SOLAR WATER PERMAFROST: IS IT DETECTED ON THE MOON? IS IT EXPECTED ON THE MERCURY?

I. Mitrofanov[1], D. Golovin[1], A. Kozyrev[1], M. Litvak[1], A. Malakhov[1] and A. Sanin[1], [1]Institute for Space Research, Profsojuznaja str. 84/32, 117997 Moscow, Russia, *imitrofa@space.ru*.

Introduction: There are only four unique places in the inner Solar System, which could contain such an exotic substance, as a *solar water*. The solar photosphere is known to produce the outflowing *solar wind*, which contains mainly ions of hydrogen. Among bodies of the inner Solar System, there are only the Mercury and the Moon, which surfaces interact directly with the solar wind, because they have no atmosphere. Hydrogen ions of solar wind penetrate to the uppermost layer of the regolith. They could escape back to the space either as atoms of H, or as the molecules of HO or H_2O. At the moderate latitudes, the surface of Moon and Mercury is heated by solar irradiation up to high temperatures >>100 °K, and water in regolith cannot be trapped.

However, the poles of the Mercury and the Moon are cold: the Sun rays are tangent to the surface, and heating is small. Moreover, there are particular regions at bottom of polar craters, which are permanently shadowed from sunlit (*Permanently Shadowed Regions*, PSRs). The surface temperature of lunar PSRs was directly measured, as 40 – 100 °K [1]. The surface temperature of PSRs at Hermean poles could be similarly small. If water ice would appear in the regolith at this temperature, it would stay there for infinitely long.

LRO detection of water ice permafrost on the Moon: Lunar Exploration Neutron Detector (LEND) of LRO measured the flux of epithermal neutrons with high spatial resolution ~10 km for the amplitude of 50 km. The LEND data from the polar caps above 80° latitude were tested for the presence of local spots of epithermal *Neutron Suppression Regions* (NSRs), which have been identified with water ice permafrost [2, 3]. Six such spots have been found, five at South pole and one at North pole (see Figure). One of them, the spot NSR S4 in the Cabeus crater, has been suggested, as the best impact site for direct evaluation of the content of lunar volatiles, including the water, by LCROSS instruments [4]. And indeed, a lot of water has been found in the plume, corresponding to 5.6 ± 2.4 weight % of water in the regolith of Cabeus [4].

Therefore, one may conclude that this and other detected NSRs at lunar poles (Figure) are the spots of lunar water ice permafrost.

The origin of water at lunar poles: The question should be understood, what is the origin of the water in NSRs. The model has been discussed (i.e. see [5]) that water could be delivered to the Moon by comets. When comets impact with the lunar surface, the vapor of *cometary* water from the temporal atmospheres condenses at cold traps of PSRs. This model predicts that all PSRs should be spots of water ice permafrost.

Two observational facts from LEND investigation do not agree with this model (see [2,3]:

- there are many PSRs, which do not manifest any detectable signatures of enhancement of hydrogen in the neutron data, and

- all detected NSRs, which are the candidates for spots of water ice permafrost, have sunlit surface, either partially or entirely.

Another model has been proposed (i.e. see [5]), which explains the origin of water at lunar poles by chemical reactions between hydrogen of solar wind with oxygen of lunar regolith. The so-called *solar* water could be produced under the sunlit surface, and than migrate either at cold traps in he local vicinity from the irradiated spot of origin, or at cold subsurface layer just below of the uppermost layer of origin.

This model still have many open questions for further considerations: the implantation of solar wind protons to the regolith at tangent angles to a surface, the chemistry of production of OH and H_2O in the regolith, the migration of water molecules from the point of origin to the point of deposition. However, the model has the important strength: it does not conflict with observations.

Testing the model of lunar polar permafrost by the data of Mercury observations: One could state that the basic physical conditions at poles of the Moon and the Mercury are rather similar:

- both bodies have a well-aligned polar axis in respect to the perpendicular to the ecliptic place – that is favorable for cold traps at their poles;

- both bodies are interacting with solar wind: that is favorable for hydrogen implantation into the subsurface;

- both bodies emit secondary neutrons due to bombardment by Galactic Cosmic Rays (GCRs).

Similarly to the Moon, there are data of radio sensing of Mercury, which points out that this planet might have the water ice deposits at poles [6]. Therefore, one may suspect that the main physics could also be similar at poles of the Moon and the Mercury:

- if the water ice deposits are on the lunar poles, they should be at the Hermean poles as well;

- if comets are not the main source for the water at lunar poles, they should not also be the main source for the polar water deposits on the Mercury.

