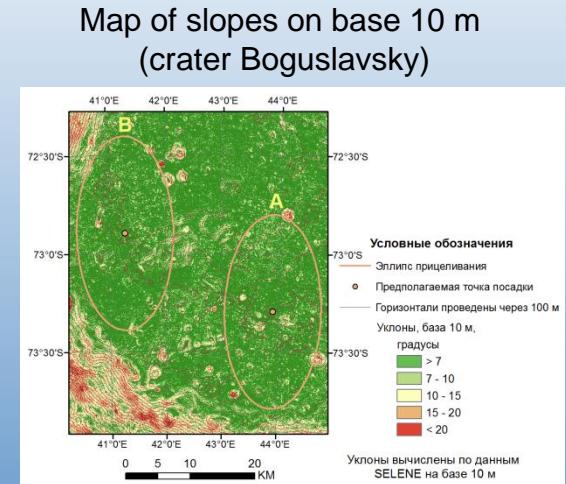
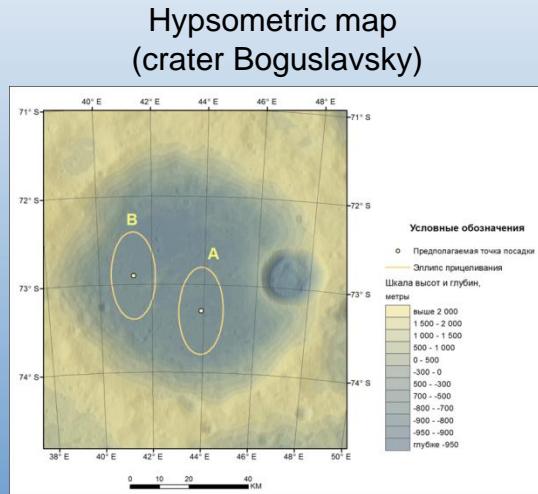


Southern sub-polar area
90 ° S



Moon: landing site selection

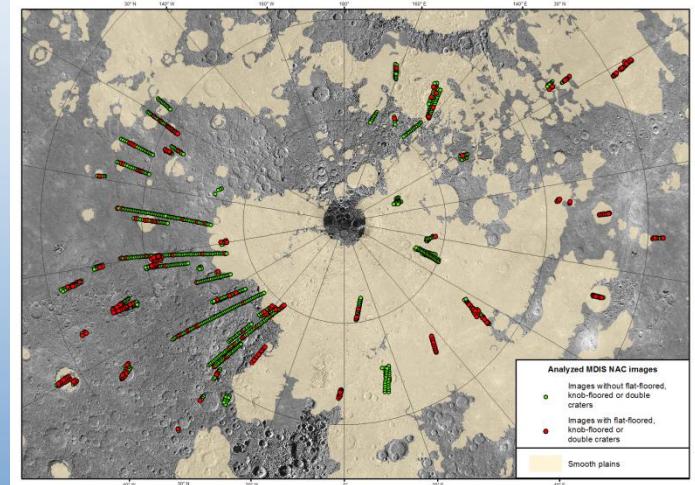
- Relief maps on different level of details.
 - Characteristics of potential landing sites.
 - Hazards detection:
 - slopes $>7^\circ$;
 - permanently shadowed areas;
 - invisibility from Earth;
 - high roughness at small scales;
 - boulders;



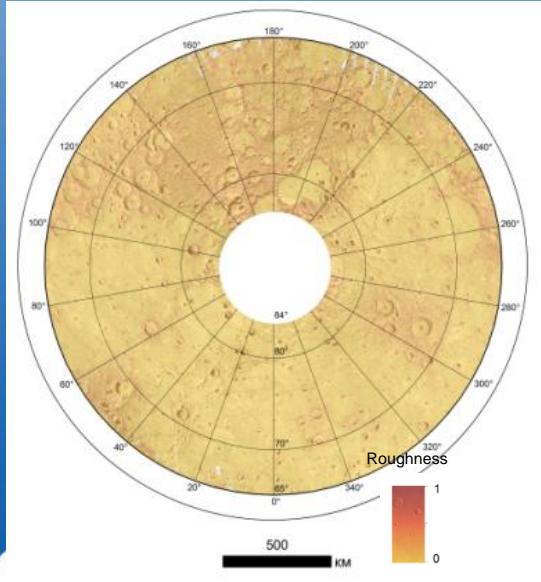
Mercury: study of surface

- Methods of roughness calculation: interquartile range of slopes, Laplacian, Hessian.
- Study of the flat-floored craters and hollows for regolith depth analysis.
- Planetology-comparative analysis of the terrestrial planets: Moon, Mercury

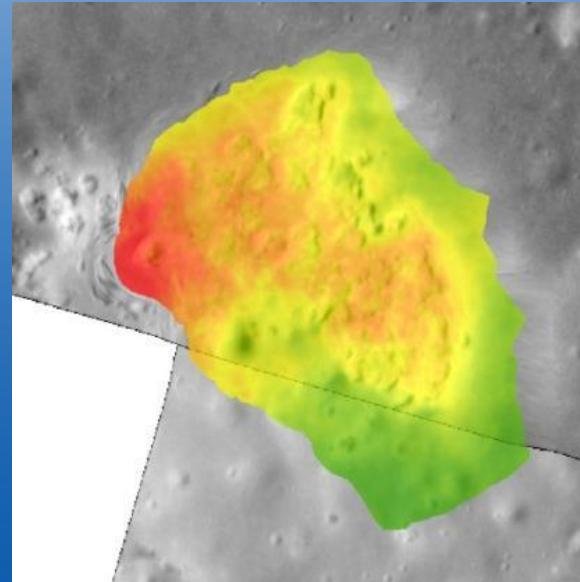
Distribution of the images with flat-floored craters in Northern subpolar area



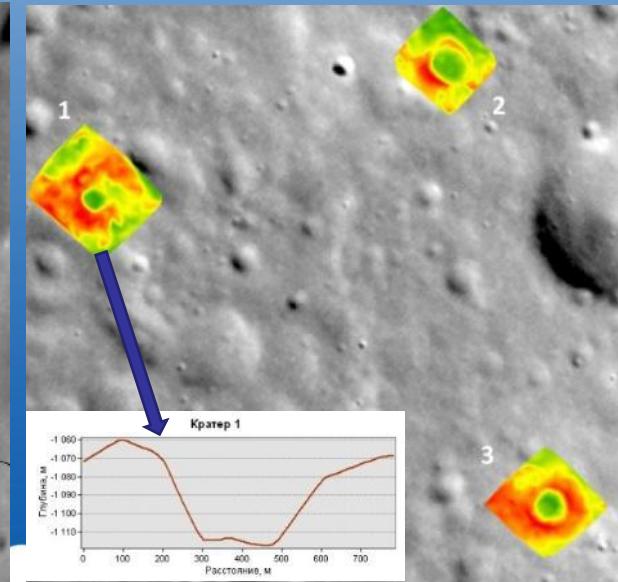
Roughness of the Northern Polar Area on base 2.8 km



