It's All Relative(istic)

INVESTIGATING DARK MATTER VELOCITY DISTRIBUTIONS AND THEIR MATTER POWER SPECTRA

Maddy Stratton, Advisor Dr. Adrienne Erickcek

UNIVERSITY OF NORTH CAROLINA CHAPEL HILL

In this project, we employ the Cosmic Linear Anisotropy Solving System (CLASS)[1] to investigate how the momentum distribution functions of warm dark matter (WDM) and cold dark matter (CDM) are related to the matter power spectrum.

MOTIVATION

> Dark matter, or particles that do not interact with light, constitutes ~ 25% of the energy density of the universe.

> Dark matter candidates can be classified by their velocity dispersion.

> These distributions determine the shape of the cut-off in the matter power spectrum, which is important for the onset of early structure formation in the universe.

> We wish to understand the connection between the shape of the matter power spectrum and the DM disrtibution function.

DEFINITIONS

> Matter Power Spectrum (P(k)): a measure of the density contrast of the universe as a function of scale.

> Transfer Function T(k):

$$T(k) = \sqrt{\frac{P_{NCDM}(k)}{P_{\Lambda CDM}(k)}}$$

> K_{half}: the value where T(k) = 1/2.

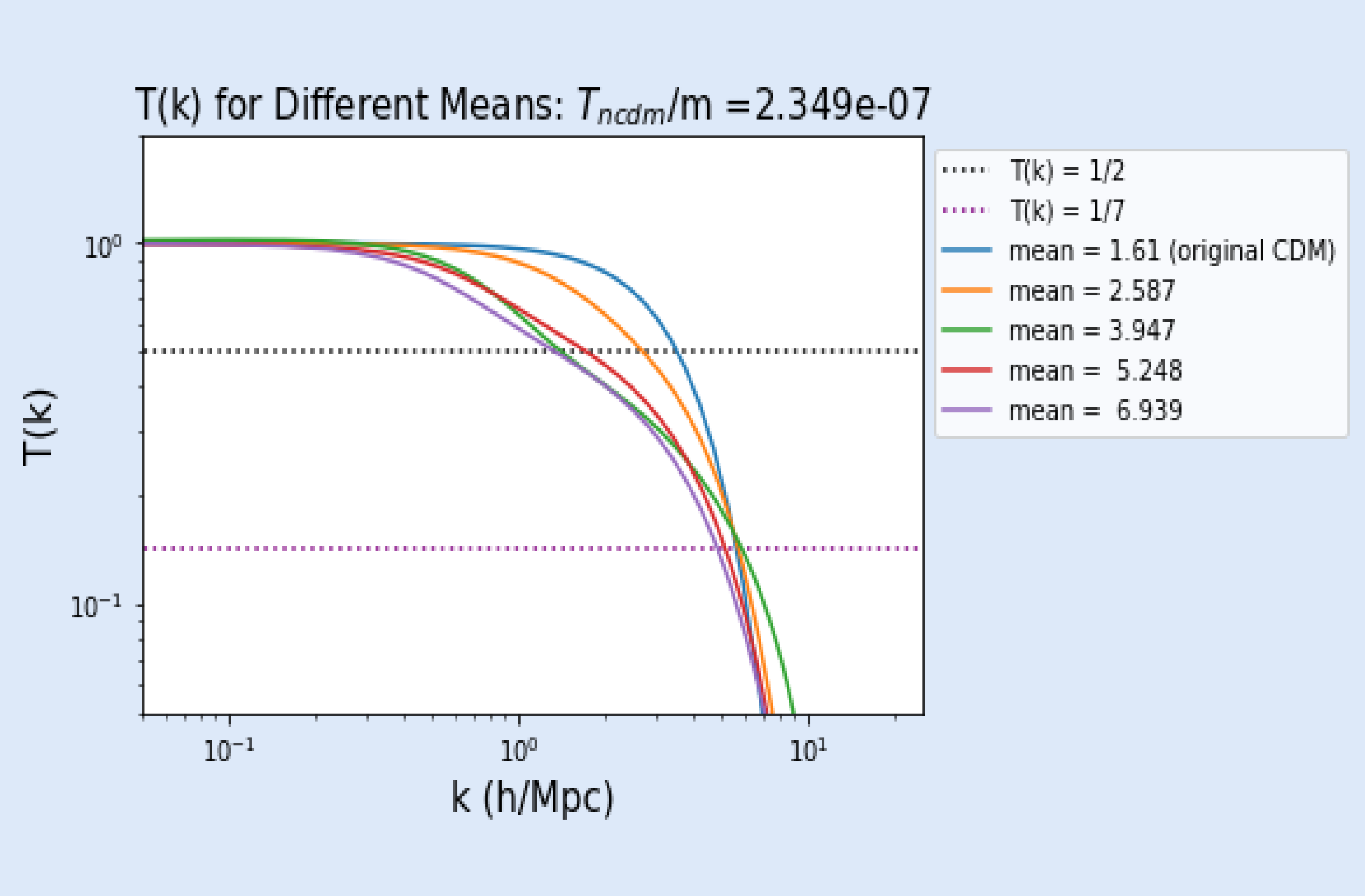

Fig 1: T(k) corresponding to distribution functions with the same median as CDM, but different means. Shows k_{HALF} not set by the median, but the median could predict a different k scale.

INVESTIGATING K_{HALF}

> Last semester, we found results that hinted that k_{HALF} could be set by the median of the DM distribution function.

> To explore this, we created a new CDM-like set of distribution functions that had the same median as CDM, but different mean values.

> Plotting the transfer functions revealed that k_{HALF} was not set by the median. However, the median seems to predict a scale at which the transfer function equals 1/7, as noted by the overlap at T(k) ~ 1/7 (see fig. 1).

LOOKING AT DIENES ET AL. 2020.[2]

> This paper proposes an analytical relationship between the DM distribution function and the matter power spectrum:

$$\left|\frac{dlog(T^2)}{dlog(k)}\right| \approx [F(k)]^2 + (3/2)F(k)$$

> where F(k) is basically how much DM is able to free-stream at a given k value and depends on the distribution function, and T^2 is the square of the transfer function.

> I will refer to the left-hand-side (LHS) of this equation as the gradient, and right-hand-side (RHS) as G(k).

