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Abstract

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The Planckian Paradigm
for
Dark Matter

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Numerous cosmological and astrophysical observations show that a significant fraction of matter in the Universe is non-baryonic, cold and dark. The existence of dark matter provides strong evidence for physics beyond the Standard Model of particle physics. Extensions of the Standard Model involving the Peccei-Quinn symmetry or supersymmetry give rise to compelling dark matter candidates. Nonetheless, the Standard Model could be self-consistent up to the Planck scale according to the present measurements of the Higgs boson mass and top quark Yukawa coupling. It is therefore possible that new physics is only coupled to the Standard Model through Planck suppressed higher dimensional operators. In this case the weakly interacting massive particle miracle is a mirage, and instead minimality as dictated by Occam's razor would indicate that dark matter is related to the Planck scale, where quantum gravity is anyway expected to manifest itself.

Planckian Interacting Dark Matter (PIDM) is a minimal scenario of dark matter assuming only gravitational interactions with the standard model and with only one free parameter, the PIDM mass. PIDM can be successfully produced by gravitational scattering in the thermal plasma of the Standard Model sector after inflation in the PIDM mass range from TeV up to the GUT scale, if the reheating temperature is sufficiently high. The minimal assumption of a GUT scale PIDM mass can be tested in the future by measurements of the primordial tensor-to-scalar ratio. While large primordial tensor modes would be in tension with the QCD axion as dark matter in a large mass range, it would favour the PIDM as a minimal alternative to WIMPs.

In a simple extension of the PIDM framework, the PIDM is charged under an unbroken $U(1)$ gauge symmetry, but remains only gravitationally coupled to the Standard Model (SM). Contrary to "hidden charged dark matter", the charged PIDM never reaches thermal equilibrium with the SM. The dark sector is populated by freeze-in via gravitational interactions at reheating. If the dark fine-structure constant α_D is larger than about 10^{-3}, the dark sector thermalizes within itself, and the PIDM abundance is further modified by freeze-out in the dark sector. Interestingly, this largely reduces the dependence of the final abundance on the reheating temperature, as compared to an uncharged PIDM. The observed CDM abundance can be obtained over a wide mass range from the weak to the GUT scale, and for phenomenologically interesting couplings $\alpha_D \sim 10^{-2}$. Due to the different thermal history, the charged PIDM can be discriminated from "hidden charged dark matter" by more precise measurements of the effective number of neutrino species N_{eff}.

Purely gravitational atoms are created together with dark matter particles in the minimal PIDM scenario. In general, particles in a yet unexplored dark sector with sufficiently large mass and small gauge coupling may form purely gravitational atoms (quantum

gravitational bound states) with a rich phenomenology. Decays of gravitational atoms can source gravitational waves or ultra high energy cosmic rays. If ordinary Einstein gravity holds up to the Planck scale, then, within the ΛCDM model, the frequency of the gravitational wave signal produced by the decays is always higher than 10^{13} Hz. An observable signal of gravitational waves with smaller frequency from such decays, in addition to probing near Planckian dark physics, would also imply a departure from Einstein gravity near the Planck scale or an early epoch of non-standard cosmology. For example, an early universe cosmology with a matter-dominated phase can give a signal in an interesting frequency range for near Planckian bound states.

If Einstein gravity with minimally coupled matter is valid up to the Planck scale, gravitational as well as non-gravitational atoms absorb gravitons of a specific frequency with Planckian cross section, $\sigma_{\text{abs}} \approx l_p^2$. Consequently, one can show that gravitational absorption by bound states is inefficient in ordinary gravity. If observed, gravitational absorption lines would therefore constitute a powerful smoking gun of new exotic astrophysical bound states (near extremal bound states) or new gravitational physics, as well as give direct evidence of the quantized nature of the gravitational field. A non-minimal coupling of the matter fields which breaks the equivalence principle on-shell provides a clear example of new gravitational physics near the Planck scale. In certain models, absorption lines in the primordial gravitational wave spectrum can be produced as a consequence of this coupling.