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GALACTIC DISCS EMBEDDED IN FUZZY DARK MATTER HALOES

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Abstract. We investigate the dynamical impact of a dark matter consisting of very light axions, fuzzy dark matter, on stellar discs of Milky-Way type galaxies. Density fluctuations resulting from the finite de Broglie wavelength of fuzzy dark matter imply force fluctuations applying on classical test particles. Discs are heated by these perturbative forces whose intensity increases when the assumed axion mass decreases. Stellar discs are simulated either in cold dark matter haloes or in fuzzy dark matter haloes with different values of the mass of the axion. For small values of this mass, we observe a thickening of the discs and only very mild non-axisymmetries which are incompatible with observations.

Keywords: galaxies, galactic dynamics, dark matter, numerical simulations

1 Introduction

Cold Dark Matter (CDM) is successful at large scales, in the ΛCDM paradigm, but encounters problems at small (i.e. galactic) scales when comparing simulations to observations, such as the core-cusp tension for DM haloes, and problems concerning subhaloes populations ("too big to fail" problem, overabundance). Baryonic physics (e.g. through supernovae feedback) may solve some of these problems. Alternatives to CDM can also be investigated. These alternatives generally aim at keeping the large-scale behaviour of CDM while differing at small scales. Fuzzy Dark Matter (FDM), which is reviewed in Hui et al. (2017), would consist of ultra-light axions (bosons) with a mass $m_{\rm ax} \sim 10^{-22}$ eV/c ^{2} (while the mass of WIMPs of CDM is of 10 GeV/c ^{2} to 10 TeV/c ^{2}). Taking a very small mass allows for a large de Broglie wavelength $\lambda_{\rm dB} = h/p = h/(m_{\rm ax}v)$, $\sim$ kpc for typical velocities in galaxies, which (through the uncertainty principle) "suppresses" small-scale structure. The "Wave dark matter" simulations of Schive et al. (2014) show large scales similar to CDM, and small scales affected by quantum interferences, with "solitons" at the centre of DM haloes.

Studies of the dynamical effect of FDM on baryons aim at finding if axions can have a mass which is large enough so that they do not perturb baryons inconsistently with observations, while remaining small enough so that FDM has the desired effects on DM small structures. Constraints on the mass of the FDM axion come from various astrophysical objects. Some constraints are sometimes obtained with debated assumptions. Studies of galactic stellar discs in Milky-Way type galaxies try to compare the thickening of the stellar discs, their vertical velocity dispersion and vertical heating rates expected from FDM to (debated) observational results (stellar kinematics and age-velocity dispersion). (Chiang et al. 2023) concludes for ex. that $m_{\rm ax} = 0.5\!-\!0.7\,10^{-22}$ eV/c ^{2}. El-Zant et al. (2020) establishes that the vertical velocity dispersion generated by FDM in a Hubble time at the solar radius is not larger than the observed one (assumed to be 30 km/s) for a mass of the FDM axion $\geq 0.3\ 10^{-22}$ eV/c ^{2}. The theoretical approach of El-Zant et al. (2020), which we use in the present work, is developed to capture the effect of FDM on classical particles (stars). This approach is based on the theoretical framework of El-Zant et al. (2016) evaluating the effect of baryonic feedback on centres of DM haloes through gravitational potential fluctuations, to solve the core-cusp problem.

In this work, we present numerical simulations of stellar galactic discs embedded in CDM or FDM haloes and study how lowering the mass of the FDM axion affects the dynamics of the disc.

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2 Simulations of stellar galactic discs in FDM haloes

2.1 Method

We use the theoretical approach of El-Zant et al. (2020), which relies on evaluating density / gravitational-potential stochastic fluctuations of FDM through Fourier expansions and computation of power spectra, for axions following the Schrödinger-Poisson system (see El-Zant et al. (2020)). Resulting forces acting on stars are computable in this approach. They are added to the gravitational force felt by a stellar particle in the N-body code `Gadget-2` (Springel 2005).