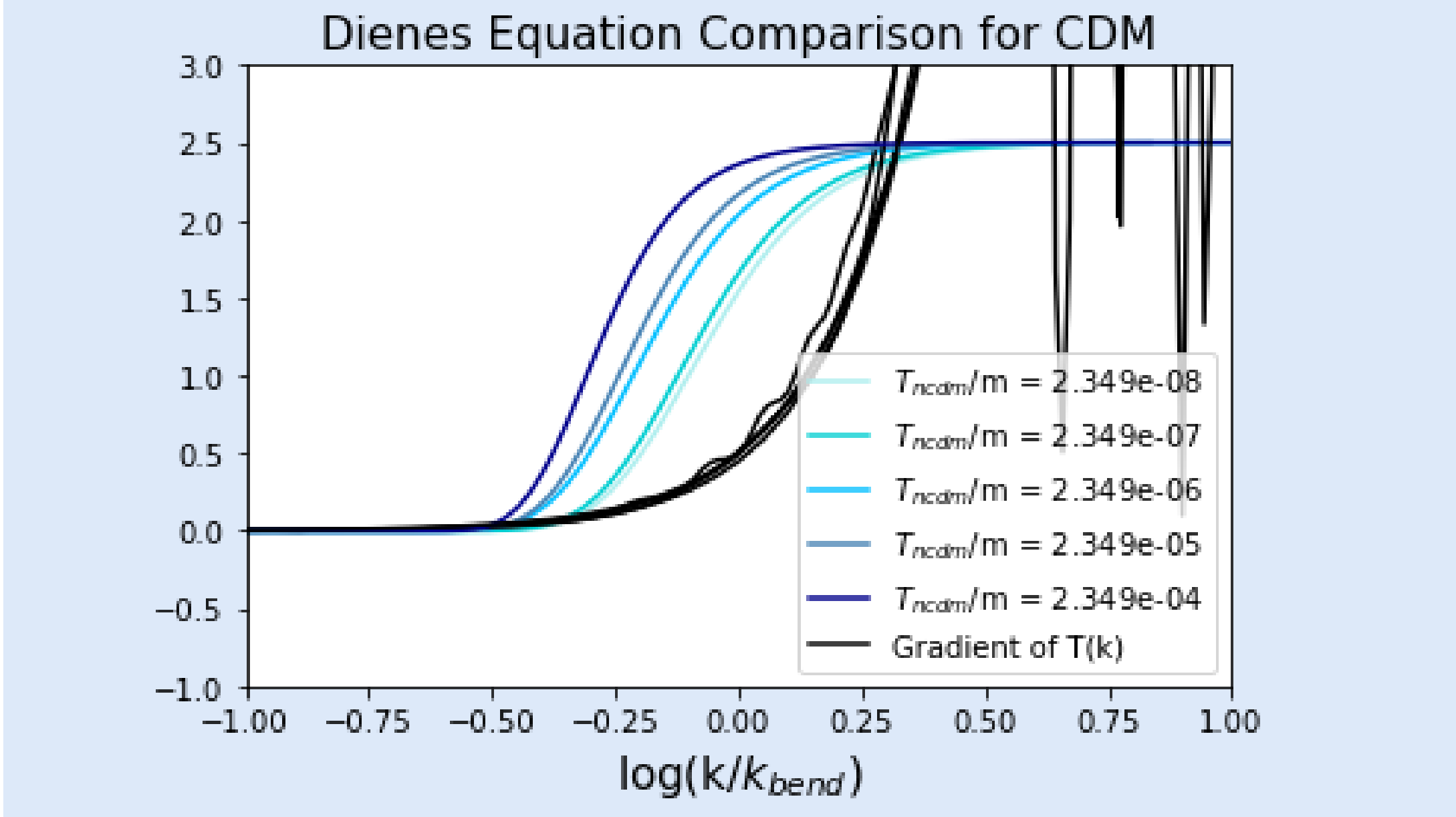

Fig 2: Comparing the gradient (LHS) to G(k) (RHS) of the Dienes equation for CDM. The highest T_{NCDM}/m values (hottest DM) show the most deviation.

