Università degli Studi di Ferrara

INFN

Strong cosmological bounds on ALPS from strings

R. Impavido, in collaboration with:
N. Barbieri, L. Caloni, M. Lattanzi, L. Visinelli

Axions in Stockholm

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Light relics' distribution function

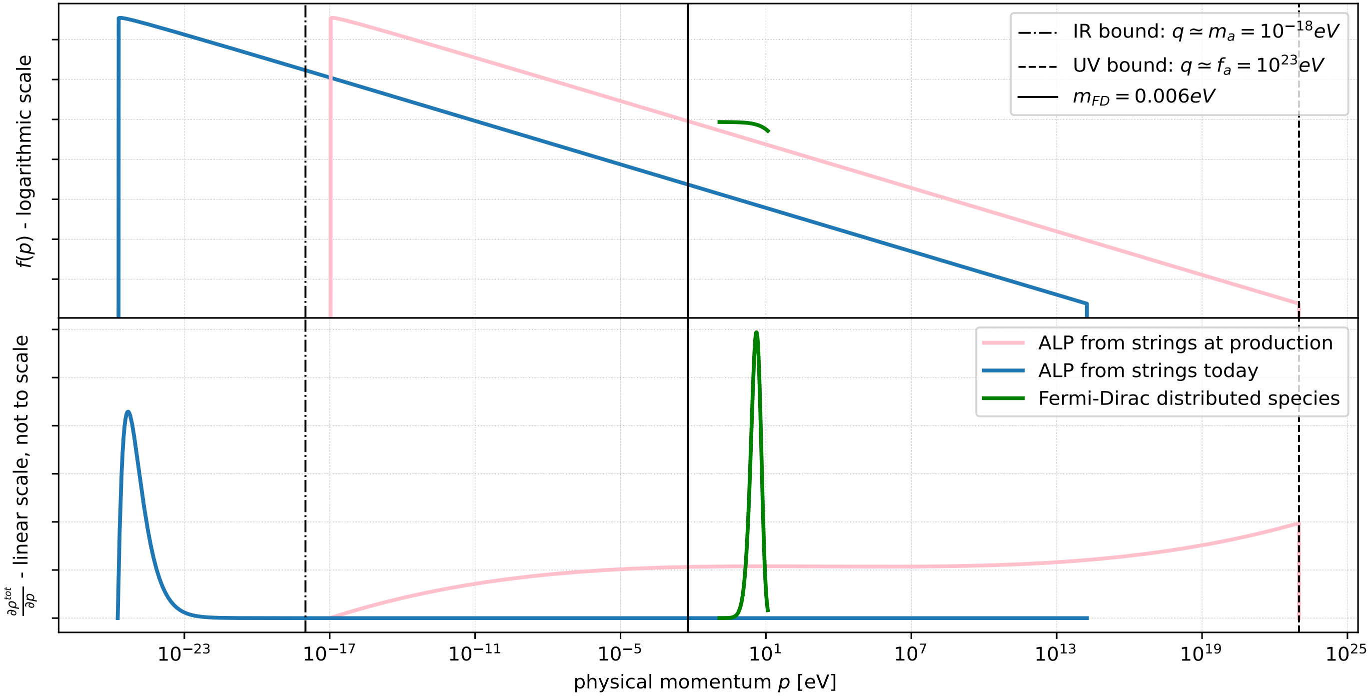
- **What we do know: Neutrinos.**
  Neutrinos in the Early Universe reach thermal equilibrium before decoupling. Thereafter, they retain a thermal Fermi-Dirac distribution with $T_\nu \simeq (4/11)^{1/3} T_\gamma \simeq 2\,K$ today.
  Small deviations from a thermal Fermi-Dirac distribution do not leave strong signatures on CMB spectra (Alvey et al 2111.12726).

- **What we wish we knew: Axions.**
  Axions, and more generically ALPs, can be produced in many ways. Among those, they may be radiated from a network of cosmic strings. Their distribution function is very non-thermal.
  Does this very non-termal relic leave a signature on cosmological observables?

