GEOTHERMAL ENERGY IN PLANETARY ICY LARGE OBJECTS VIA COSMIC RAYS MUON–CATALYZED FUSION. A. de Morais, Brazilian Center of Physics Research (Rua Dr. Xavier Sigaud, 150, 3º andar, Urca, Rio de Janeiro, RJ, 22290-180, Brasil, Email: antonioamore@yahoo.com).

Introduction: In this brief paper, we propose the possibility that p^+-d^+ and d^+-d^+ fusions intermediated and catalyzed by the elementary particles muons (μ^-), produced by cosmic rays, might hypothetically add energy to geothermal reservoirs in the interior of planetary icy large objects of the Solar System, and of other extra-solar planetary systems, interesting for astrobiological considerations. We are learning that Pluto (and to a lesser extent, Charon) show complex, dynamical, present geologic activity. Models involving tidal dissipation, which would indicate geologically "quiet" worlds, do not account for such present geological activity at Pluto, as for the existence of tidal dissipation is necessary orbital eccentricity, which is practically zero in the Pluto–Charon system. Besides such forms of geothermal energy sources as tidal and radiogenic heating, there is another one, fusion of protons in planetary interiors which was mentioned in the literature. It is usually assumed that such nuclear reactions occur only in the stars interiors, but there is an elementary particle, muon (μ^-), that can intermediate such reactions in the low-temperature planetary conditions (as compared as to temperatures inside stars). This natural phenomenon is known as muon–catalyzed fusion (MCF). The most abundant source for muons is cosmic rays, which origins are solar, galactic and extra-galactic. Daily on planet Earth, an enormous quantity of high (~ 10^2 MeV) to extremely high (> 100 TeV), and higher energy (~ 10^{19} eV) protons and nuclei strike nuclei of atoms in the atmosphere, producing cascades of pions (other elementary particle) which decay into muons. Such muons arrive at the Earth surface with energies ranging typically from 10 GeV to 100 TeV and, depending on their energies and on the material, they can penetrate most deeply into liquid and ices than into rocks. For instance, for E_μ = 10 GeV it can penetrate 0.05 Km, and for E_μ = 10 TeV it can penetrate 6.09 Km into rocks. Inside the ices of Antarctica it was measured many muons as deep as 7 km, and inside the Baikal lake it was measured muons at 6 Km deep, and at the Mediterranean sea it was measured muons at > 10 Km deep. About data on cosmic rays in the Solar System, we are fortunate because the two Voyagers are in operational status. The Voyagers' cosmic ray subsystem measured a somewhat spatial steady flux of cosmic rays throughout their trajectories in the Solar System, but varying in time and anti-correlated with sunspots activity. The measured fluxes began to rise in the outer regions of the heliosphere, where the Sun's magnetosphere is weaker due to the distance. For objects in the outer Solar System, an enormous quantity of muons are daily produced by an enormous quantity of cosmic rays striking the icy surfaces of the Jovian moons, and of the Trans–Neptunian Objects (TNOs) as the dwarf planet Pluto. During the flybys of the Jupiter and Saturnian systems by the Voyagers, they collected data on the energy and flux of high-energy cosmic rays protons trapped into the Jovian magnetospheres, fed constantly. The trapped protons energies of ~ 10^2 Mev to 1 GeV in the leading and trailing sides of both planets bombards constantly their moons, creating continuous showers of muons into their interiors. For more MCF to occur it is necessary the existence of a large quantity of deuterons. The observed D/H ratio in the inner Solar System is ~ 10^{-4}, which are believed to be higher in the outer Solar System, perhaps with D/H ~ 10^{-3}. These ratios are small, but due to the fact the icy bodies are so abundant in the Solar System, the quantity of deuterons might be sufficient for regular MCF to occur via cosmic rays muons. So, integrating time over 4 Gyrs, there was enough time for many muons to have intermediated catalyzed fusion via pdμ and ddμ reactions, yielding regular energy for the interiors of large icy objects in the Solar System. Even being so small in geological energy terms (1 GeV = 1.6 x 10^{-10} J) such MCF energy might have being significant for the energy balance inside the primitive Earth, Mars, the Jovian icy moons, the icy TNOs, and icy worlds of extra-solar planetary systems. Such deposited fusion energy might hypothetically be significant for geological activities observed on the surfaces of the Jovian moons and Pluto, with $\langle T_s \rangle$ ~ 110 K and $\langle T_s \rangle$ ~ 44 K, respectively, and other icy TNOs. In such low temperatures, a small quantity of fusion energy might appear on the surface as geological activity. And we also propose that MCF might also be significant for the energy balance in the formation of geothermal reservoirs (with liquid water) inside those icy large objects (hydrated minerals, ponds, small lakes and seas), long enough in time for the maintenance of internal chemistries interesting for astrobiology.