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Gravitino, a new candidate for Dark Matter

Dark Matter remains one of the biggest mysteries in fundamental physics. Many theoretical proposals (axions, WIMPs) and 40 years of extensive experimental search failed to provide any explanation of the nature of Dark Matter. Several years ago, in a theory unifying particle physics and gravity, new, radically different Dark Matter candidates were proposed, superheavy charged gravitinos. Very recent paper in Physical Review Research by scientists from the University of Warsaw and Max Planck Institute for Gravitational Physics, shows how new underground detectors, in particular JUNO detector starting soon to take data, even though designed for neutrino physics, are also extremely well suited to eventually detect charged Dark Matter gravitinos. The simulations combining two fields, elementary particle physics and very advanced quantum chemistry, show that the gravitino signal in the detector should be unique and unambiguous.

In 1981 Murray Gell-Mann, Nobel Prize laureate for the introduction of quarks as fundamental constituents of matter, noticed the intriguing fact that the particles of the Standard Model, quarks and leptons, are contained in a theory formulated purely mathematically 2 years earlier, N=8 supergravity, distinguished by its maximal symmetry. N=8 supergravity contains, besides Standard Model matter particles of spin 1/2, also gravitational part: graviton (of spin 2) and 8 gravitinos of spin 3/2. If the Standard Model is indeed related to N=8 supergravity, the relation may possibly point to a path to solve the most difficult problem of fundamental theoretical physics -- unifying gravity with particle physics. N=8 supergravity in the spin 1/2 sector contains exactly 6 quarks (u,d,c,s,t,b) and 6 leptons (electron, muon, tauon and neutrinos) and forbids the presence of any other matter particles. After 40 years of intensive accelerator research failing to discover any new matter particles the N=8 supergravity matter content is not only consistent with our knowledge but remains the only known theoretical explanation of the number of quarks and leptons in the Standard Model! However, direct connection of N=8 supergravity with the Standard Model had several

drawbacks, the main one being that the electric charges of quarks and leptons were shifted by $\pm 1/6$ with respect to the known values, for example electron had charge $-5/6$ instead of -1 . Several years ago Krzysztof Meissner from the Faculty of Physics at the University of Warsaw, Poland and Hermann Nicolai from the Max Planck Institute for Gravitational Physics (Albert Einstein Institute/AEI), Potsdam, Germany returned to the Gell-Mann's idea and were able to go beyond $N=8$ supergravity and modify the original proposal obtaining correct electric charges of the Standard Model matter particles. The modification is very far reaching pointing to an infinite symmetry $K(E_{10})$, little known mathematically and replacing the usual symmetries of the Standard Model.

One of the surprising outcomes of the modification, described in papers in *Physical Review Letters* and *Physical Review*, is the fact that the gravitinos, presumably of the extremely large mass close to the Planck scale i.e. billion billion proton masses, are electrically charged: 6 of them have charge $\pm 1/3$ and 2 of them $\pm 2/3$. The gravitinos, even though they are extremely massive, cannot decay since there are no particles they could decay into. Meissner and Nicolai proposed therefore that 2 gravitinos of charge $\pm 2/3$ (the other 6 have much lower abundance) could be Dark Matter particles of very different kind than anything proposed so far. Namely, the widely advertised usual candidates, either extremely light like axions or intermediate (proton) mass like WIMPs (weakly interacting massive particles) were electrically neutral, in compatibility with the name 'Dark Matter'. However, after more than 40 years of intensive search by many different methods and devices no new particles beyond the Standard Model were detected.

However, gravitinos present a new alternative. Even though they are electrically charged, they can be Dark Matter candidates because being so massive they are extremely rare and therefore observationally 'do not shine on the sky' and avoid the very tight constraints on the charge of Dark Matter constituents. Moreover, the electric charge of gravitinos suggested a completely different way of trying to prove their existence. The original paper in 2024 in *Eur. Phys. J.* by Meissner and Nicolai pointed out that neutrino detectors, based on scintillators different from water, could be suitable for the detection of Dark Matter gravitinos. However, the search is made enormously difficult by their extreme rarity (presumably only one gravitino per 10,000 km^3 in the Solar System), which is why there is no prospect of detection with currently available detectors. However, new giant, oil or liquid argon underground detectors, are either constructed or planned and realistic possibilities for searching for these particles are now opening up.

Among all detectors, the Chinese Jiangmen Underground Neutrino Observatory (JUNO) now under construction, seems predestined for such a search. It aims to determine the properties of neutrinos (actually antineutrinos) but since neutrinos interact extremely weakly with matter the detectors must have very large volumes. In the case of the JUNO detector, this means 20,000 tons of an organic, synthetic oil-like liquid, commonly used in chemical industry, with special additions, in a spherical

vessel with a diameter of approximately 40 meters with more than 17 thousand photomultipliers around the sphere. JUNO is scheduled to begin measurements in the second half of 2025.

The recently published paper in *Physical Review Research* by Meissner and Nicolai, with collaborators Adrianna Kruk and Michal Lesiuk from the Faculty of Chemistry at the University of Warsaw, presents a detailed analysis of the specific signatures that events caused by gravitinos could produce at JUNO and in future liquid argon detectors such as the Deep Underground Neutrino Experiment (DUNE) in the United States. The paper describes not only the theoretical background both on the physics and chemistry sides but also very detailed simulation of the possible signatures as a function of the velocity and track of a gravitino traveling through the oil vessel. It required very advanced knowledge of quantum chemistry and intensive CPU-time consuming calculations. The simulations had to take into account many possible backgrounds – decay of radioactive C14 present in the oil, dark count rate and efficiency of photomultipliers, absorption of photons in oil etc. The simulations show that, with the appropriate software, passage of a gravitino through the detector will leave a unique signal impossible to be wrongly identified with a passage of any of the presently known particles. The analysis sets new standards in terms of interdisciplinarity by combining two different areas of research: theoretical and experimental elementary particle physics on one hand and very advanced methods of modern quantum chemistry on the other.

The detection of the superheavy gravitinos would be a major step forward in the search for a unified theory of gravity and particles. Since gravitinos are predicted to have masses on the order of the Planck mass, their detection would be the first direct indication of physics near the Planck scale and could thus provide valuable experimental evidence for a unification of all forces of nature.

Faculty of Physics at the University of Warsaw

Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics, the Department of Mathematical Methods in Physics, and the Astronomical Observatory. The research covers almost all areas of modern physics on scales from quantum to cosmological. The Faculty's research and teaching staff consists of over 250 academic teachers. About 1,100 students and over 170 doctoral students study at the Faculty of Physics UW. The University of Warsaw is among the 300 best universities in the world, educating in the field of physics according to Shanghai's Global Ranking of Academic Subjects.

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YOUTUBE CHANNEL:

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