Dark Matter Velocity Distributions and the Matter Power Spectrum

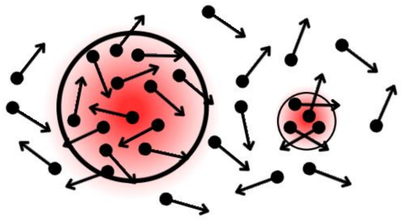
Meredith Pritchard, Adrienne Erickcek

Department of Physics and Astronomy, University of North Carolina at Chapel Hill

Effect of Dark Matter Temperature

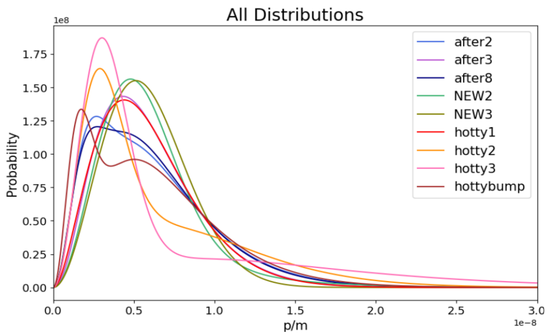
- Dark matter particles with random thermal motion erase density fluctuations on scales smaller than the distance they can traverse, a phenomenon known as "free-streaming"
- The matter power spectrum describes density fluctuations on different spatial scales with this free-streaming being responsible for a cut-off in the matter power spectrum
- The current methods for computing the matter power spectrum are computationally expensive and offer no physical insight

Free Streaming:



Distributions

- Nine unique dark matter velocity distributions were created



p/m – momentum today divided by mass

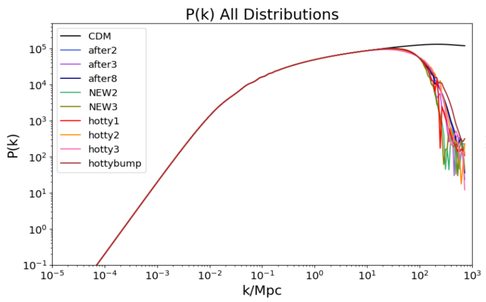
References

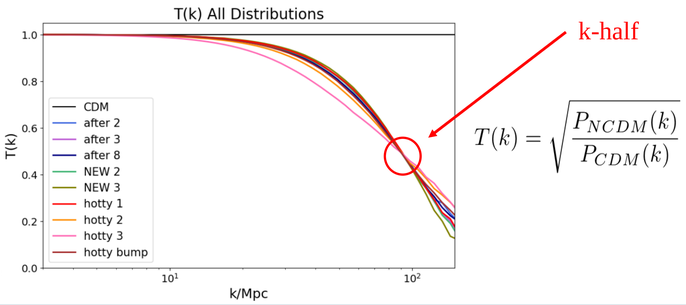
Lesgourgues, J. (2022). CLASS: the Cosmic Linear Anisotropy Solving System.
CLASS Download. http://class-code.net/
https://doi.org/10.48550/arXiv.1104.2932

Dienes, et al. (2001). Deciphering the Archaeological Record: Cosmological
Imprints of Non-Minimal Dark Sectors
https://arxiv.org/abs/2001.02193

P(k) and T(k)

- The matter power spectrum *P(k)* for each distribution was computed using the Cosmic Linear Anisotropy Solving System (CLASS)
- The transfer functions *T(k)* were then calculated and their momentum was tailored to shift each transfer function to the same k-half mode



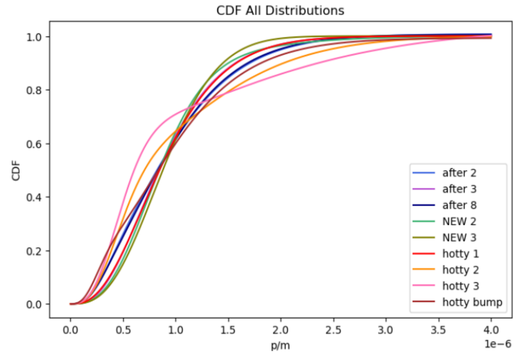


k-half

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

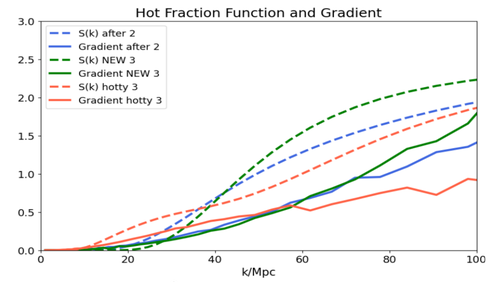
Cumulative Distribution Functions

- No universal intersection was found with some of the hot-tailed distributions showing the most discrepancy



