Ultralight Dark Matter:

A very short review

Margionet Díaz[1], Mariano Dominguez[2]

[1]Facultad de Ciencias, ULA (margionet.f.diaz@mi.unc.edu.ar)
[2]IATE-OAC-CONICET (mariano.dominguez@unc.edu.ar)

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Abstract

In this a very short review we show some Ultra-light Dark Matter (ULDM) models as an alternative on small scales, where there is discrepancies between simulations and observations of Cold Dark Matter (CDM) models. ULDM represent an interesting alternative of addressing some of the small scale challenges of λCDM, with an large masses ranging bosons from 10^{-22} eV $< m <$ eV.

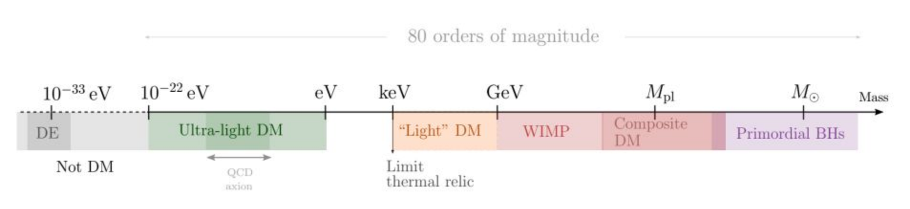

Figure 1: Sketch (not to scale) of possibly DM models (Ferreira E., 2021)

Dark Matter (DM)

What about dark matter?

- Cosmic density: DM $\rightarrow 26\%$; ordinary matter $\rightarrow 6\%$; vacuum energy $\rightarrow 68\%$
- Local density: of DM $\rightarrow$ one proton * cm^{-3} / one solar mass * lightyear^{-3}
- Local velocity dispersion of DM around $\sigma_v = 200 km/s$
- DM nonrelativistic $v \sim c$ and negligible pressure. For boson λ_{Br} small comparaed to galaxy clustering scale
- DM long before CBM formed, before was 1 year old. For light bosonic DM (axion) $\rightarrow$ lastest epoch of particle creation
- DM cannot interact with itself or with ordinary matter strongly

Discrepancies: observation vs. simulation

- Cusp-Core Problem (De Blok, 2009)
  Theory: cusp/NFW profile.
  Observations: core
- Missing Satellites Problem (Bullok J., 2009)
- Diversity vs Regularity: Scaling Relations

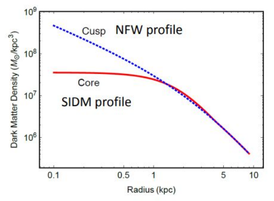

Figure 2: (Tulin & Yu, 2015)

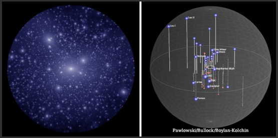

Figure 3: (Tulin & Yu, 2015)

Ultralight Dark Matter (ULDM): an altenative?

ULDM models

are composed of ultra-light bosons, that form a Bose Einstein Condensate (BEC) or superfluid on galactic scales. This DM presents a wave nature, while behaving as CDM on large scales. The classification (fig. 4) is based on the ways they achieve condensation (Ferreira, 2021. Sharma et al. 2019)

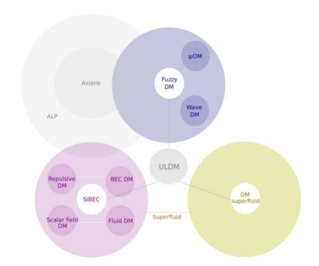

Figura 4: Map of ULDM models (Ferreira, 2021)

$$\Delta^2(k) = \frac{1}{2\pi^2} k^3 P(k)$$

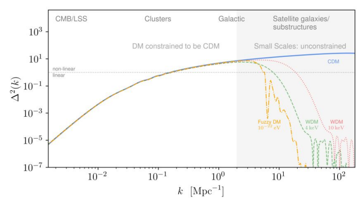

Figure 5: Power spectrum as a funtion of the wavenumber k, by many large and small scale observables (Kuhlen et al., 2012)

Fuzzy Dark Matter

We are focusing in **Fuzzy Dark Matter** (FDM, φDM, wave DM) (Hu W., et al., 2000. Hui L., et al., 2017).

FDM

- Boson mass: $m \sim 10^{-22}$eV.
- Gravitational attraction is counteracted by the quantum pressure.
- Described by an ultra-light scalar field under the influence of gravitational potential.
- Forms BEC on galactic scales.

$$i\dot{\varphi} = -\frac{1}{2m}\nabla^2\varphi + V_{grav} \tag{1}$$

Axion as a solution:

Axion may populate the universe in a coherent wake-like state with slow moving, so it cold.

- $\lambda = \frac{h}{m\nu} \rightarrow mc^2 + \frac{1}{2}m\nu \rightarrow$ macroscopic wave-like behavior.

Axion

Cosmic Structure Formation: Gravity → inhomegeneities

Evolution: Gross-Pitaevski-Poisson Eqs. (non-linear Schrödinger eqs.) [1]

- De Broglie λ small scales: energy dominates over gravity.
- Axion stars: High density → axion forms solitons.
- Turbulence ad interference: Axion have dynamic velocities (Maxwell-Boltzmann distribution) → coherent flows → interference patterns in filaments (Hiu et al., 2021)

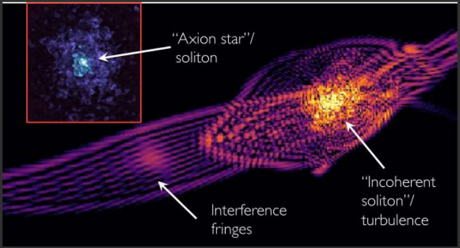

Figure 3: Simulation of cosmic web formed by gravitational interaction (Chanda-Day et al., 2022)

[1] https://science.org/doi/10.1126/sciadv.abj3618

Finally

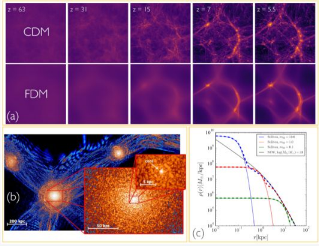

Figura 6: Snapshots FDM (lower panel): halos are connected via filaments. CDM(upper panel): has filament fragmented into subhalos. b) Density field of FDM. Cores of DM grow as particles are acretted and surrounded by virialised halos. c) Solid lines show FDM cores for different axion masses. (Boldrine P., 2021)

Future

- Study of galaxy formation in models of ULDM evaluating its feasibility and eventually its detection.
- It will be possible using data from the Vera. C Rubin Observatory.
- Modify codes appropriately as `21cmvFAST`, `21cmMCMC`, `axionCAMB` Muñoz, 2019; Veltmaat, Niemeyer, Schwabe, 2018

+ Main references of the presentation: Ferreira E., 2021; Chadha-Day F. 2022.

END