Moscow State University of Geodesy and Cartography (MIIGAiK)
MIIGAiK Extraterrestrial Laboratory (MExLab)

Modern methodology for planetary mapping

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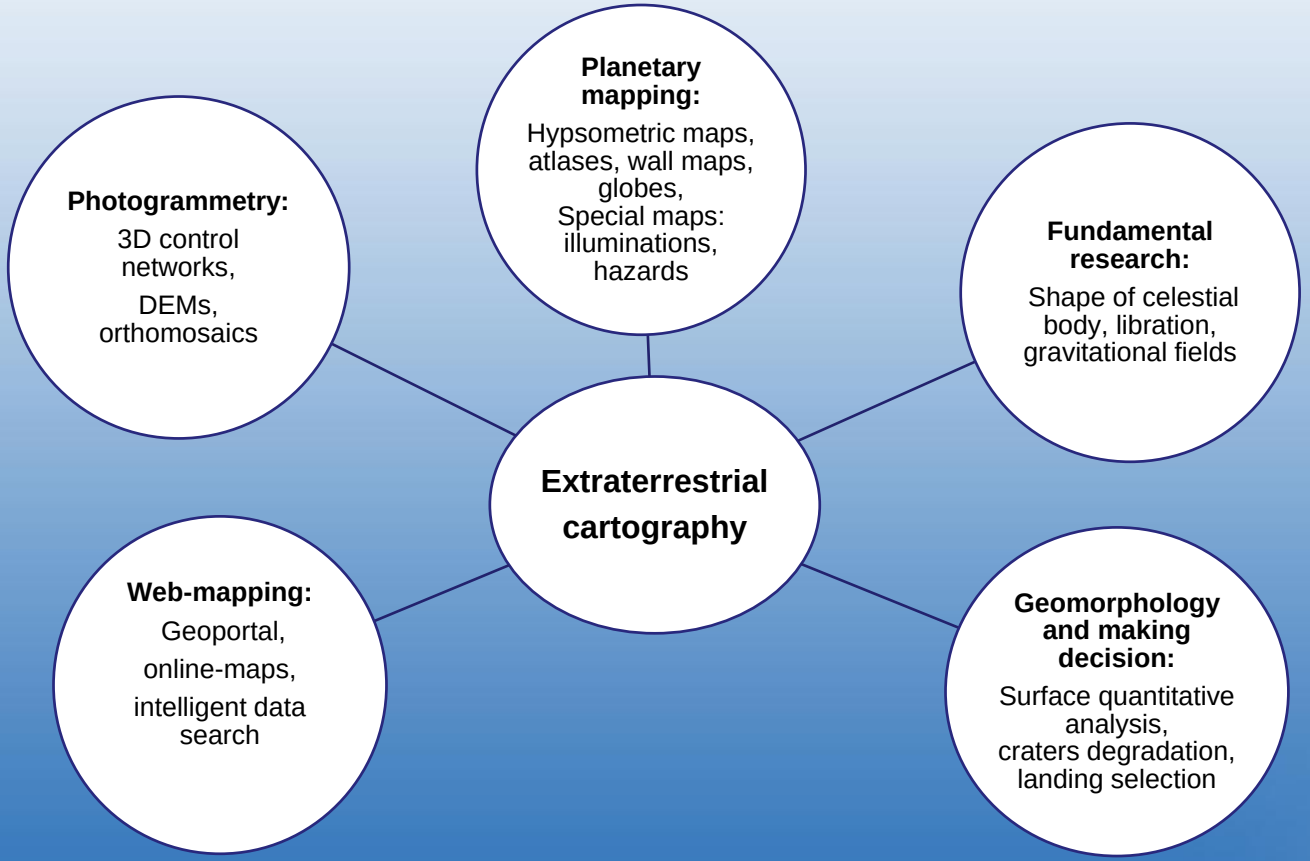
**1st ICA European Symposium on Cartography,
Vienna, 11, November**

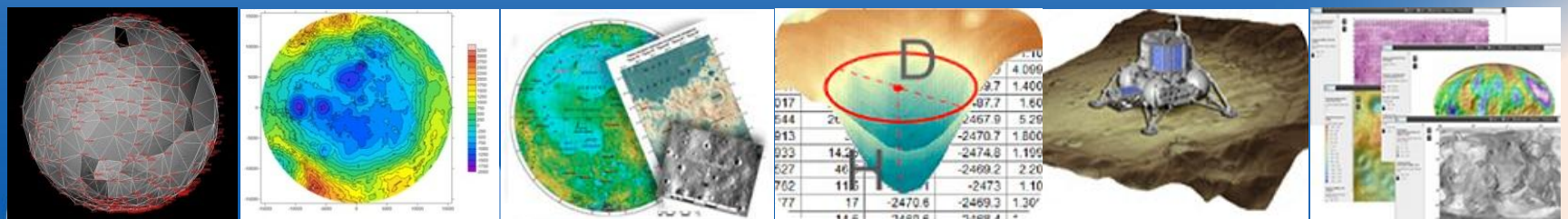
ICA European Symposium on CARTOGRAPHY
VIENNA, 10–12 NOVEMBER 2015
WE MAPS
INTERNATIONAL MAP YEAR 2015–2016

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

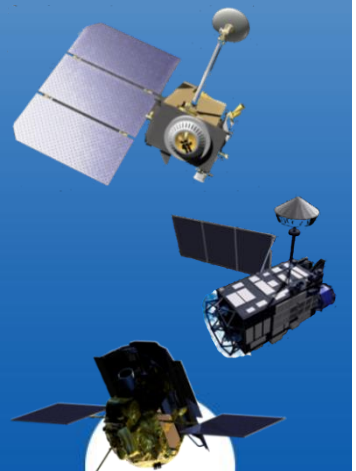


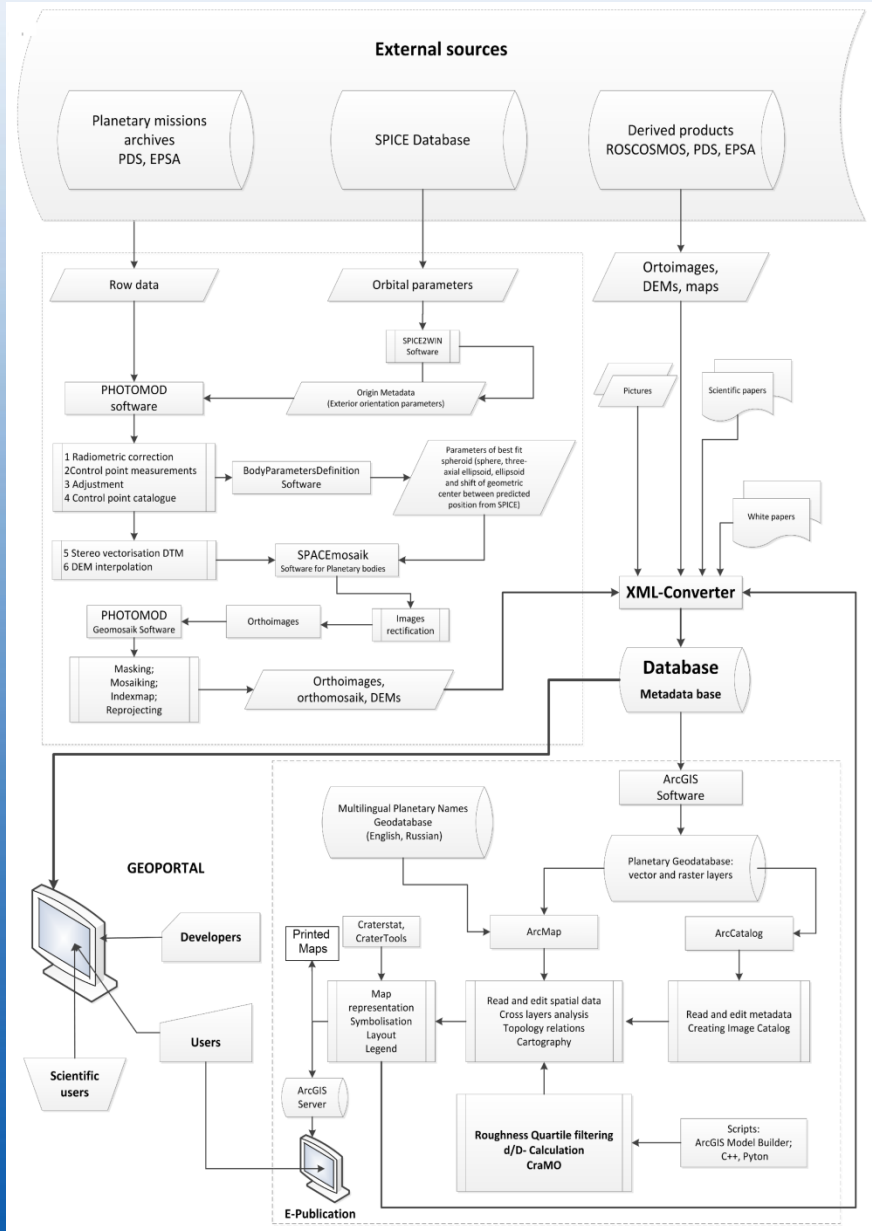


Flowchart of extraterrestrial cartography

- 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, Kallisto, Europa, Enceladus)..