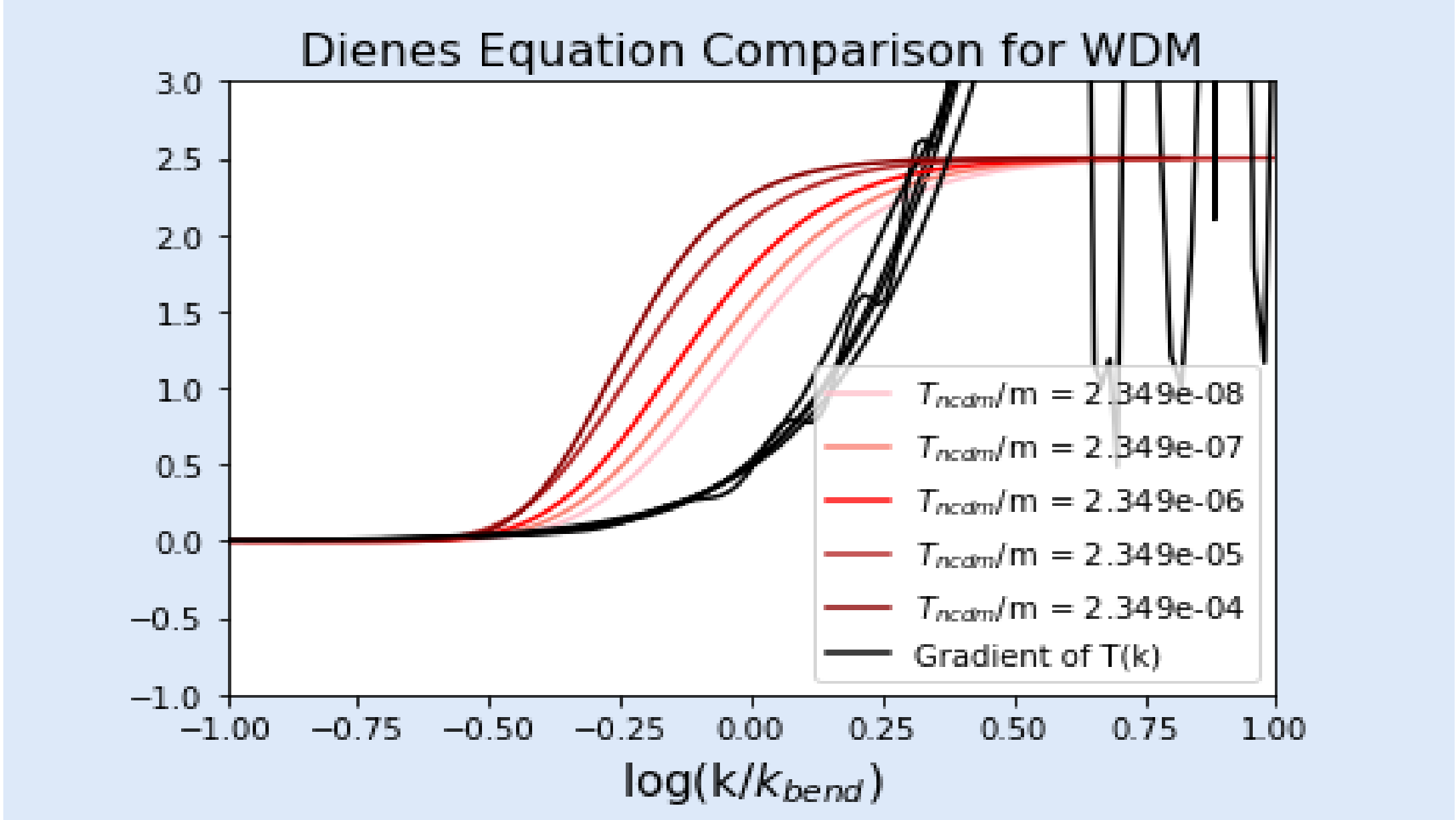

Fig 3: Comparing the gradient (LHS) to G(k) (RHS) of the Dienes equation for WDM. Like CDM, the highest T_{NCDM}/m values (hottest DM) show the most deviation.

> In Figs. 2 & 3, we plot both sides of the Dienes equation for CDM and WDM, for different average momenta, or T_{NCDM}/m values. The plots are overlapped at a new scale, k_{BEND}, where the gradient (LHS) is = 0.5. There is less agreement as T_{NCDM}/m is increased for both distributions, which could be due to relativistic effects (Fig. 4).