Dienes Conjecture

- The Dienes et al. 2020 paper suggests the following relationship where F(k) is the hot fraction or the fraction of particles that can free stream at a certain scale

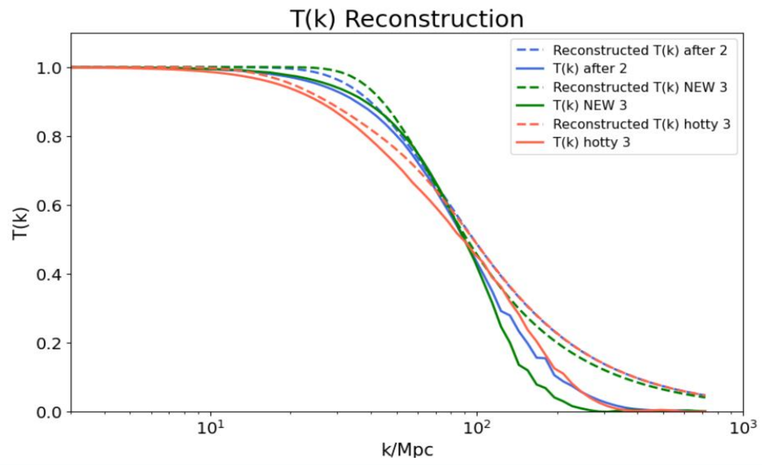


$$\left|\frac{dlogT(k)^2}{dlogk}\right| = [F(k)]^2 + \frac{3}{2}F(k)$$

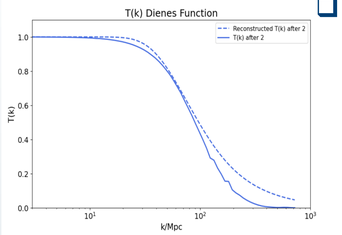
Transfer Function Reconstruction

- The hot fraction function can then be used to reconstruct the transfer functions using the following relationship where *S(k)* is the hot fraction function

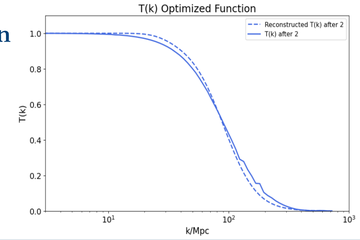
$$T(k) = \sqrt{exp[\int_{k_{min}}^{k_{max}} S(k)\frac{dk}{k}]}$$



Optimizing Function

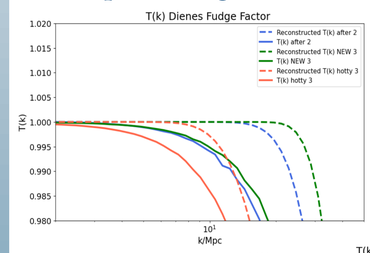


- Optimization algorithms were used to find a function that minimized the residual between T(k) and the reconstruction
- Dienes Function Mean Residual: 0.026
- Optimized Function Mean Residual: 0.017



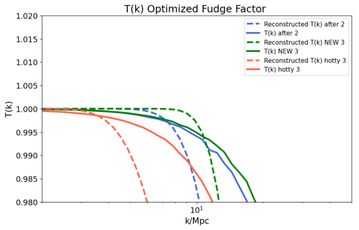
Optimizing "Fudge Factor"

- Creating the hot fraction F(k) requires mapping momentum (p/m) to k with the following equation where ξ is a "fudge factor" which helps to improve the gradient to hot fraction relation



$$F(k) = \xi\frac{\int_{p_k}^{\infty} p^2 f(p)dp}{\int_0^{\infty} p^2 f(p)dp}$$

- Dienes Fudge Factor: 1.67
- Optimized Fudge Factor: 0.6



Conclusion

- No decisive method for connecting dark matter velocity distributions to matter power spectra was found
- The method suggested in the Dienes paper was improved upon by optimizing parameters to fit a set of distributions
- The reconstructions of the transfer function are still inaccurate, suggesting either further modifications or a new method is needed