Data sources and storage

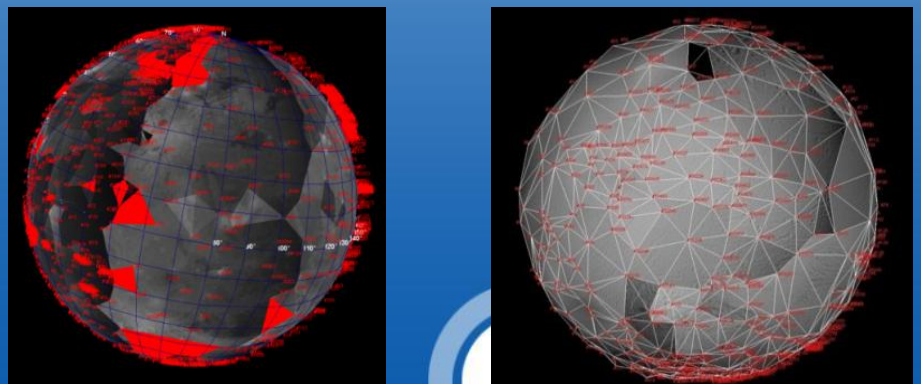


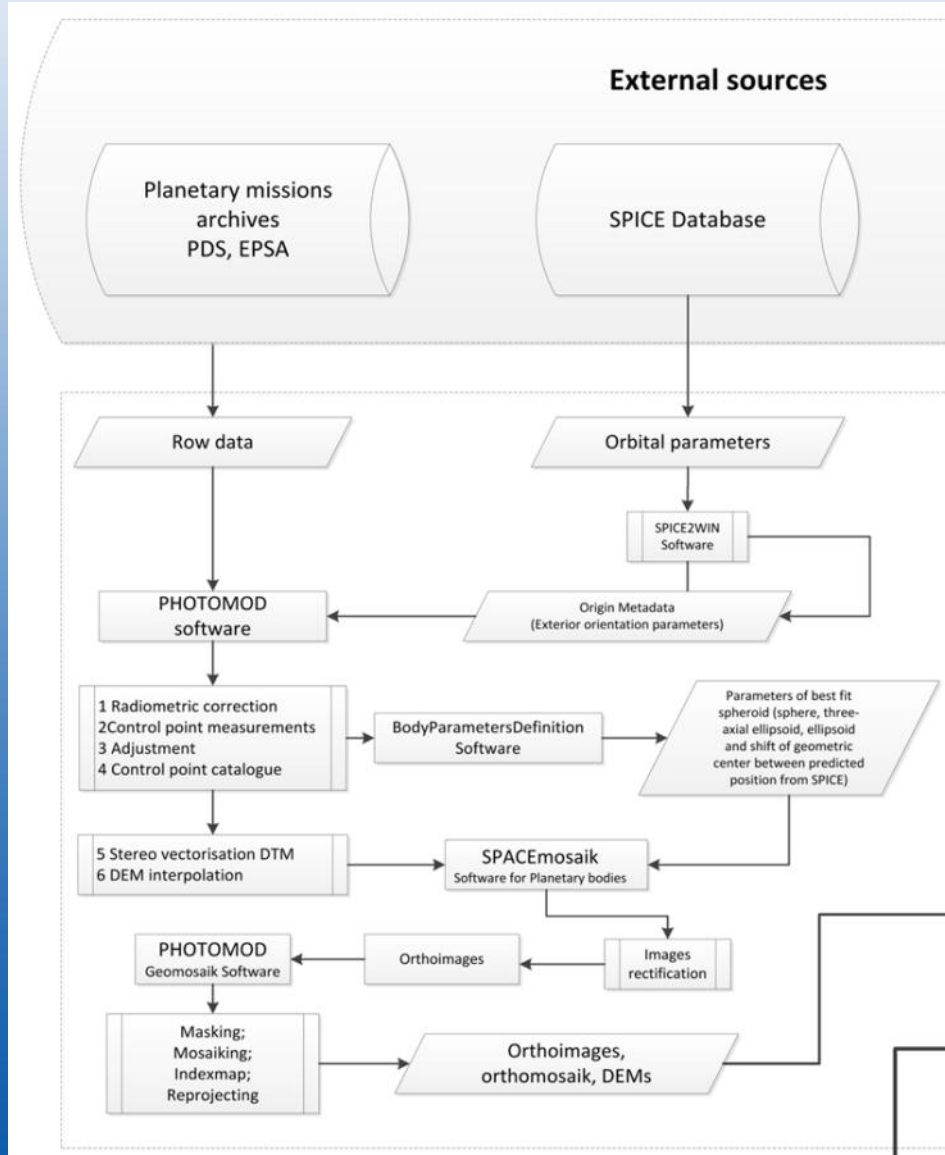


Planetary coordinate system

- 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)

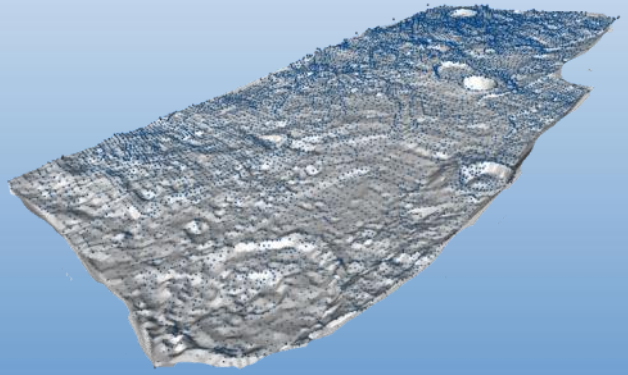




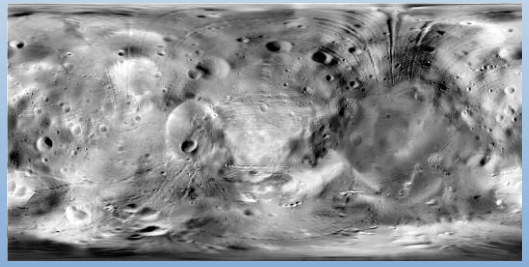
Results of photogrammetry image processing

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

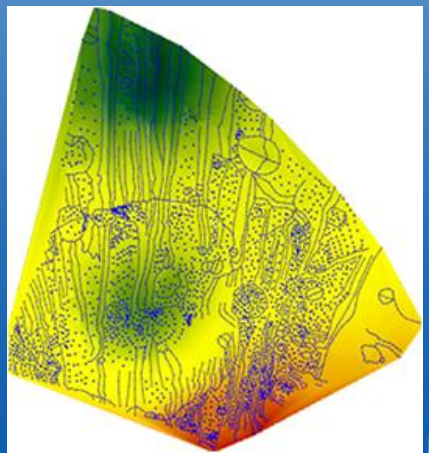
Producing local DEMs for Ganymede
(Voyager-2, resolution ~100 m)



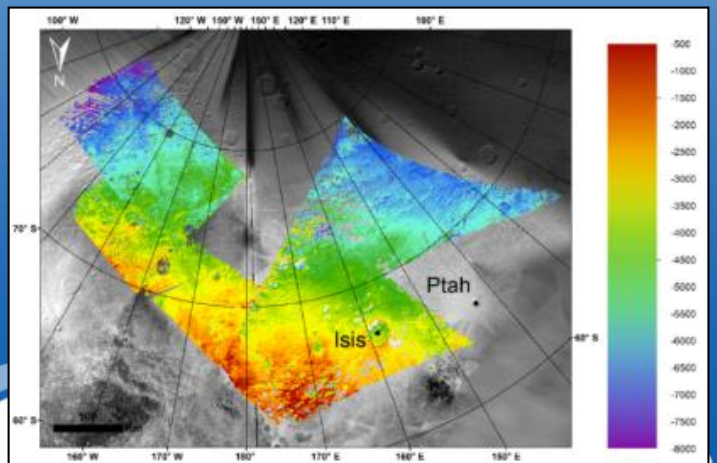
Orthomosaic of Phobos surface
(MIIGAiK, 2014),
resolution – 5 m/px

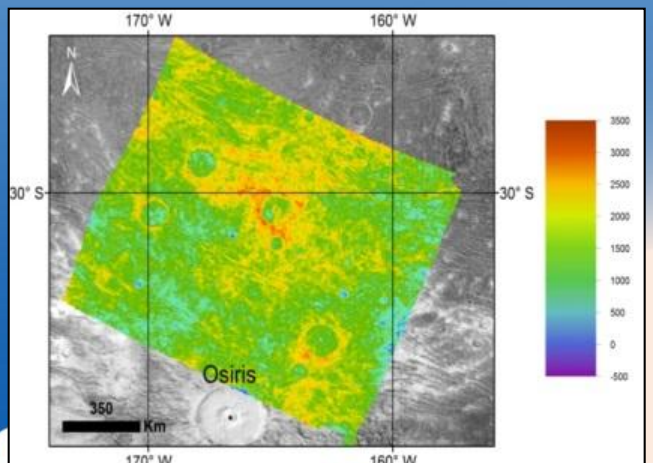


Detailed DEM
Phobos crater Drunlo
(resolution 10 m/px)



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

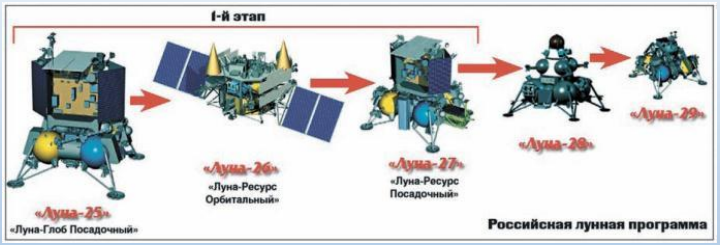


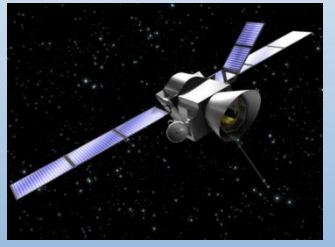


Cartographic support of future missions

Future space missions

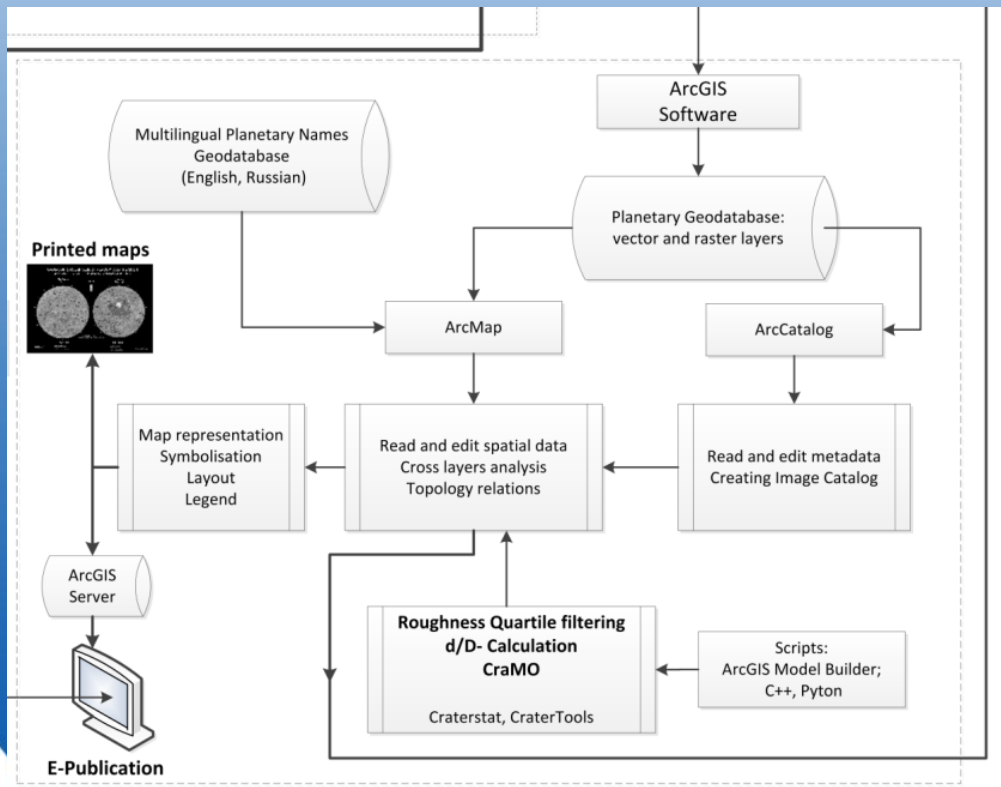
- Roscosmos: Landing on the Moon: Luna-25, 27.
- ESA: Flight to the Mercury: Bepi Colombo.
- ESA: JUICE mission (Jovian system, Ganymede).
- Roscosmos: Boomerang, sample return mission to Phobos.





For making decisions:

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



Surface analysis: crater measurements

Methods:

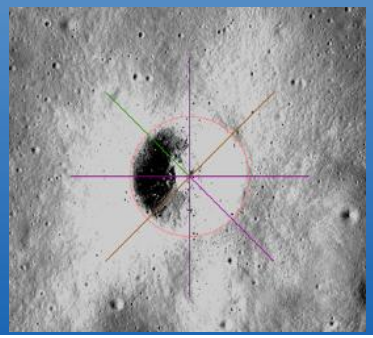
- Automatic measurements of crater arrays;
- Automatic profiles building.