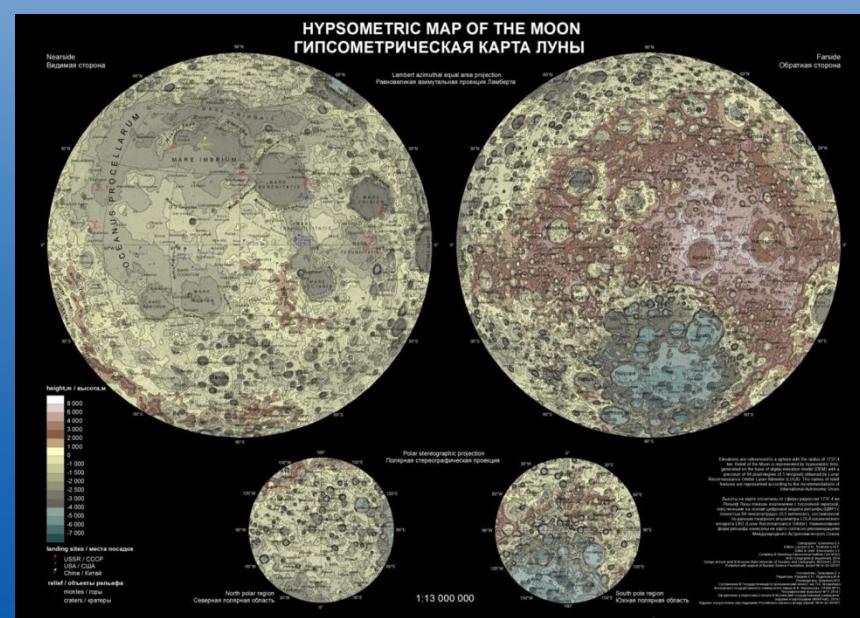
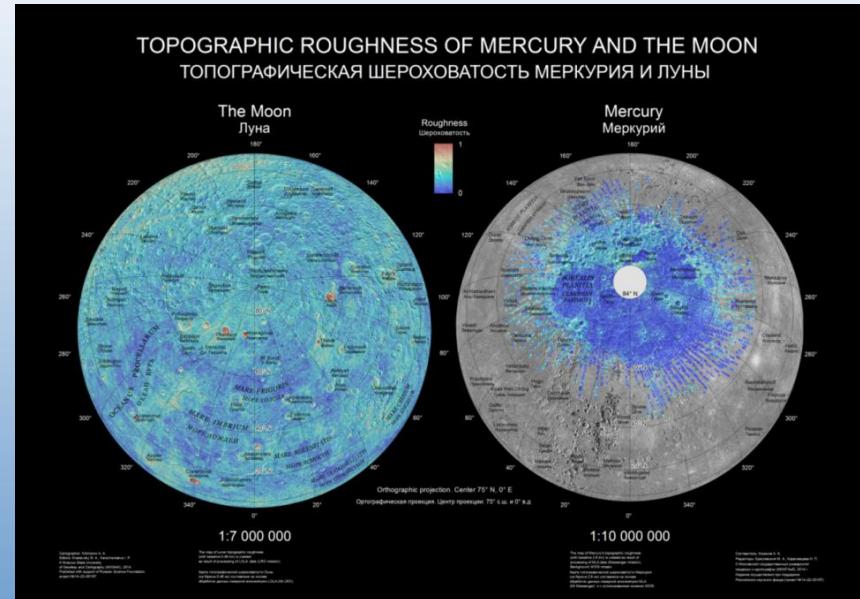
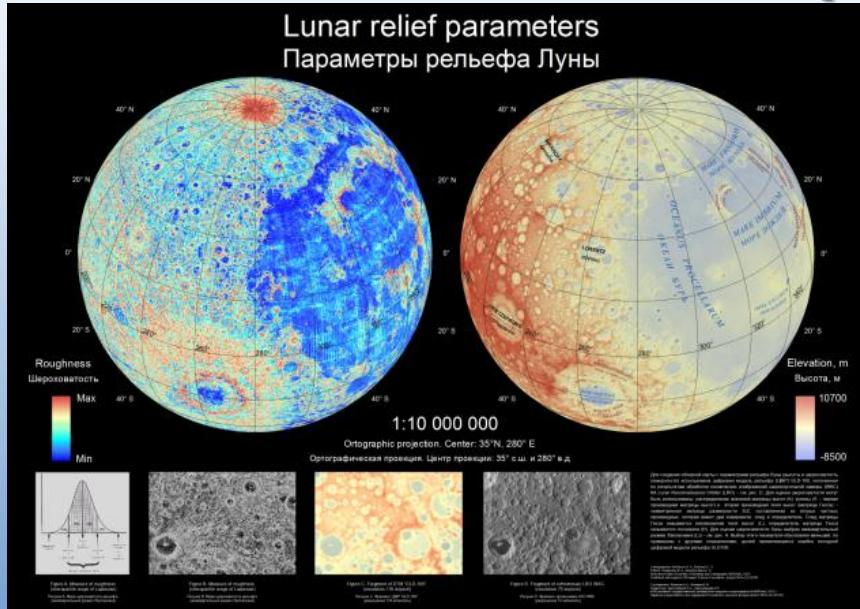
Local DTM for area with hollows



Local DTMs for flat-floored craters



Planetology-comparative analysis: wall-maps and globe



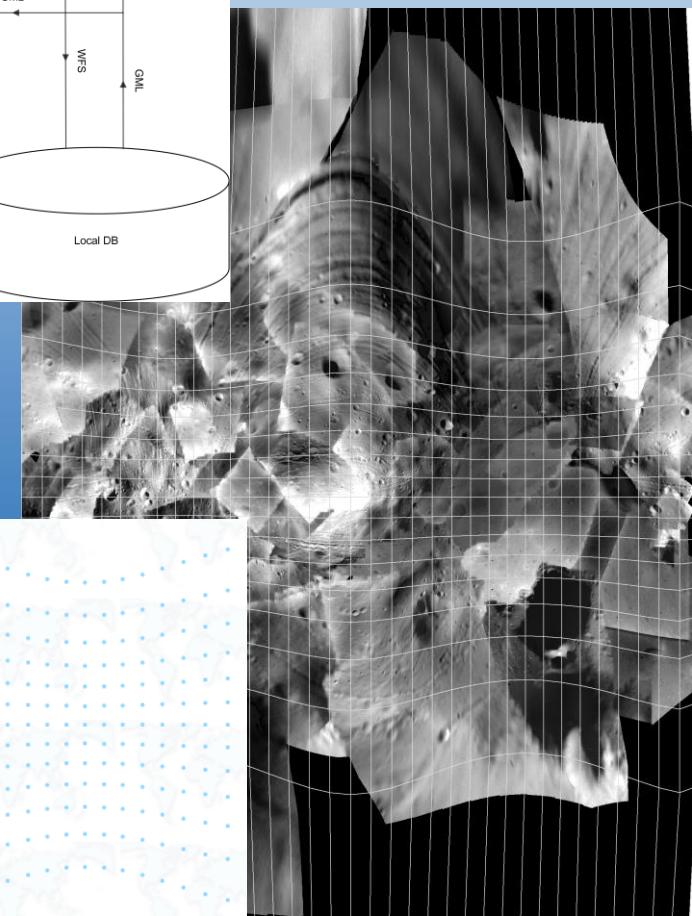
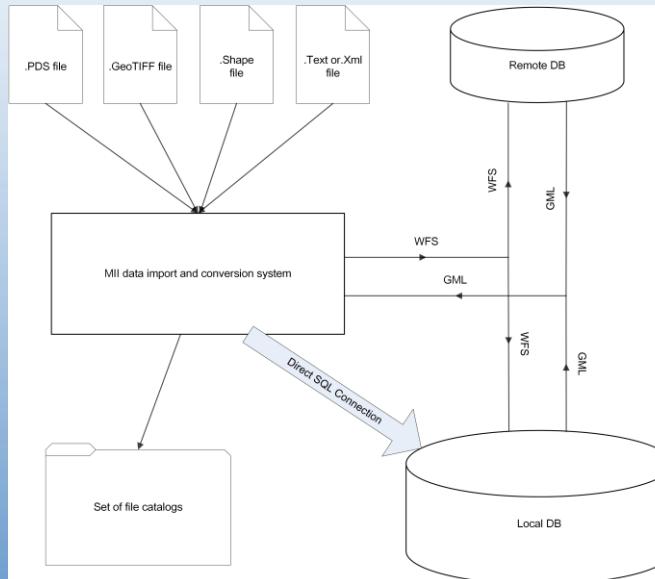
New software and tools

- **Software (XML, C++):**

- XML-converter: for data standardization and conversion from various format and uploading to SQL-geodatabase;
- Modeling of surface shadows;
- Modeling visibility from celestial body;
- Calculation of the surface illumination;
- Artificial modeling of the panoramic images using DEM.

