Do protons decay? The answer might be on the moon

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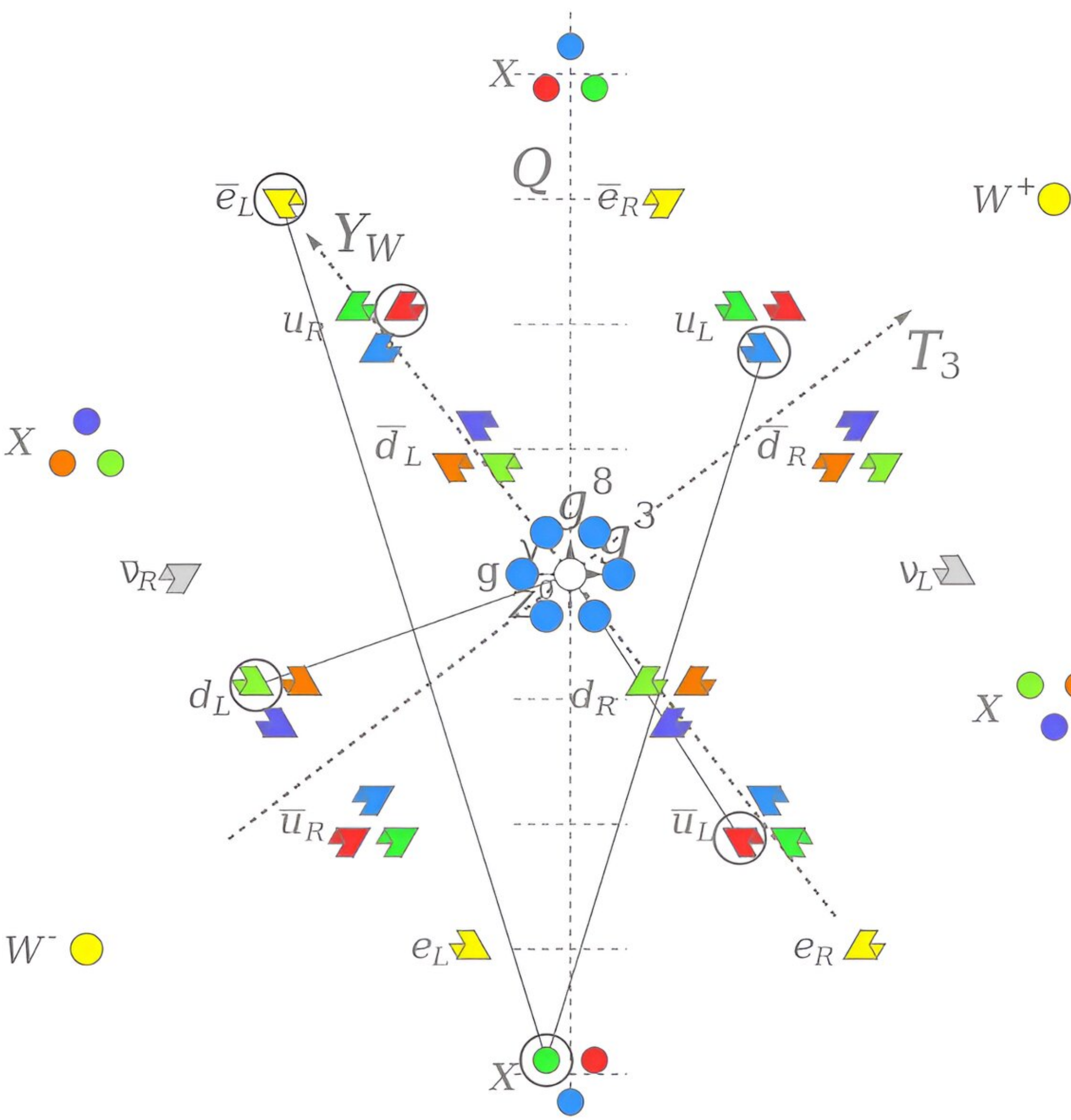

Model of proton decay. Credit: Wikipedia/Cjean42; Creative Commons Attribution-Share Alike 3.0 Unported license

Does proton decay exist and how do we search for it? This is what a recently submitted study to the *arXiv* preprint server hopes to address as a team of international researchers investigate a concept of using samples from the moon to search for evidence of proton decay, which remains a hypothetical type of particle decay that has yet to be observed and continues to elude particle physicists.

This study holds the potential to help solve one of the longstanding mysteries in all of physics, as it could enable new studies into deep-level and the laws of nature, overall.

Here, Universe Today discusses this research with Dr. Patrick Stengel, who is a postdoctoral fellow in the Cosmology Group at INFN Ferrara Division, regarding the motivation behind the study, significant results, significance of searching for proton decay, implications for confirming the existence of proton decay, and turning their concept into reality. Therefore, what is the motivation behind the study?

Dr. Stengel tells Universe Today this research started around 2018 with lead author, Dr. Sebastian Baum, and other scientists regarding the use of paleo-detectors, which is a proposed method to examine particles that span vast periods of geological timeframes.