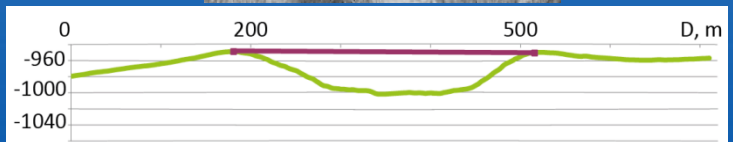
Results:

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

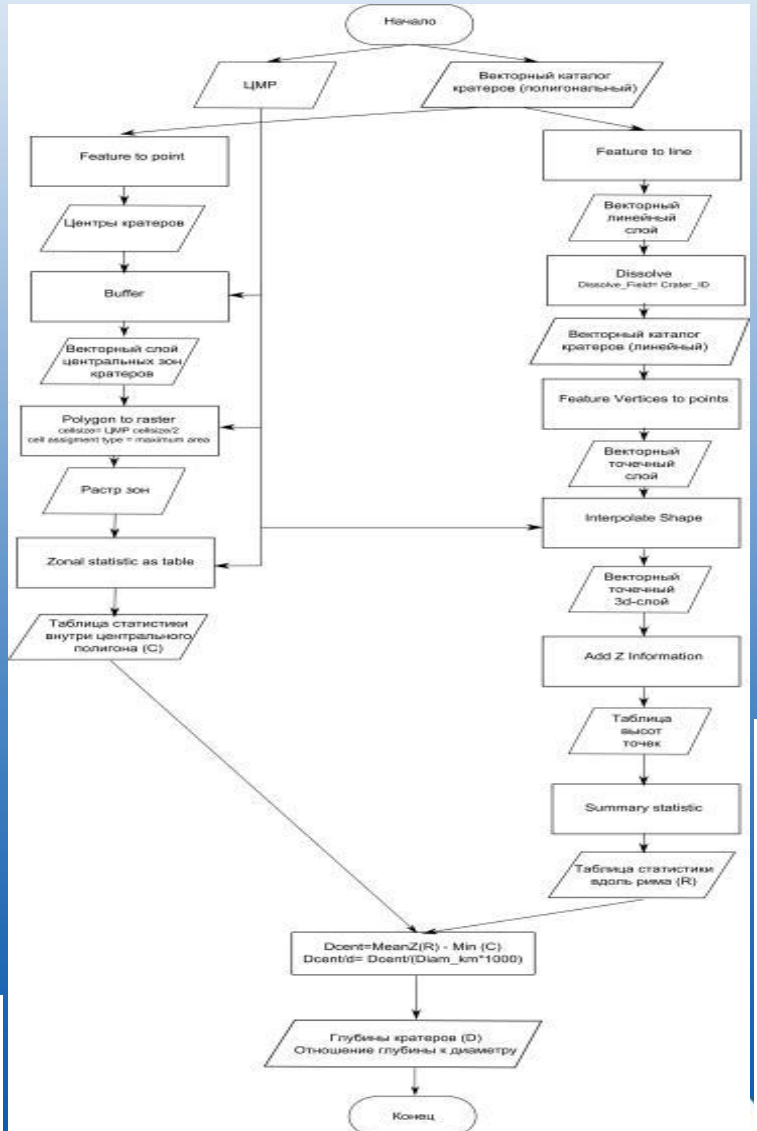
Fundamental study: evidence of water ice in Moon polar area

Automatic created rose of profiles for maximum slope estimation



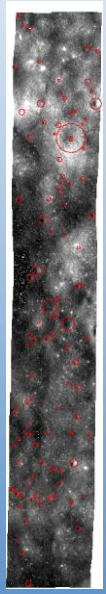


Algorithm of the relative depth calculation

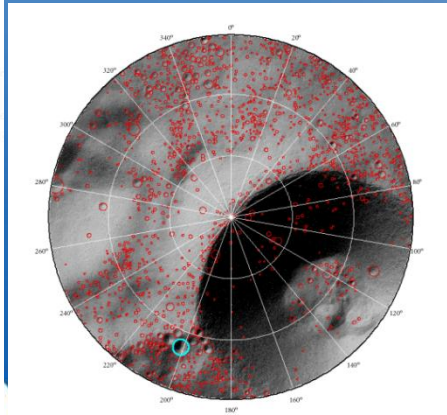


Crater catalogues of areas

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°;

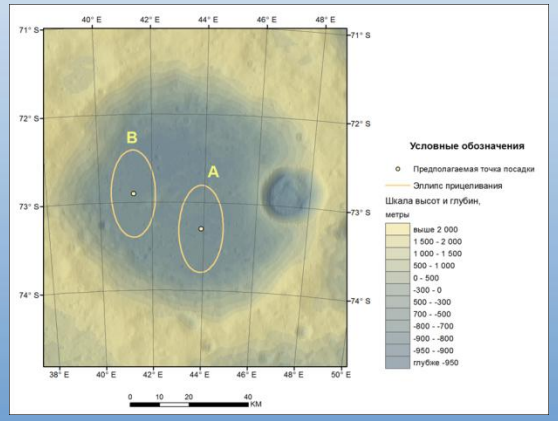
  -permanently shadowed areas;

  -invisibility from Earth;

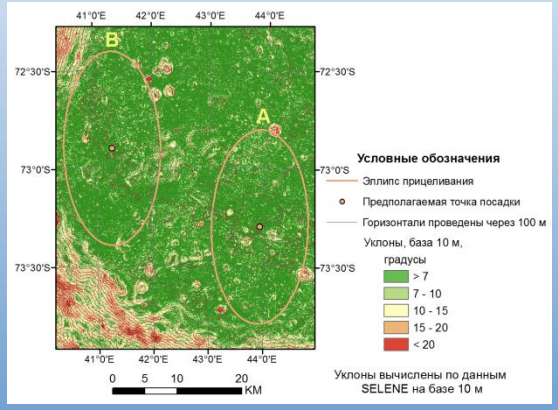
  -high roughness at small scales;

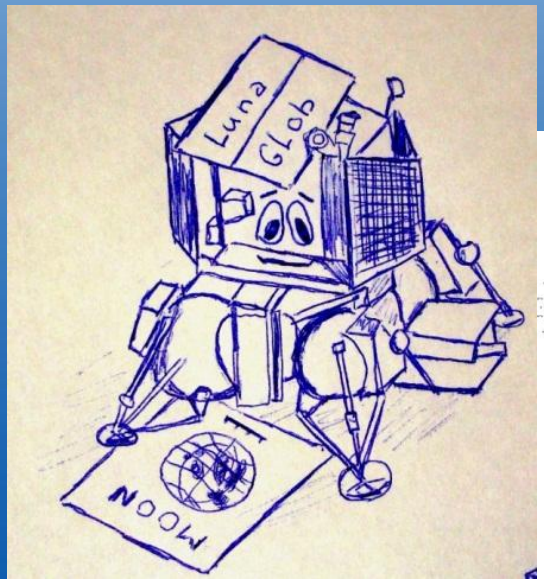
  -boulders;

Hypsometric map
(crater Boguslavsky)



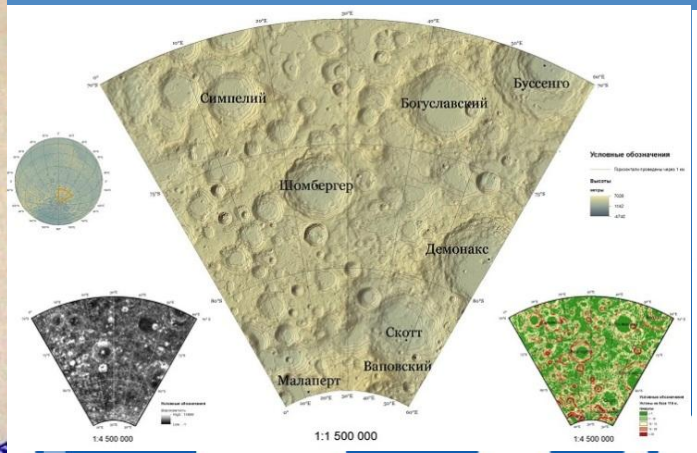
Map of slopes on base 10 m
(crater Boguslavsky)



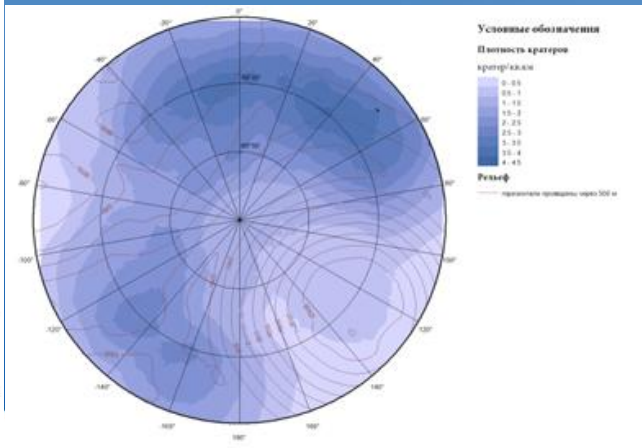


South polar area

Map of relief parameters



Map of craters density

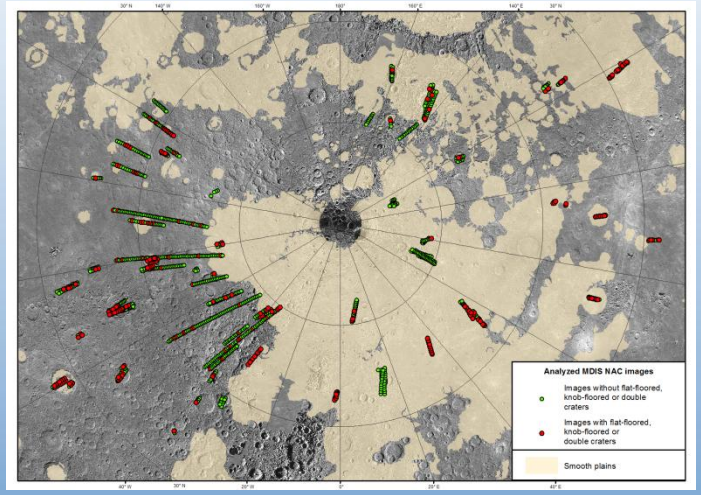


Mercury: study of surface

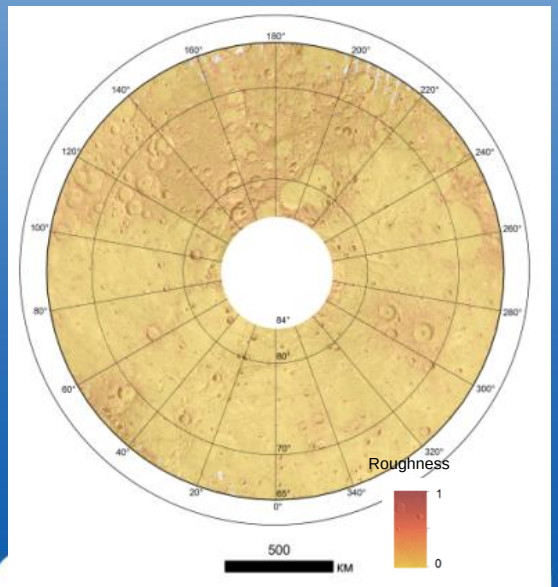
- Methods of roughness calculation: interquartile range of slopes, Laplacian, Hessian.
- Study of the flat-floored craters and hollows for regolith depth analysis.

- Planetology-comparative analysis of the terrestrial planets: Moon, Mercury

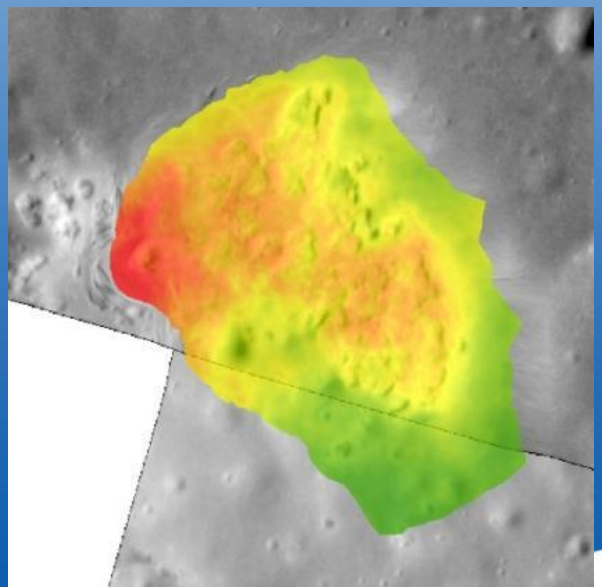
Distribution of the images with flat-floored craters in Northern subpolar area



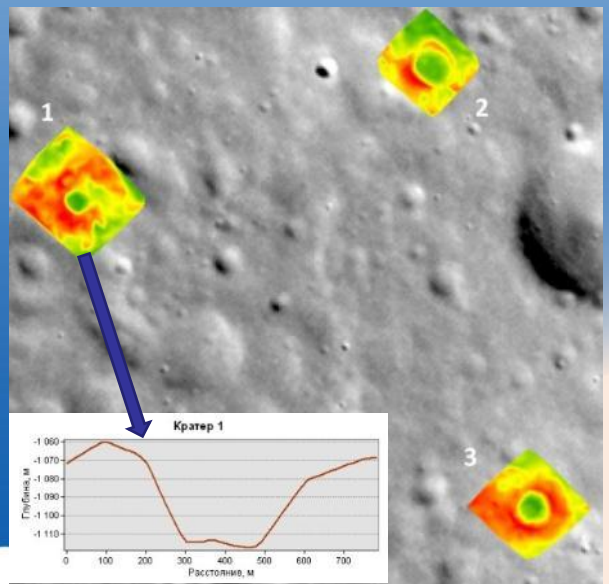
Roughness of the Northern Polar Area on base 2.8 km