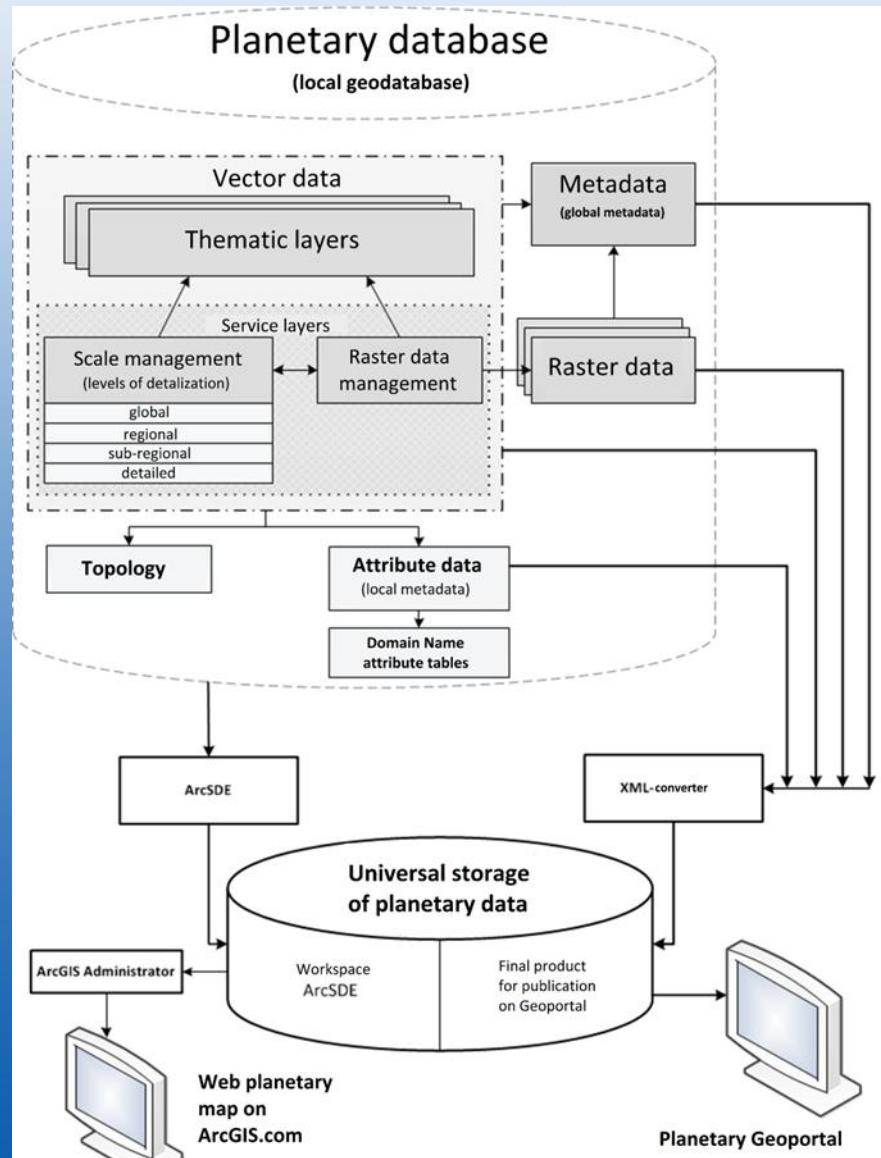
GIS-tools (Python, ModelBuilder):

- “CRAMO” for calculation of the crater depth relative to the surrounding surface;
- “Roughness Quartile” for calculation of the surface roughness;
- Automatic profile builder;
- Automatic projection calculation for 3-exial ellipsoid.



Information system and web-mapping

- Friendly interface (English and Russian);
- Spatial queries and access to the contents selecting from the list of available data set;
- Quantitative and qualitative characteristics of the objects in graphical and tabular forms;
- 4 different projections, including polar.
- Different levels of detail: from global to local scales;
- Flash -> HTML5 + JavaScript;
- User can download data;
- User authorization service, security and access control;
- Modeling and creating metadata;
- Control of the quality of topology;



Extension of planetary data model

- Planetary data model (A. Naas & S. Van Gasselt): standardization and classification of planetary data.
- Extensions:
 - Support of multi-scale representation of objects.
 - Control of big data arrays.
 - New planetary objects from geomorphological analysis.

Classified types of grooves

- Цепочки соприкасающихся воронок
- Желоба
- Разорванные цепочки воронок

Morphological classification of craters and slope processes

Кратеры более 200 м в диаметре

Морфология кратеров



простые чищеобразные

со сложной внешней морфологией



полигональные



эллиптические

со сложной внутренней морфологией



концентрические



плоскодонные



с центральным поднятием

Степень деградации кратеров (D>2 км)



