

Scalar-field dark matter from CDM, and constraints from cosmological data

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Outline

- What/why of scalar field dark matter? (according to a cosmologist)
- Cosmological history of scalar DM.
- Constraints from cosmological data.
- Future work.









- · Very light boson particle.
- · Coherent wave-like behaviour at galactic scales.





$$\mathcal{L} = |\partial \Psi|^2 - m^2 |\Psi|^2 - \lambda |\Psi|^4 \qquad \hat{H} = \int \mathrm{d}^3 x \Big[\hat{\Psi}^\dagger \frac{-\nabla^2}{2m} \hat{\Psi} + \frac{g}{2} \hat{\Psi}^\dagger \hat{\Psi}^\dagger \hat{\Psi} \hat{\Psi} + m \Phi \hat{\Psi}^\dagger \hat{\Psi} \Big]$$





What is scalar field dark matter?

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What is scalar field dark matter?

$$\begin{split} \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) &= 0 \\ \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} + \frac{1}{\rho} \nabla P + \nabla Q + \nabla \Phi &= \mathbf{0} \\ \swarrow & \swarrow & \swarrow \\ P &= \frac{g}{2m^2} \rho^2 & \qquad \text{``SIBEC DM''} \\ Q &= -\frac{1}{2m^2} \frac{\nabla^2 \sqrt{\rho}}{\sqrt{\rho}} & \qquad \text{``Fuzzy DM''} \end{split}$$

Madelung eqs.

Interaction pressure

Quantum potential



What is scalar field dark matter?

Madelung eqs.

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- We know there is a lot of "dark matter".
- We have no idea what this dark matter is...
- Proposes to fix small-scale issues.
 - Small-scale = dwarf galaxy size.







Why scalar field dark matter?

Cusp-core problem: Fuzzy DM







Why scalar field dark matter?

Cusp-core problem: SIBEC DM

No cosmological simulations yet... Can assume hydrostatic equilibrium

$$ho(r)=
ho_0rac{sin(\omega r)}{\omega r}$$
, where $\omega=\sqrt{rac{4\pi Gm^2}{g}}$
Typical core radius $R_c=\sqrt{rac{g\pi}{4Gm^2}}$



An obvious problem with the pressure...

$$P = \frac{g}{2m^2}\rho^2 \propto (1+z)^6$$

Relativistic treatment gives three phases

$$\omega = \frac{P}{\rho} = 1 \quad \rightarrow \frac{1}{3} \quad \rightarrow \frac{g}{2m^2}\rho$$







From Li *et al*, 1310.6061



Alternative scenario: SIBEC DM as the product of some transition from an initially cold gas (essentially CDM). (e.g. on arxiv: 1111.2032, 1503.01877, 1105.5189)

Not as nice...

Constraints on the phenomenology of such a cold-SIBEC transition?



Phenomenological model for cold-SIBEC DM transition:

Effective single-fluid approach: Have an equation of state that evolves as

$$\omega = 0 \to \frac{1}{3} \to \omega_0 a^{-3}$$

Achieved by

$$\omega = \frac{(a/a_t)^{\kappa}}{1 + (a/a_t)^{\kappa}} \times \frac{1}{3} \frac{1}{1 + a^3/3\omega_0}$$



Phenomenological model for cold-SIBEC DM transition:

Two-fluid approach: Separate CDM and SIBEC DM fluids

$$\bar{\rho}_{\chi_{1}}' + 3\mathcal{H}\bar{\rho}_{\chi_{1}} = a\bar{Q},$$
$$\bar{\rho}_{\chi_{2}}' + 3\mathcal{H}\bar{\rho}_{\chi_{2}}(1+\omega_{\chi_{2}}) = -a\bar{Q}$$
$$\bar{\rho}_{\chi_{1}} = \bar{\rho}_{0}a^{-3} \left[1 - \frac{(a/a_{t})^{\kappa}}{1+(a/a_{t})^{\kappa}}\right]$$

Approach inspired by Bringmann *et al*, 1803.03644 (CDM => DR)

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Cosmological history of SIBEC DM

Extra parameters:

 ω_0 Equation of state today, related to SIBEC self-interaction

 a_t Time of cold-SIBEC transition

 ${\cal K}$ Rate/width of transition





Constraints from cosmological data

We have an amazing wealth of cosmological data, so why not use it?

Implement eqs. from cosmological perturbation theory into CLASS. (Audren *et al*, 1210.7183) Run MCMC with MontePython. (Blas *et al*, 1104.2933)

Planck 2018: CMBPantheon:SN1aBOSS:BAO



Constraints from cosmological data

95% credible regions.

Standard cosmological parameters essentially unchanged.



SH, H. A. Winther, D. F. Mota, 2108.07496



Constraints from cosmological data

Two approaches very similar for fast transitions. Weaker constraints in two-fluid approach for slow transitions.

solid = single-fluid dashed = two-fluid





Constraints from cosmological data

If we demand that SIBEC DM resolves core-cusp problem, but not get too large halos.



SH, H. A. Winther, D. F. Mota, 2108.07496



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Future work

- Explore other possible SIBEC-DM histories.
 - SIBEC-DM from warm DM (current work an "upper limit")
 - SIBEC-DM with initial stiff phase



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- Explore other possible SIBEC-DM histories.
 - SIBEC-DM from warm DM (current work an "upper limit")
 - SIBEC-DM with initial stiff phase
- Explore late-universe structure formation with cosmological simulations.
 - Probe small-scale structure in SIBEC-DM universe.





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Thank you!