ALPS from strings: distribution function

$$f(p, m_a, f_a) = \frac{4}{\pi^2} \frac{\xi_\star(m_a, f_a)\mu_\star(m_a, f_a) m_a^2}{p^3\sqrt{p^2+m_a^2}} \left[1 + \mathcal{O}(\log\left(f_a/m_a\right), p^{q_a - 1})\right] \overset{m_a \ll p \ll f_a,\, q_a \to 1}{\propto} \frac{1}{p^4},$$

(Gorghetto et al 2101.11007)



Effects + CLASS Implementation

background.c

$$\rho_a, P_a \sim \int \left(\sqrt{q^2+m^2}\right)^{A_1} (q^2)^{A_2} f_0(aq) dq$$

Just once in the code

Very accurate quadrature strategy

$$H^2 = \frac{8\pi G}{3} a^2(\rho_a + \rho_{\rm else})$$

$$\frac{1}{\rho_a}\frac{\mathrm{d}\rho_a}{\mathrm{d}\ \log a} = -3(1+w_a(a))$$

perturbations.c

$$\delta, \theta, \delta P, \sigma \sim \int \left(\sqrt{q^2+m^2}\right)^{A_1} (q^2)^{A_2} f_0(aq) \Psi(q) dq$$

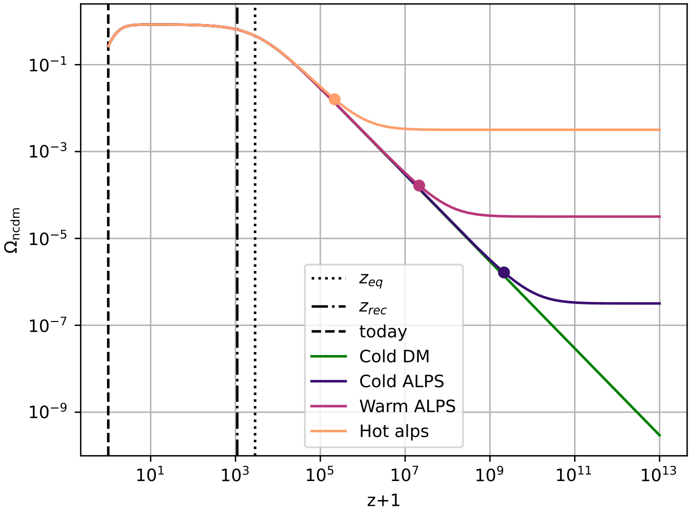
Over and over again

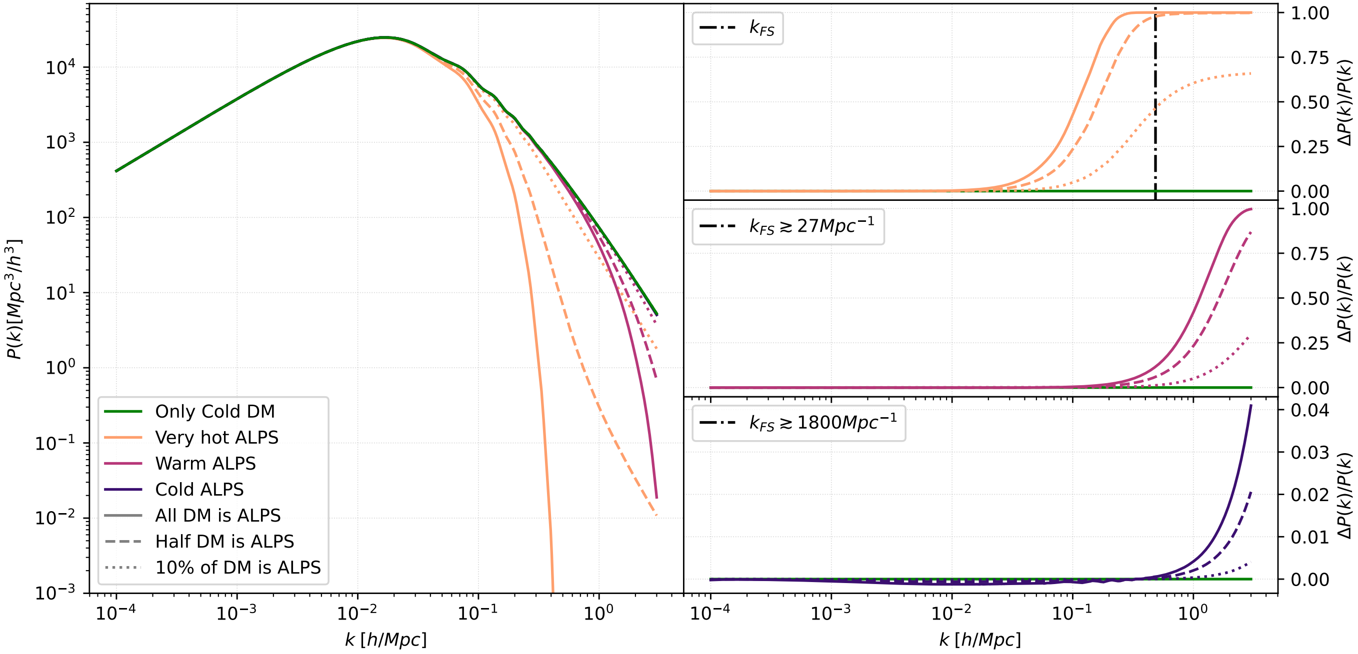