разрушенные



сплюснутые



чёткие

Оползневые явления



оползневые тела



внутренние склоны кратеров
с потоками обломочного материала

не выражающиеся в масштабе карты



внутренние склоны кратеров
с потоками обломочного материала



оползневое тело



сочетание оползневых склонов и тел

Прочие морфологические объекты

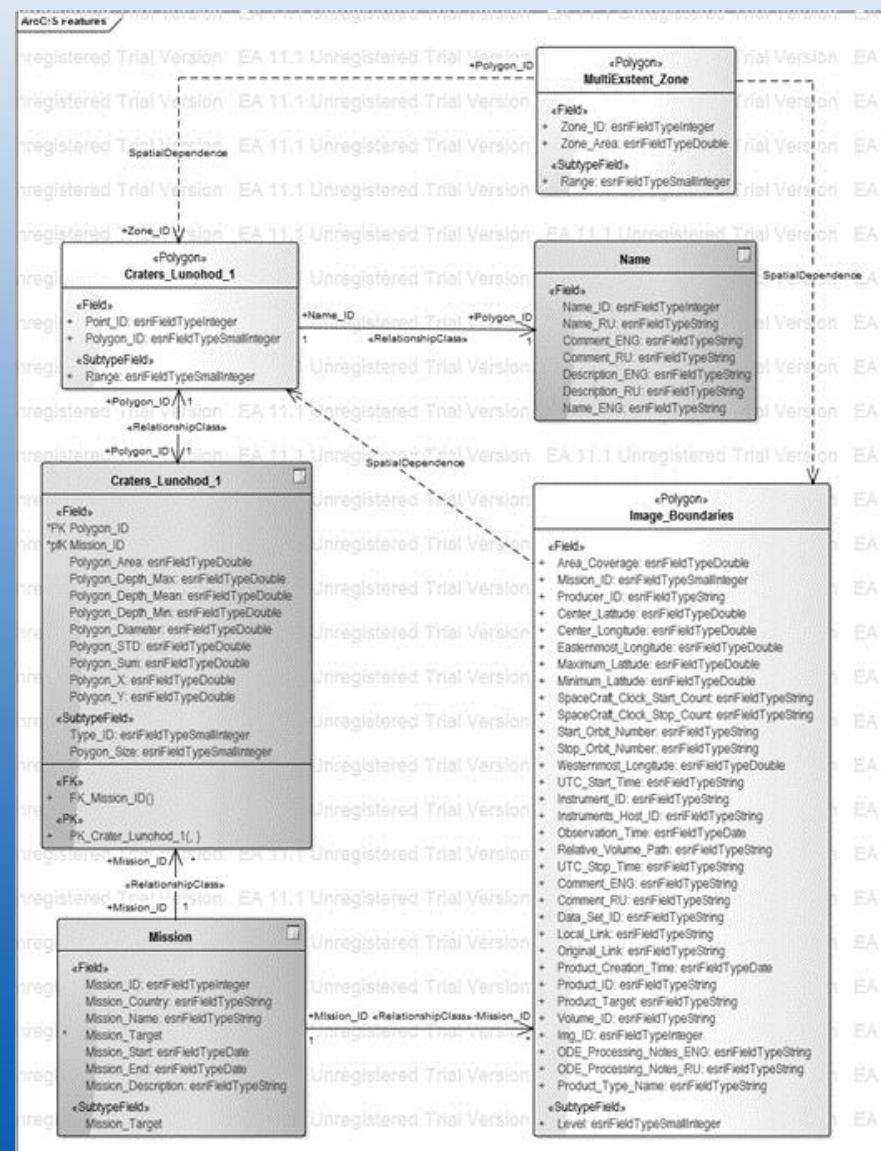


закратерные выбросы



борозды

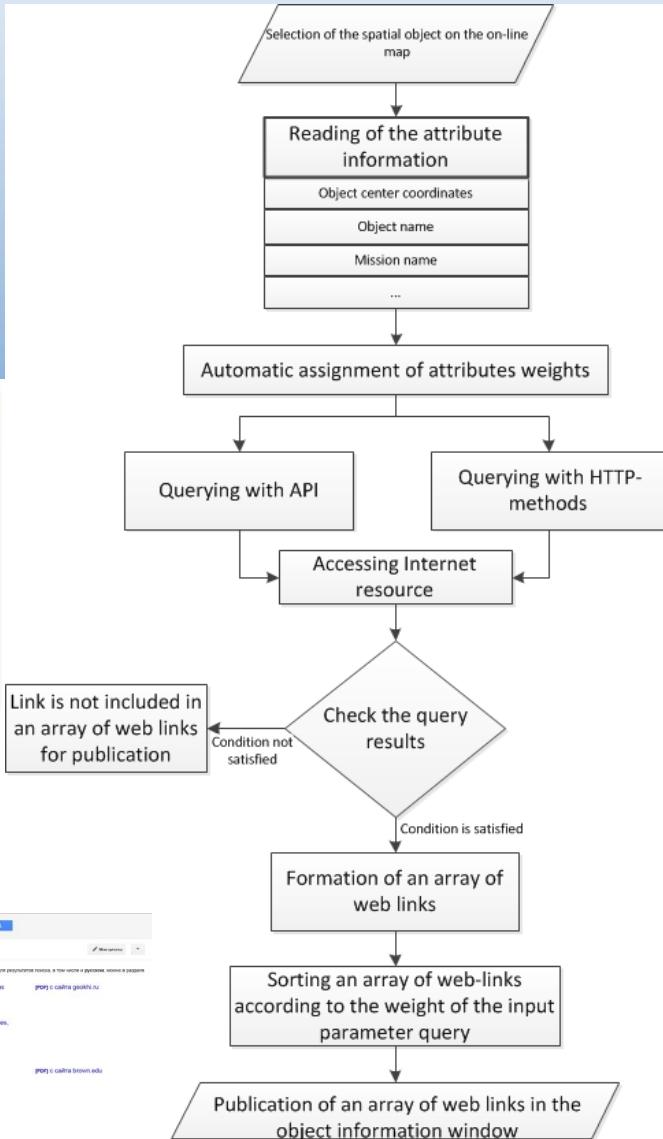
Lunar objects data model



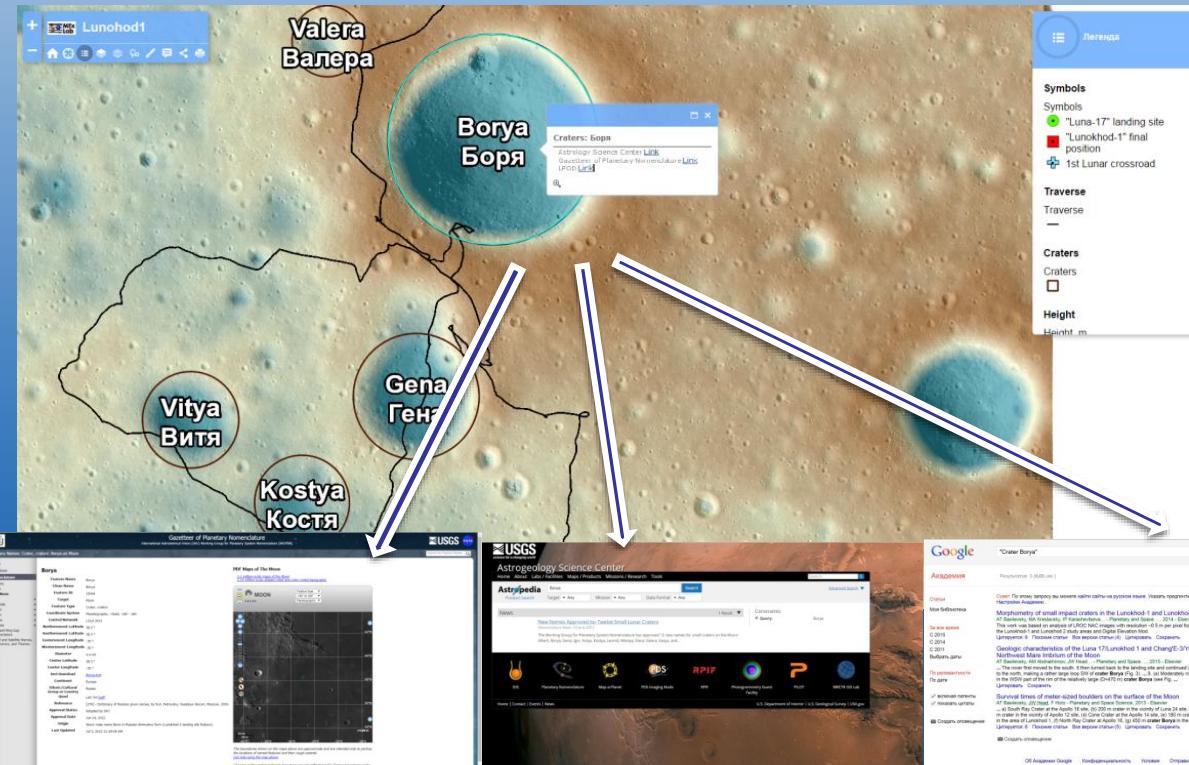
Intelligent search of planetary data

- Classification - to specify search by predefined criteria.
- Cluster analysis - to create a self-expanding and variable logic of the web-service.
- Time-series analysis - to take into consideration previous searches of the user.

Algorithm of the intelligent search



ArcGIS online map



Design of planetary maps

- Traditional design in modern software;
- Specially developed hypsometric and color scales;
- The hypsometric scale highlights relief objects;
- Conformity of color scales to multispectral images.

MRO (NASA)



Mercury

Mars Express (ESA)



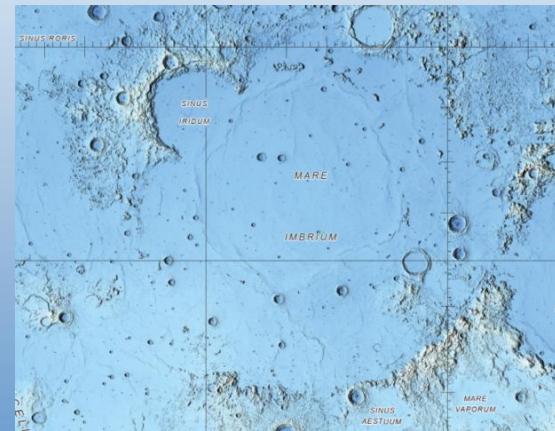
Phobos

Hypsometric map of the Moon
(SAI&MIIGAiK)

