Superfluid Dark Matter flow around Cosmic Strings

Aline Favero Heliudson Bernardo
Robert Brandenberger

McGill University - Department of Physics

June 9, 2023

Table of Contents

Table of Contents

Cosmic Strings

- One-dimensional topological defects
  ($\sim$ vortex lines in superfluids)
- Symmetry breaking phase transition in the Early Universe
- Probes of particle physics in very high energies
- Lines of trapped energy density
  (structure formation, seeding of BH's etc.)
- Dimensionless quantity $G\mu$ ($< 10^{-7}$)
- Network of long strings and loops

Abelian-Higgs strings

$$V = \frac{\lambda}{4}\left(|\phi|^2 - \eta^2\right)^2$$

- Vacuum manifold $\mathcal{M} \simeq S^1$
- Finite temperature corrections $\sim T^2|\phi|^2$
- Critical temperature T_c:
  - High temperatures: $\langle\phi\rangle = 0$
  - Low temperatures: $\langle\phi\rangle = \eta e^{i\theta}$
- Causality: no correlation in the values of $\langle\phi\rangle$ for distances $> t_H$
- $\mu \sim \eta^2$ and $w \sim \lambda^{-1/2}\eta^{-1}$

Table of Contents

Superfluid Dark Matter

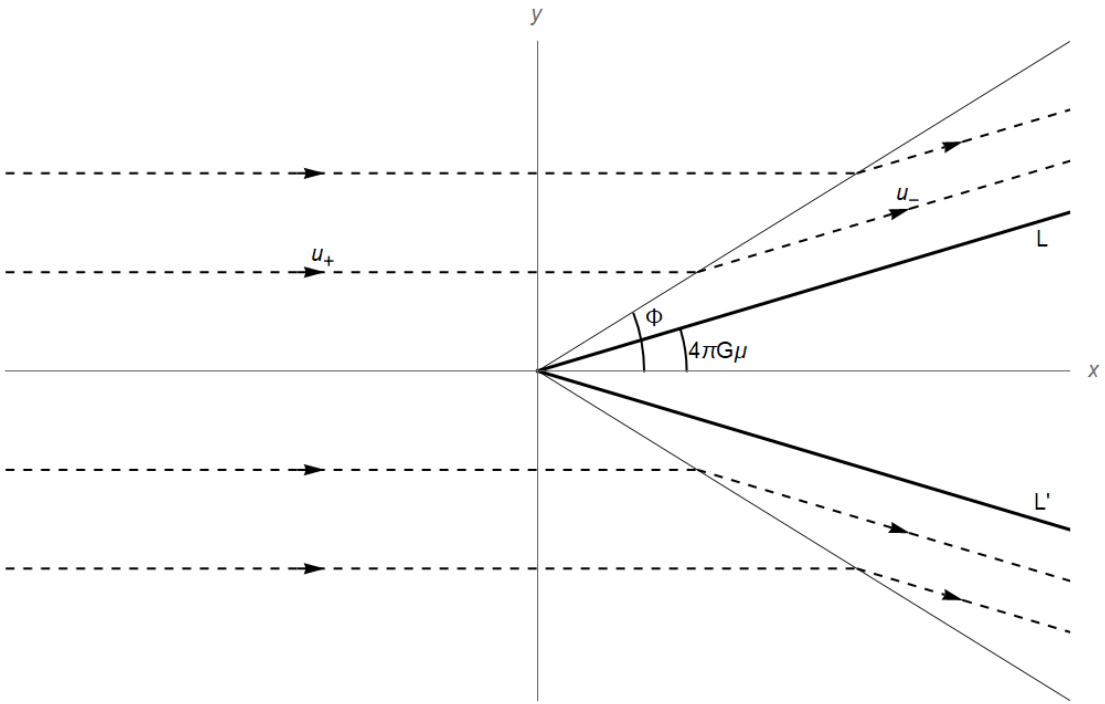
- Axion-like particles (light bosons, $\sim$ eV)
- Cosmological scales:
  - Cold, colisionlless fluid ($\sim \Lambda$CDM)
- Galactic scales:
  - Larger densities $\rightarrow$ phase transition $\rightarrow$ superfluid phase
  - λ_{dB} overlap
  - Phonons couple to baryons $\rightarrow$ long-range forces ($\sim$ MOND)
- Landau's two-fuid model
- Field theory approach to superfluids (Nicolis, 2011)

Table of Contents

Shocks in the superfluid flow

- A moving string induces a shock (discontinuity in the fluid variables)
- Rankine-Hugoniot juction equations:

$$[j^\mu]\, n_\mu = 0, \quad [T^{\mu\nu}]\, n_\nu = 0$$



- Weak shocks: linearized solutions
- Strong shocks: T increase $\rightarrow$ destroys the BEC