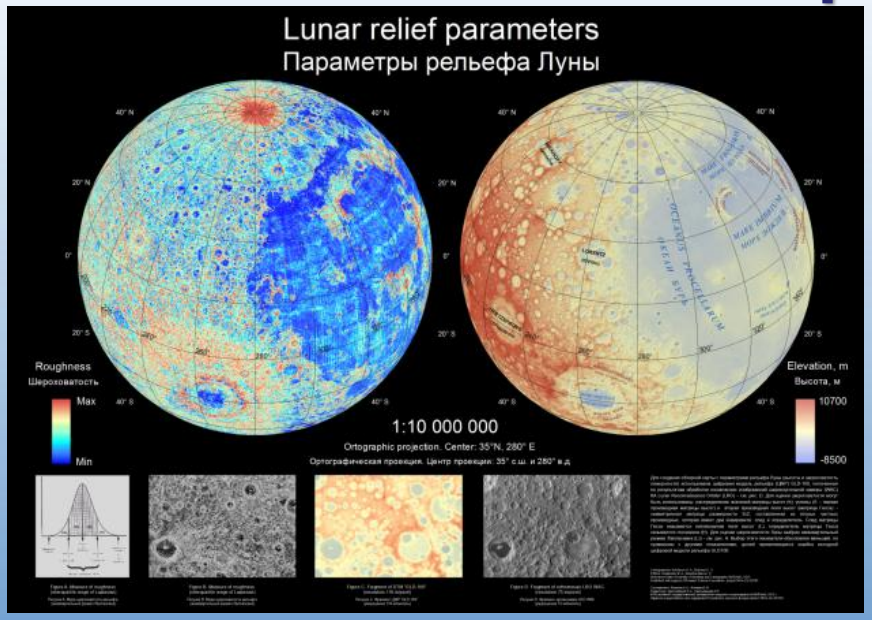
Local DTM for area with hollows

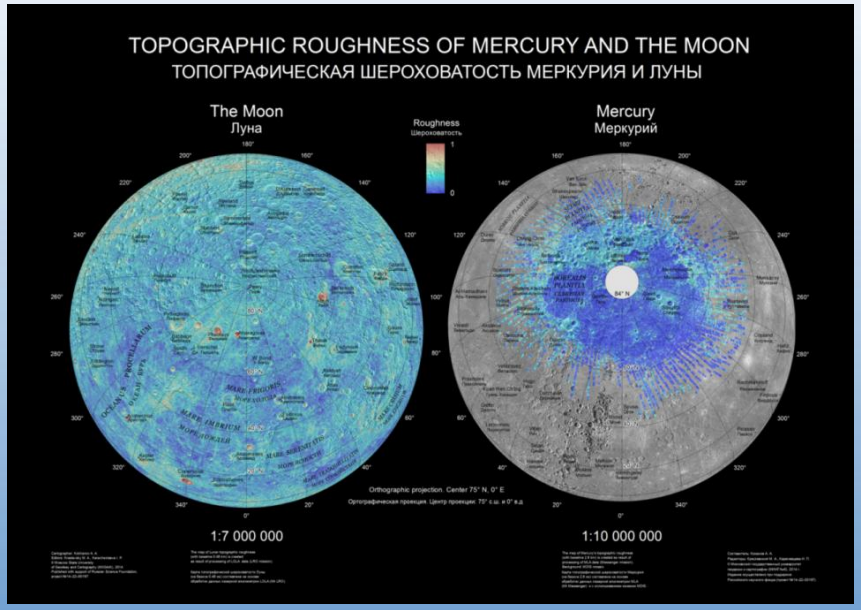


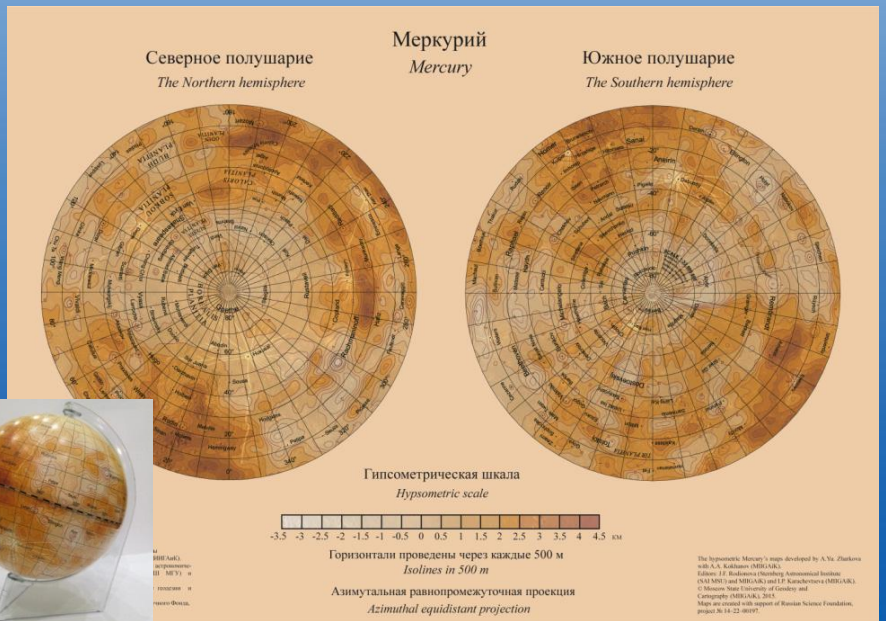
Local DTMs for flat-floored craters

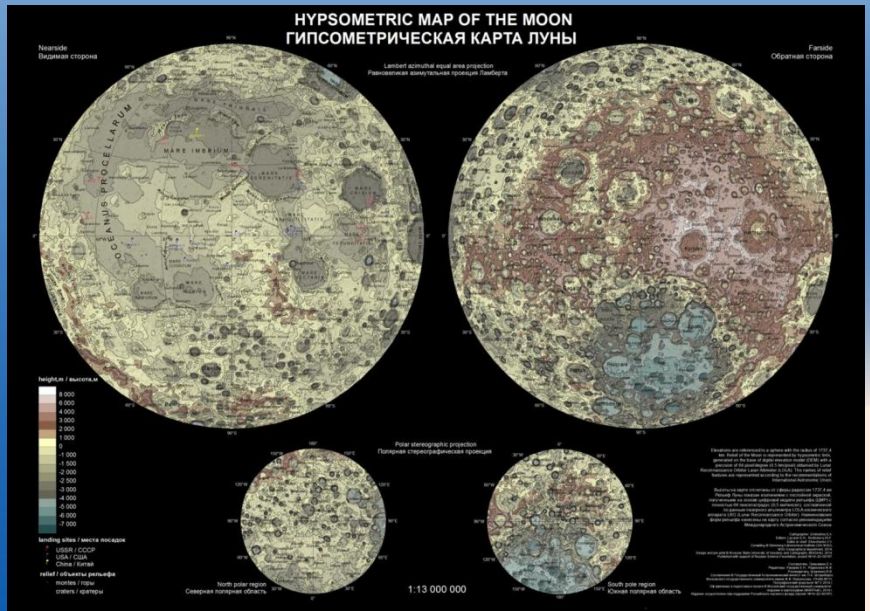


Planetology-comparative analysis: wall-maps and globe





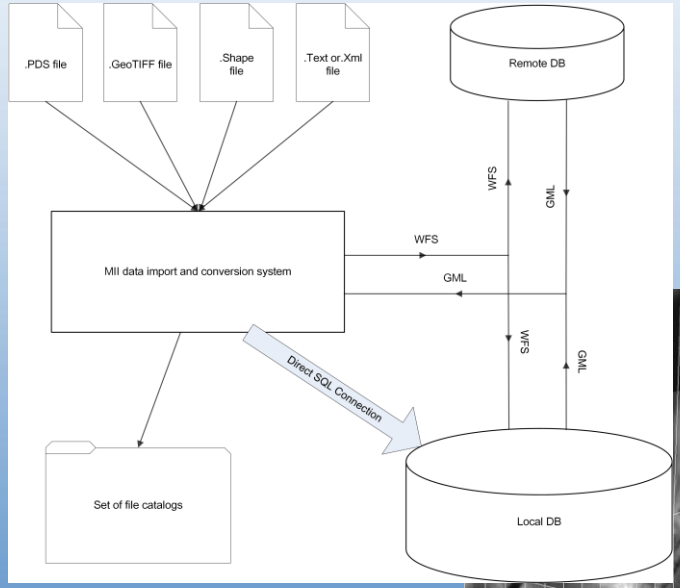


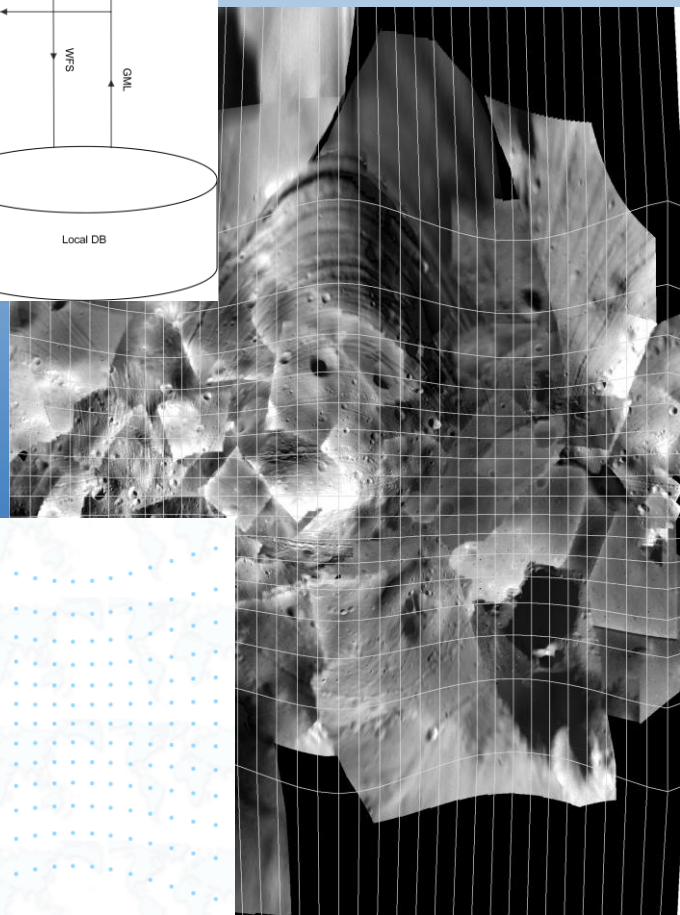


New software and tools

- **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.

