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The first Stars in the Universe as Dark Matter Laboratories

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Authors: Cosmin Ilie, Caleb Levy, Jacob Pilawa, Katherine Freese, Saiyang Zhang

The first stars in the Universe, soon to be observed with the James Webb Space Telescope (JWST) can be extremely powerful DM probes. If DM does not play a significant role in the formation of some of the first stars, then, zero metallicity Hydrogen burners (Population III stars) form. Conversely, for scenarios where DM plays a significant role during the formation of a star from a primordial gas cloud, Dark Stars (DS) can form. The later are powered by DM annihilations and can grow to be supermassive (SMDSs), with masses as large as a million suns. As such, SDMSs are easily observable with JWST. The discovery of any Dark Star would constitute indirect evidence of annihilating Dark Matter. For more details on Dark Stars please see talk by Katherine Freese: "Dark Stars in JWST and Roman Space Telescope."In our presentation we mainly focus on the role of Population III stars as DM laboratories, and how the method we propose complements Direct Detection experiments, as explained in detail in PRD 104 (123031).

Dark matter (DM) can be trapped by the gravitational field of any star, since collisions with nuclei in dense environments can slow down the DM particle below the escape velocity (vesc) at the surface of the star. If captured, the DM particles can self-annihilate, and, therefore, provide a new source of energy for the star. We investigate this phenomenon for capture of DM particles by the first generation of nuclear burning stars [Population III (Pop III) stars], by using the multiscatter capture formalism. Pop III stars are particularly good DM captors, since they form in DM-rich environments, at the center of ~10ˆ6 M☒ DM minihalos, at redshifts z ~ 15. Assuming a DM-proton scattering cross section (σ) at the current deepest exclusion limits provided by the XENON1T experiment, we find that captured DM annihilations at the core of Pop III stars can lead, via the Eddington limit, to upper bounds in stellar masses that can be as low as a few M☒ if the ambient DM density (ρX) at the location of the Pop III star is sufficiently high. Conversely, when Pop III stars are identified, one can use their observed mass to place bounds on the product between the ambient DM density and the proton-DM scattering cross section (sigma). Using adiabatic contraction to estimate the ambient DM density in the environment surrounding Pop III stars, we place projected upper limits on σ, for Pop˜III stars in the 100 M☒–1000 M☒ range, and find bounds that are competitive with, or deeper than, those provided by the most sensitive current direct detection experiments for both spin-independent and spin-dependent (SD) interactions, for a wide range of DM masses. Most intriguingly, we find that Pop III stars with mass M☒ ☒ 300 M☒ could be used to probe the SD proton-DM cross section below the "neutrino floor,"i.e. the region of parameter space where DM direct detection experiments will soon become overwhelmed by neutrino backgrounds. Conversely, if Direct Detection experiments pin down the proton-DM cross section, our method can be used to constrain the DM densities at the center of high redshift mini halos, a parameter which is unaccessible via current or foreseeable future dynamic measurements and for which we currently only have simulations to rely on.

Primary author: ILIE, Cosmin (Colgate University)

Presenter: ILIE, Cosmin (Colgate University)

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