NEUTRON SUPPRESSION REGIONS AT LUNAR POLES, AS LOCAL AREAS OF WATER-RICH PERMAFROST. I. G. Mitrofanov[1], M. L. Litvak[1], A. B. Sanin[1], D. V. Golovin[1], W. V. Boynton[2], G. Chin[3], J. B. Garvin[3], L. G. Evans[4], K. Harshman[2], A. S. Kozyrev[1], T. McClanahan[3], R. Sagdeev[5], V. Shevchenko[7], V. Shvetsov[8], R. Starr[6], J. Trombka[5], [1]Institute for Space Research, 117997 Moscow, Russia imitrofa@space.ru, [2]University of Arizona, Tucson, AZ USA, [3]NASA Goddard Space Flight Center, Greenbelt, MD USA, [4]Computer Science Corporation, Greenbelt, MD USA, [5]University of Maryland, Collage Park, MD USA, [6]Catholic University, Washington DC, USA, [7]Sternberg Astronomical Institute, Moscow, Russia, [8]Joint Institute of Nuclear Research, Dubna, Russia.

Introduction: Discovery of "New Polar Moon". It became clear now that polar regions of the Moon are quite different from *in-situ* inspected Moon at moderate latitudes. The main signature of "New Polar Moon" is the presence of rather high content of water and another volatiles in the polar regolith. The first possible detection of water ice in polar craters has been claimed by the radar team of *Clementine* mission [1], but this result was not supported later on by ground radar measurements [2]. Non-direct evidence for the presence of water ice in polar regolith was provided by *Lunar Prospector Neutron Spectrometer* (LPNS), as extended suppressions of neutrons emission around lunar poles [3]. However, poor spatial resolution of LPNS did not allow to resolve extended polar suppressions of neutrons, as contributions of individual local regions with high content of water ice – the alternative interpretation was also possible, which associate neutron suppression with average enhancement of hydrogen in the polar regolith . The first direct detection of H_2O and/or OH in the top layer of polar regolith was performed by IR mapping spectrometer M^3 onboard *Chandraiaan-1* mission [4], but IR data characterizes the upper most layer of few microns only.

The final proof for the presence of local areas with high content of water and another volatiles at lunar poles has been recently provided by direct measurements of NASA's LRO and LCROSS missions: orbital neutron telescope LEND of LRO has identified the crater of *Cabeus*, as the most promising impact site with high content of hydrogen [5], and instruments onboard LRO and LCROSS have measured direct signatures of water, H_2 and another volatiles in the plum material from the artificial impact crater [6, 7].

Observations: local water-rich areas at lunar poles, as Neutron Suppression Regions (NSRs). Currently available neutron data from LEND allowed to identify several local areas around both lunar poles, which might have rather high content of water ice about several % by mass within ~1 meter layer of subsurface. They are detected as *Neutron Suppression Regions*, or NSRs. Among all of them, the strongest suppression effect of epithermal neutrons is found for NSR of *Cabeus* [5]. Neutron emission from the Moon is produced by energetic particles of galactic cosmic rays inside the upper most 1 meter of subsurface. Primary neutrons have energy about several MeVs, and before leaking out, they are moderated down to epithermal and thermal energies by collisions with nuclei of regolith. Higher content of hydrogen in regolith provides more efficient thermalization of neutrons, so suppression of epithermal particles is the signature of presence of hydrogen: increasing suppression corresponds to higher content of hydrogen (e.g. see [5]).

The NSR of *Cabeus* has the total area of about 700 km^2 (see Figure, *top)*. Its northern part about 300 km^2 lies in the permanently shadowed region (PSR) of *Cabeus*: the surface of this part is never illuminated by Sun light, and its temperature is constantly below 100 K [8]. The southern part of *Cabeus* NSR is about 400 km^2. It is illuminated during polar day, when surface temperature at this part may increase well above 100 K, and water ice should intensively sublime from the regolith.

Another well-seen NSR with area about 1500 km^2 was detected within another polar crater *Shoemaker* (see Figure, *middle*). Its boundary coincides very well with the contour of PSR in the bottom of this crater. In this case the surface of NSR is permanently cold, and there are perfect conditions for permanent storage of frozen water in the regolith. On the other hand, there are many another craters at south and north poles, which also has PSRs, but do not manifest any detectable signature of neutron suppression.

The third example of strong local NSR is located around (130°E; 85°N) close to the north pole (see Figure, *bottom*). In this case NSR with total area of about 1400 km^2 does not overlap with any of PSRs at all.

Therefore, according to LEND mapping data there are all three cases of relationship between NSRs and PSRs: partial overlapping (crater *Cabeus*), full overlapping (crater *Shoemaker*) and no overlapping at all.

