Исследования планет методом ядерной спектроскопии
Exploration of planets with nuclear spectroscopy methods

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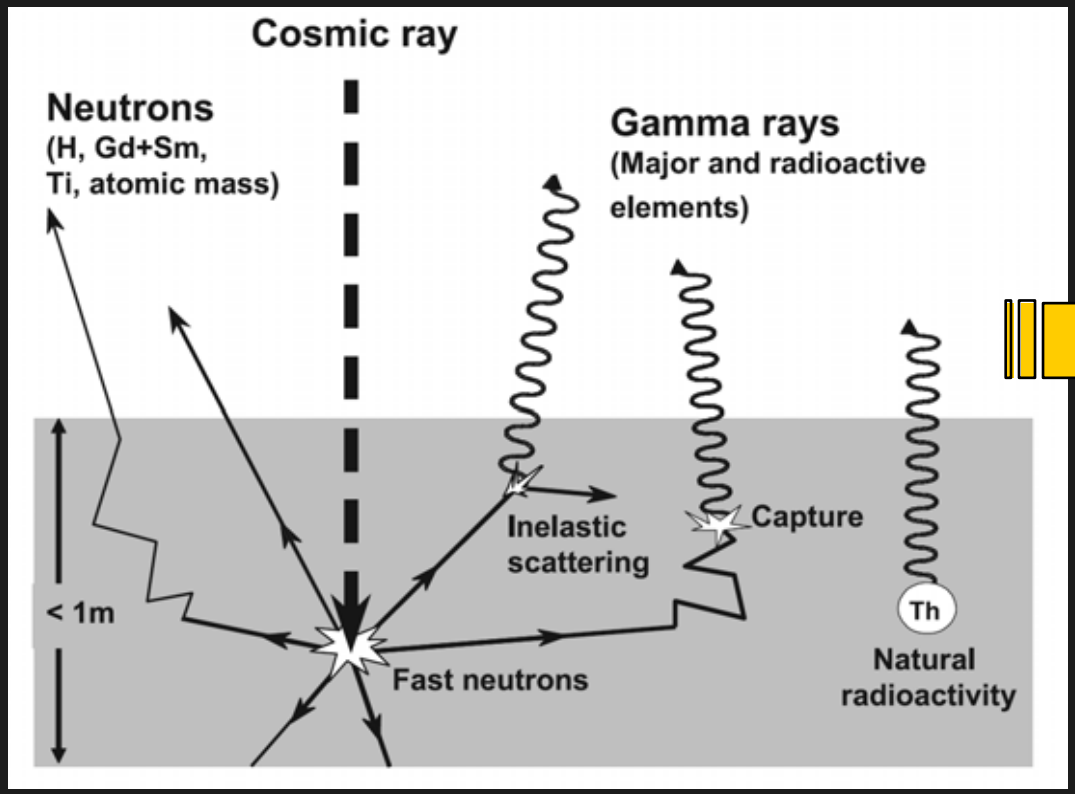
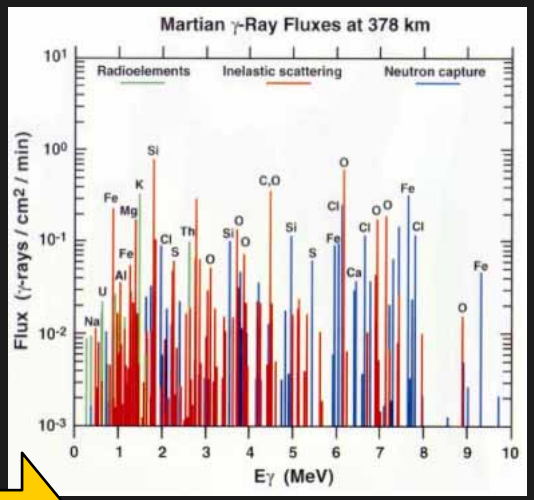
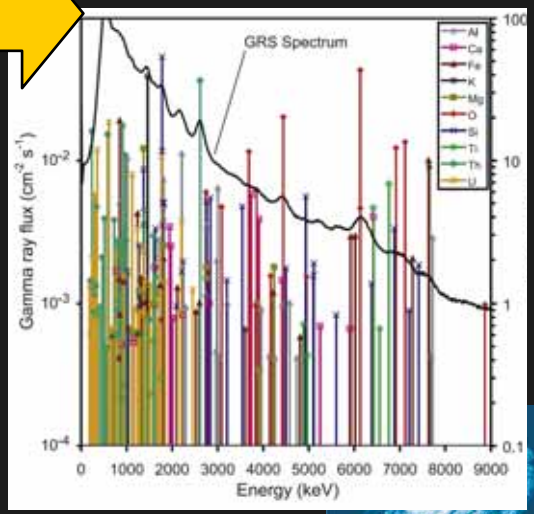
Производство гамма и нейтронного излучения в приповерхностном слое

