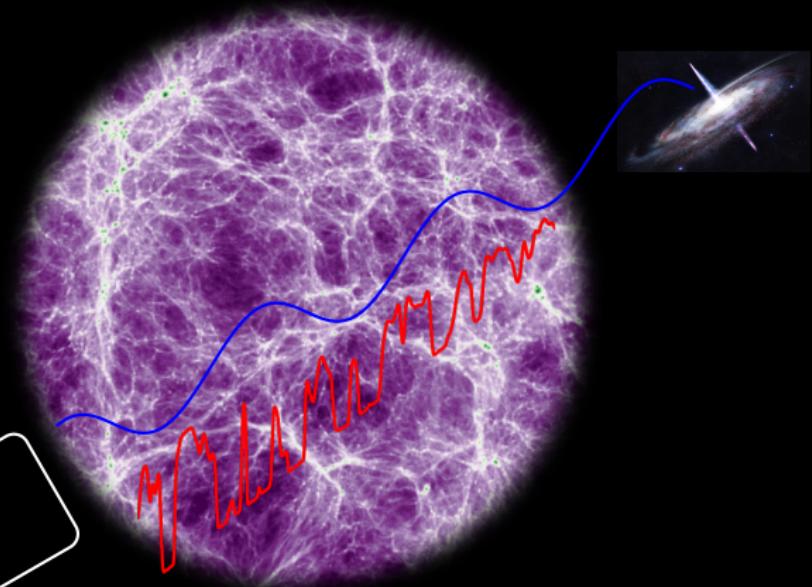
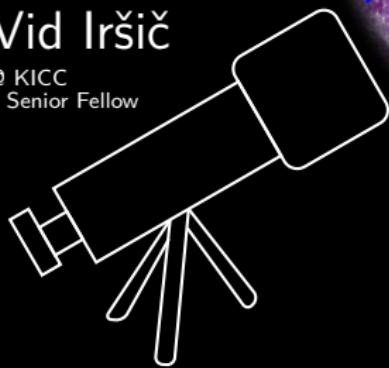


# Fuzzy dark matter from IGM



Vid Iršič

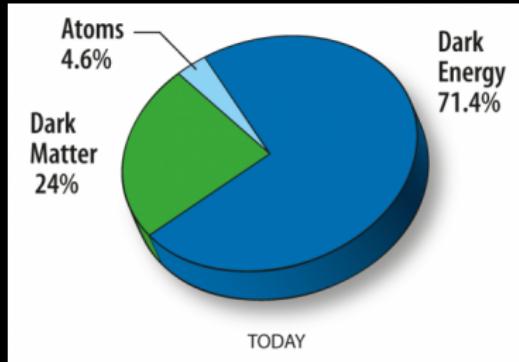
@ KICC  
Kavli Senior Fellow



KICC 10th Anniversary Symposium

Sept 17, 2019

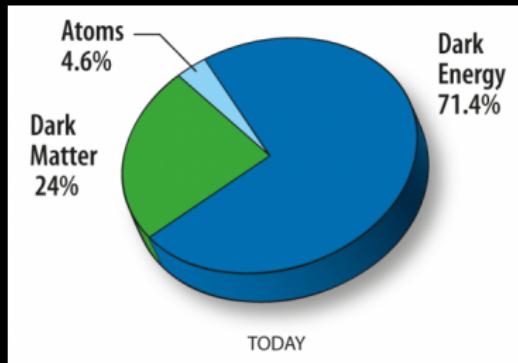
# Cold Dark Matter problems (?)



Cold Dark Matter (CDM):

heavy, non-interactive particle(s)  $\rightarrow$  WIMPs

# Cold Dark Matter problems (?)



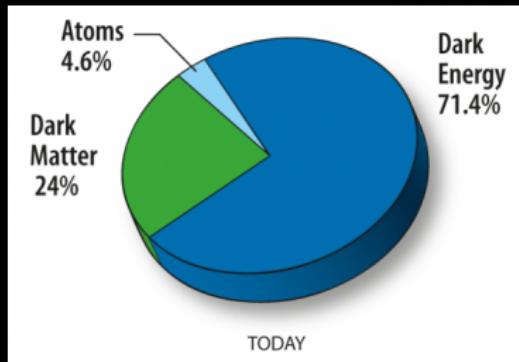
Cold Dark Matter (CDM):

heavy, non-interactive particle(s)  $\rightarrow$  WIMPs

CDM problems of small-scale  
physics:

- Missing satellites
- Core/Cusp problem
- ...