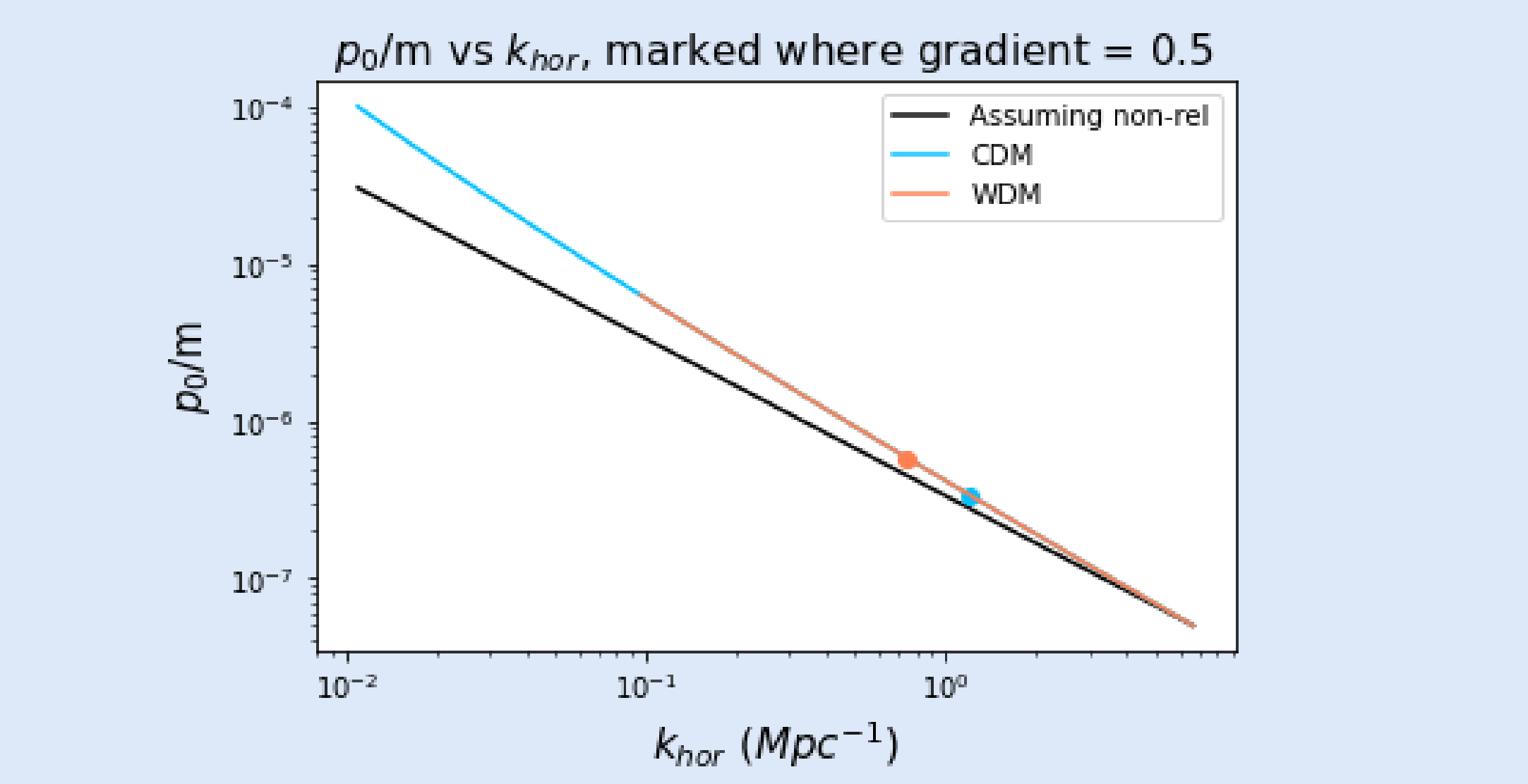

Fig 4: The relationship between average momentum and the k-mapping for the F(k) calculation is affected by relativistic effects (non-linear red and blue overlapped lines). K_{BEND} is marked (dots) for both CDM and WDM. Assuming no relativistic effects yields the black line. This plot is for T_{NCDM}/m = 2.349*10^{-7}.

> Plotting our new scale, k_{BEND}, against T_{NCDM}/m revealed that k_{BEND} follows the same power law relationship as k_{HALF} (Fig. 5).