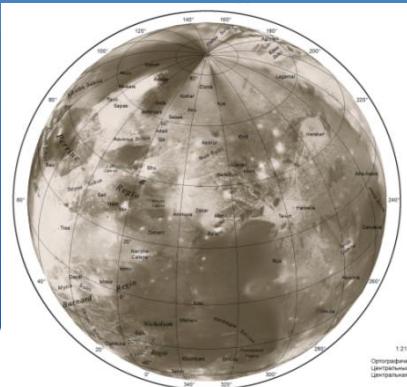


Contours provides information about height

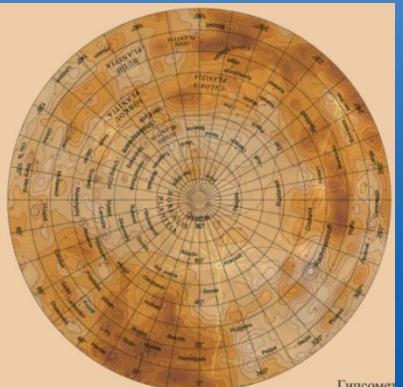
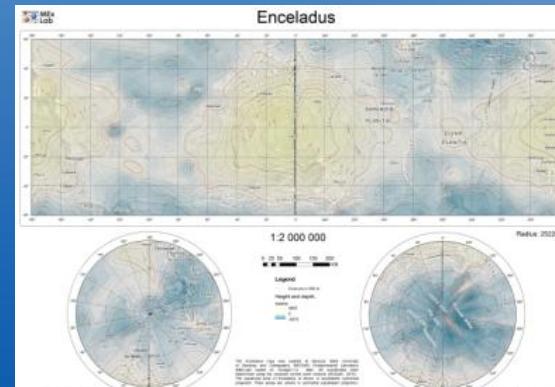
Topographic map of the Moon, USGS



Ganymede

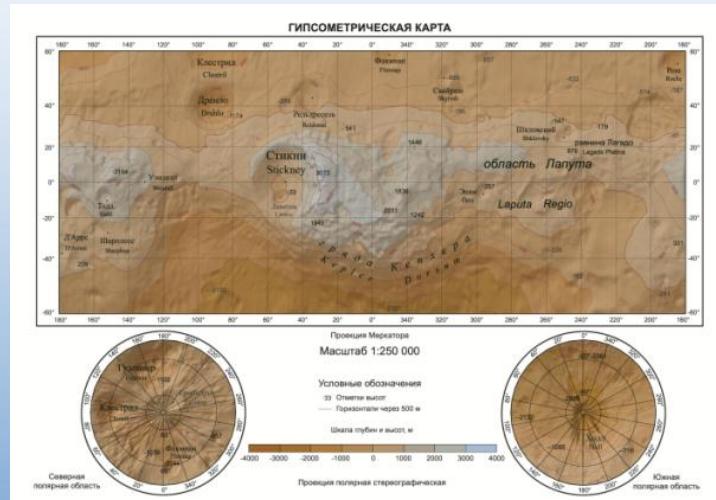


Enceladus



New mapping: Phobos Atlas

Hypsometric map of Phobos



Structure - 4 chapters:

- I. History of Phobos mapping.
- II. Control point network, shape model and gravity field of Phobos.
- III. Quantitative spatial analyses of Phobos surface in GIS.
- IV. Geomorphologic studies of Phobos.

Levels of details - 3 LODs:

Global maps:

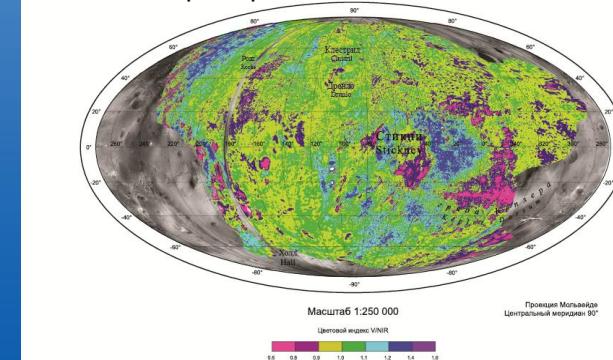
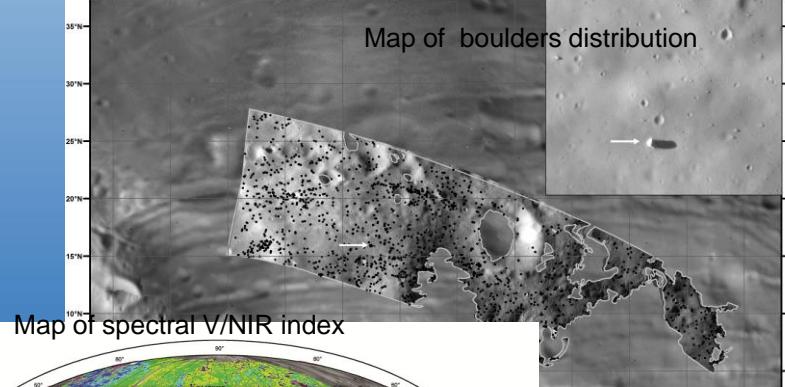
- Physical and Thematic 1:250 000.

Middle-Scale maps:

- Sheets of craters distribution map 1:150 000;
- Sheets of topographic map 1:75 000.

Large-Scale maps:

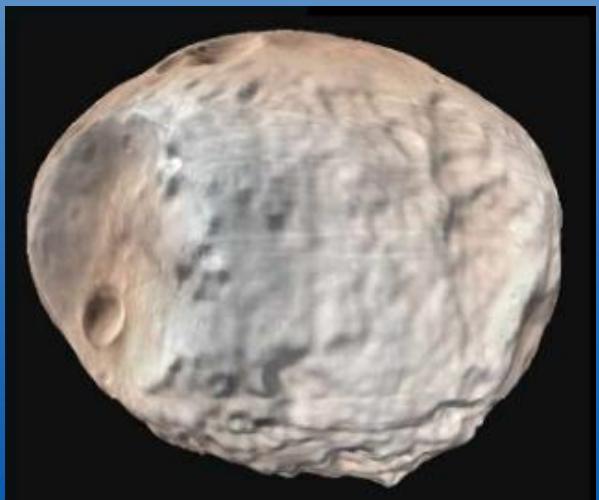
- Maps of craters relief 1:60 000;
- Maps of boulders distribution 1:30 000.



Content of atlas

List of maps

- The Phobos atlas: results of study:**
- Size and shape-model (Nadezhina and Zubarev, 2014);
 - Geology (Basilevsky et al., 2014);
 - Roughness estimation (Karachevtseva et al., 2012);
 - Morphometry studies (Koknanov et al., 2012);
 - Multi-fractal approach (Uchae Dm. et al., 2012);
 - Surface compositional studies using HRSC data (Patsyn et al., 2012);
 - Phobos information system (Karachevtseva et al., 2014).



Part	No	Name	Scale
I	1.	Map of surface in Bugaevsky projection	1:200 000
II	2.	Map of control points network errors	1:250 000
II	3.	Map of images resolution	1:250 000
II	4.	Global map of surface	1:250 000
II	5.	Index of relief maps of Drunlo and Stickney	1:250 000
II	6.	Map of crater Stickney	1:60 000
II	7.	Map of crater Drunlo	1:60 000
II	8.	Map of gravity potential	1:250 000
II	9.	Map of centrifugal potential	1:250 000
II	10.	Map of tidal potential	1:250 000
II	11.	Map of attractive potential	1:250 000
II	12.	Map of dynamic heights	1:250 000
III	13.	Index of base map	1:250 000
III	14-21	Base map of surface (8 sheets)	1:75 000
III	22.	Hypsometric map	1:250 000
III	23.	Topographic map	1:250 000
III	24.	Global map of craters distribution	1:250 000
III	25-30.	Map of craters distribution by zones (6 sheets)	1:150 000
III	31.	Map of craters density	1:250 000
III	32.	Map of boulders distribution	1:40 000
III	33.	Map of surface, based on Stooke mosaic (Stooke, 2012)	1:250 000
III	34.	Map of albedo. Blue channel	1:250 000
III	35.	Map of albedo. Green channel	1:250 000
III	36.	Map of albedo. Red channel	1:250 000
III	37.	Map of albedo. NIR channel	1:250 000
III	38.	Map of color index V/NIR	1:250 000
IV	39.	Geomorphological map of craters	1:250 000
IV	40.	Geomorphological map of grooves	1:250 000
IV	41-42.	Map of slopes (dynamic and geometric heights)	1:250 000
IV	43.	Map of roughness	1:250 000