# Cold Dark Matter problems (?)



Cold Dark Matter (CDM):

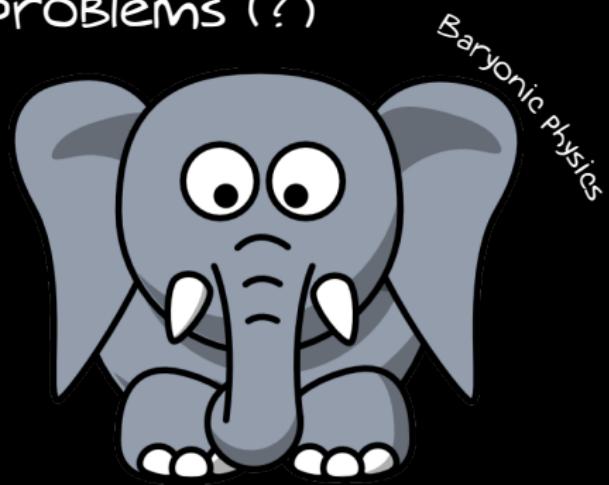
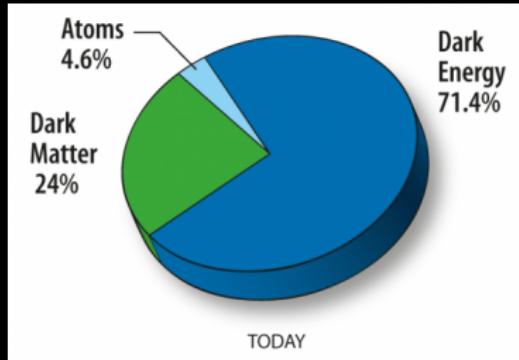
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CDM problems of small-scale  
physics:

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- ...

}  $\rightarrow$  Alternative DM models  
(Warm DM, Fuzzy DM,  
Self-interacting DM, ...)

# Cold Dark Matter problems (?)



Cold Dark Matter (CDM):

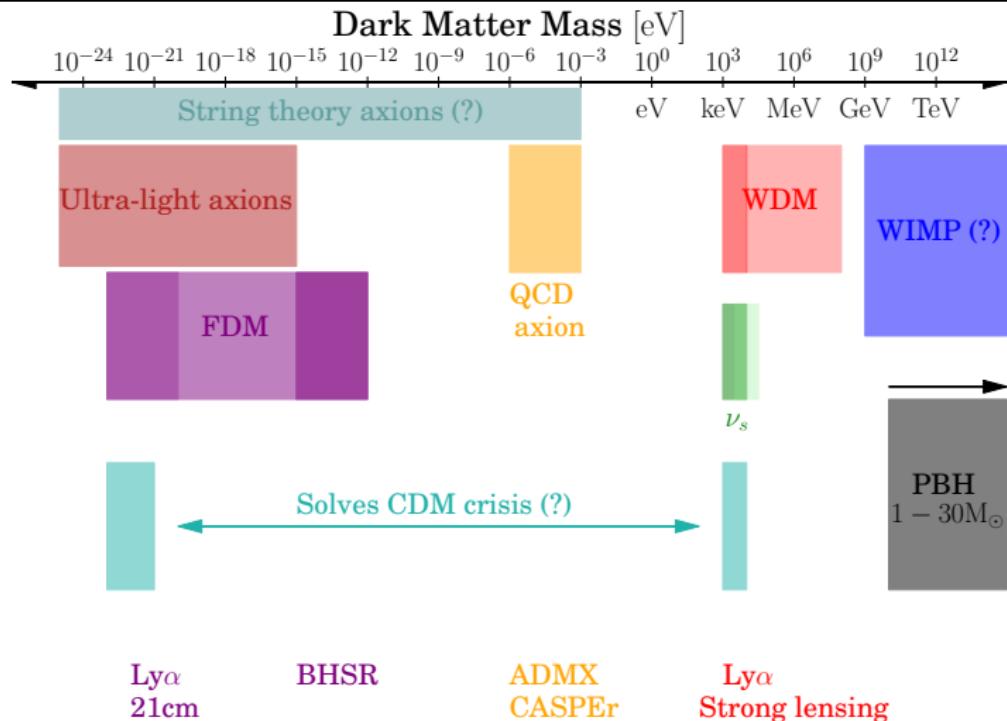
heavy, non-interactive particle(s)  $\rightarrow$  WIMPs

