

A Bound on DM mass

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"Global" fuzzy DM

$\langle S_{DM} \rangle$ arises from homogeneous oscillations of a field

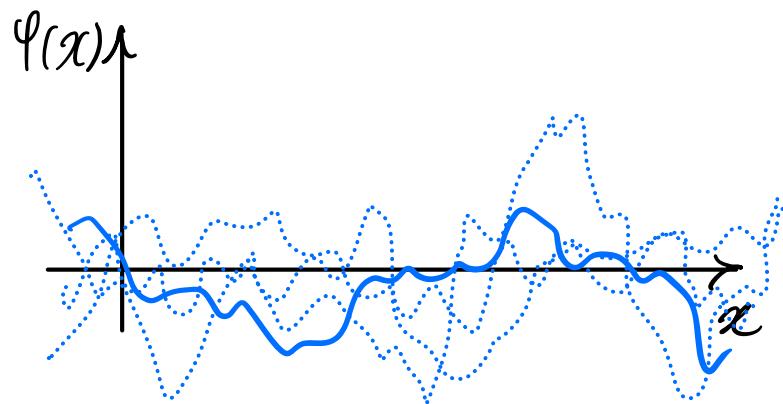


Example: ~~PK~~ pre-inflation

Nothing new to say !

"Local" fuzzy DM

$\langle S_{DM} \rangle$ arises from inhomogeneous oscillations.

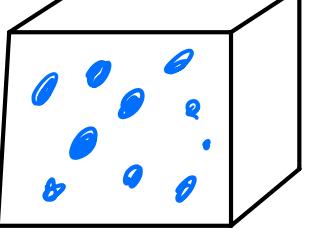


Example: ~~PK~~ post-inflation

$$m > 10^{-18} \text{ eV}$$

White noise

A random distribution of particles leads to a flat spectrum of density perturbations at low k .

$$P(\vec{x}) = \sum_i m \delta^3(\vec{x} - \vec{x}_i)$$


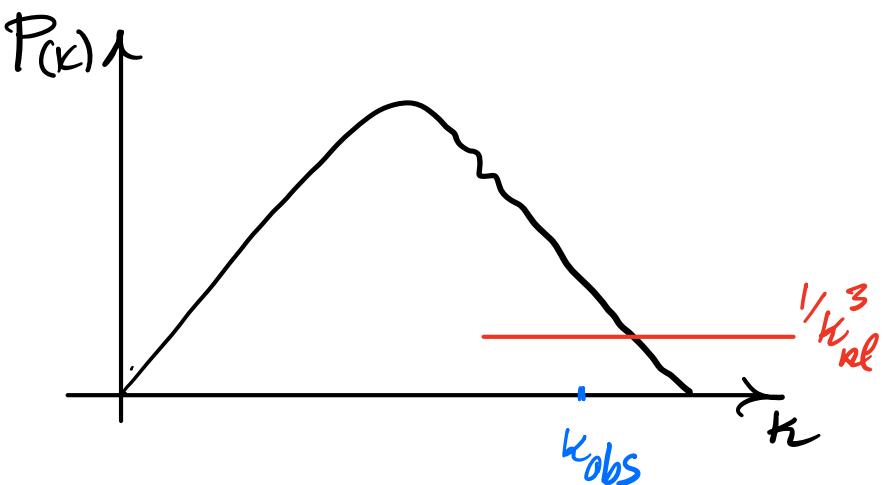
$$\bar{n} = m \bar{r}$$

$$P(k) = \left\langle \frac{\delta P(\vec{k})}{\bar{P}} \quad \frac{\delta P(-\vec{k})}{\bar{P}} \right\rangle$$

$$\xrightarrow{k \ll \bar{n}^{1/3}} P(k) = \frac{1}{\bar{n}} \equiv \frac{1}{k_{nl}^3}$$

Observed Matter Power Spectrum

Such a white noise has not been seen.



$$P^{ad}(k_{obs}) > \frac{1}{k_{nl}^3}$$

$$\Rightarrow k_{nl} > \Delta_{ad}^{1/3} k_{obs}$$

$$\Rightarrow k_{nl} > 10^3 k_{obs} \sim 10^4 \text{ Mpc}^{-1}$$

Upper bound

Since $\bar{P} = m \bar{n}$ is fixed

lower bound on $k_{nl} \sim \bar{n}^{1/3}$ leads
to an upper bound on m :

$$m < 100 M_\odot$$

Murgia et al. '19

Lower bound

In the "local" fuzzy DM model there
is a white noise:

$$\bar{P} = \frac{m^2}{2} \int \frac{d\vec{k}}{(2\pi)^3} P_\varphi(k) \quad \text{dominated by } k \sim k_* > 0$$