Production of gamma and neutron radiation in the subsurface





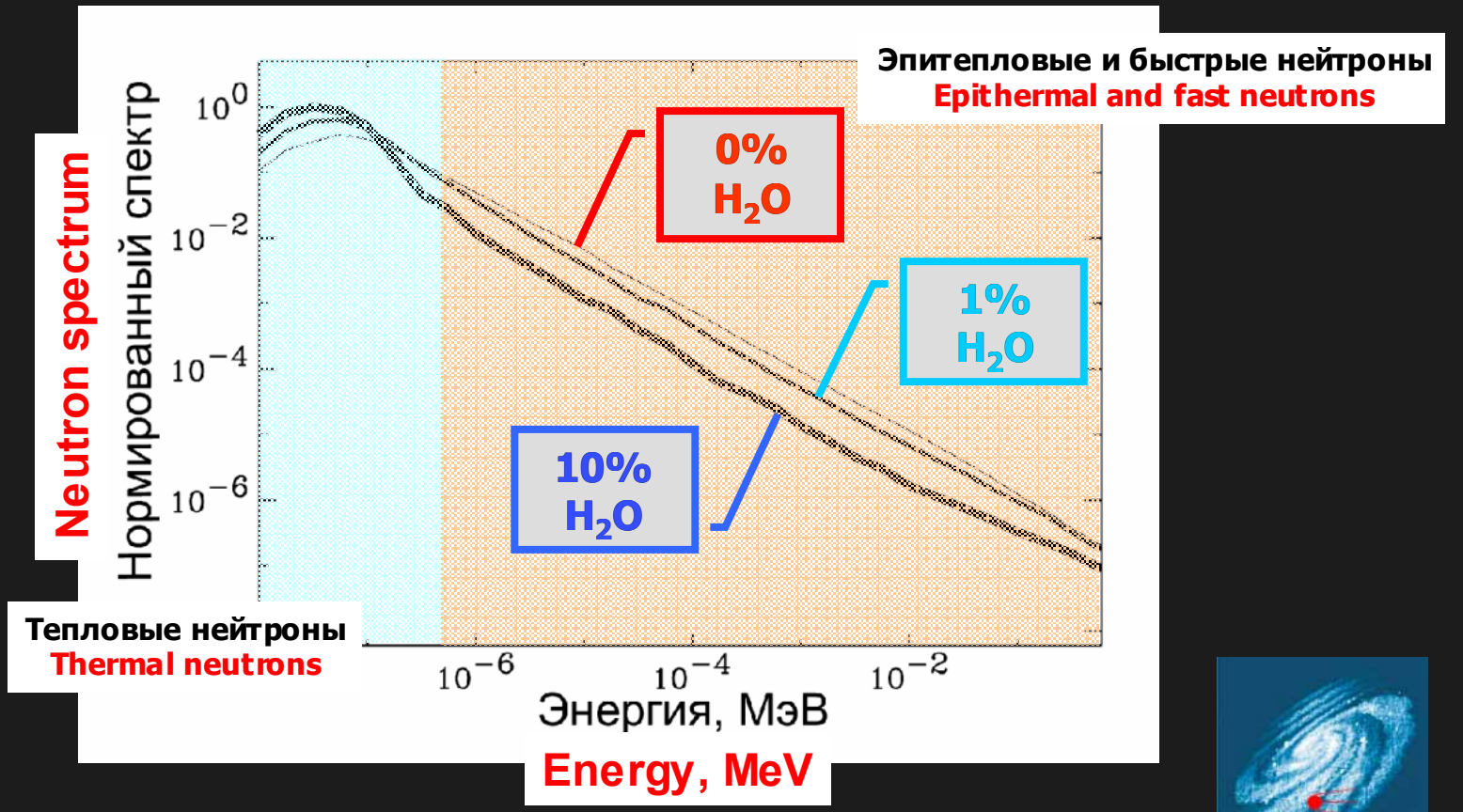


Определение элементного состава поверхности по гамма линиям

Analysis of elemental composition through detection of gamma lines

Поиск воды по данным измерений нейтронного альбедо

Search of water from measurements of neutron albedo



Missions with nuclear spectroscopy instruments

Name	Time Frame	Planet Body	Instruments	Results
Ranger missions/USA	Early 1960s	Moon	NaI(Tl) Scintillation gamma spectormeters	Measurements of cosmic gamma ray background and gamma-spectra from Moon surface
Luna-10/USSR Luna-12/USSR	1966	Moon	NaI(Tl) Scintillation Gamma-ray spectrometer	Measurements of cosmic gamma ray background and gamma-spectra from Moon surface
Apollo-15/USA Apollo-16/USA	1971-1972	Moon	NaI(Tl) Gamma-Ray spectrometer	Mapping (Altitude ~ 100-120 km, covering of ~20% of Moon surface) of elemental composition (including Fe Th, and Ti)
Venera-8/USSR Venera-9/USSR Venera-10/USSR	1972-1975	Venus (landing module)	HPGe Gamma spectrometer	Measurements of gamma lines form radioactive elements Th, U, K at the landing sites
Mars-5/USSR	1974	Mars	NaI(Tl) Gamma-Ray spectrometer	Abundance of O, Si, Fe, U Th and K in the equatorial regions of Mars (elliptical orbits around Mars with periapsis ~ 1760 km)
Vega-1/USSR Vega-2/USSR	1985	Venus (landing module)	CsI(Tl) Gamma-Ray spectrometer	Measurements of gamma lines form radioactive elements Th, U, K at the landing sites
Phobos/USSR	1988	Mars and Phobos	CsI(TL) Gamma-Ray spectrometer	Abundance of O.Si, Fe, K and Th in the equtorial regions of Mars (two elliptical orbits around Mars with periapsis ~ 900 km)
Mars Observer/USA	1992	Mars	HPGe Gamma spectrometer and plastic neutron detector	Failed prior Mars orbit insertion
Mars-96/Russia	1996	Mars	HPGe Gamma spectrometer	Failed prior insertion to the interplanetary orbit
NEAR/USA	1996	Eros asteroid	NaI(Tl) [with BGO anticoincidence shield] Gamma-Ray spectrometer	Abundances for O,MG,Si,Fe and K

Name	Time Frame	Planet Body	Instruments	Results
Lunar Prospector/ USA	1998	Moon	BGO gamma ray spectrometer + boron plastic and ^{3}He proportional counters as neutron detectors	Mapping of elemental composition of Moon surface including Hydrogen at polar regions (with spatial resolution ~60km)
Mars Odyssey/USA	2001-	Mars	HPGe Gamma spectrometer + plastic scintillator as neutron spectormeter + High Energy Neutron Detector (Russia)	Mapping (Altitude ~ 400 km) of elemental composition of major and radioactive elements, Discovery of water ice in the high-latitude regions, observation of mars seasonal CO2 cycle
MESSENGER/USA	2004-	Venus (landing module)	HPGe Gamma spectrometer + boron loaded plastic neutron detectors	On his way to Mercury (To perform maps of elemental composition + search for water ice)
Dawn/USA	2007-	Vesta and Ceres	CdZnTe and BGO Gamma-Ray spectrometer+boron loaded plastic neutron detectors	On his way to asteroids (To get global maps of major and radioactive elements and ice, circular polar orbits around each asteroids)
Selene/Japan	2007-	Moon	HPGe Gamma spectrometer	On his way to the Moon (To get global maps of major and radioactive elements, polar circular orbit with altitude ~100km)
LRO/USA	2008-	Moon	Collimated neutron detector LEND (provided by Russia) based on 3He proportional counters	Under preparation (To get abundance of H at the polar regions of Moon with spatial resolution ~10km)

Name	Time Frame	Planet Body	Instruments	Results
MSL/USA	2009-	Mars	Active neutron logging along the path of rover (DAN instrument provided by Russia)	Under preparation (To get depth distribution of bound water along the path of MSL rover)
Phobos-Grunt/Russia	2009-	Phobos	$LaBr_3$ gamma spectrometer + neutron spectrometer based on 3He tubes and Stilben cristal	Under preparation (To get abundances of major and radioactive elements including H at the landing site)
BepiColombo/ESA	2013-	Mercury	$LaBr_3$ gamma spectrometer + neutron spectrometer based on 3He tubes and Stilben cristal (Provided by Russia)	Under preparation (to get maps of major and radioactive elements and H abundances at polar cold traps)

Lunar Prospector Results




Prettyman et al., 2006

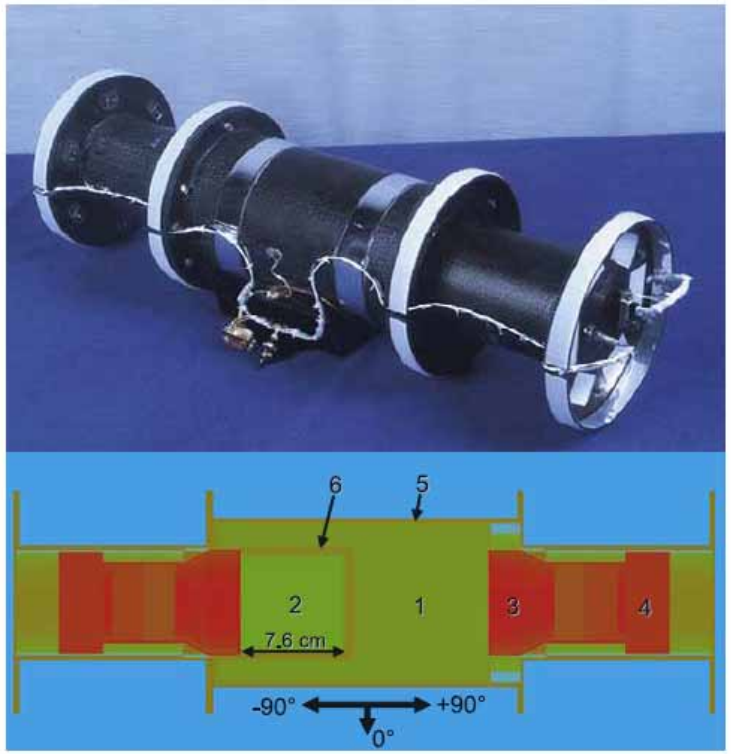


Figure 11. A photograph of the GRS is compared to the geometric model used to simulate the instrument response. The nadir direction for three latitudes (for the high-altitude spin-axis orientation) is indicated by arrows. The arrows also indicate the direction to the source in the experiments described in Appendix C. Selected zones of the geometric model are labeled as follows: (1) the anti-coincidence shield; (2) the BGO crystal; (3) a photomuliplier tube and (4) bleeder board assembly; (5) the instrument's housing; and (6) packaging material around the BGO crystal.