CDM problems of small-scale  
physics:

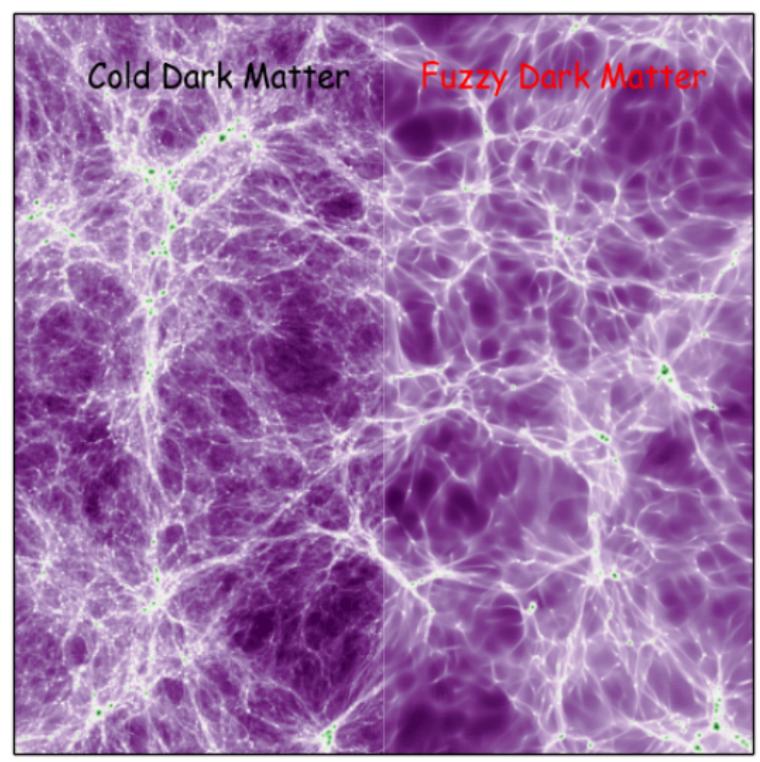
- Missing satellites
- Core/Cusp problem
- ...

}  $\rightarrow$  Alternative DM models  
(Warm DM, Fuzzy DM,  
Self-interacting DM, ...)

# Where to look for DM?



# FDM erases small scale structure



Typical FDM particle mass from local small-scale structure :  $m_{\text{FDM}} \sim 1 - 10 \times 10^{-22} \text{ eV}$

Fuzzy Dark Matter (FDM):

Jeans scale

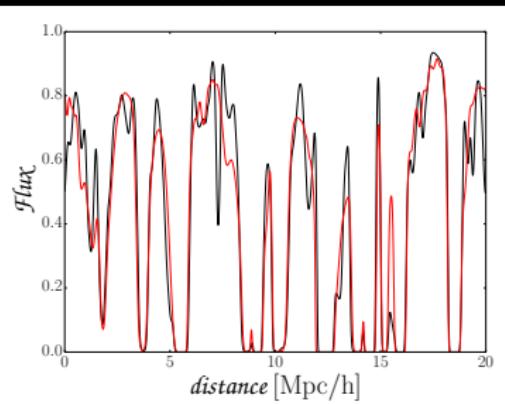
of ultra-light DM scalar

$$k_{J,\text{eq}} = 9 \left( \frac{m_{\text{FDM}}}{10^{-22} \text{ eV}} \right)^{1/2} \text{ Mpc}^{-1}$$

