Dark Kinetic Heating in Population III stars

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Introduction

Dark Kinetic Heating is the phenomenon whereby a star’s temperature rises due to the transfer of kinetic energy from Dark Matter particles to the star after either single or multiple collisions.

There exist multiple ways in which a star’s temperature could increase due to effects concerning Dark Matter, so the aim is to compare the effects of Dark Kinetic Heating in Population III stars with those of Dark Matter Annihilation, which were studied by former students.

Single Collision Capture

One can start with a simple model in which Dark Matter particles are captured inside the star after a single collision. Tb he transfer of kinetic energy in an average collision between a Dark Matter particle and a Hydrogen atom is given by

$$\Delta E \simeq 2\,\frac{\mu_n^2}{m}\,v_{esc}^2$$

Where $\boldsymbol{\mu}_n$ is the reduced mass of the Dark Matter particle-proton system, m is the mass of the proton, and v_{esc} is the speed of the Dark Matter particle with respect to the star.

In this model, the Dark Matter particles are captured after a single collision with the constituents of the star. This model is valid for low energy Dark Matter particles, which would have a low impact speed, or low mass. At higher Dark Matter masses, a single collision would not be enough for the particles to be captured inside the star, and multiple collisions would be required.

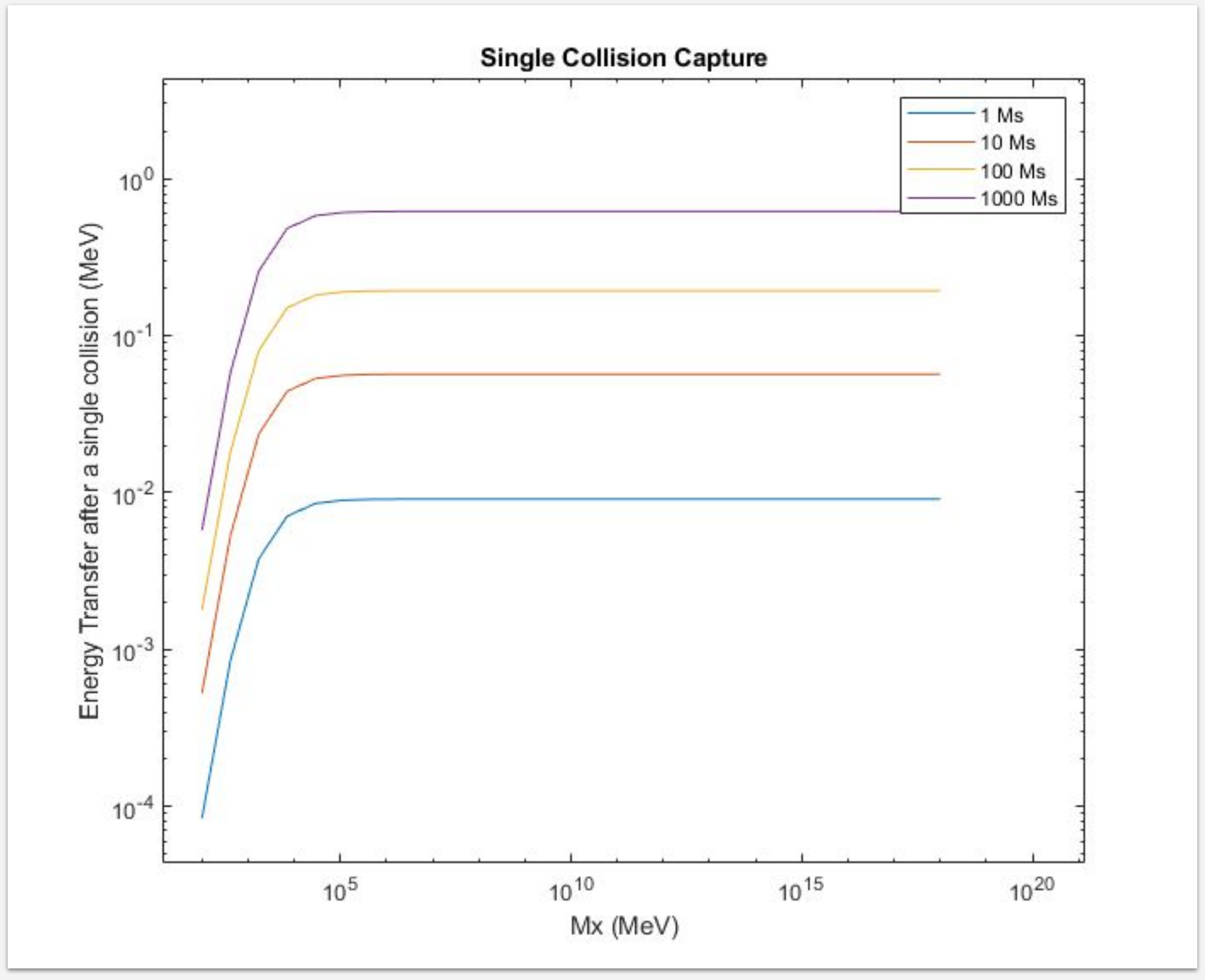

Fig1. Energy transferred to different Pop. III stars (from 1 stellar mass to 1000) after a single collision. For higher masses (as the curves start flattening), the single scatter model is no longer valid.

Multiple Collision Capture

To calculate the energy transferred to the star when a single collision is not enough for the Dark Matter particle to get captured, one has to consider the sum of the kinetic energy contributions of all collisions. The maximum number of collisions between Dark Matter particles and protons in a neutron star is given by the $\boldsymbol{\tau}$ parameter:

$$\tau = 2R_s\sigma_x n_p$$

Where R_s is the radius of the star, $\boldsymbol{\sigma}_x$ is the collision cross section, and n_p is the number density of protons inside the star. Then, the total energy transferred by each Dark Matter particle after being captured is equal to $\boldsymbol{\Delta E\tau}$.