Prettyman et al., 2006

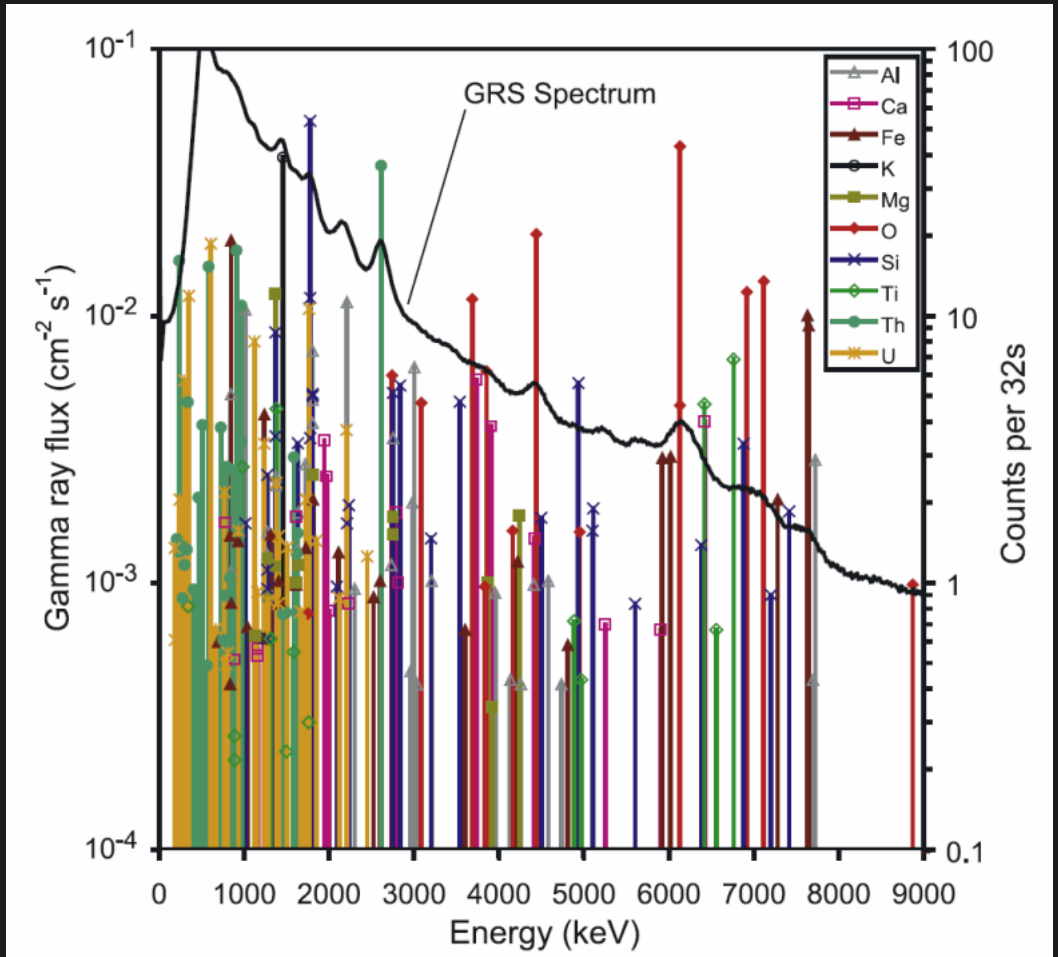
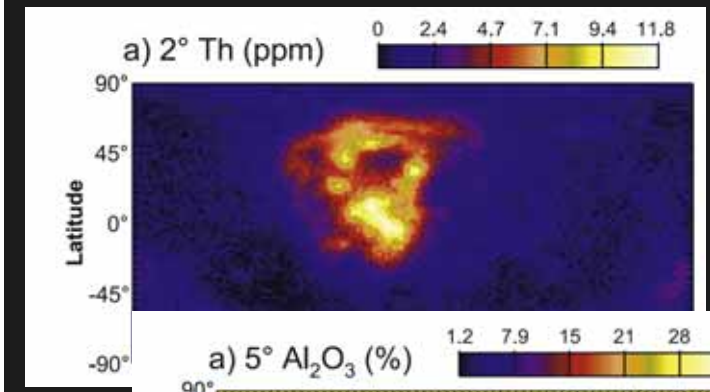
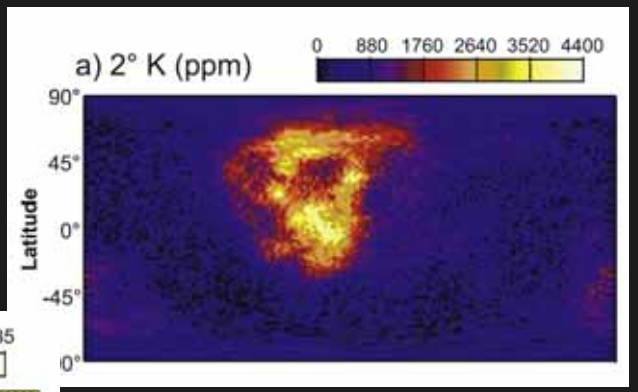
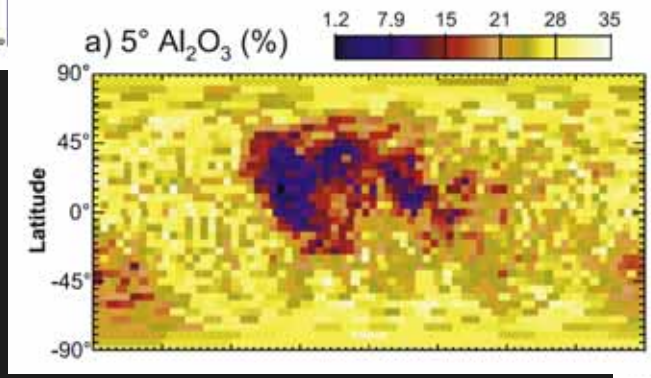


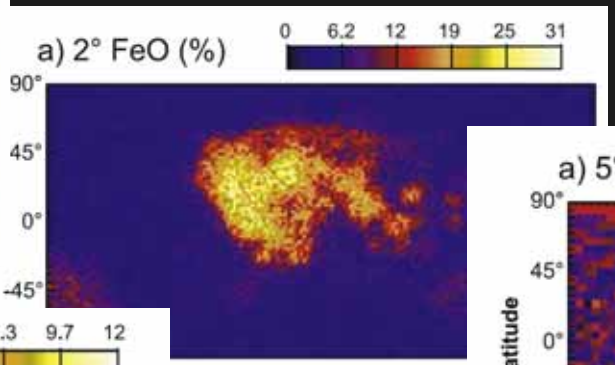
Figure 2. Discrete gamma ray lines are compared to a spectrum acquired by the GRS.

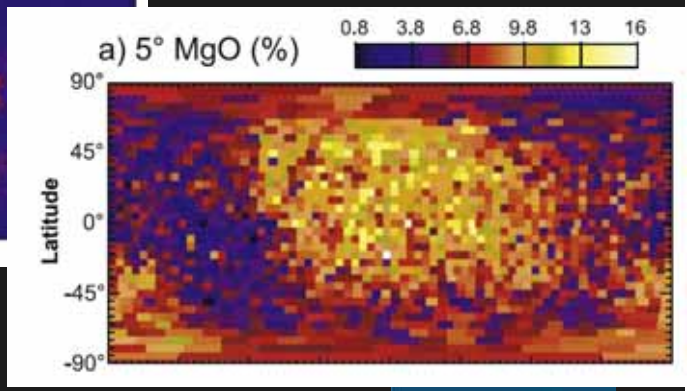


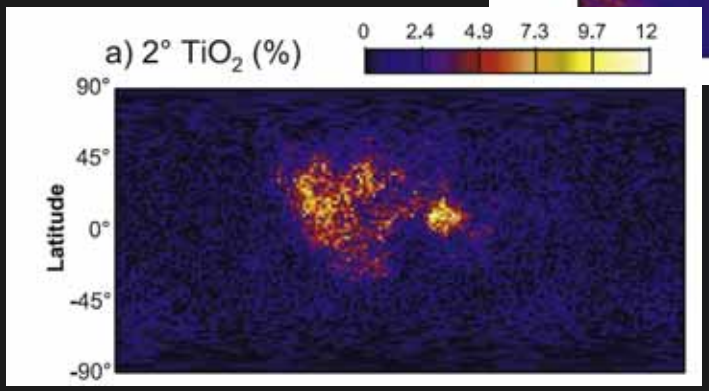


Prettyman et al., 2006









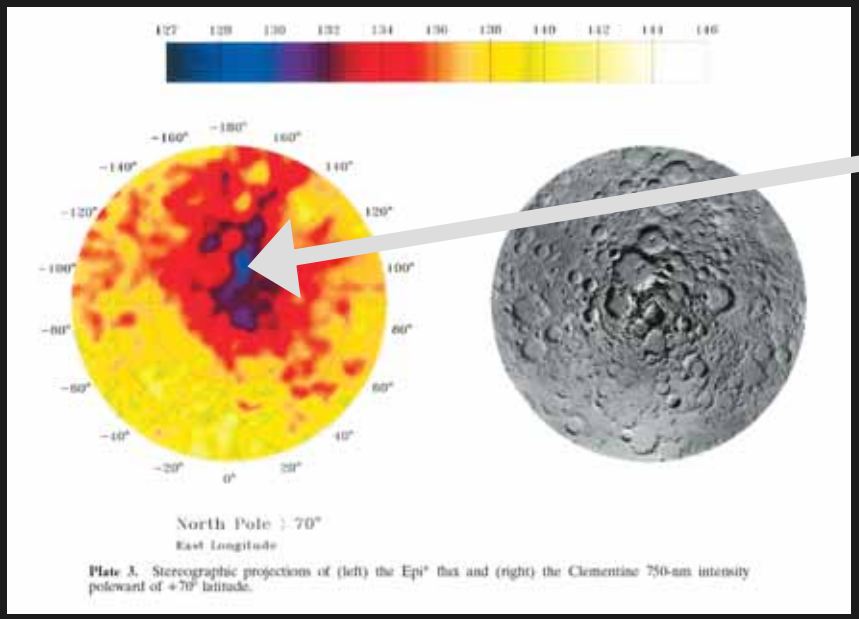


Plate 3. Stereographic projections of (left) the Epi* flux and (right) the Clementine 750-nm intensity poleward of +70° latitude.