However, one should also take into account that the Moon and the Mercury have rather different physics of interaction between the plasma of solar wind and the surface:

- the Mercury have the dipole magnetic field, which is large enough to shield the equatorial belt of the planet from the direct interaction with the plasma of solar wind [7];

- flux of solar wind and solar radiation at the orbit of Mercury are much larger than they are at the Earth orbit.

- the average temperature of illuminated spots at Hermean poles is much larger than the temperature of illuminated spots at poles of the Moon.

So, assuming the similarity between the origin of water ice permafrost at the Moon and the Mercury, and taking into account the physical differences at poles of these two celestial bodies, one may suggest that neutron data of the Mercury observations are very much useful to answer to both questions at the title of this paper.

Conclusions: In addition to current neutron data from LRO [2,3], the data from MESSENGER [8] should be studied for better understanding of polar water ice deposits at the Moon and at the Mercury. Additional data will be provided by neutron mapping [9] from the BeppiColombo spacecraft [10], which will map neutron albedo of bother Hermean poles (the MESSENGER maps only the southern hemisphere).

First of all, one have to test that Mercury have extended suppression regions of epithermal neutrons around both poles, as the Moon has. If hydrogen at polar regolith is delivered by the solar wind, the polar suppression of Mercury should be rather different from one of the Moon, because Hermean magnetosphere should chanelize the plasma of solar wind plasma toward the poles.

Second, one have to test the presence of local NSRs at the Hermean poles and to compare them with the lunar NSRs. If NSRs at both celestial bodies are associated with deposits of solar water, one could expect to find more water rich permafrost on the Mercury than on the Moon at areas with similarly cold surfaces, because at the same thermal conditions production rate of water molecules from the solar wind should be higher on Mercury than on the Moon.

References: [1] Paige D. (2010), *Science*, 330, 479. [2] Mitrofanov I. et al. (2010), *Science*, 330, 483-486. [3] Mitrofanov I. et al. (2012), submitted to *JGR-Planets*. [4] Colaprete A. (2010), *Science*, 330, 463. [5] Vondrak R.R. and Crider D.H. (2003), *American Scientist*, 91, 322-329. [6] Slade M. at al. (1992), *Science*, 258, 635. [7] Kallio E. and Janhunen P. (2003), *Annales Geophysicae*, 21, 2133-2145. [8] Solomon S. (2007), *Space Science Reviews*, 131, 1-4, 3 – 39. [9] Mitrofanov I. (2010), *Planetary and Space Science*, 58, 1-2, 116-124. [10] Benkhoff J. (2010), *Planetary and Space Science*, 58, 1-2, 2-20. [11] Mazarico E. (2011), *Icarus*, 211, 2, 1066 – 1081.

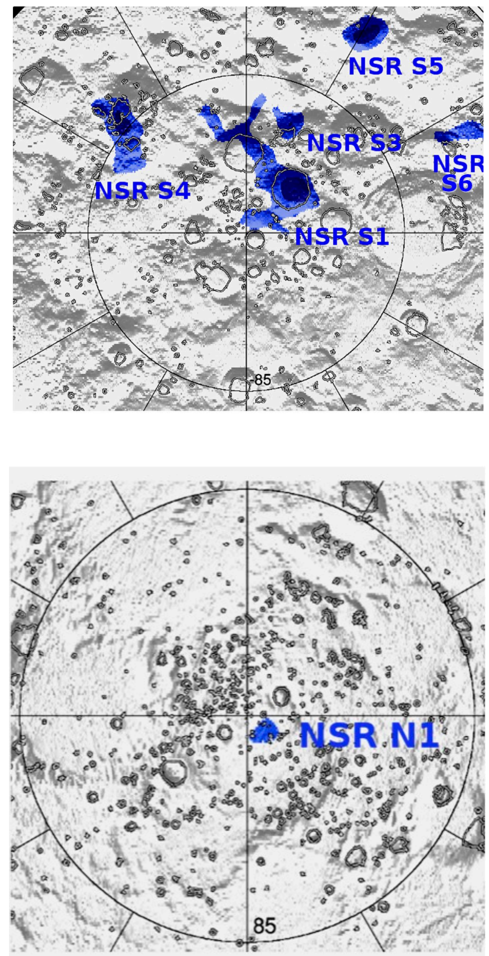

Figure: South (*top*) and North (bottom) poles: blue and dark blue spots represent local Neutron Suppression Regions (NSRs) detected by relative suppression thresholds -2.5% and -5.0% in LEND mapping data, respectively. Gray background represents the lunar relief according to LOLA data [11], and black contours show the boundaries of PSRs.