Fast and accurate enough quadrature

$$\dot{\vec{\Psi}} = A\vec{\Psi} + B$$

Results

C_ℓ : ALPS are almost indistinguishable w.r.t CDM
$P(k)$: ALPS damp the power at small scales!





Sum Up + Conclusions

Theory:
There are models to produce non thermal Dark Matter, e.g. from cosmic string networks

Phenomenology:
There are codes and tools to precisely characterize a non cold Dark Matter

Data:
There are many CMB and LSS experiments giving more constraining data

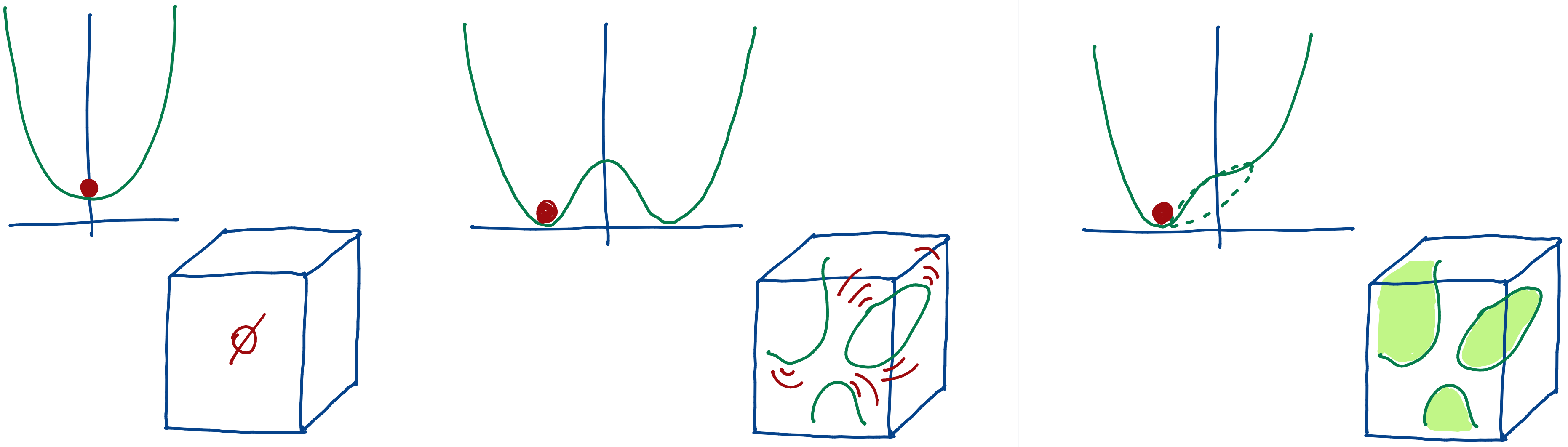
There is good chance to put strong bounds on ALPS from string networks using CMB+LSS

The matter power spectrum is the best observable to do so

ALPS from string network

$$H \leq f_a = T_{U(1)_{SSB}} \qquad\qquad H \leq m_a$$

time



Before **SSB**:
no strings

After **SSB**:
Strings and radiated axions
in the **scaling regime**

After the **tilt of the potential**:
Strings + domain walls