Water ice remnants?

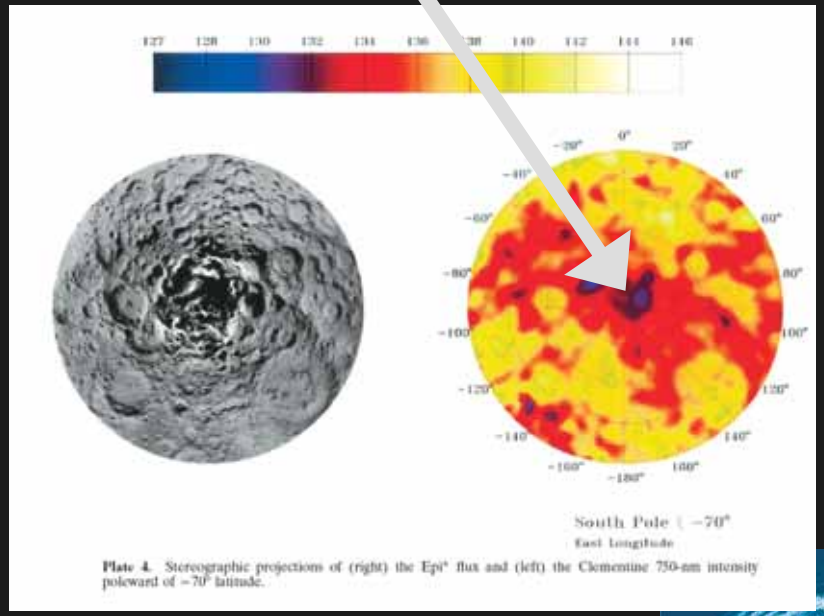


Plate 4. Stereographic projections of (right) the Epi* flux and (left) the Clementine 750-nm intensity poleward of −70° latitude.

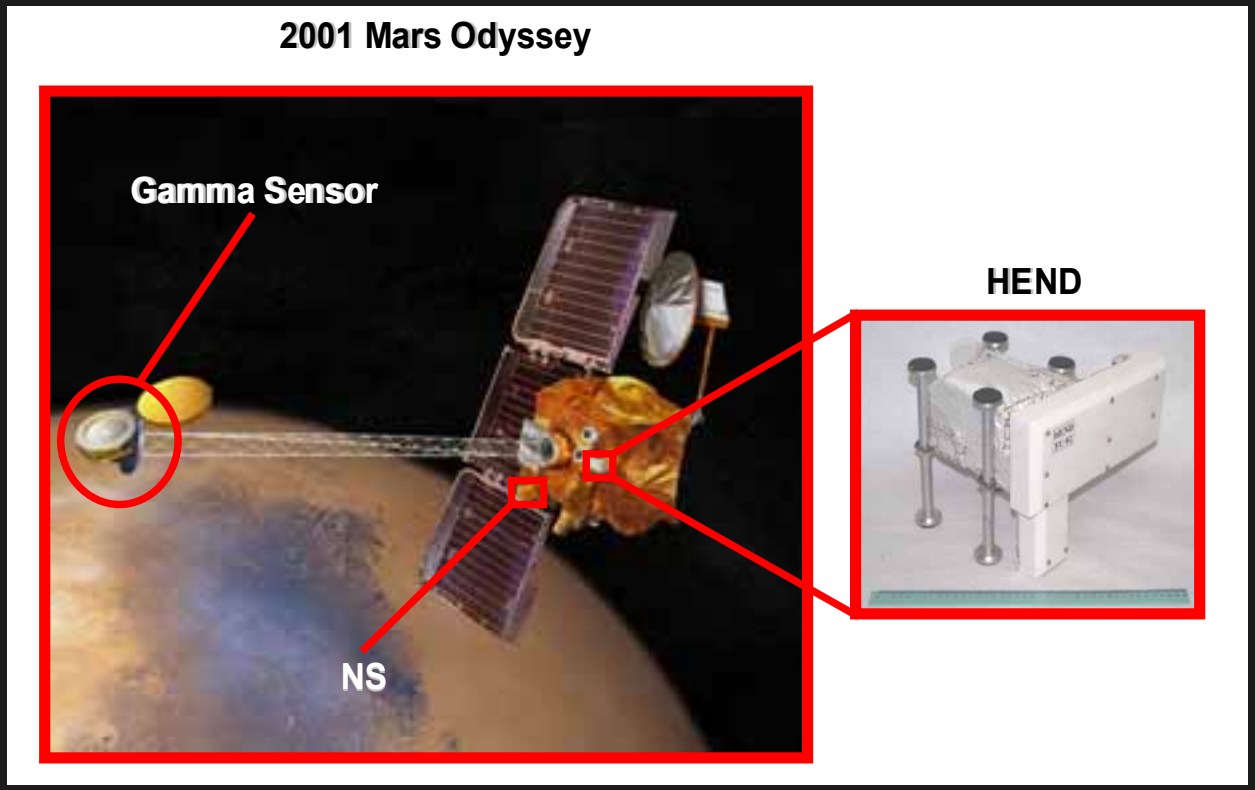
Feldman et al., 2001

Mars Odyssey Results

Симпозиум “Исследования Солнечной системы”

2-3 Октября, 2007, ИКИ РАН, Москва

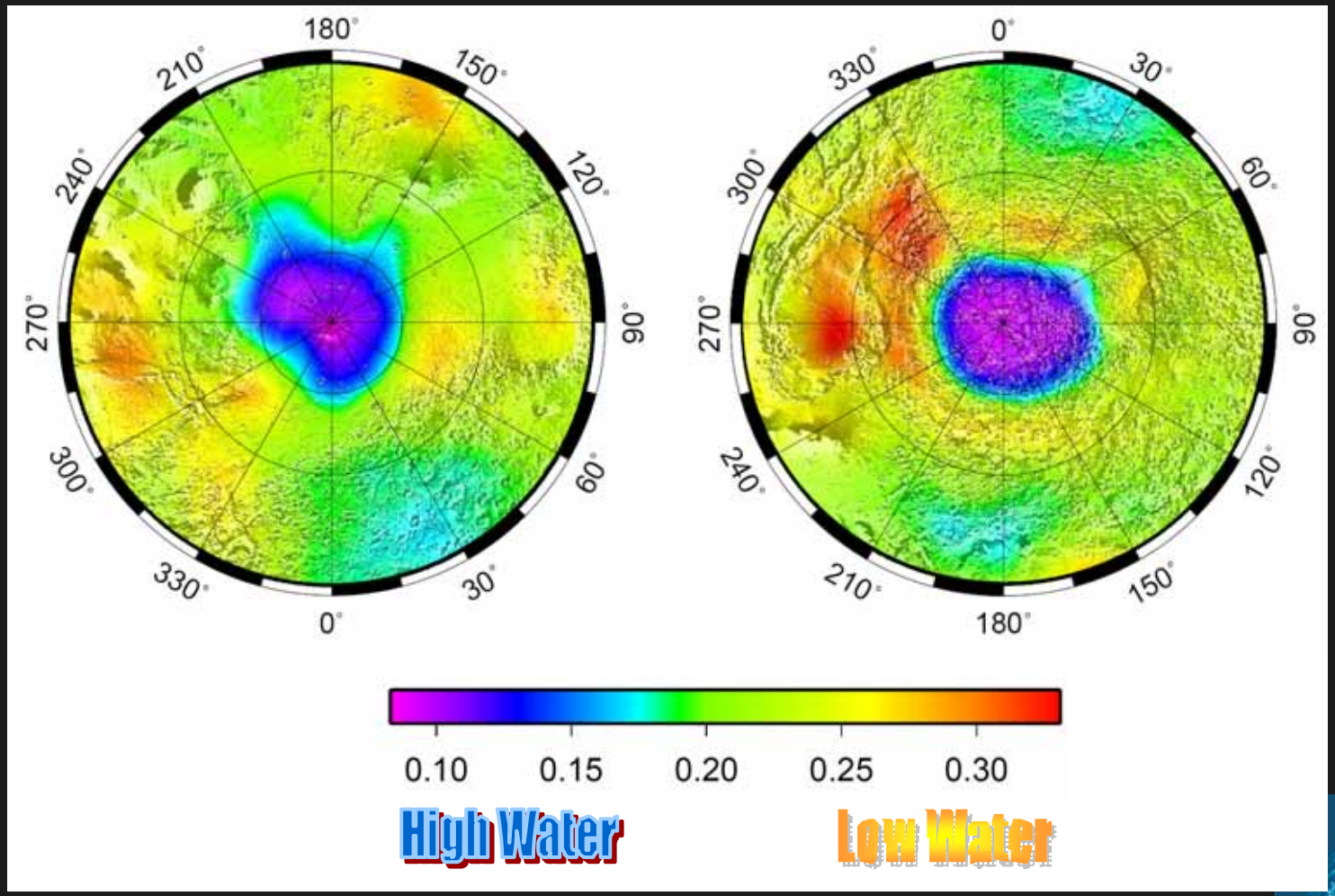
HEND instrument onboard Mars Odyssey: Main Results