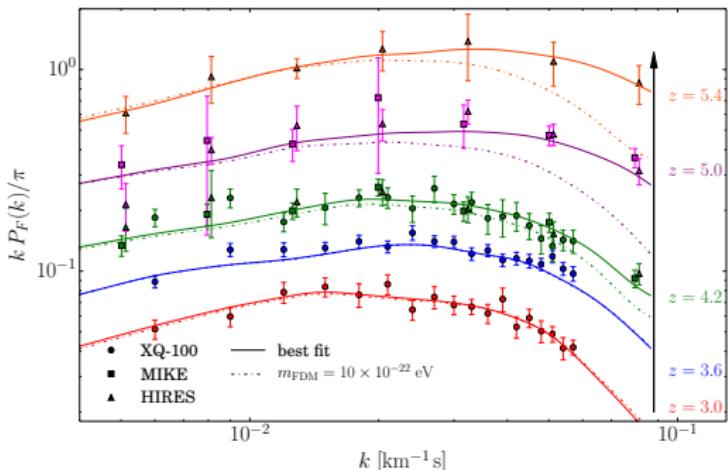
Nonlinear soliton solutions  
~ kpc

⇒ erases small scale structure

Typical  $\lambda \sim \text{Mpc}/\text{h}$



# FDM mass constraints



Low- $z$  data:

XQ-100 ( $3 < z < 4.2$ )

High- $z$  data:

HIRES/MIKE ( $4.2 < z < 5.4$ )

Typical DM mass:

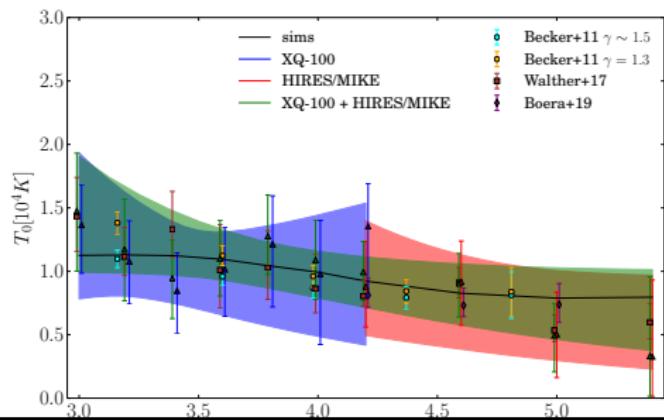
$$m_{\text{FDM}} \sim 1 - 10 \times 10^{-22} \text{ eV}$$

$T_0(z)$  is power-law

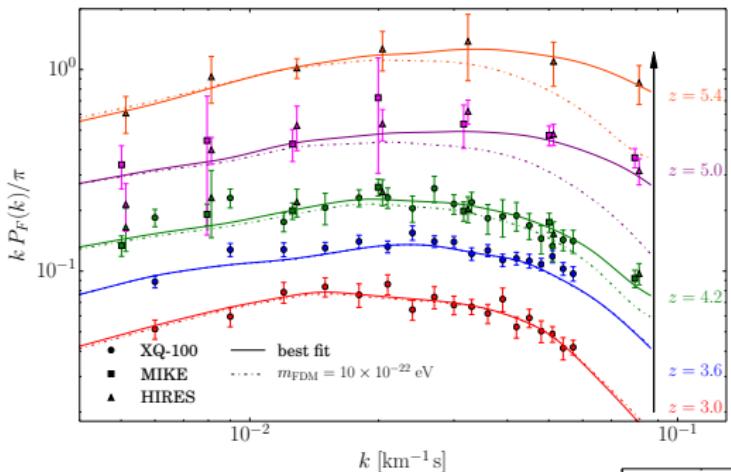
$$\rightarrow m_{\text{FDM}} > 37.5 \times 10^{-22} \text{ eV} @ 2\sigma$$

$T_0(z)$  free +  $\frac{\partial T_0}{\partial z}$  bounded

$$\rightarrow m_{\text{FDM}} > 20.4 \times 10^{-22} \text{ eV} @ 2\sigma$$



# FDM mass constraints



Results later confirmed by independent group:

Armengaud et al. 2017 (FDM)

Typical DM mass:

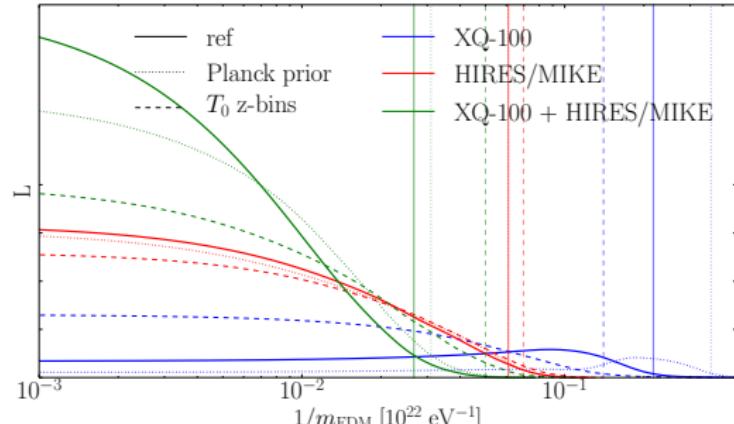
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$T_0(z)$  is power-law