Cartographic heritage and traditions

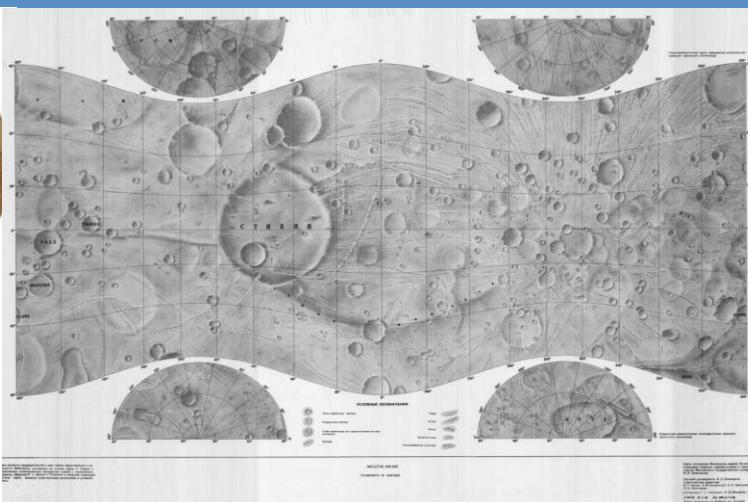
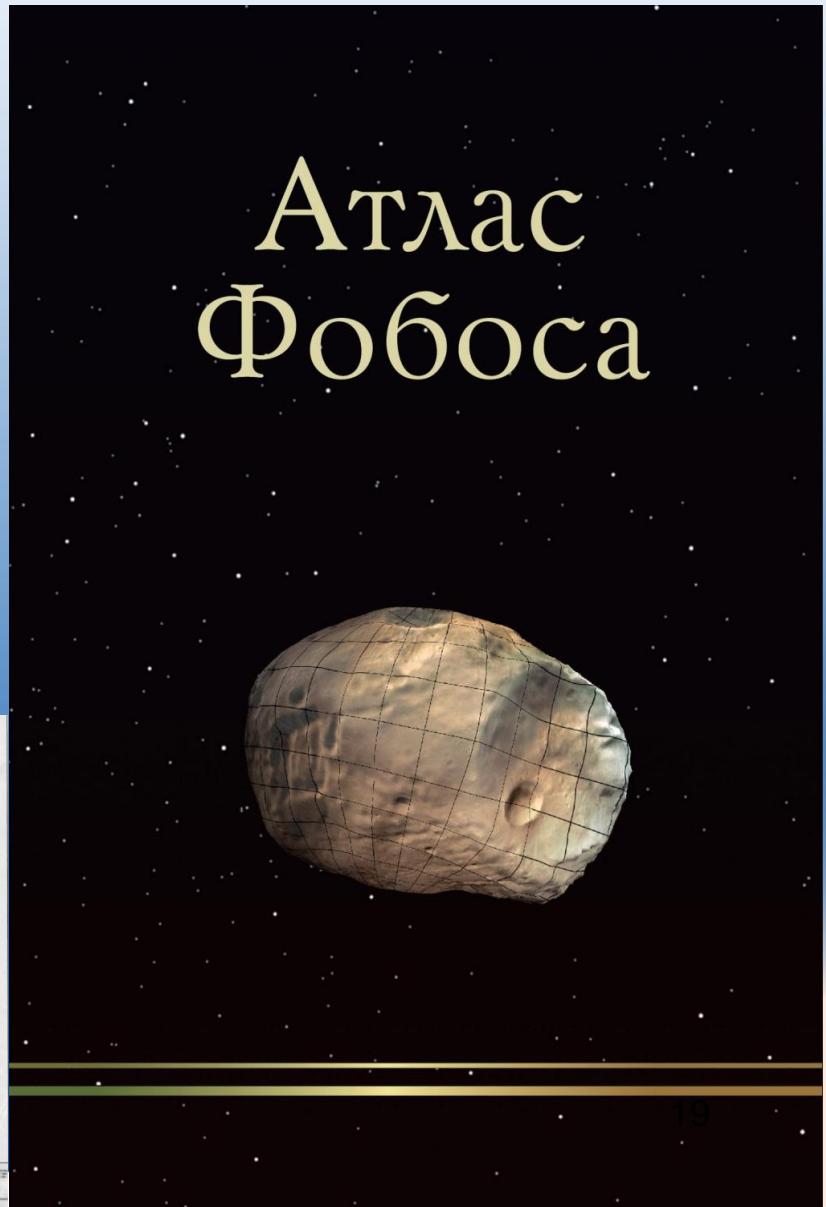
The Phobos atlas is dedicated to the memory of Russian cartographers:



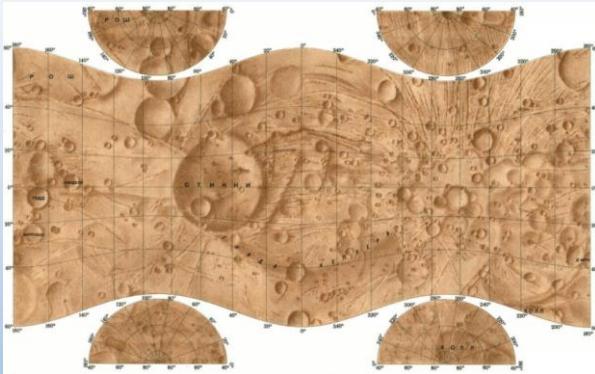
Lev Bugaevsky
(18.03.1921 – 04.08.2010)



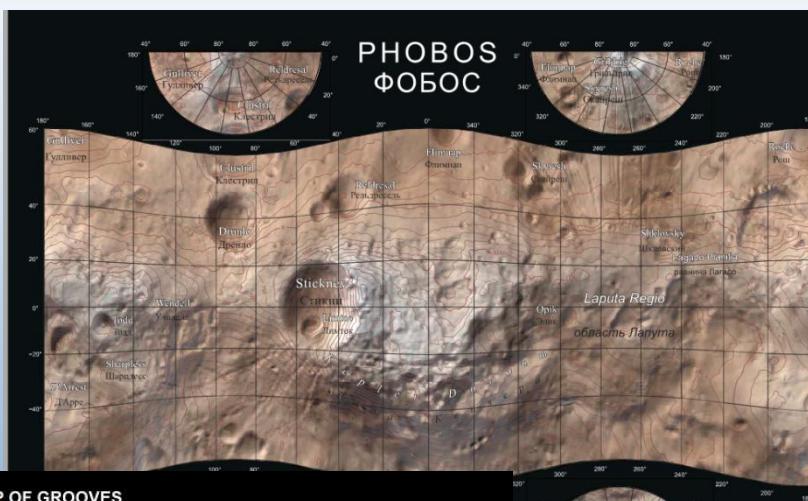
Kira Shingareva
(09.01.1938 – 15.09.2013)



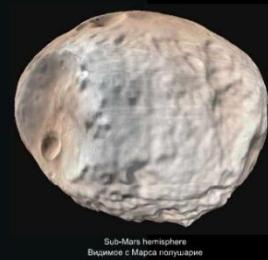
Cartographic heritage and traditions



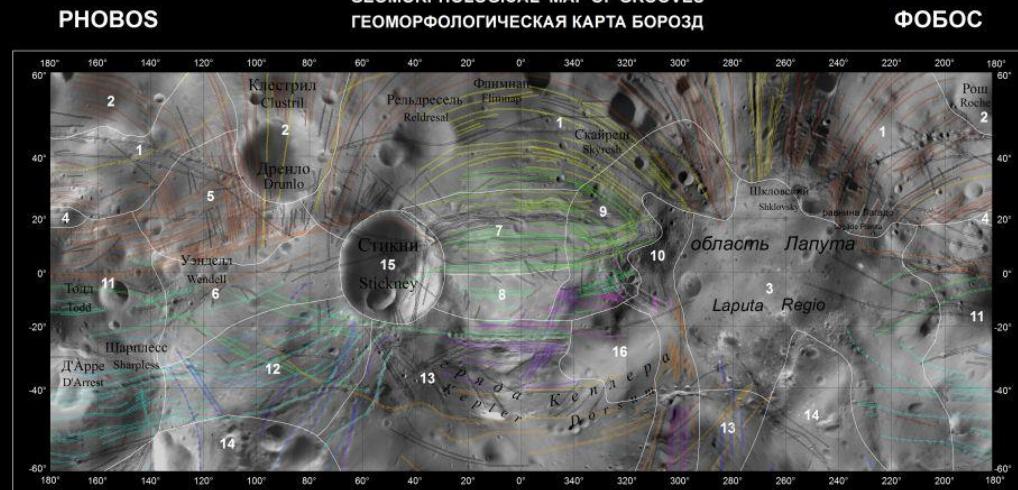
Phobos in Atlas of terrestrial planets, 1992