HEND instrument onboard Mars Odyssey:

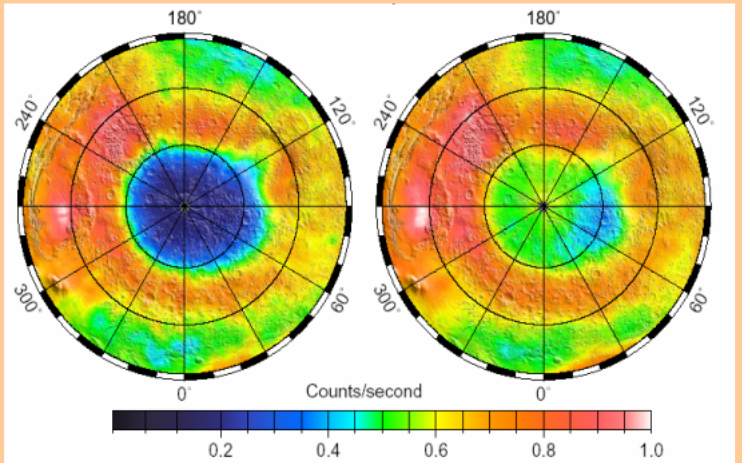
More than four years on Martian orbit. More than two Martian years of mapping of Martian surface. Continuous observation of neutron albedo of Mars in wide energy range. Discovery of subsurface water ice distribution in polar regions and long term monitoring of Martian seasonal caps.

HEND instrument onboard Mars Odyssey: Main Results

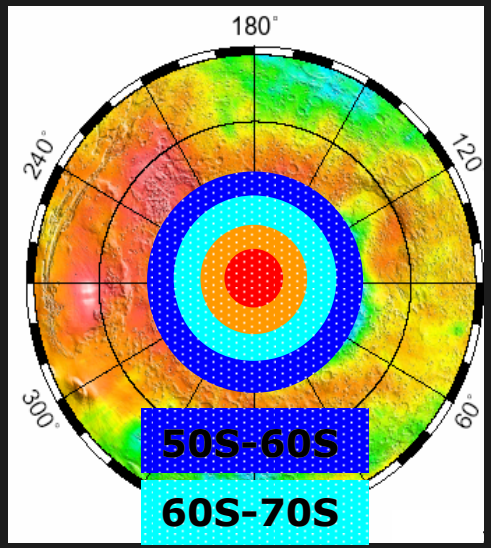


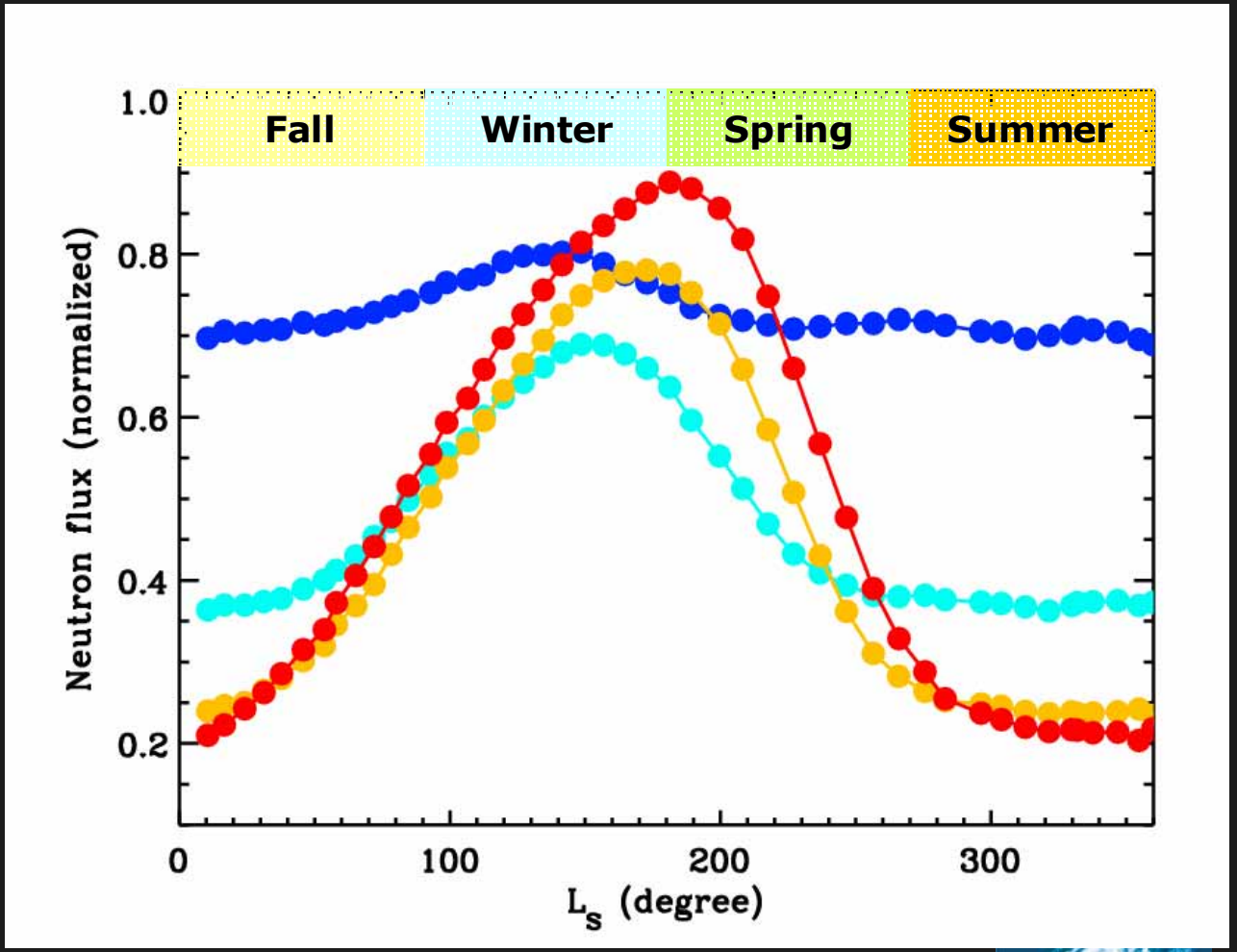
Observations of seasonal variations of neutron flux produced in Martian subsurface: monitoring of growth and sublimation of seasonal caps