Simulations are performed with a stellar disc (and bulge) in DM haloes of different profiles, Plummer or NFW, such that the circular velocity at the solar radius is $v_C(R_\odot)$ = 200 - 250 km/s. We present here one set of simulations with a Plummer profile for the haloes.

2.2 Results

The forces due to FDM fluctuations are $\propto (1/m_{\rm ax})^2$. Stellar discs are hence expected to be all the more affected by FDM as the axion mass is low.

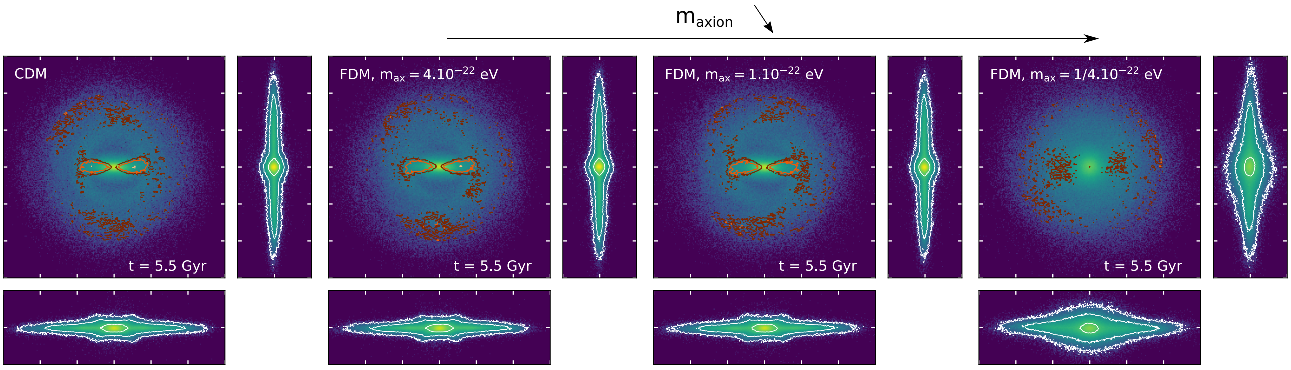

Fig. 1. Four panels consisting each of a face-on view and two edge-on views, showing the same stellar disc after 5.5 Gyr of evolution in a CDM halo (left) or a FDM halo with the same density profile and a value of the FDM axion mass given on the face-on view (three right panels). The discs are rotated so that the bars are parallel to the x-axis. These plots are realised using `GalaXimView`, available at `https://vm-weblerma.obspm.fr/~ahalle/galaximview/`

Fig. 1 shows the same stellar disc evolved from an axisymmetric configuration, after a few (5.5) Gyrs, when embedded in a CDM halo (left panel) or FDM haloes with the same density profile, for three different masses of the FDM axion (three right panels). Coloured contours of non-axisymmetries are overplotted on face-on views, while white contours of surface density (with the same set of values in all the panels) are overplotted on edge-on views, to emphasise the thickening of the discs. FDM fluctuations impact bar speed and strength. Bars cannot be sustained if the FDM axion mass is low, as on the right panel, for an FDM axion mass $m_{\rm ax} = 0.25\,10^{-22}$ eV/c ^{2}. The thickening of the stellar disc, especially visible for this lowest considered FDM axion mass, is associated with an increase in vertical velocity dispersion. These findings are investigated in further detail, for different profiles of dark-matter haloes.

The forces are computed from an integration on wavelengths up to a maximal value so as to remain in the "diffusion" regime (in which the time-scale of force fluctuations is less than the dynamical time of stars). We are testing how this wavelength limit affects the discs by potential global bending modes.

3 Conclusions

We have introduced fuzzy dark matter (FDM) force fluctuations in N-body simulations to study the effect of FDM on stellar discs, using the theoretical approach of El-Zant et al. (2020). Simulations show that low axion masses prevent galaxies from keeping a stellar bar and heat them in ways inconsistent with observations. Some tests varying DM halo and stellar disc parameters are on-going. We are also investigating the limits of the theoretical framework.

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