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A new framework could aid the search for heavy thermal dark matter

November 26 2019, by Ingrid Fadelli

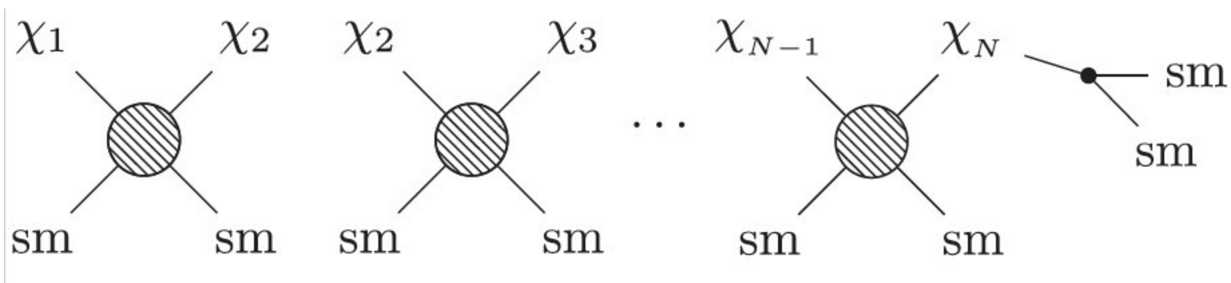

Figure outlining the mechanism proposed by the researchers. Credit: Kim & Kuflik.

Astrophysicists have been searching for dark matter for several decades, but these searches have so far yielded disappointing results. In a recent study, two researchers at Weizmann Institute of Science and the Hebrew University of Jerusalem in Israel have introduced a new theoretical framework outlining a mechanism of elementary thermal dark matter with a mass up to 10^{14} GeV.

The dark matter considered in their work consists of several almost degenerate particles that scatter in the nearest-neighbor chain in a way that is aligned with the standard model used in dark matter studies. The new framework presented by these researchers, outlined in a paper published in *Physical Review Letters*, could ultimately inform future searches for heavy dark matter.

"The nature of dark matter is a longstanding problem in modern day physics," Hyungjin Kim, one of the researchers who carried out the study, told Phys.org. "A particle that is as heavy as Higgs boson, and is involved in interactions whose strength is that of electroweak interaction, is thought to be a particularly well-motivated dark matter candidate, as it often naturally arises when addressing another key problem: the hierarchy between the electroweak scale and the Planck scale."

The particle that is thought to be a good dark matter candidate, known as a weakly interacting massive particle (WIMP), could be produced naturally from interactions between standard model particles in the early universe while they are in thermal equilibrium. This particular process goes by the name of the 'thermal freeze-out mechanism."

Based on current astrophysics theory, the final abundance of WIMPs in our universe today would thus be insensitive to details of initial conditions or model parameters. However, a common lore originating from a 1990 paper by Kim Griest and Marc Kamionkowski suggests that this thermal freeze-out mechanism does not work when dark matter is heavier than 100 TeV (i.e., a thousand times heavier than the Higgs boson).

"In our recent paper, we prove this common lore wrong and show that thermal freeze-out is possible even when dark matter is several orders of magnitude heavier than the Higgs mass, if there are a set of dark particles that scatter off the standard model particles with nearest-neighbor interactions," Eric Kuflik, the other researcher behind the study, said. "The relic abundance of the dark matter is then determined by stochastic interactions between the dark particles and the Standard Model particles."

The mechanism proposed by Kim and Kuflik describes a set of dark matter particles scattering with ordinary matter through nearest-neighbor interactions, which change between species. In other words, it suggests that the dark matter takes a 'random walk' among dark matter species, continuously changing its identity. Based on the framework introduced by the researchers, therefore, the abundance of dark matter is thermally determined in the early universe, enabling extremely heavy dark matter masses.

"We have shown that dark matter can be produced from the early universe thermal bath while being in thermal equilibrium, even for dark matter masses substantially heavier than conventional wisdom would allow," Kim explained. "Interestingly, the abundance of dark matter particles in our scenario depends only on the interaction strength of the dark particles with the Standard model particles."

The new framework developed by Kim and Kuflik could have important implications for studies investigating the cosmic microwave background, structure formation and cosmic rays. In addition, it could serve as a benchmark for heavy dark matter experimental searches, as it suggests that decays to ordinary matter particles in the late universe could leave interesting astrophysical and cosmological signatures, which researchers could look for when searching for dark matter.

"There are two promising directions we hope to pursue in our future work," Kim said. "First, our mechanism inevitably predicts dark matter particles decaying to Standard Model particles throughout the history of the universe. This could leave interesting astrophysical signatures, such as ultra-high energy cosmic rays and so on. The implications for cosmology are also interesting."

So far, Kim and Kuflik have described the basic idea of superheavy dark matter and provided a 'simple toy model' of it by parameterizing the interaction strength between dark particles and standard model particles. In their next studies, however, Kim and Kuflik plan to conduct a detailed study of particle physics theories that could realize their mechanism of superheavy thermal dark matter.

"Explicit realizations in particle physics will help to identify the full suite of experimental signals predicted by the mechanism, which will teach us the best means to either exclude or detect such dark matter," Kuflik added.

More information: Hyungjin Kim et al. Superheavy Thermal Dark Matter, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.191801

Kim Griest et al. Unitarity limits on the mass and radius of dark-matter particles, *Physical Review Letters* (2002). DOI: 10.1103/PhysRevLett.64.615