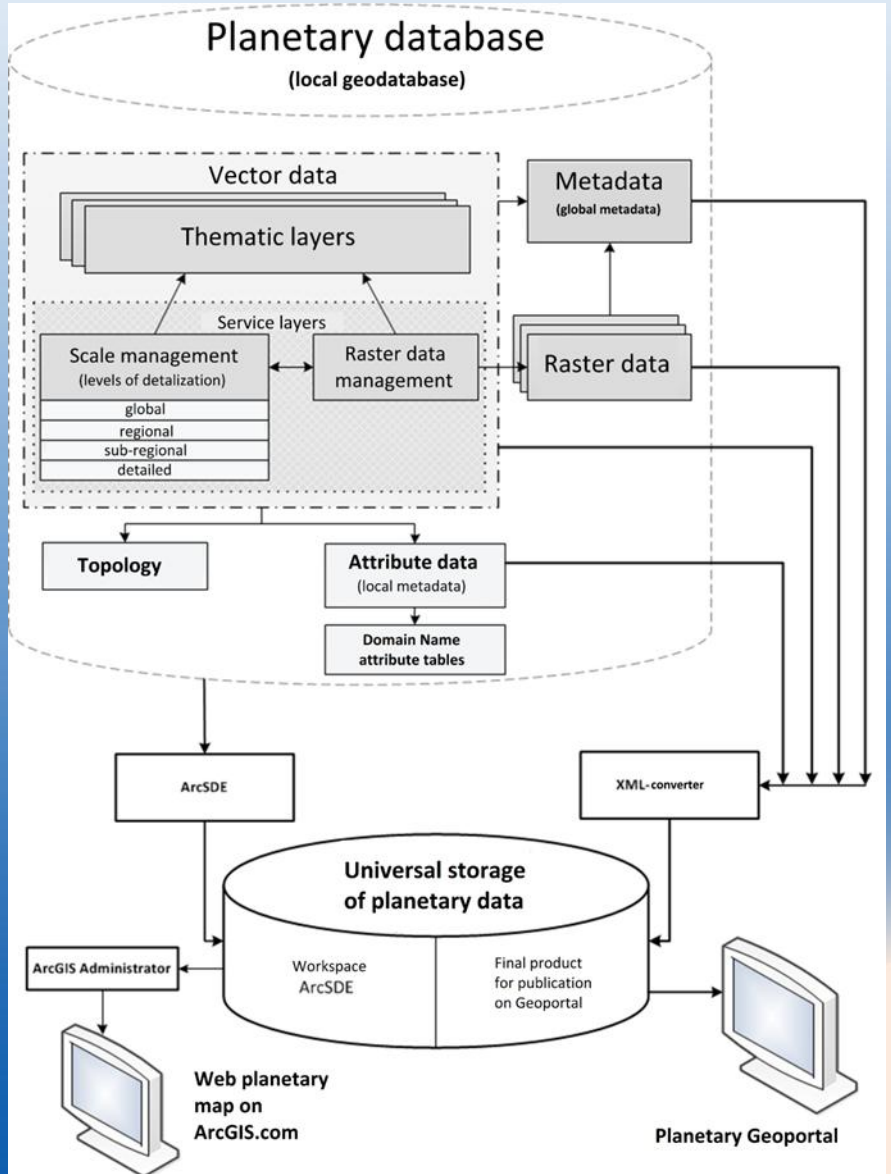
GIS-tools (Pyton, ModelBuilder):
- “CRAMO” for calculation of the crater depth relative to the surrounding surface;
- “Roughness Quartile” for calculation of the surface roughness;
- Automatic profile builder;
- Automatic projection calculation for 3-exial ellipsoid.





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;

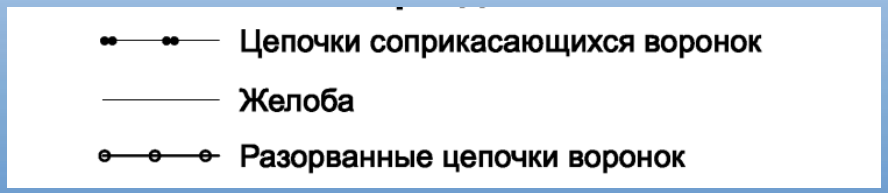


Extension of planetary data model

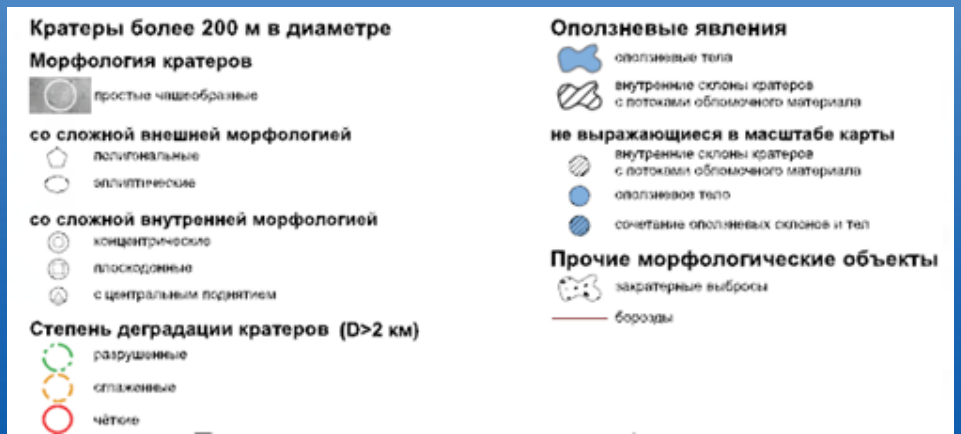
- Planetary data model (A. Naas & S. Van Gasselt): standardization and classification of planetary data.
- Extensions:

- Support of multi-scale representation of objects.
- Control of big data arrays.
- New planetary objects from geomorphological analysis.