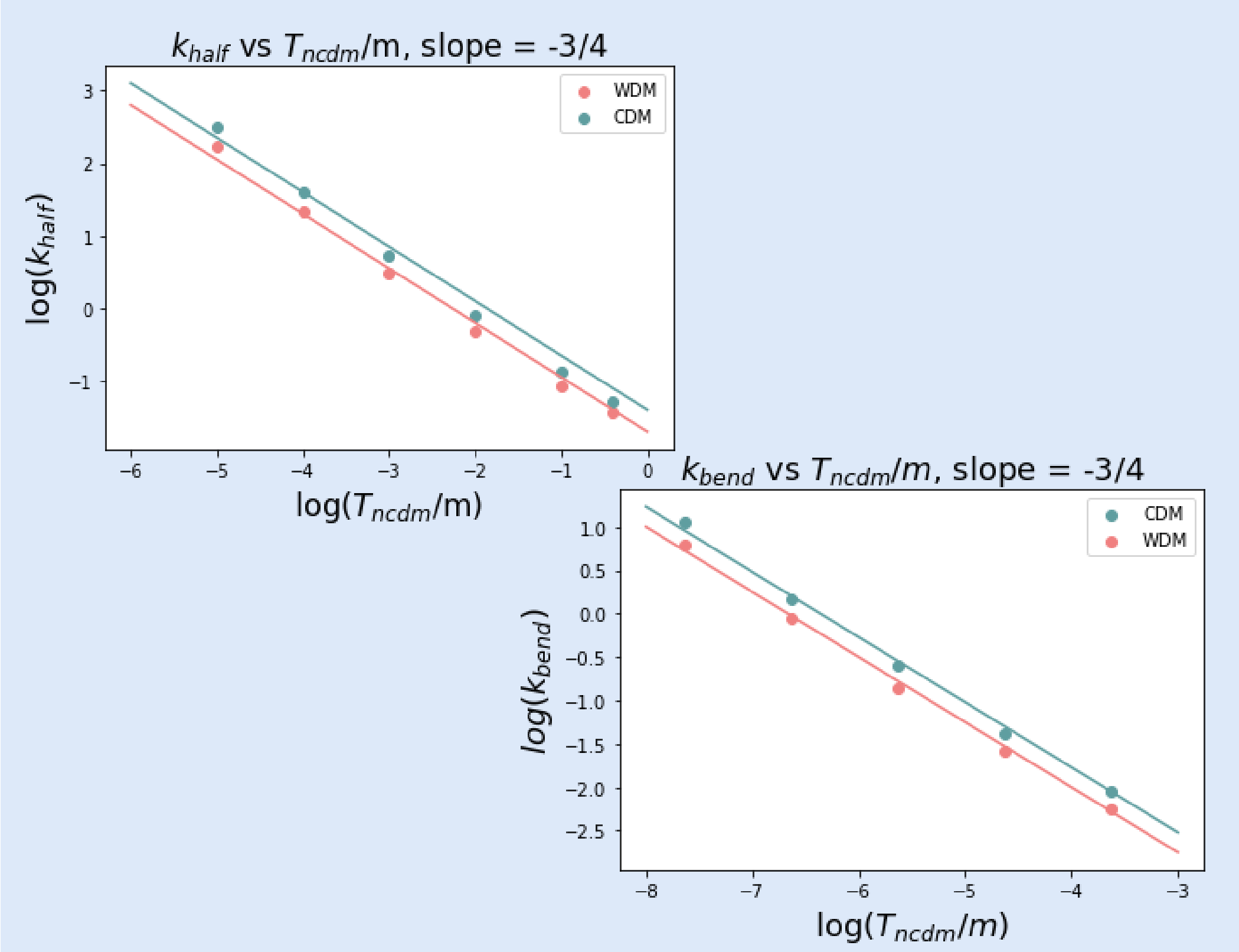

Fig 5: Both scales, k_{HALF} and k_{BEND}, showcase the same power law trend for CDM and WDM.

> To understand how F(k) is evolving with increasing average momentum at the k_{BEND} scale, we plotted F(k), a proxy for the fraction of DM with a free-streaming length > λ = 2π/k, against T_{NCDM}/m. Doing so illustrates that there is a temperature dependence in the calculation of F(k), since this plot shows a clear trend for both CDM and WDM (Fig 6).