Southern hemisphere



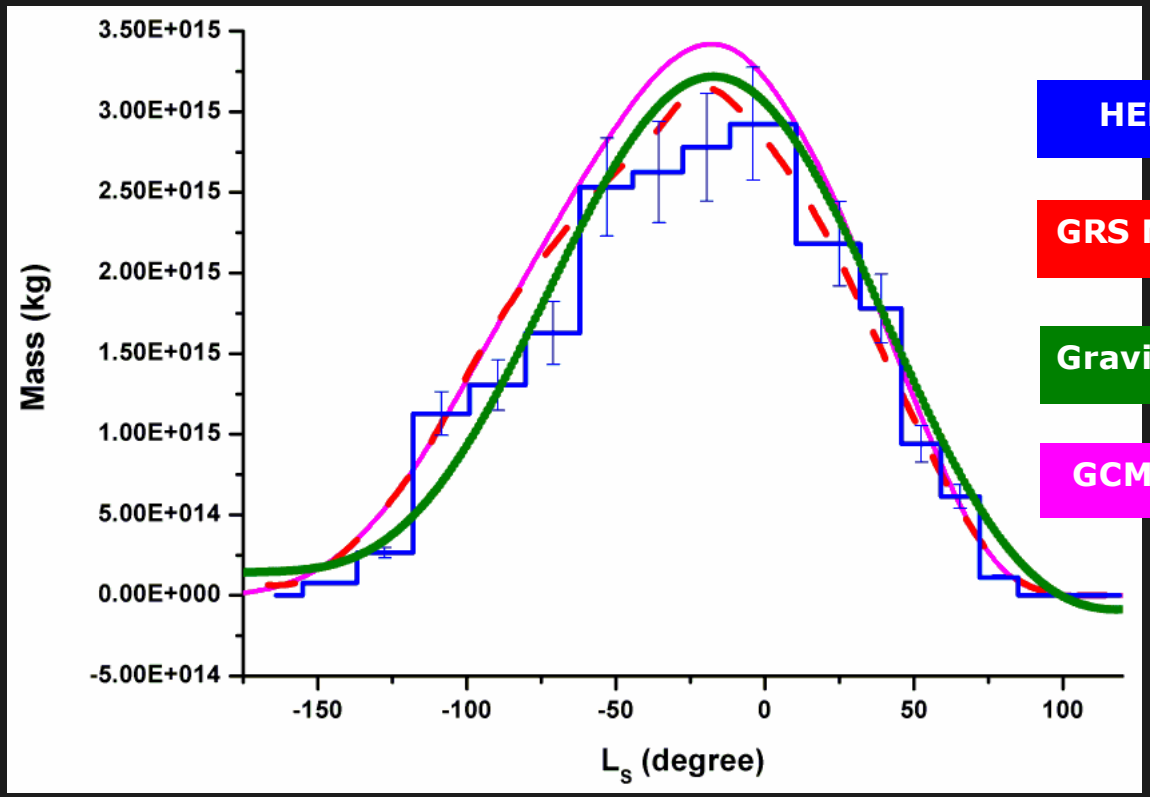
Summer → Winter


180°
240°
120°
300°
60°
50S-60S
60S-70S
70S-80S
80S-90S


Fall
Winter
Spring
Summer
Neutron flux (normalized)
1.0
0.8
0.6
0.4
0.2
0
100
200
300
L_S (degree)

HEND instrument onboard Mars Odyssey: Main Results

Mass of northern seasonal cap



HEND Mass 60N-90N

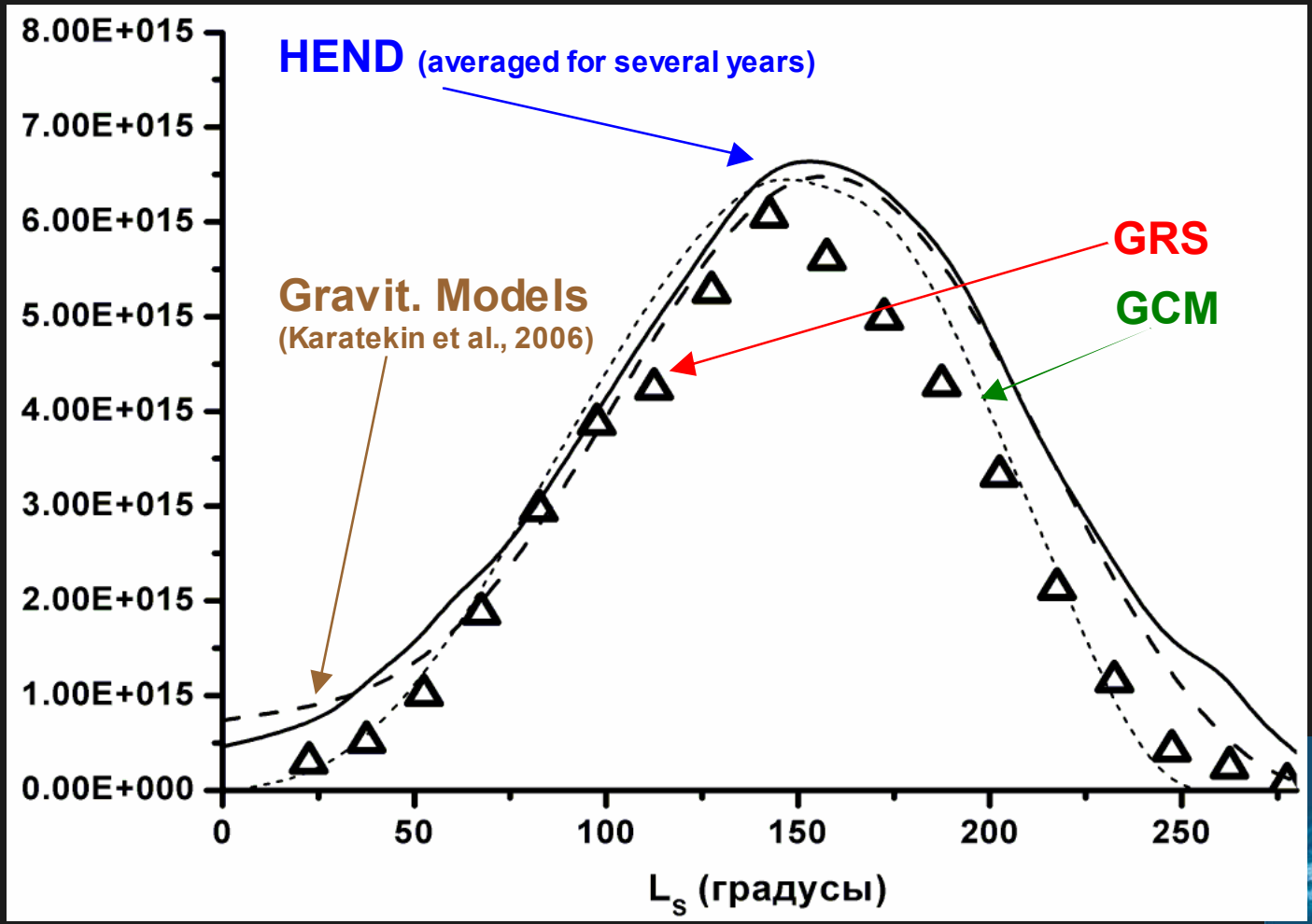
GRS Mass 60N-90N, (Kelly et al., 2007)

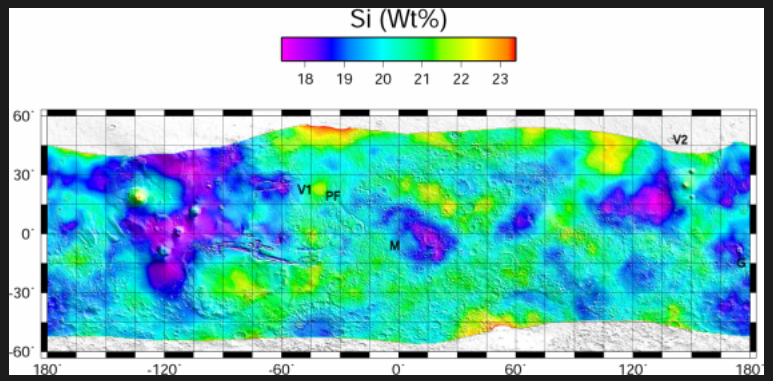
Gravity Mass, (Karatekin et al., 2006)

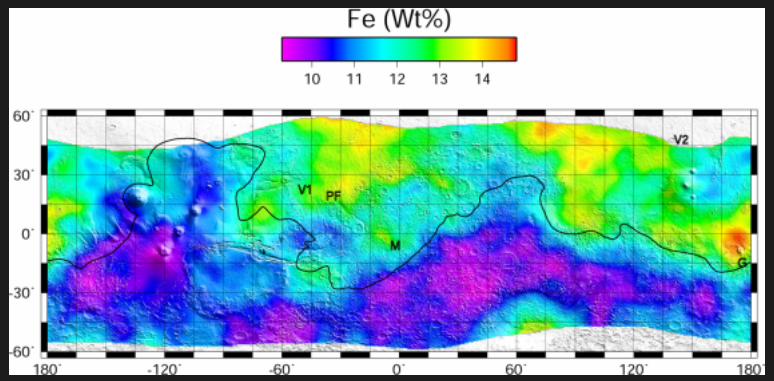
GCM Mass 56N-90N

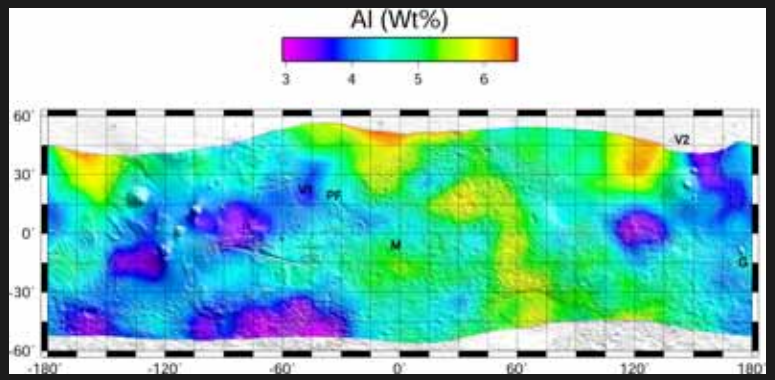
HEND instrument onboard Mars Odyssey: Main Results

