Massive Pop III Star Formation via Dark Matter Annihilation

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Abstract
We present the preliminary results of the protostellar evolution simulation of Population-III stars under the metal-free environment and influence of dark-matter minihalos (~10^5 M☉/halo). The leading model of dark matter particles is Weakly Interacting Massive Particles (WIMPs) with mass ranges 1GeV-1TeV (Fermi-LAT 2015). The self-annihilations of these particles could provide enough heating energy to support the protostar up to very high mass (~1,000 - 10,000 M☉), potential progenitors for very massive black holes. The WIMP annihilation luminosity is proposed to be a power law of the protostar radius, L_{wimp}~R^3 (Natarajan, Tan, O’Shea 2009). We investigate the effect of different WIMP masses, WIMP capture models, and the combination of different scenarios to the final mass of the pop III protostars.

WIMP Mass & Capture Models:
While Equation 1 should hold for all WIMP mass, R, and p_{wimp} are different. R = 1, 10, 100 AU and \( p_{wimp} = 10^4, 10^2, 10^0 \) GeV/cm^2 for M = 1 TeV, 100 GeV, and 10 GeV, respectively. This different in core radius also affects the wimp luminosity generated within the protostars, in turn affects their evolution and final mass (see Figure 2 and 3).

WIMP capture model, or how the protostar replenish their DM particles also affect their evolution (also see Figure 3 and 4).

Model A: \( C \sim m_{WIMP}/M_{int} \) … (2)
Model B: \( C \sim \rho_{wimp} \delta M_{dm}/dR \) (Spolyar et al. 2009)

Accretion Rate & Core Percentage:
As we see before, different WIMP capturing models could yield substantial difference in the final mass of a pop III protostar. Accretion rate and core percentage also impact the final mass as well. As in Figure 6, for capture model A, k=3 could produce a factor of \( \sim2 \) more massive pop III stars than k=1, where \( M_{final} \sim k^{15/7} \). The effect may be more subtle in for model B, since WIMP replenish rate is not directly proportional to accreted mass as Model A. For model B, at M=100 GeV, core percentage, or the region where WIMP luminosity is input, yield the factor of \( \sim2 \) in final mass as well, when going from injected WIMP annihilation energy into the central 10% to 5% of the total mass, as in Figure 7.

References:
Fermi-LAT Collaboration, 2015, arXiv. 1511.02938