Phobos three-dimensional models
Трёхмерные модели Фобоса

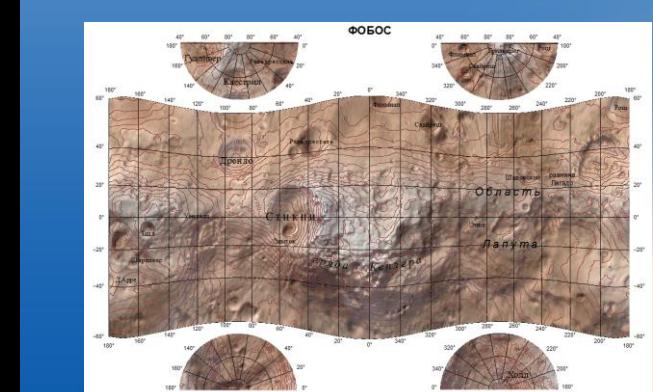


GEOMORPHOLOGICAL MAP OF GROOVES
ГЕОМОРФОЛОГИЧЕСКАЯ КАРТА БОРОЗД



Предыдущие издания:
1. Публикация в Справочнике астрономии планет, что это и как составляется Гидиография планет из планетарных изображений. Астрономическая обсерватория АН СССР, 1970 г.
2. Публикация в Альбоме изображений планет из космоса. Ученые записки АН СССР, 1971 г.
3. Публикация в Альбоме изображений планет из космоса. Ученые записки АН СССР, 1972 г.
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16. Публикация в Альбоме изображений планет из космоса. Ученые записки АН СССР, 1985 г.

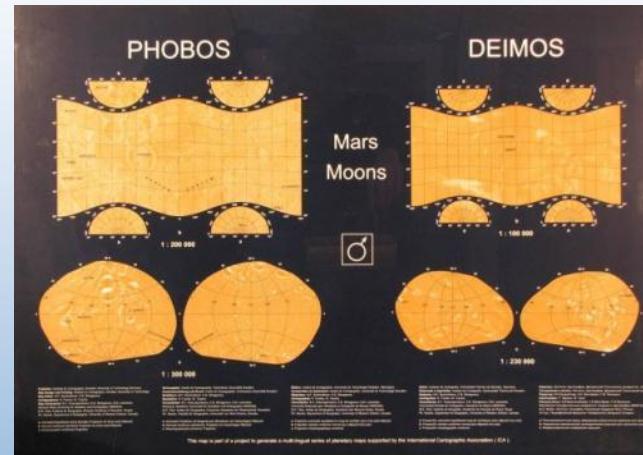
The Phobos map scale 1:100 000 was created at Moscow State University of Geodesy and Cartography (MVGAK). Extraterrestrial images of Phobos were obtained by the Soviet Mars Express (MEx) lander. The map is based on a digital elevation model (DEM) obtained at MExLab. 3D coordinates were determined using the reference control point network (RCPNEx) of the Phobos-2 mission. The map is based on the following data: DEM (1:100 000 scale), topographic maps (1:100 000 scale), geological maps (1:100 000 scale), and geological models (1:100 000 scale); images from the Phobos-2 mission (1988–1990), images from the Phobos-1 mission (1989–1990), and images from the Mars Global Surveyor (MGS) mission (1997–2001). The equatorial area of Phobos is shown in normal polar stereographic projection. The polar areas are shown in azimuthal equidistant along meridian projection for three-axis ellipsoid. The original layout of the map was developed by V. A. Kabanov and V. V. Kabanova. The map was prepared by V. A. Kabanov and V. V. Kabanova. Cartographer: Kabanov V. A., Kabanova V. V. Consultant: Pina M. E. Reviewer: Kabanov V. A., Kabanova V. V. © Moscow State University of Geodesy and Cartography (MVGAK), 2014. Published with support of Russian Science Foundation (RSF), project NSh-144.2014.017. The Phobos map scale 1:100 000 was created at Moscow State University of Geodesy and Cartography (MVGAK). Extraterrestrial images of Phobos were obtained by the Soviet Mars Express (MEx) lander. The map is based on a digital elevation model (DEM) obtained at MExLab. 3D coordinates were determined using the reference control point network (RCPNEx) of the Phobos-2 mission. The map is based on the following data: DEM (1:100 000 scale), topographic maps (1:100 000 scale), geological maps (1:100 000 scale), and geological models (1:100 000 scale); images from the Phobos-2 mission (1988–1990), images from the Phobos-1 mission (1989–1990), and images from the Mars Global Surveyor (MGS) mission (1997–2001). The equatorial area of Phobos is shown in normal polar stereographic projection. The polar areas are shown in azimuthal equidistant along meridian projection for three-axis ellipsoid. The original layout of the map was developed by V. A. Kabanov and V. V. Kabanova. The map was prepared by V. A. Kabanov and V. V. Kabanova. Cartographer: Kabanov V. A., Kabanova V. V. Consultant: Pina M. E. Reviewer: Kabanov V. A., Kabanova V. V. © Moscow State University of Geodesy and Cartography (MVGAK), 2014. Published with support of Russian Science Foundation (RSF), project NSh-144.2014.017.



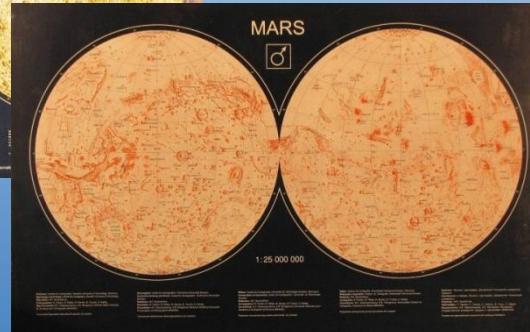
Cartographic heritage and traditions



Multilingual map series of terrestrial planets, 2005
(under support of ICA)

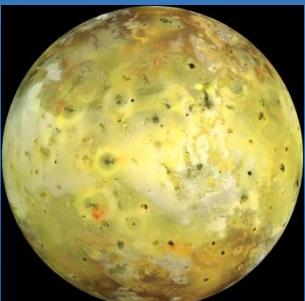


<http://planetologia.elte.hu/ipcd/>



Further work:

Multilingual map series of outer planets satellites: Jupiter Galilean moons (Io, Europa, Ganymede and Callisto) and Saturnian moon – Enceladus



Planetary Geoportal: Geodesy and Cartography Node



<http://cartsrv.mexlab.ru/geoportal/#body/>

The screenshot displays the Planetary Geortal interface for the Mercury dataset. The main view shows a polar stereographic projection of the Mercury surface, with a color scale representing roughness values. A legend on the left lists various roughness maps, and a table view at the bottom provides detailed information about the selected product. The interface also includes a search bar, a language selection dropdown, and a sidebar with file preview and download options.

The screenshot shows the MExLab Geoportal software. On the left, there's a 'Products/Layers' panel with a tree view of datasets like 'photos.Albedo_mosaic', 'photos.Basis_Cthoromatic', etc. A 'Photos' layer is selected. In the center, a 'Map View' window displays a 3D perspective of a cratered surface with numerous purple and green translucent spheres representing different geological features or data points. Below the map, status bars show 'Longitude: 202.404373°' and 'Latitude: 79.46484573°'. To the right, a 'File Browser' window shows files like 'mexn-roughness - Prairiefile id.tif' and 'SLD100_01.tif'. At the top, a navigation bar includes links for Yandex, Python, ТВС, Кошки, Книги, WoW!, GameZZZZ, Полезности, Развлечения, Авто, Медиа, Получки, Ноты, Сервисы Ведомка, Внезапные зал., Заплакан Опера, and NAS_Home. The title bar reads 'Planetary Geoportal MIIGAIK Extraterrestrial Laboratory (MExLab) Moscow State University of Geodesy and Cartography (MGU)'.