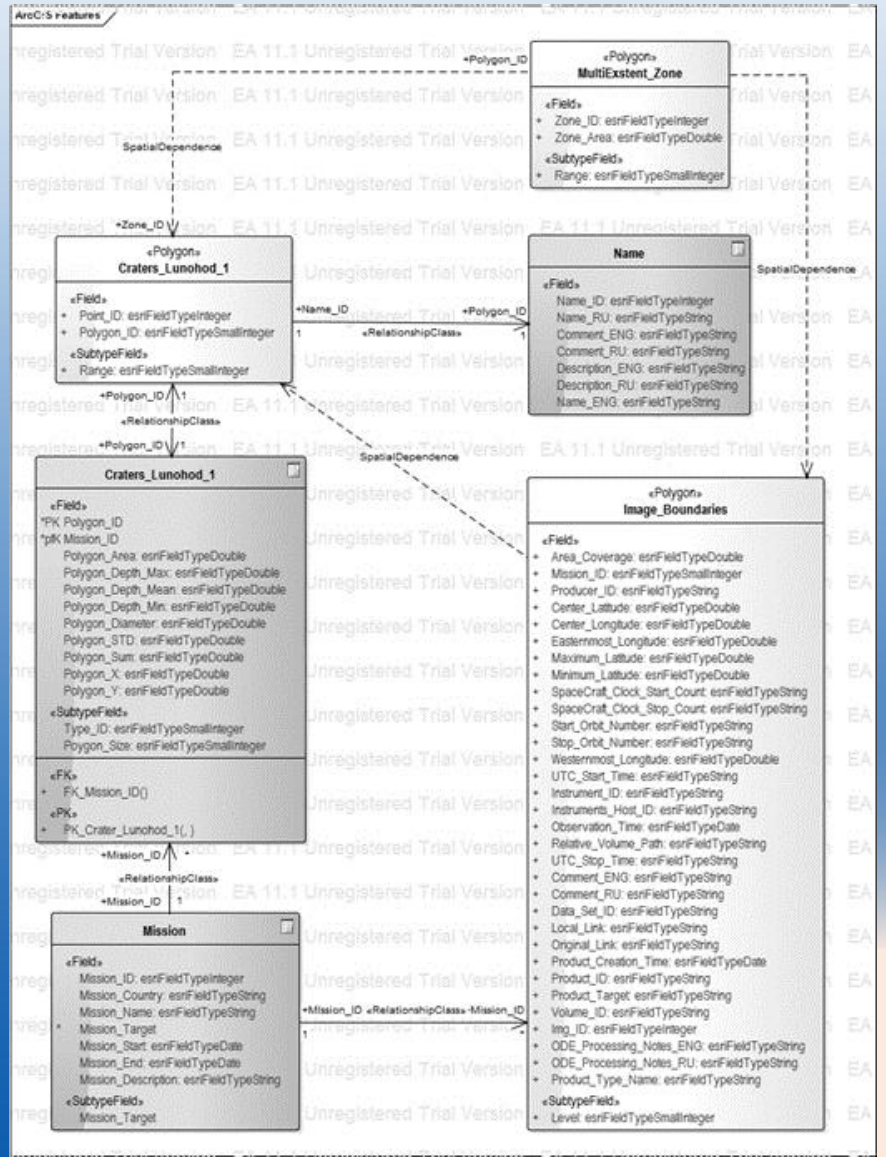
Classified types of grooves



Morphological classification of craters and slope processes



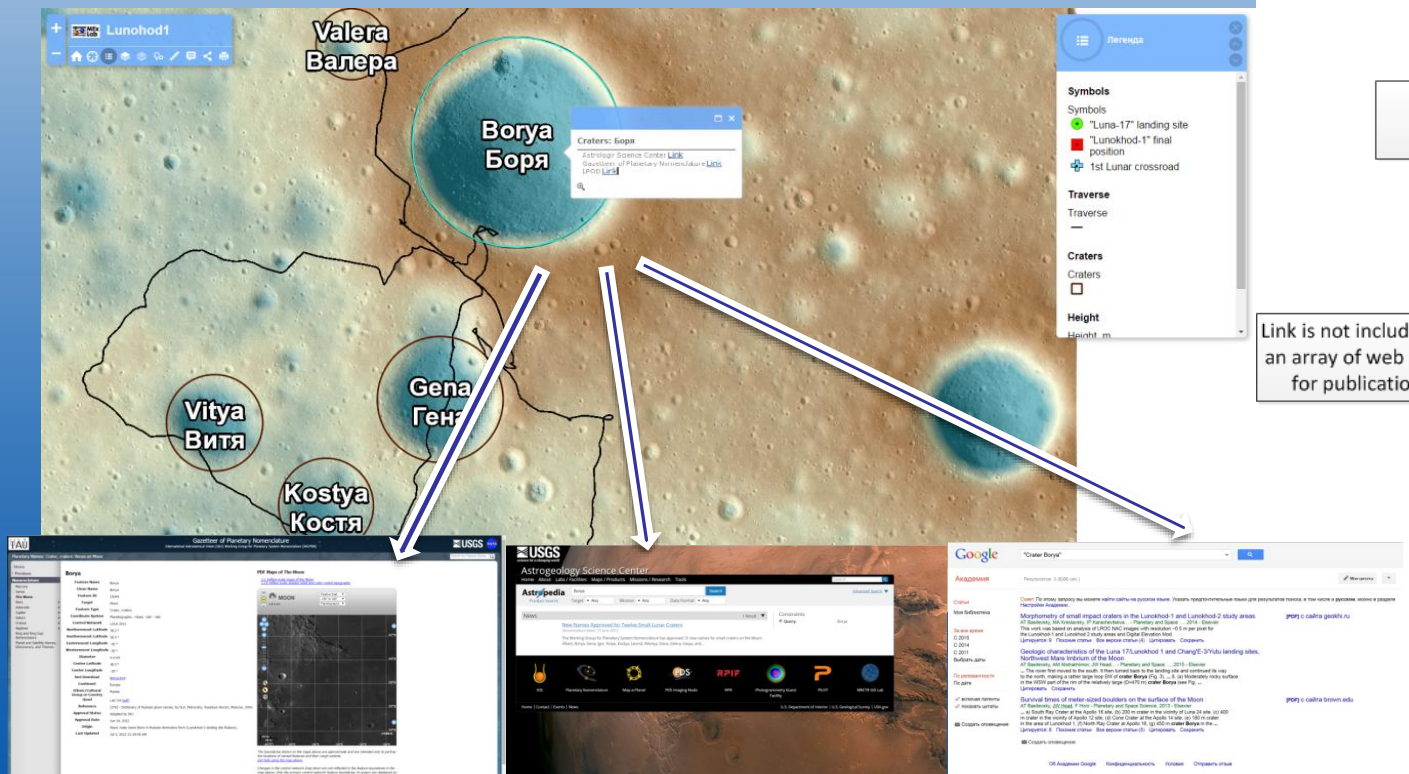
Lunar objects data model



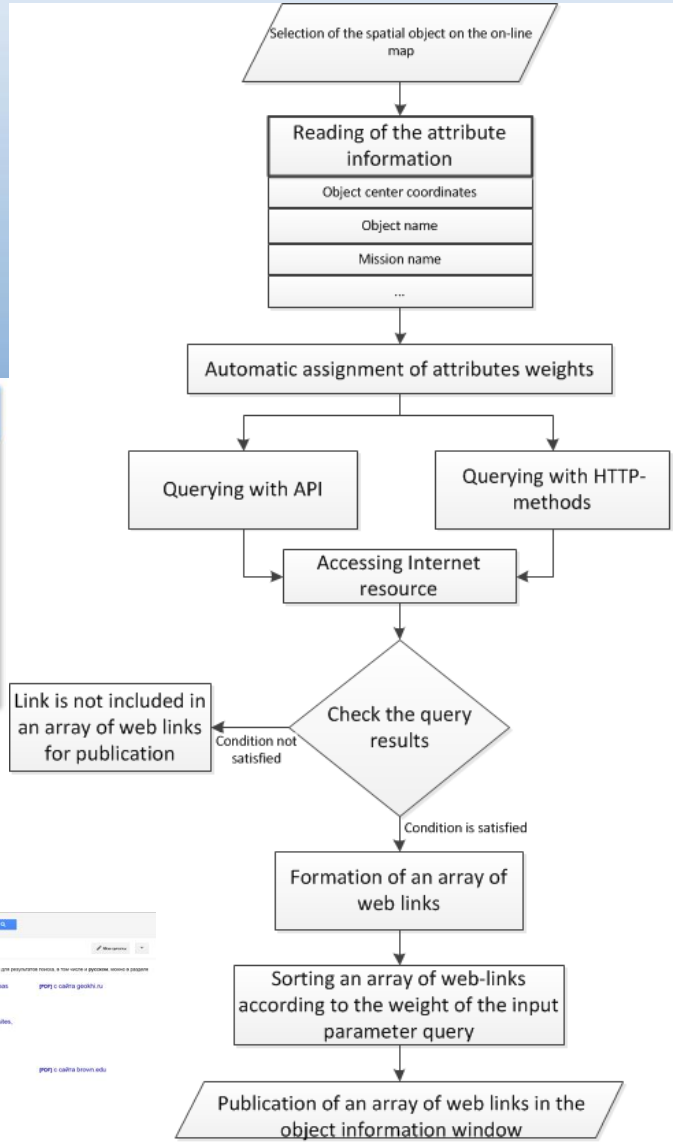
Intelligent search of planetary data

- 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.

ArcGIS online map



Algorithm of the intelligent search



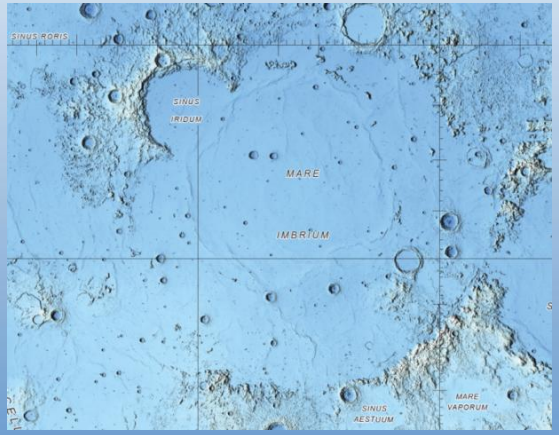
Design of planetary maps

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

Hypsometric map of the Moon (SAI&MIIGAiK)

Contours provides information about height

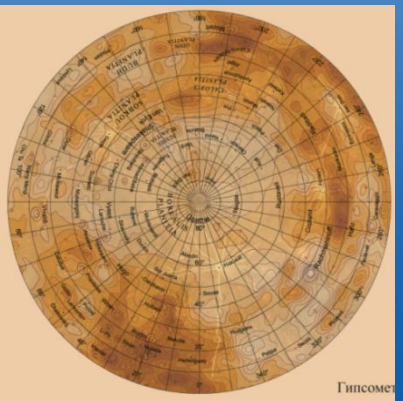
Topographic map of the Moon, USGS



MRO (NASA)

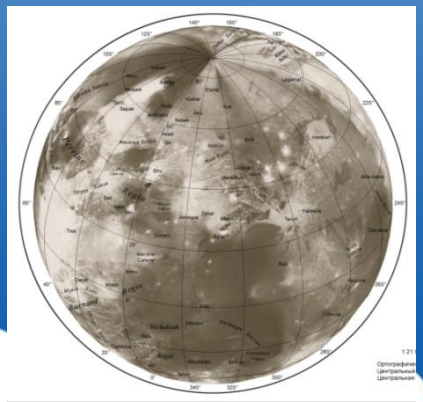
Mars Express (ESA)

Mercury

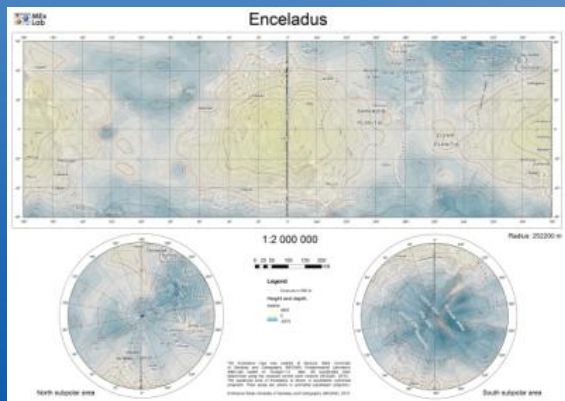


Phobos

Ganymede



Enceladus



New mapping: Phobos Atlas

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.

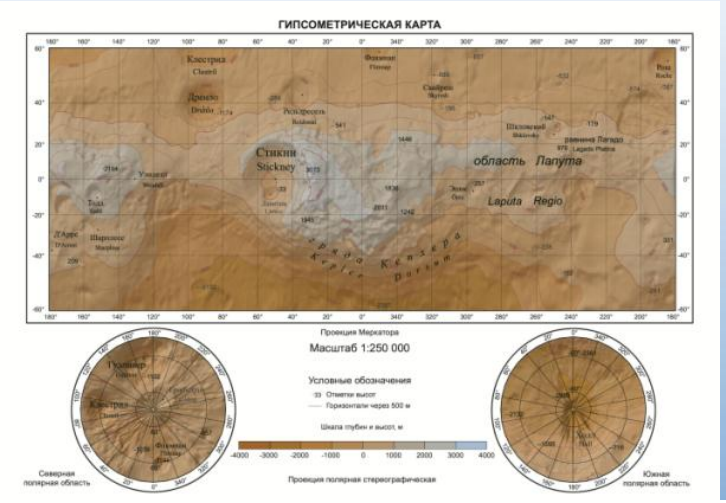
Middle-Scale maps:

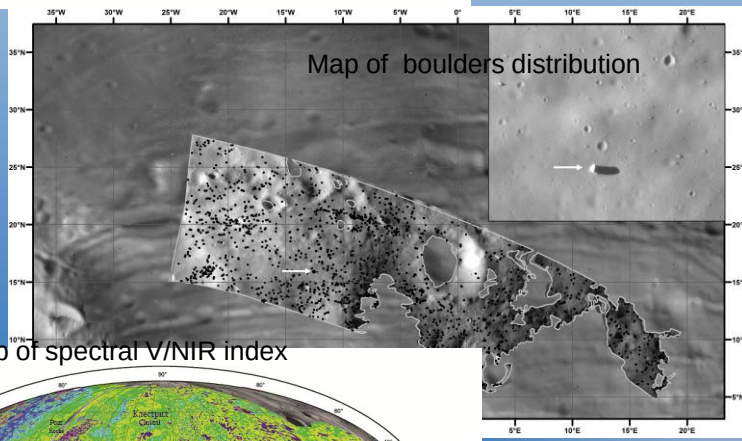
- Sheets of craters distribution map 1:150 000;
- Sheets of topographic map 1:75 000.

Large-Scale maps:

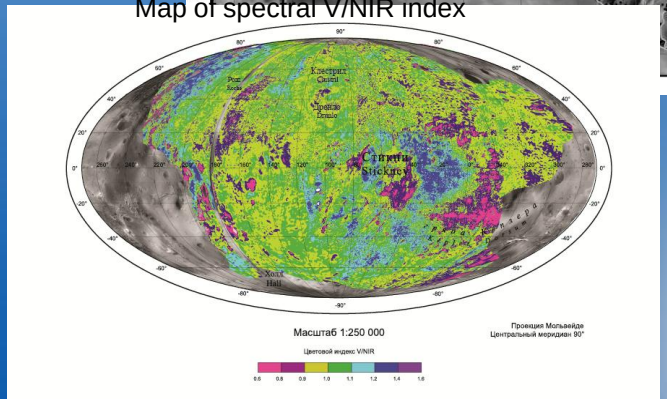
- Maps of craters relief 1:60 000;
- Maps of boulders distribution 1:30 000.

Hypsometric map of Phobos





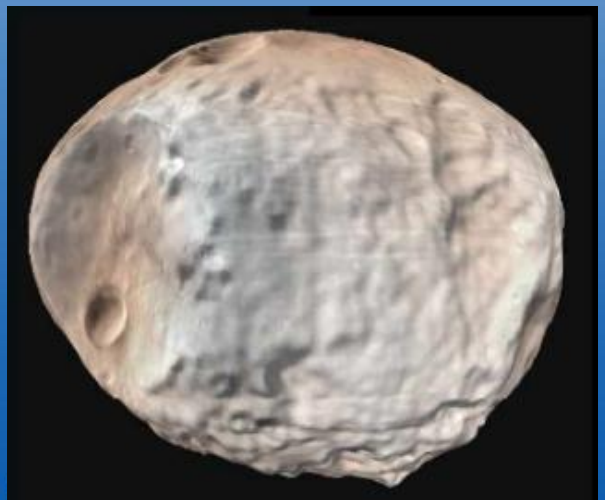
Map of spectral V/NIR index



Content of atlas

The Phobos atlas: results of study:

- Size and shape-model (Nadezhdina and Zubarev, 2014);
- Geology (Basilevsky et al., 2014);
- Roughness estimation (Karachevtseva et al., 2012);
- Morphometry studies (Koknanov et al., 2012);
- Multi-fractal approach (Uchaev Dm. et al., 2012);
- Surface compositional studies using HRSC data (Patsyn et al., 2012);
- Phobos information system (Karachevtseva et al., 2014).