This led to discussions with study co-author, Dr. Joshua Spitz—who became interested in paleo-detectors after several papers examined their potential to search for dark matter—and one of Dr. Spitz's Ph.D. students, regarding how paleo-detectors could be used to discover the existence of proton decay. However, the team published a study discussing how finding proton decay on Earth wasn't possible due to atmospheric neutrinos.

"About one year after finishing atmospheric neutrino paper, Spitz suggested we consider mineral samples from the moon," Dr. Stengel tells Universe Today. "Due to the lack of an atmosphere, the cosmic ray-induced neutrino flux on the moon is highly suppressed compared to the Earth. The corresponding suppression of the cosmic ray-induced neutrino interactions in paleo-detectors allows for a search for proton decay to at least be feasible in principle."

For the study, the researchers proposed a hypothetical concept using paleo-detectors that would involve collecting mineral samples from more than 5 kilometers (3.1 miles) beneath the lunar surface and analyzing them for presence of proton decay, either on the moon itself or back on Earth.

The researchers note these lunar paleo-detector samples could yield proton lifetimes up to 10^{34} years. For context, the age of the universe is approximately 13.7 x 10^{9} years. Therefore, what are the most significant results from this study?

Dr. Stengel tells Universe Today, "For a lunar mineral sample which is both sufficiently radiopure to mitigate radiogenic backgrounds and buried at sufficient depths for shielding from other cosmic ray backgrounds, we show that the sensitivity of paleo-detectors to proton decay could in principle be competitive with next-generation conventional proton decay experiments."

As noted, proton decay continues to be a hypothetical type of particle decay and was first proposed in 1967 by the Soviet physicist and Nobel Prize laureate, Dr. Andrei Sakharov. As its name implies, proton decay is hypothesized to occur when protons decays into particle smaller than an atom, also called subatomic particles.

As noted by this recent study and various previous studies, proton decay has yet to be discovered or observed. However, it is hypothesized to have the potential for better understanding our universe and the origin of life with quantum tunneling being proposed as a process of proton decay.

Therefore, what is the significance of searching for proton decay, and what implications could its existence have for science, and specifically the field of particle physics, overall?

Dr. Stengel tells Universe Today, "Proton decay is a generic prediction of particle physics theories beyond the Standard Model (SM). In particular, proton decay could be one of the only low energy predictions of so-called Grand Unified Theories (GUTs), which attempt to combine all of the forces which mediate SM interactions into one force at very high energies. Physicists have been designing and building experiments to look for proton decay for over 50 years."

Dr. Stengel continues, "The discovery of proton decay, whether in a mineral detector or a more conventional experiment, would have incredible implications for science in general and particle physics in particular. Such a discovery would be the first confirmation of particle physics beyond the SM. Depending on how well the proton decay signal could be characterized, we could learn something about the fundamental theory of nature."

As noted, the hypothetical concept proposed by this study using paleo-detectors to detect proton decay on the moon would require collecting samples at least 5 kilometers (3.1 miles) beneath the lunar surface. For context, the deepest humans have ever collected samples from beneath the lunar surface was just under 300 centimeters (118 inches) with the drill core samples obtained from the Apollo 17 astronauts.

On Earth, the deepest human-made hole is the Kola Superdeep Borehole in northern Russia and measures approximately 12.3 kilometers (7.6 miles) in true vertical depth, along with requiring several holes to be drilled and several years to achieve. While the study notes the proposed concept using paleo-detectors on the moon is "clearly futuristic," what steps are required to take this concept from futuristic to realistic?

Dr. Stengel tells Universe Today, "As we are careful not to stray too far from our respective areas of expertise related to particle physics, we chose not to speculate much at all about the actual logistics of performing such an experiment on the moon. However, we also thought that this concept was timely as various scientific agencies across different countries are considering a return to the moon and planning for broad program of experiments."

Dr. Stengel continues, "As you mention, the mineral samples would need to be extracted from at least about 5 km deep in the lunar crust. Thus, there would need to be a drilling rig delivered to and operated on the moon which is capable of reaching such depths. While this logistical challenge seems daunting, we point out that, e.g., NASA envisions sufficiently large payloads eventually being delivered to the moon as part of the Artemis program."

As noted, this study comes as NASA's Artemis program plans to return astronauts to the lunar surface for the first time in more than 50 years with the goal of landing the first woman and person of color on the lunar surface, as well. Additionally, as scientific interest in paleo-detectors continues to grow, the concept proposed in this study could prove to be scientifically beneficial for not only discovering proton decay, but for us better understanding our place in the universe. Finally, it turns out that only a small sample will be necessary to make this proposed concept worth it.

Dr. Stengel tells Universe Today, "Due to the exposure of paleo-detectors to proton decay over billion-year timescales, only one kilogram of target material is necessary to be competitive with conventional experiments. In combination with the scientific motivation and the recent push towards returning humans to the moon for scientific endeavors, we think paleo-detectors could represent the final frontier in the search for proton decay."

More information: Sebastian Baum et al, The Final Frontier for Proton Decay, *arXiv* (2024). DOI: 10.48550/arxiv.2405.15845

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