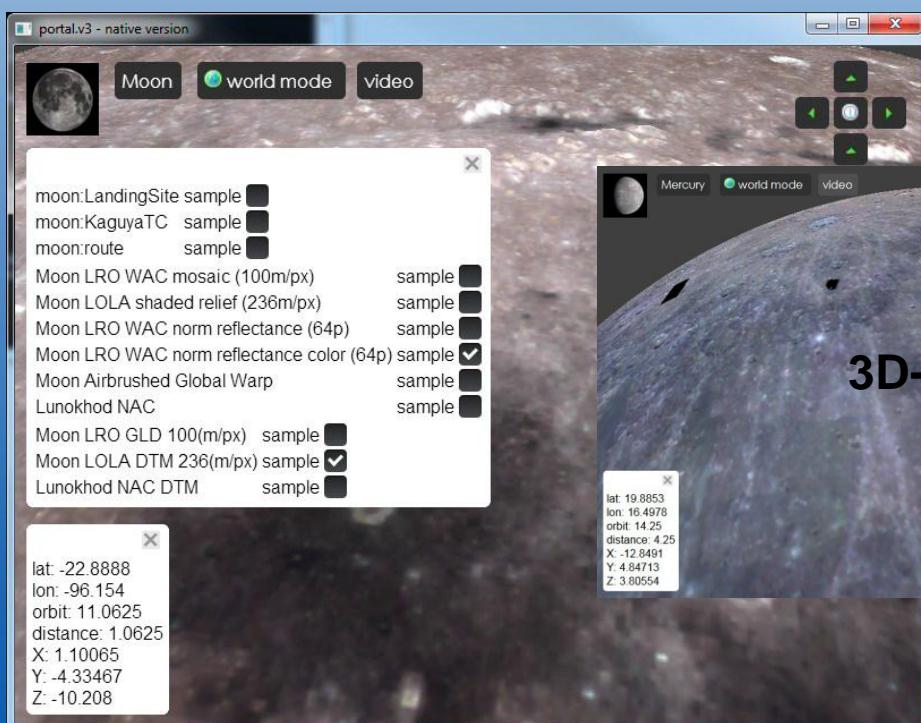
The screenshot shows a complex software interface for planetary data analysis. In the center is a 3D rendering of the Moon's surface with a prominent blue line representing a selected route or path. To the left, a legend lists various data types such as 'Chaos' (red), 'Bassaine' (orange), 'moon_imageFragment' (yellow), 'moon_imageFragmentGeoRef' (light yellow), 'moon_imageDTM' (green), 'moon_imageTIC' (light green), 'moon_LandingSite' (blue), 'moon_LRO_M2C' (cyan), 'moon_LRO_M2C_DEM' (light cyan), 'moon_PanoramaCentral' (purple), 'moon_PanoramaCentralDEM' (light purple), and 'moon_PanoramaCentralDtm' (pink). A checked box indicates 'moon_PanoramaPathProjected'. On the right, there are several small thumbnail images labeled '6-201.tif', '6-202.tif', '6-203.tif', '6-204.tif', and '6-205.tif'. At the bottom, a table provides detailed information about the selected product, including its name ('Lunar surface panoramic image'), description ('Digital terrain model of the Moon's surface implemented for new studies of lunar surface'), and technical details like resolution (2000 x 2000 pixels) and projection (mercator). A dropdown menu at the bottom right allows users to filter results.

Innovation: 3D-web GIS as online Laboratory

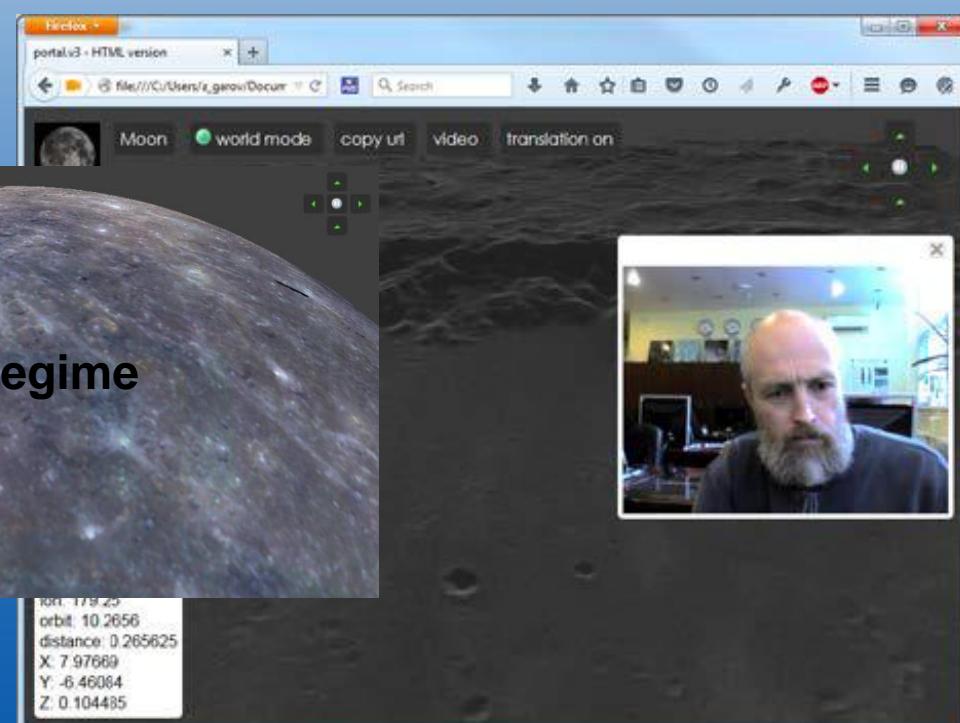
We are developing a new software architecture which provides:

- web-GIS tools for planetary surface study;
- modular approach with possibilities for system reconfiguration;
- cross-platform solutions: an application for the three types of platforms: desktop (Windows, Linux, OSX), web platform (any HTML5 browser), and mobile application (Android, iOS);
- Common spatial context with teleconference regime, including video/audio broadcasting, for geo-collaboration of scientific community.

Native-version



HTML-version



3D-regime

International Map Year

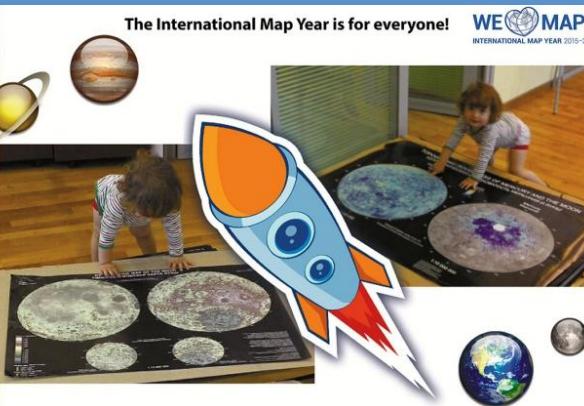
Planetary maps exhibitions:

- Berlin, WG IV/8-meeting “Planetary Mapping and Spatial Databases”, September, 2015.
- Moscow, “6th International Solar system symposium”, October, 2015.
- Zvezdny gorodok (Moscow region, ROSCOSMOS, Cosmonautic operation Center), “IV International conference Manned space flight”,

10-12, November, 2015.

Maps production:

- The Phobos Atlas, December, 2015.
- Wall geomorphologic map of Phobos, 2016.
- Set of outer planets maps, 2016-2017.
- Web-atlas of lunar relief, 2016-2017.



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