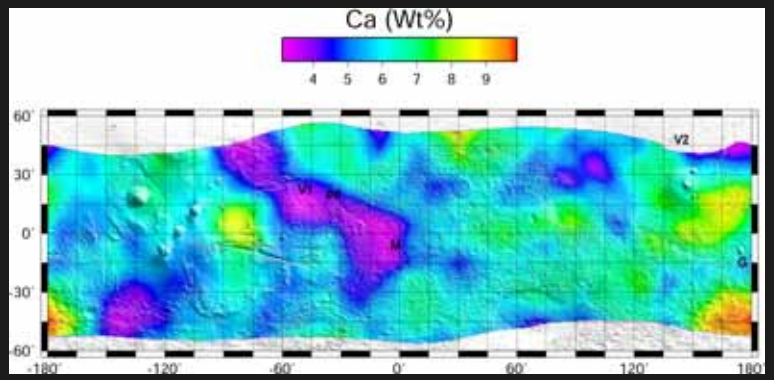
Mass of southern seasonal cap









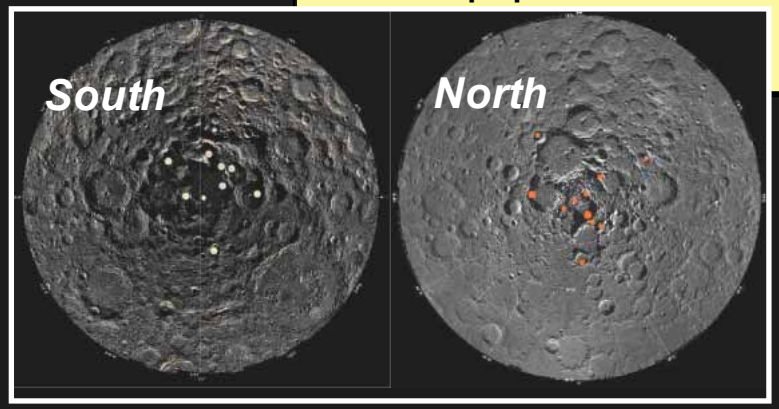


Boynton et al, 2007 Preliminary GRS elements abundance maps

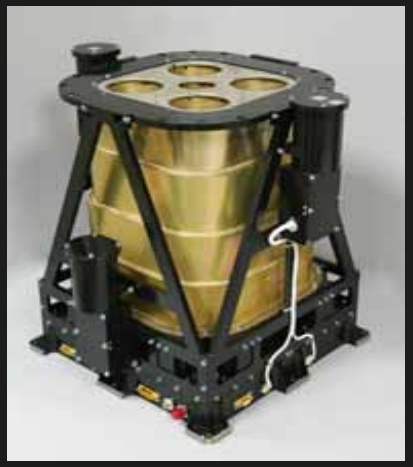
Future Missions

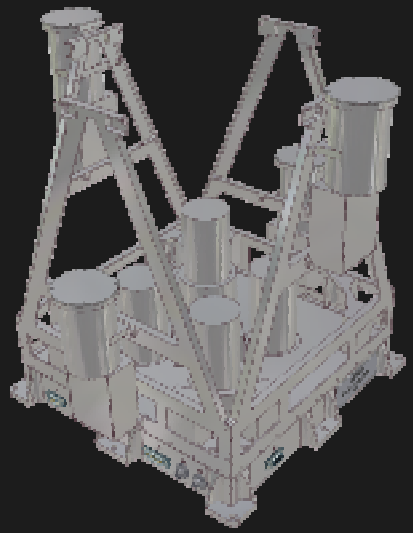
LRO Instruments: LEND

LRO Mission Requirement	LEND Data Products
The LRO shall obtain high spatial resolution hydrogen mapping of the Moon's surface to a 20% accuracy and 5 km resolution at the poles.	The content of Hydrogen in subsurface at polar regions with spatial resolution from 5 km (Half-Width Half-Maximum) and with variation sensitivity from 100 parts per million (ppm)
The LRO shall identify putative deposits of appreciable surface or near surface water ice in the Moon's polar cold traps at 100m scale spatial resolution	The water ice column density on polar regions of the Moon with spatial resolution from 5-20km.
The LRO shall characterize the deep space radiation	Global distribution of neutrons at Moon's orbit with spatial resolution of 50 km at different energy ranges from thermal energy up to >15 MeV separately for periods of quiet Sun and for periods of Solar Particle Events.



LRO Instruments: LEND

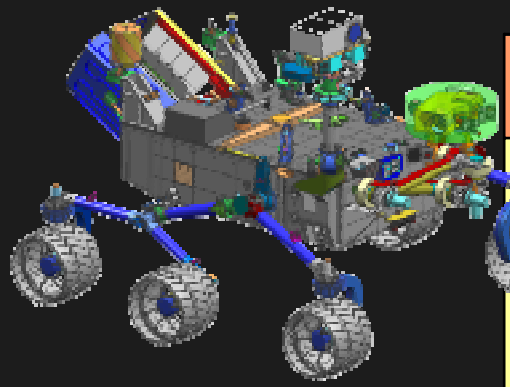




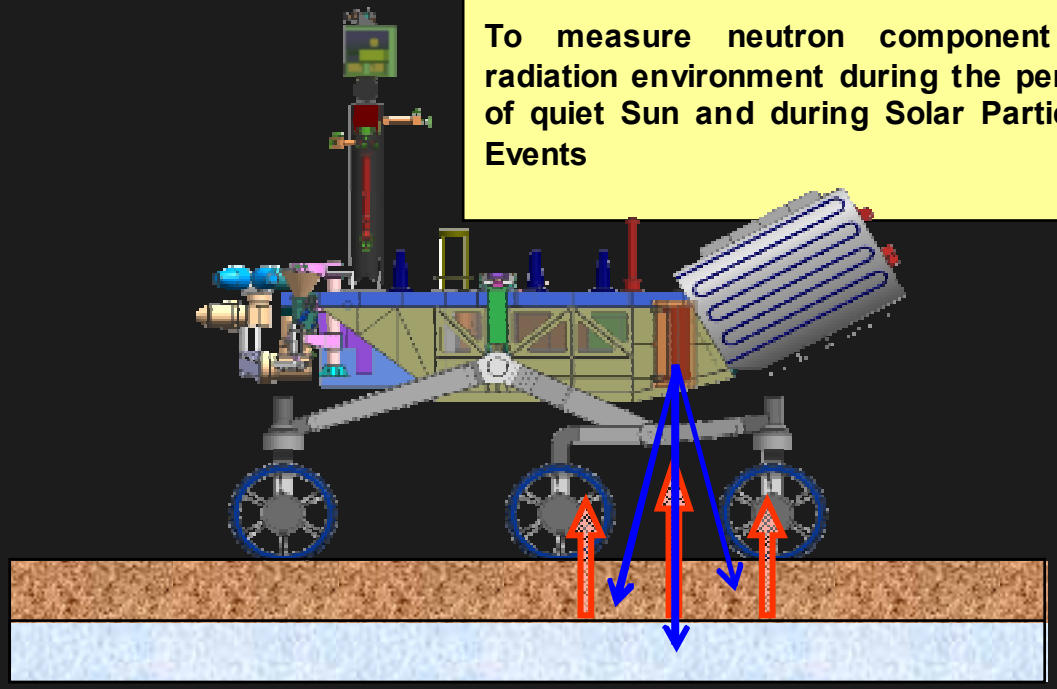
Instrument parameter	Value
Mass (with MLI, kg)	23.7
Sizes (mm)	460 x 460 x 438
Operational power (W)	9.5
Heating power (W)	3.5
Telemetry rate	3 kbps
Total daily telemetry	250 Mb
Number of commands	7
Energy ranges of neutron measurements	Thermal neutrons < 0.4 eV, Epithermal neutrons 0.4 eV – 10 keV, Fast neutrons 10 keV – 1 MeV; High energy neutrons 1.0 MeV-15MeV
Time resolution (sec)	>1.0
Spatial resolution (@50 km)	Radius 5 km

