A Little Theory of Everything

The standard model of particle physics is tremendously successful in describing the properties of the known particles, but it doesn't account for several key phenomena that we think must be there. Cosmological inflation is widely believed to provide the seed density perturbations in the early Universe that condensed to form galaxies, stars, and planets. Dark matter is known to also be crucial in this process. And our existence depends on there being more matter than antimatter in the Universe. All of these are unexplained by the standard model, which also fails to account for the tiny observed masses of neutrinos.

In our work, we provided a new framework to supply these missing ingredients in a novel and economical way, that ties them closely together rather than considering them as disconnected pieces of a puzzle. First we proposed a new theory of inflation (when the Universe undergoes a super-fast period of expansion) that produces the particle-antiparticle asymmetry during inflation instead of afterwards, as is normally assumed. In other words we don't need a separate mechanism to make the asymmetry: inflation does it for us.

This asymmetry is originally stored in three new species of heavy neutrinos (called Heavy Neutral Leptons, HNLs). Two of these transfer the asymmetry from the inflation to standard model particles, eventually becoming the ordinary matter that comprises us. The third is the dark matter, with a mass of the same order as that of the proton. Our theory predicts it is a stable particle (as dark matter should be) if the lightest neutrino is exactly massless, which is a surprising connection between two particles that are usually assumed to be unrelated. The two other HNLs are unstable and can be discovered in laboratory experiments that are currently under development.

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Why this is important

We present a minimal framework that supplies all the ingredients missing from the standard model of particle physics — inflation, baryogenesis, dark matter, and the origin of neutrino masses —and ties them together in an interesting and testable way.

Below: Predictions for the dark matter particle mass, coupling, and density from the theory. [Source: arXiv:2001.11505]