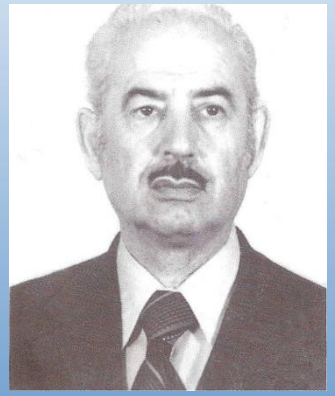


List of maps

Part	№	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

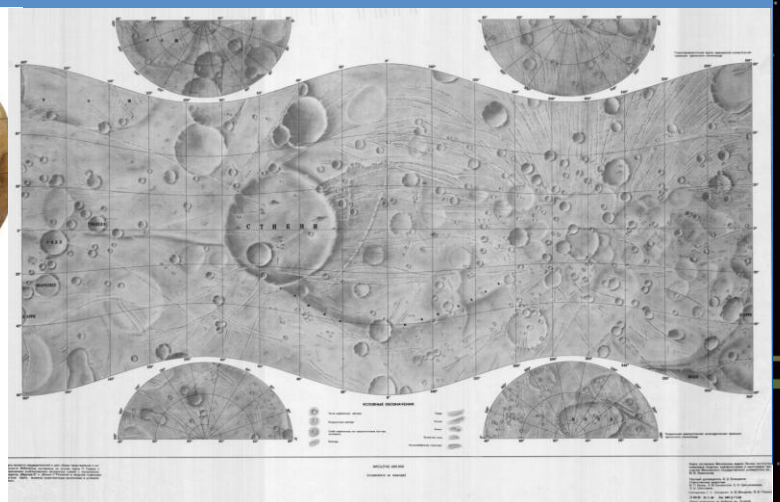
Cartographic heritage and traditions

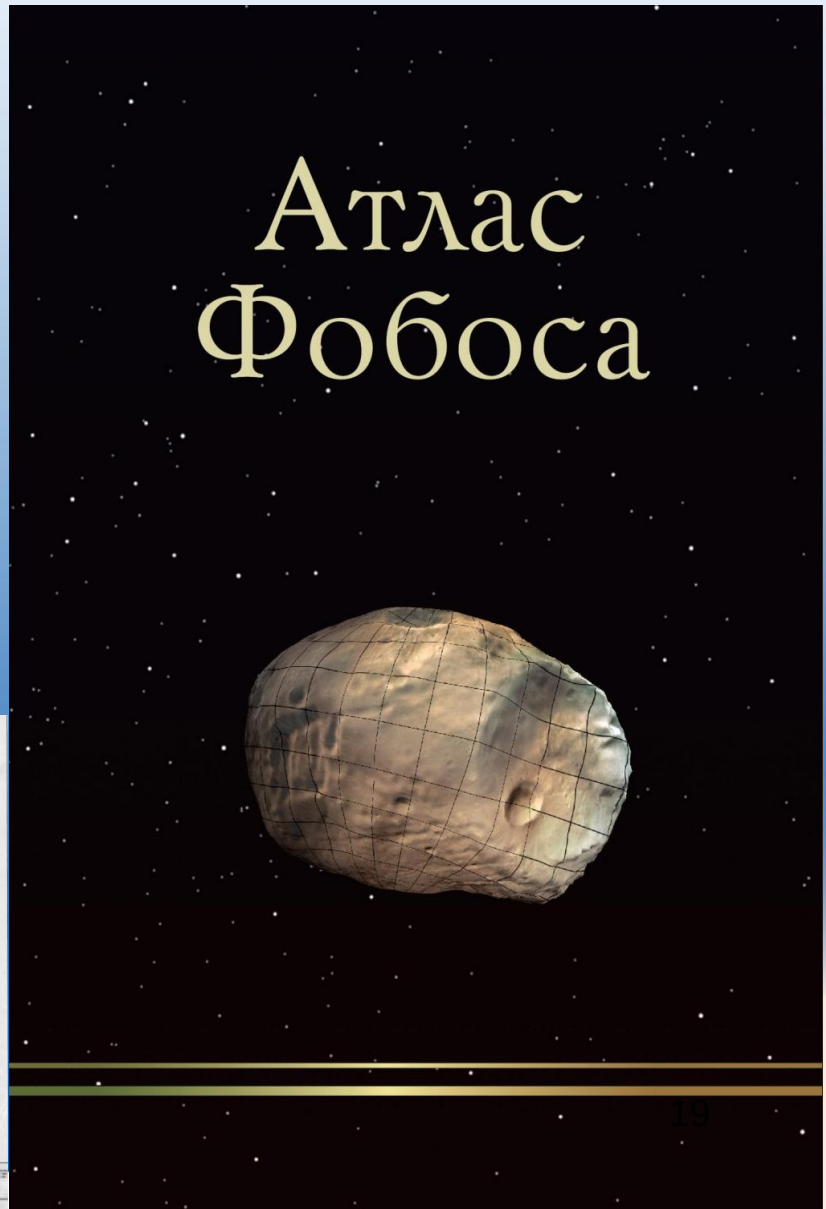
The Phobos atlas is dedicated to the memory of Russian cartographers:



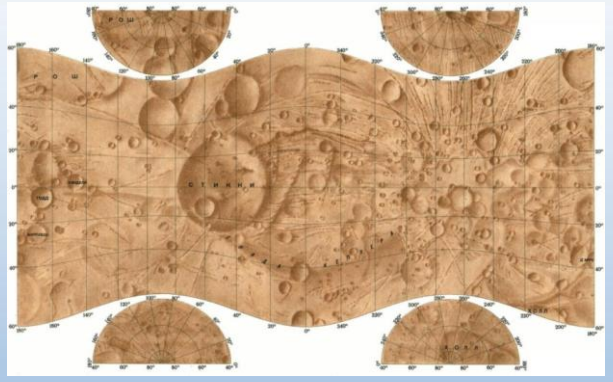
Lev Bugaevsky
(18.03.1921 – 04.08.2010)

Kira Shingareva
(09.01.1938 – 15.09.2013)

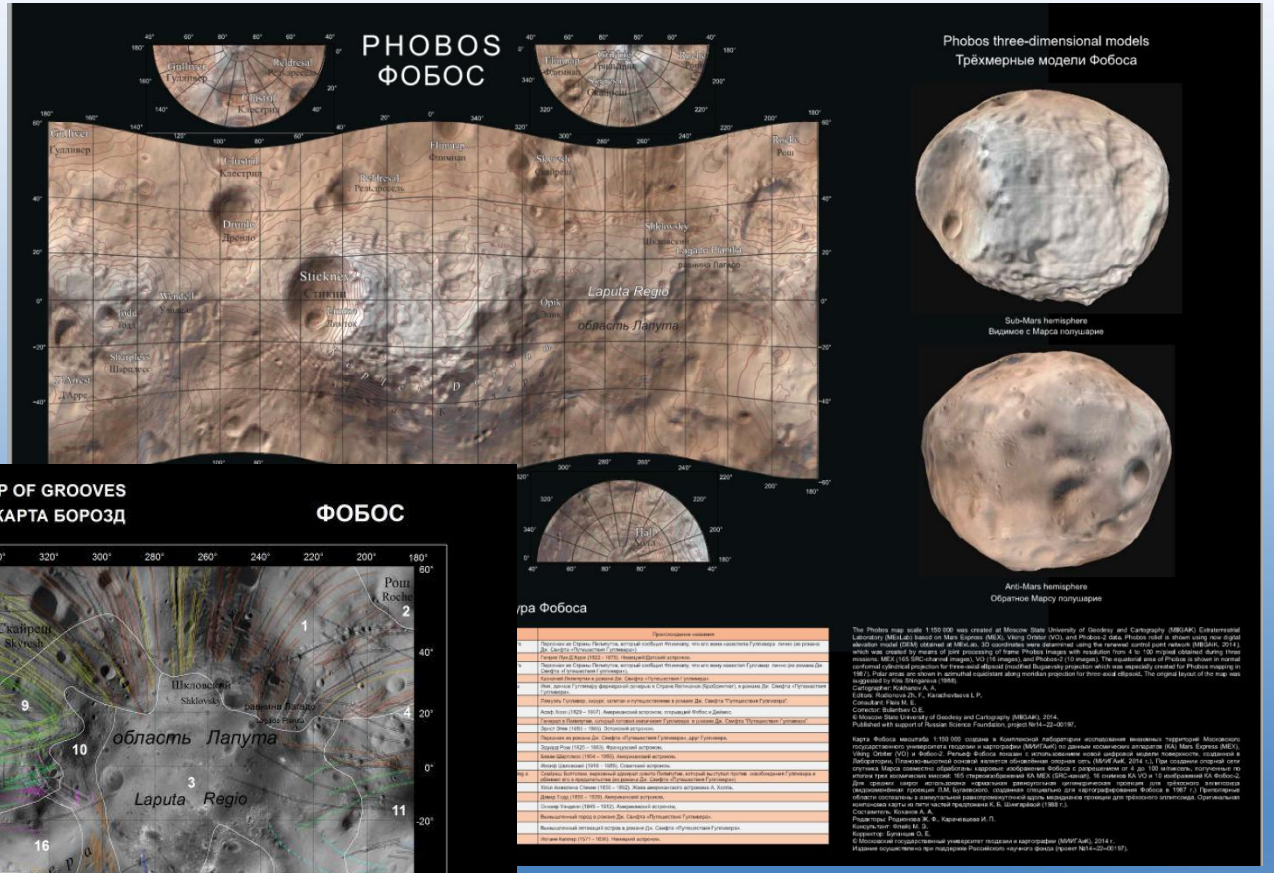


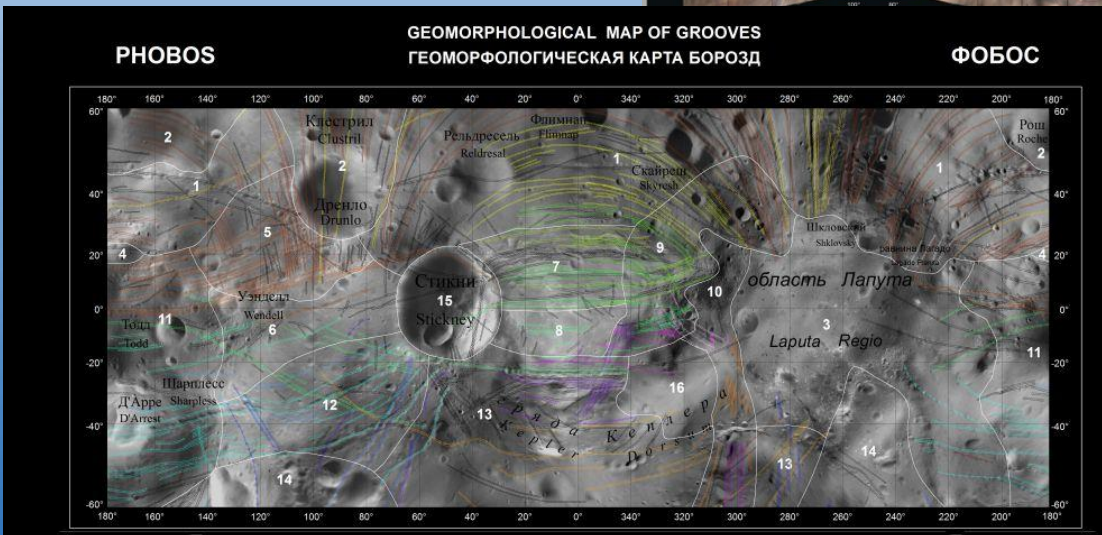


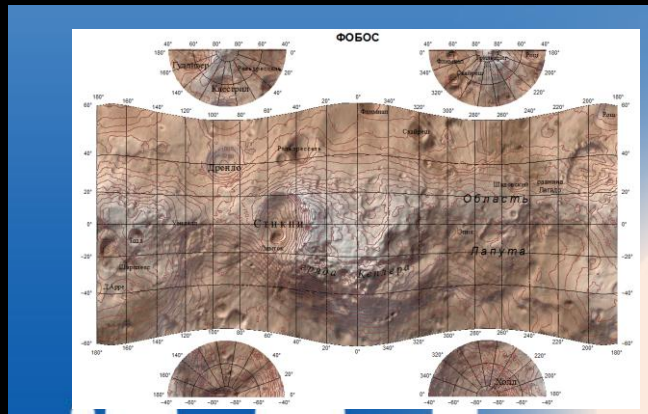
Cartographic heritage and traditions



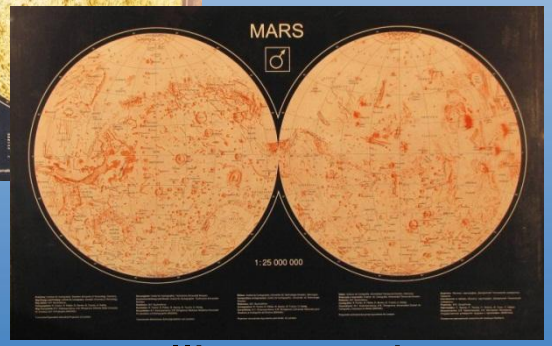
Phobos in Atlas of terrestrial planets, 1992