Questions to be addressed about "New Polar Moon": There are several questions about water-linked processes at recently found NSRs, which shall be addressed in the presented talk:

(1) *Which combination of physical conditions is necessary for a local area at lunar pole to become*

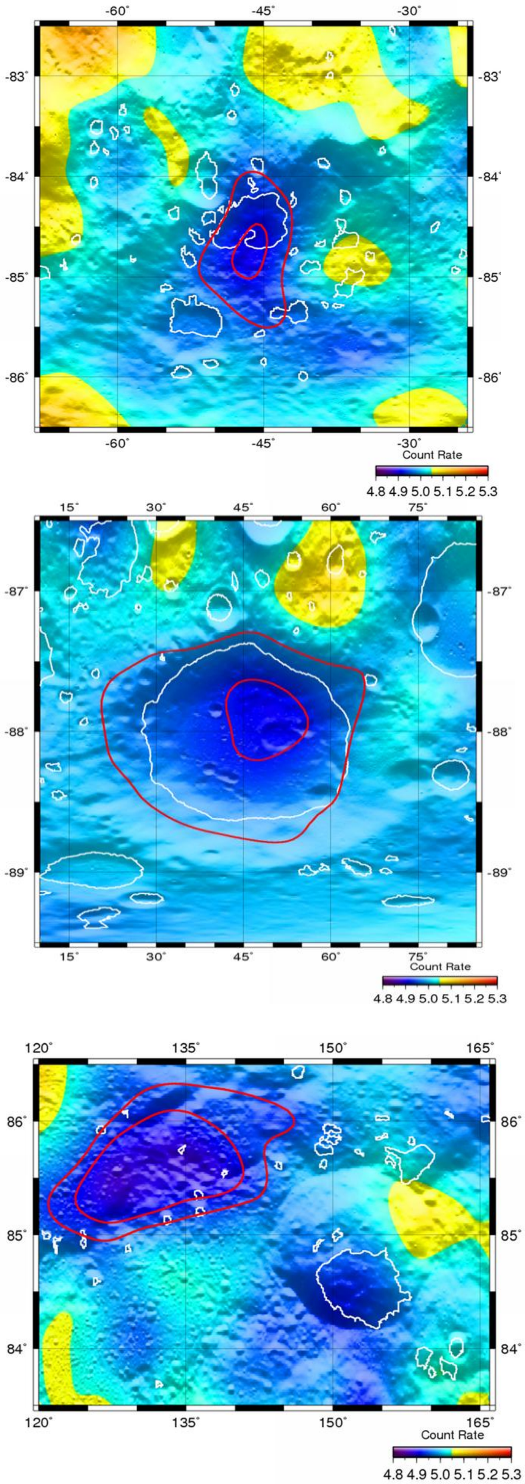

Figure. LEND maps of epithermal neutrons around crater *Cabeus* (*top*), crater *Shoemaker* (*middle*) and at (130°E; 85°N) (*bottom*), blue corresponds to suppressed flux of epthermal neutrons. Boundaries of NSRs and PSRs are shown by red and white contours, respectively. Surface relief is shown by grey shadow according to LOLA altimetry.

NSR with permanent water ice in the shallow subsurface? Initially one thought that permanent shadow could be enough and sufficient condition for deposition and preservation of water ice in regolith. Current experimental data does not support such a simple idea, many PSRs do not manifest suppression of epithermal neutrons, and there are cases, when NSRs have illuminated surface.

(2) *What is the origin of water in NSRs?* One hypothesis assumes that water was delivered to the Moon by comets. The hypothesis of “comet water” was generically related with the model of PSRs, as “cold traps” for water vapor from the post-impact transient atmosphere. “Comet water” was delivered in separate impact episodes, and one has to explain current location of water in NSRs by time history of these events. Second hypothesis proposes that lunar water is continuously produced in chemical reactions in regolith between implanted protons of solar wind and oxygen of the soil [9, 10].

(3) *Which process could transport water molecules over the surface from the place of initial release to the site of deposition?* Detection of local NSRs with enhancement of hydrogen and/or water points out that there should be some mechanism of “*horizontal migration*”, which delivers molecules toward some particular places of deposition on the lunar surface. It could be random ballistic hops of particles in the exosphere, but this process does not explain gathering of water molecules at some particular sun-lit areas of NSR. One should also consider the transport of water molecules by lunar dust grains, which migration over the surface could be driven by variable electrostatic field.

(4) *How could water propagate down to lunar subsurface?* The presence of water in the regolith in sunlit conditions points out that ice is the most likely preserved in the permanently cold layer of permafrost, which is covered by dry regolith, which temperature varies according to diurnal cycle of solar irradiation. Some kind of “*vertical migration*” transport should be considered for explanation of NSR formation, which brings water from the surface down to cold layer of permafrost.

References: [1] Nozette S. et al. (1996) *Science, 274*, 1495. [2] Campbell D. et al. (2006) *Nature, 443*, 835. [3] Feldman W. et al. (1999) *Science*, *281*, 1496. [4] Pieters C. et al. (2009) *Science. 326*, 568. [5] Mitrofanov I. et al. (2010) *Science, 330*, 483. [6] Colaprete A. et al. (2010) *Science, 339*, 463 [7] Gladstone R. et al. (2010) *Science*, *330*, 472 [8] Paige D. et al. (2010) *Science*, *330*, 479. [9] Crider D. and Vondrak R. (2003) *JGR, 108*, 5079. [10] Crider D. and Vondrak R (2003) *Adv. Space Sci.*, *31*, 2293.