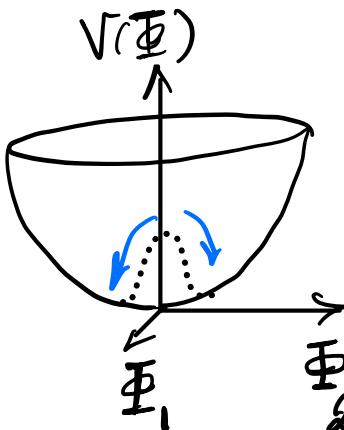
$$\left\langle \frac{\delta P(\vec{k})}{\bar{P}} \quad \frac{\delta P(-\vec{k})}{\bar{P}} \right\rangle_{k \ll k_*} \approx \frac{\frac{m^4}{2} \int d\vec{q} \left(P_\varphi(q) \right)^2}{\left(\frac{m^2}{2} \int d\vec{q} P_\varphi(q) \right)^2}$$

$$= O(k_*^{-3})$$

It is natural to expect that k_* increases with
 m , therefore $\min(k_*) \Rightarrow \min(m)$?

Example: Global string network

- After PQ, $\varphi = \text{phase}(\Phi)$ changes randomly over $\ell \sim H_{\text{PQ}}^{-1}$, leading to a string network.



- The scaling solution (few strings/Hubble volume) means $\ell(t) \sim H(t)^{-1}$.
- The network decays when $H(t_m) \sim m$.
- Afterward φ is approximately free

so

$$K_* \sim \frac{\alpha(t_m)}{\ell(t_m)} \sim \alpha(t_m) m$$

$$K_{\text{NL}} \sim K_* \sim \alpha(t_m) m$$

Under these assumptions

$$\frac{K_{\text{NL}}}{K_{\text{eq}}} \sim \sqrt{\frac{m}{H_{\text{eq}}}}$$

$$K_{\text{NL}} > 10^3 K_{\text{obs}} \implies m > 10^{-17} \text{ eV}$$

Irsic et al '19

*Caveat: If axions are produced with non-negligible velocity \Rightarrow

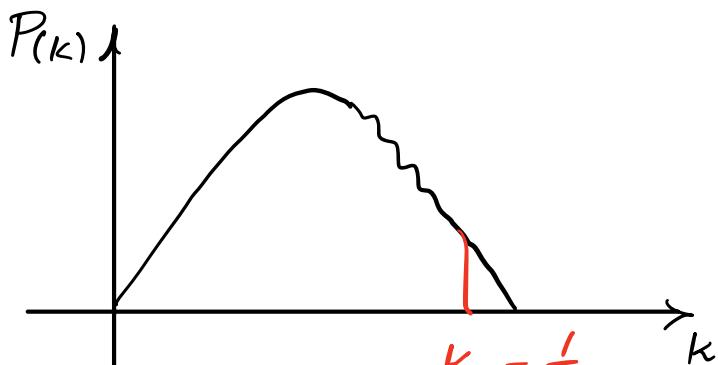
$K_* \gg \alpha(t_m) m \Rightarrow$ weaker bound on m

Free streaming

Making $k_* \gg a(t_m) m$ makes DM too warm:

$$R_{FS} = \int dt \frac{k_*/\alpha^2(t)}{\sqrt{m^2 + k_*^2/a^2(t)}}$$

$$\sim \frac{k_*}{a_{eq}^2 m H_{eq}} \ln \frac{t_{eq}}{t_{n.r.}} \sim 10$$



$$k_{FS} = \frac{1}{R_{FS}}$$

\checkmark
 k_{obs}

WN + FS

$$k_* > 10^3 k_{obs} \quad \left. \begin{array}{l} \\ k_{FS} > k_{obs} \end{array} \right\} \Rightarrow \frac{m}{H_{eq}} > 10^3 \left(\frac{k_{obs}}{k_{eq}} \right)^2 \ln \frac{t_{eq}}{t_{n.r.}}$$

$$\Rightarrow m > 10^{-18} \text{ eV}$$

- * Introducing multiple scales $k_{*,1}, k_{*,2}, \dots$ typically improves the bound.
- * FS dip + WN plateau is a signature of "local" fuzzy DM models.
- * H_{inf} has to be quite high for post-infl. DQ