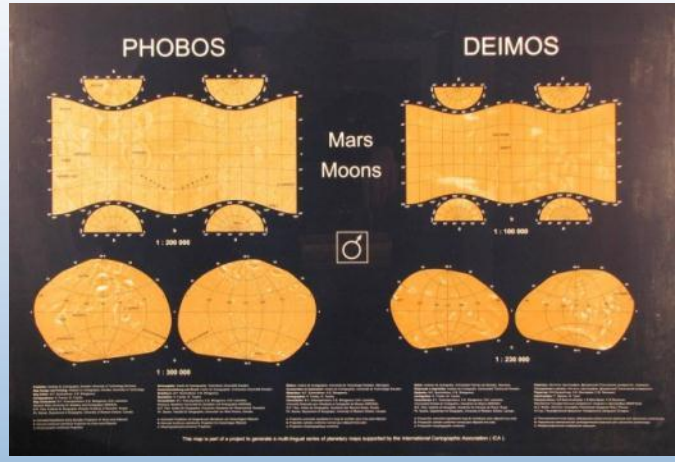




Cartographic heritage and traditions



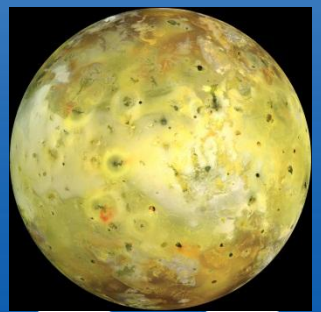
Multilingual map series of terrestrial planets, 2005
(under support of ICA)

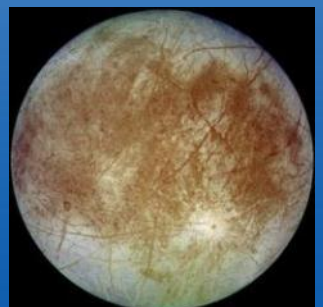


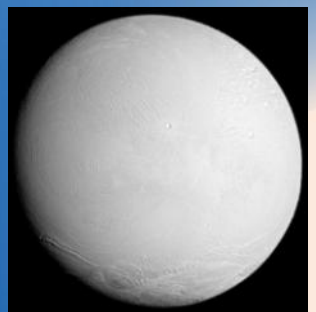
http://planetologia.elte.hu/ipcd/

Further work:

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

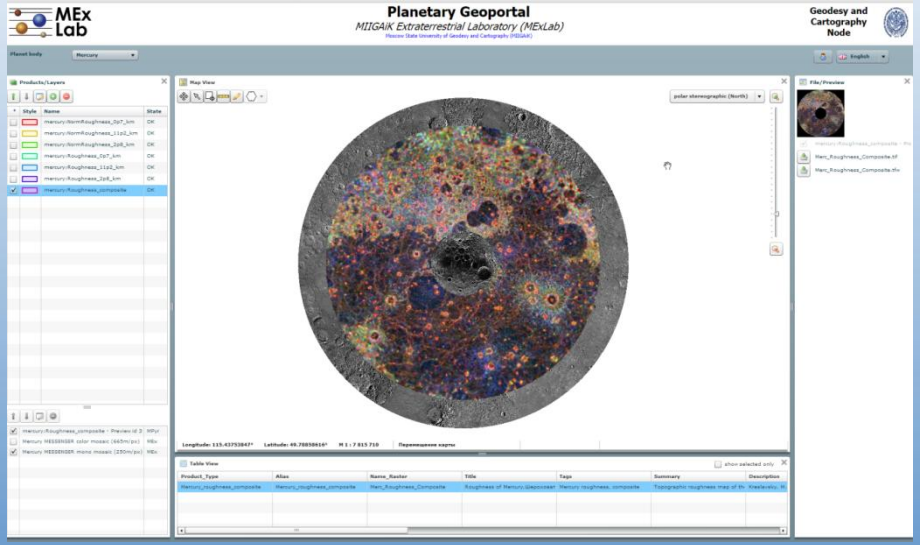


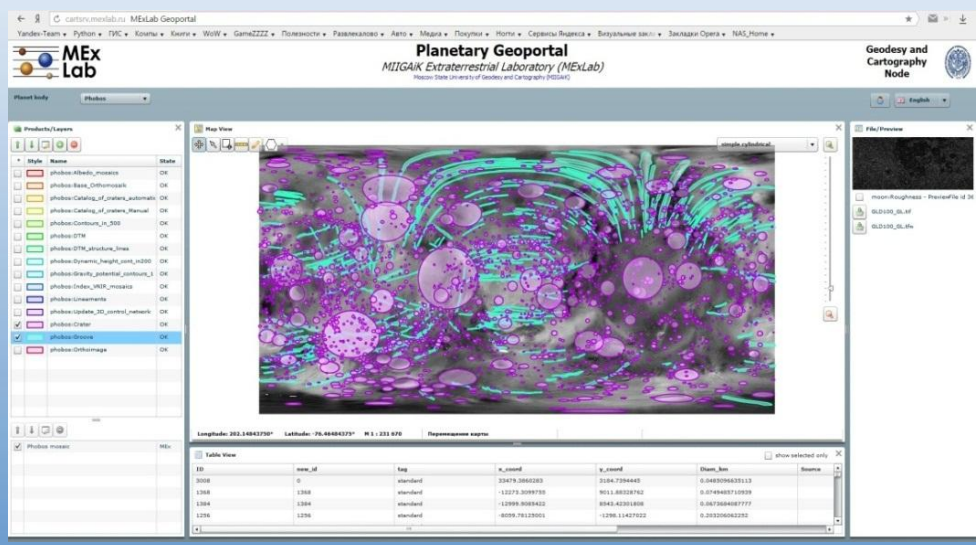


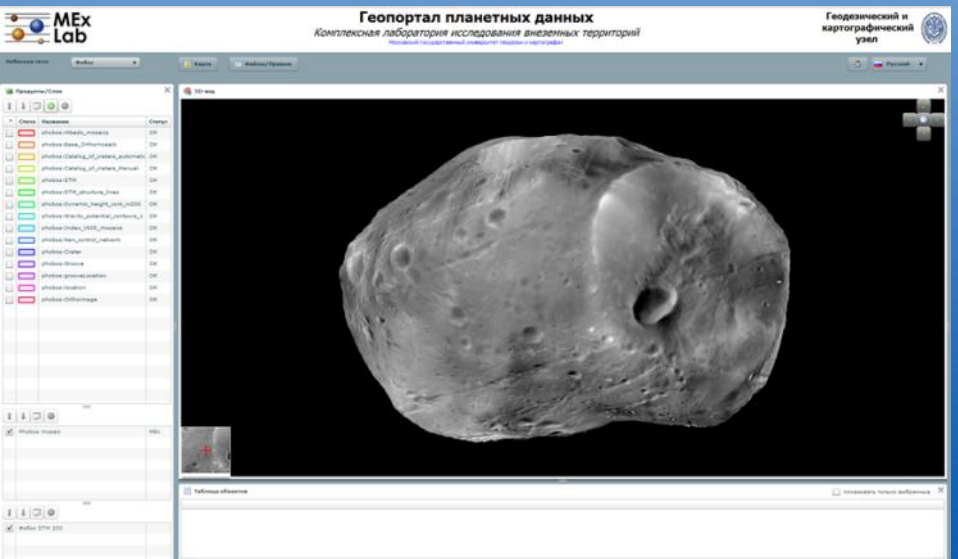


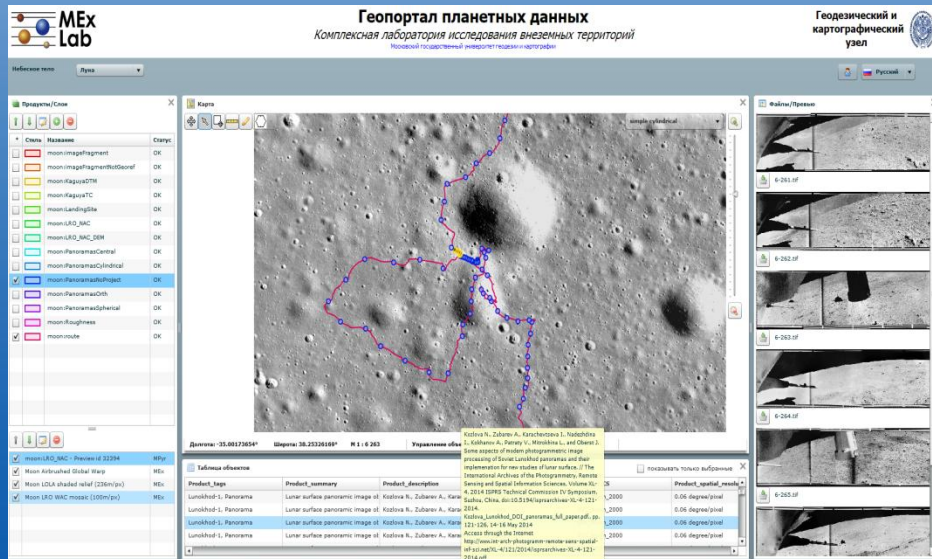
Planetary Geoportal: Geodesy and Cartography Node

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









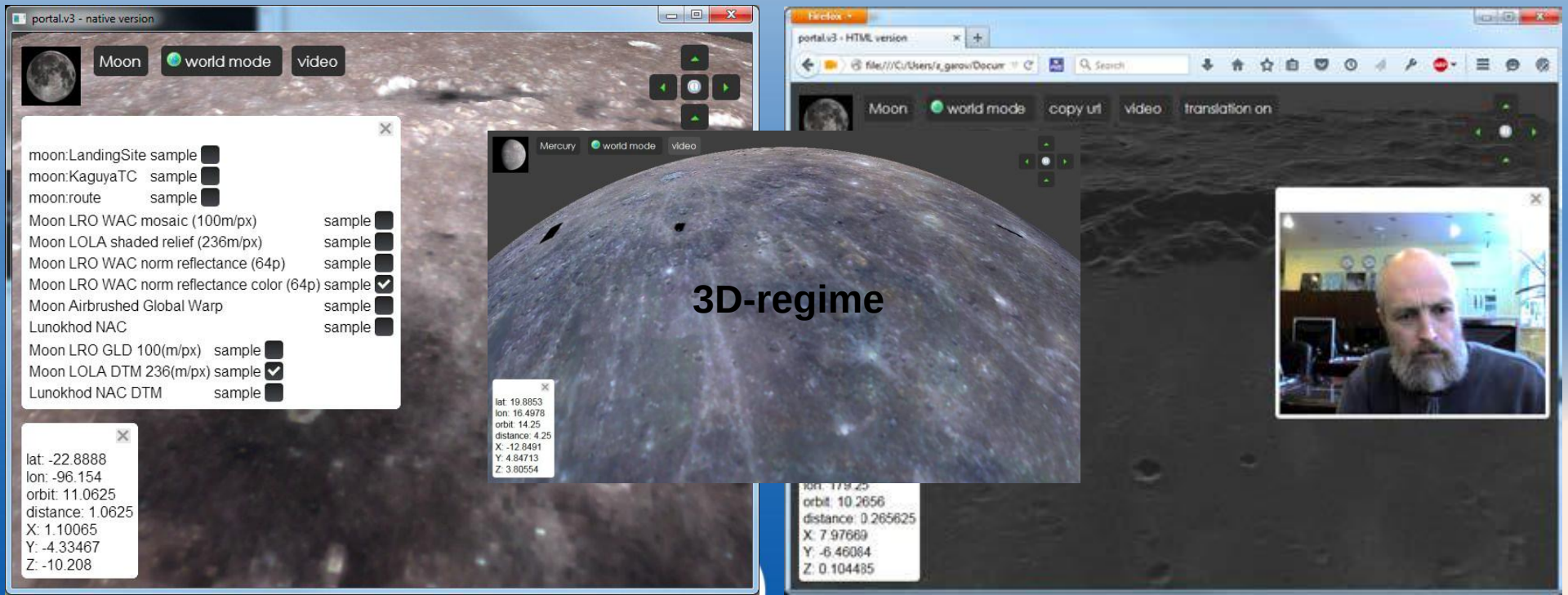
Innovation: 3D-web GIS as online Laboratory

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



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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Acknowledgments

This work was carried out in MIIGAiK and supported by Russian Science Foundation, Project “Study of fundamental geodetic parameters and relief of planets and satellites”, No.14-22-00197