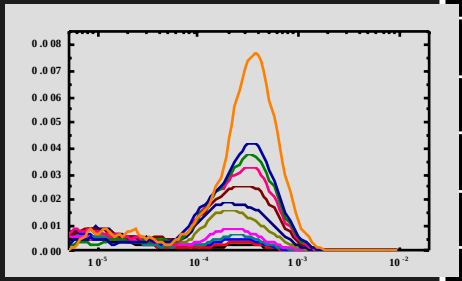
Provider: Space Research Institute, Russia

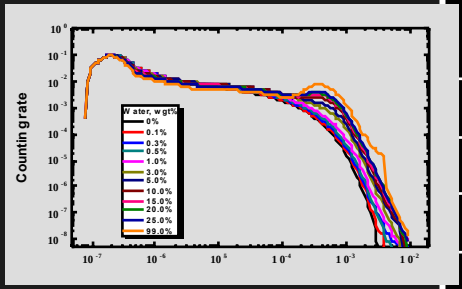
MSL Instruments: DAN



MSL Mission Requirement	DAN Data Products
To perform either at least 10^5 *monitoring measurements* of H content with sensitivity or 1 wt% (water equivalent), or at least 500 measurements of H content with *high sensitivity* of 0.1 wt% (water equivalent)	The depth distribution of Hydrogen in subsurface (down to 0.5 m) along the trace of MSL with spatial resolution from 0.5 meter to tens of meters
To measure neutron component of radiation environment during the period of quiet Sun and during Solar Particles Events	The fluxes of thermal and epithermal neutrons along the trace of MSL with for periods of quiet Sun and for periods of Solar Particle Events.



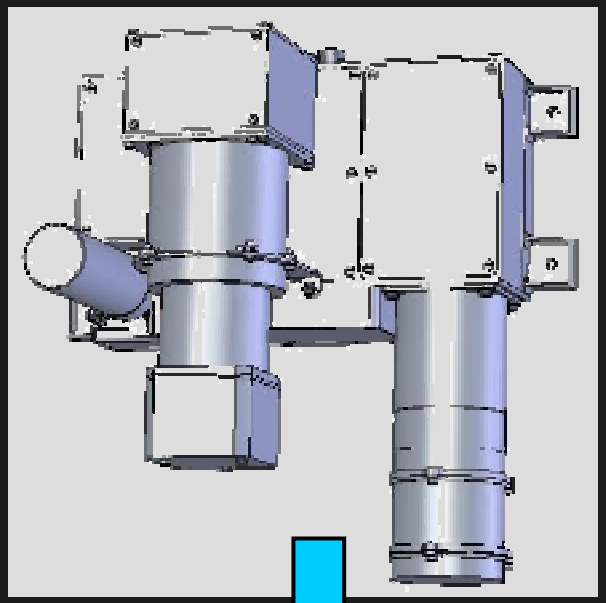


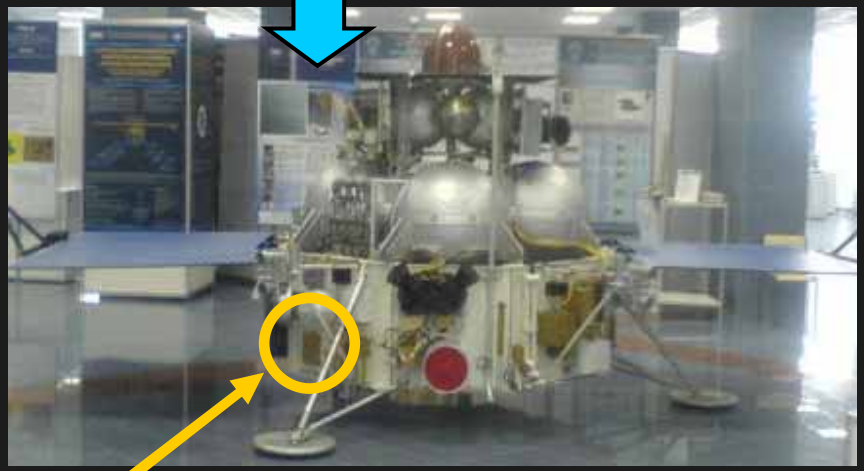


PARAMETER	DAN/DE	DAN/PNG
Mass	1.9 kg + 0.2 kg	2.7 kg + 0.1 kg
Power	<3.5 W	<12 W
Max Dimensions	204 x 61 x 210 mm	125 x 45 x 339 mm
Functions	Neutron detection	Neutron emission
Energy Band	Thermal and epithermal neutrons in wide energy range	Fast neutrons with energy = 14 MeV in pulses 1-2 μs with 10^7 particles
Temporal resolution	10-1000 μs	<1 μs
Spatial Horizontal resolution	< 1 m	< 1 m
Vertical resolution	1 m	1 m
Life time	5 years	3 years and/or 10^7 neutron pulses

Provider: Space Research Institute, Russia

Phobos-Grunt Instruments: NS HEND





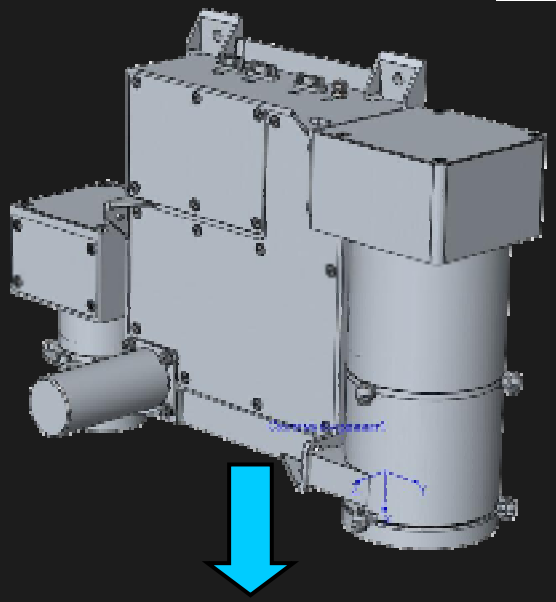
NS-HEND: main characteristics

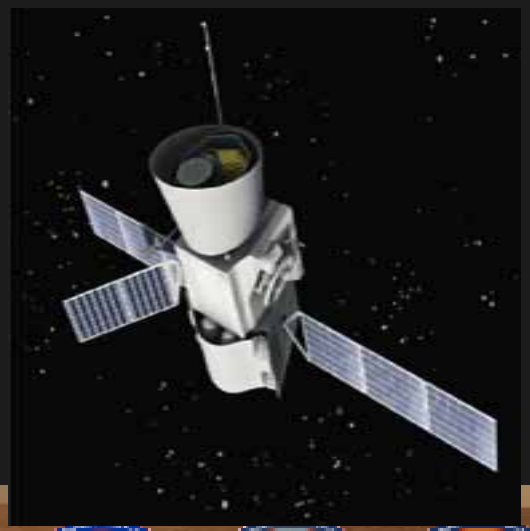
Science objectives: Abundances of hydrogen, major and radioactive elements

PARAMETER	VALUE
Mass	3,8 kg
Power	6 W
Volume	
Time Resolution	> 0.25 sec
Energy range, neutrons	Multi energy bands covering 0.4 eV – 15MeV
Energy range, gamma	Multi energy bands covering 30 keV – 10 MeV
Temperature range	(-40C, 40C)
Detectors	3He – proportional counters, stilben crystal, LaBr3 crystal
Position	Phobos Grunt
Altitude	Phobos surface

BepiColombo Instruments: MGNS

MGNS: main characteristics





Science objectives: Mapping of major and radioactive elements, search for Hydrogen in polar cold traps

PARAMETER	VALUE
Mass	5.2 kg
Power	5 W
Volume	-
Surface Resolution	400 km
Time resolution	20 sec
Energy range, neutrons	Multi energy bands covering 10^{-3} eV – 15 кеV
Energy range, gamma	300 keV – 10 MeV
Energy resolution, gamma	3% at 662 keV
Detectors	3He – proportional counters, stilben crystal, $LaBr_3$ crystal
Temperature range	(-20C, 40C)
Position	ESA: BepiColombo
Altitude	400 km – 1500 km