Going a step further, to calculate the total luminosity due to kinetic energy transfer, one must calculate the number of Dark Matter particles going through the star per second. This value depends on the ambient density of Dark Matter and its dispersion velocity, which roughly equals 10 km/s.

Thus, the final estimation of the luminosity in Pop. III stars due to Dark Kinetic Heating is

$$I_K \approx 2\frac{\mu_n^2}{m_p}v_{esc}^2 n_x v_x \sigma_x^2 R_s n_p$$

Where n_x is the ambient number density of Dark Matter near the star.

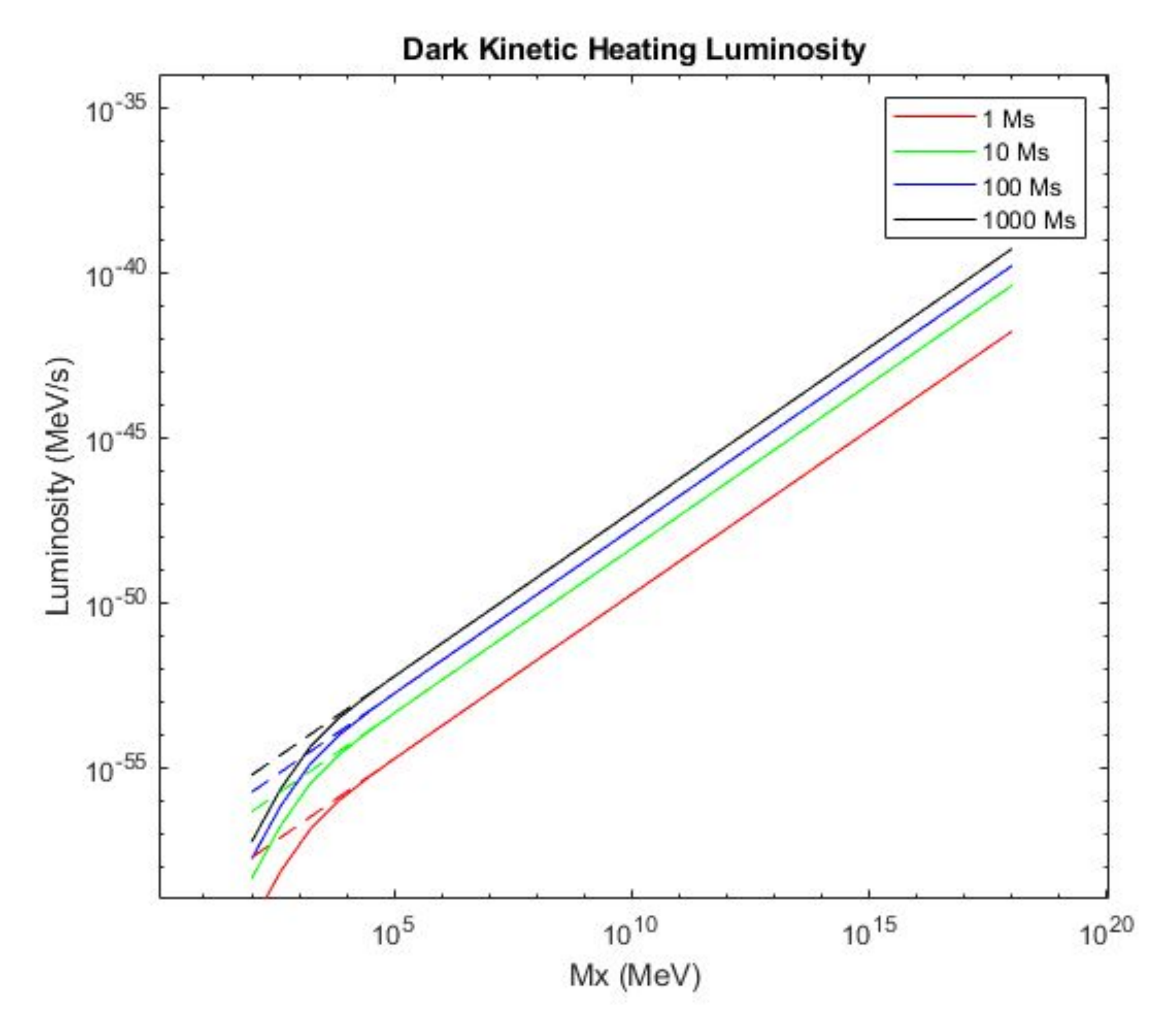

Fig2. Luminosity due to Dark Kinetic Heating for different Pop III. stars. The dashed lines represent the semi-analytical forms, which obey a power law with parameter 0.997, which is practically a linear relation.

The results show that, when compared to Dark Matter Annihilation, Dark Kinetic Heating can be safely ignored, due to it being several orders of magnitude below the effects of annihilation.

In the future, it would be of interest to look for objects in which Dark Kinetic Heating plays a more important role in a star’s luminosity. This objects will likely be dense, compact objects, such as white dwarfs or neutron stars, and if they might be detectable with current-year observation tools.

Works Cited: *-Bramante, Delgado, Martin. Multiscatter capture of Dark Matter 2017*
-Baryakhtar, Bramante, Li, Linden, Raj. Dark Kinetic Heating of Neutron Starsand An Infrared Window On WIMPs, SIMPs, and Pure Higgsinos