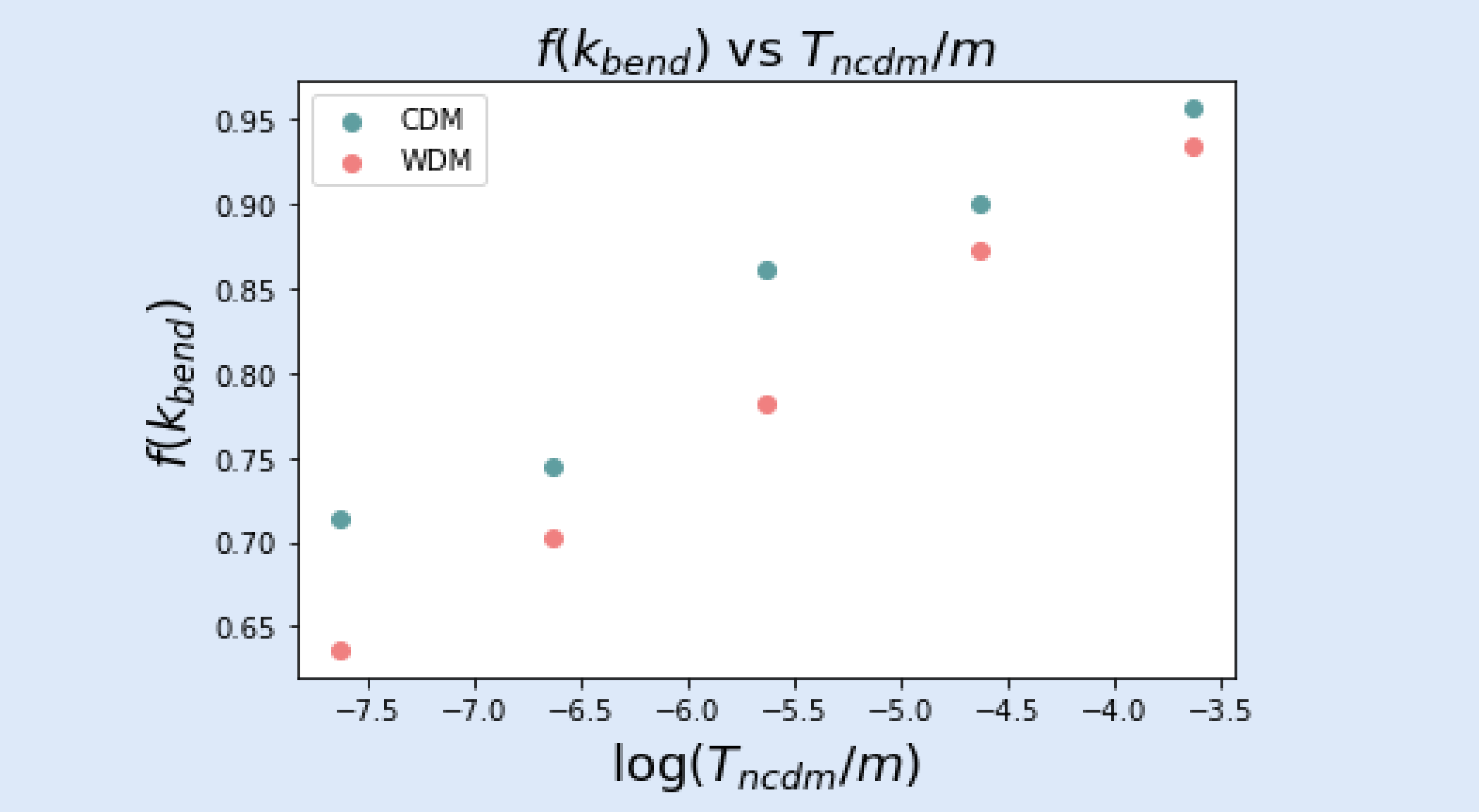

Fig 5: Plotting the fraction of DM that can free-stream as T_{NCDM}/m is increased reveals a definite trend, which implies a temperature dependence in the calculation of F(k).

SUMMARY

> We have shown there to be a temperature dependence in the Dienes results where increasing T_{NCDM}/m causes deviation from their proposed analytical relationship between the DM distribution function and the related matter power spectrum. This makes it harder to predict the shape of the transfer function from the DM velocity distribution.

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1. Blas, D., Lesgourgues, J., & Tram, T. (2011). The Cosmic Linear Anisotropy Solving System (CLASS). Part II: Approximation schemes. Journal of Cosmology and Astroparticle Physics, 2011(07), 034. https://doi.org/10.1088/1475-7516/2011/07/034

2. Dienes, et al. (2001). Deciphering the archaeological record: Cosmological imprints of nonminimal dark sectors. https://doi.org/10.11032Fphysrevd.101.123511