Table of Contents

Superfluid phase inside cosmic string wakes

- A moving string produces a wake (region of higher density)
- Conditions for formation of a BEC:
  - $\lambda_{\rm th}$ larger than inter-particle separation,

$$m \lesssim 30.67\text{eV},$$

  - DM particles have to thermalize,

$$\frac{\sigma}{m} \gtrsim 4.08 \times 10^{-2} \frac{\text{cm}^2}{\text{g}}.$$

Mass × redshift relation

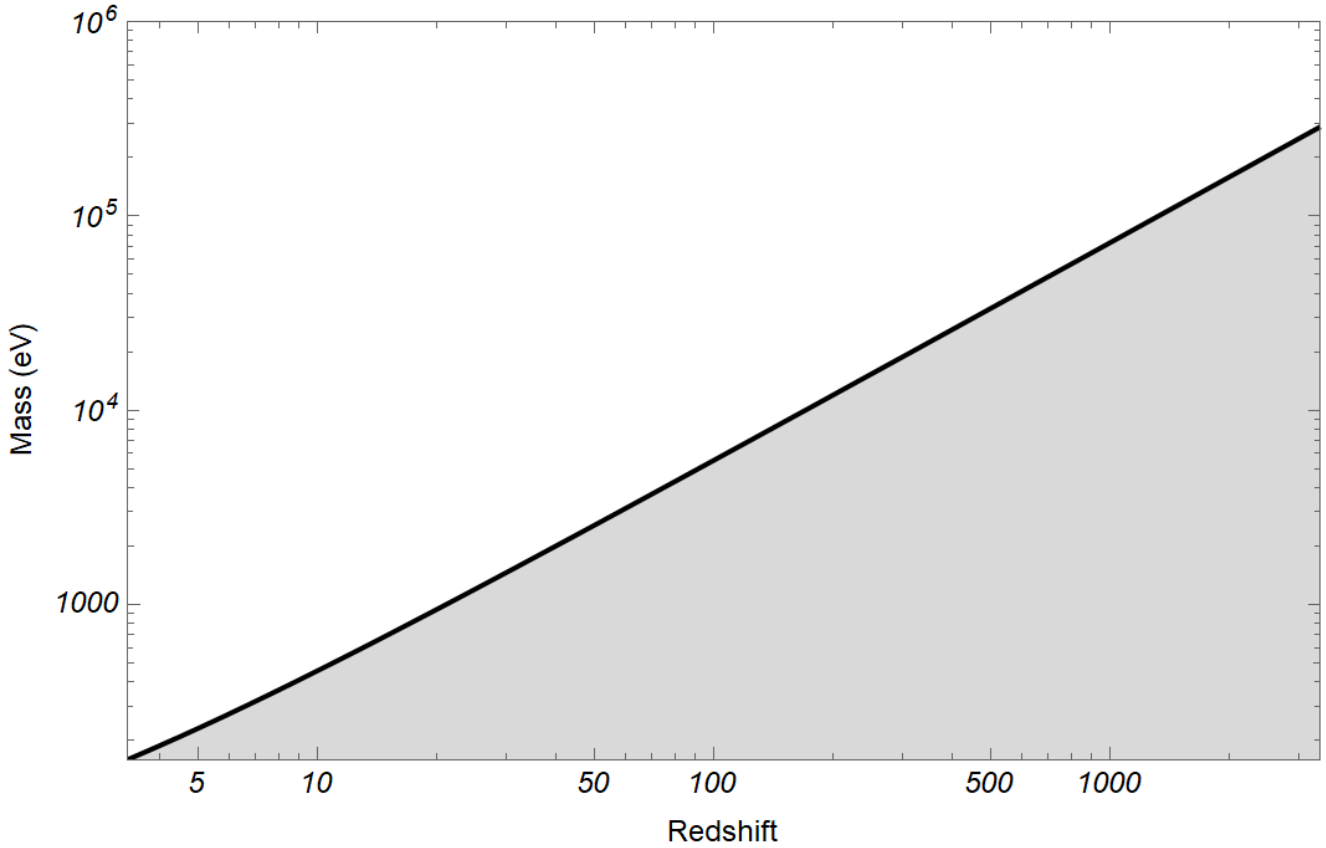


Figure 1: Log-log plot of the mass (in eV) as a function of the redshift, $m\,(z)$. The shaded region shows the range of allowed masses.

Conclusions

- Observational implications,
- Modified Zel'dovich approximation,
- Vortex motion around cosmic strings.