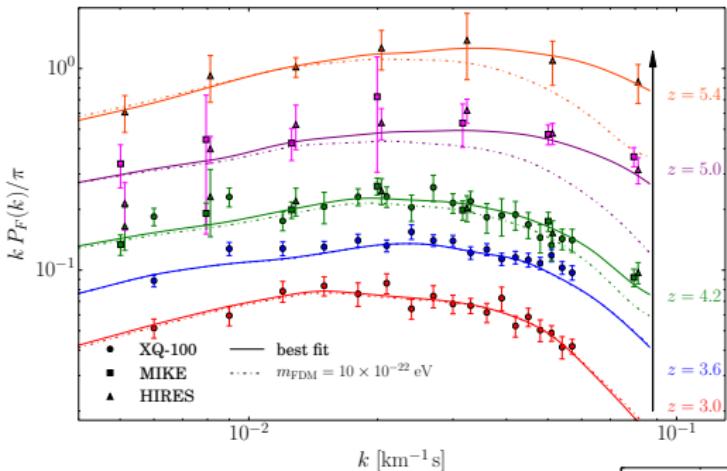
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$T_0(z)$  free +  $\frac{\partial T_0}{\partial z}$  bounded

$$\rightarrow m_{\text{FDM}} > 20.4 \times 10^{-22} \text{ eV} @ 2\sigma$$



# FDM mass constraints



Fluid approximation of the Schrödinger-Poisson equations  
 $\Rightarrow$  Quantum pressure term in Euler equation

$$\frac{\hbar^2}{2a^3 m^2} \vec{\nabla} \left( \frac{\nabla^2 \sqrt{\rho}}{\sqrt{\rho}} \right)$$

$T_0(z)$  is power-law

$$\rightarrow m_{\text{FDM}} > 37.5 \times 10^{-22} \text{ eV} @ 2\sigma$$

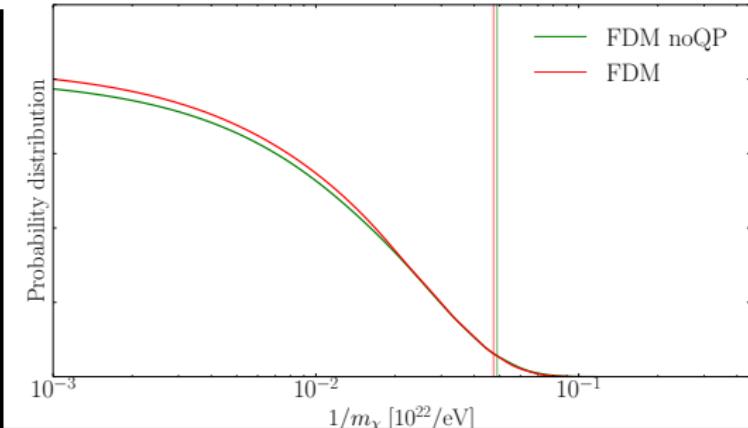
$T_0(z)$  free +  $\frac{\partial T_0}{\partial z}$  bounded

$$\rightarrow m_{\text{FDM}} > 20.4 \times 10^{-22} \text{ eV} @ 2\sigma$$

FDM + Quantum Pressure

$$\rightarrow m_{\text{FDM}} > 21.1 \times 10^{-22} \text{ eV} @ 2\sigma$$

Nori, Murgia, Vi, Baldi, Viel (2018)



# Conclusions

- Fuzzy dark matter is a viable (well motivated) alternative to CDM
- Lyman- $\alpha$  forest is a unique probe of the IGM (redshift range, small scales) – talk by E. Puchwein
- Robust constraints on DM models (e.g. WDM, FDM)
  - [astro-ph/1702.01764](https://arxiv.org/abs/1702.01764) (talk by M. Viel), [astro-ph/1703.04683](https://arxiv.org/abs/1703.04683)
- Statistically dominated at high- $z$  – need more high quality QSO sightlines  
 $z > 5.0$