Simulation of Fuzzy Dark Matter

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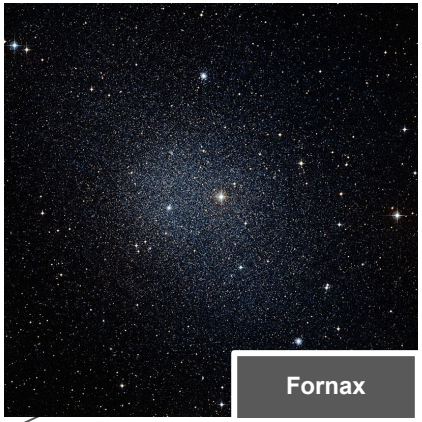
Research Strategy

CDM Simulation

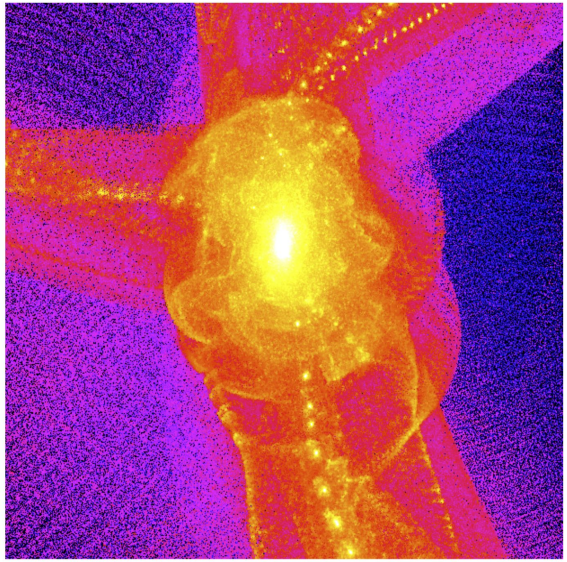
Local Universe



Missing satellite
Diversity problem
Eridanus II star cluster
Crater II large core
Too many thin disks….

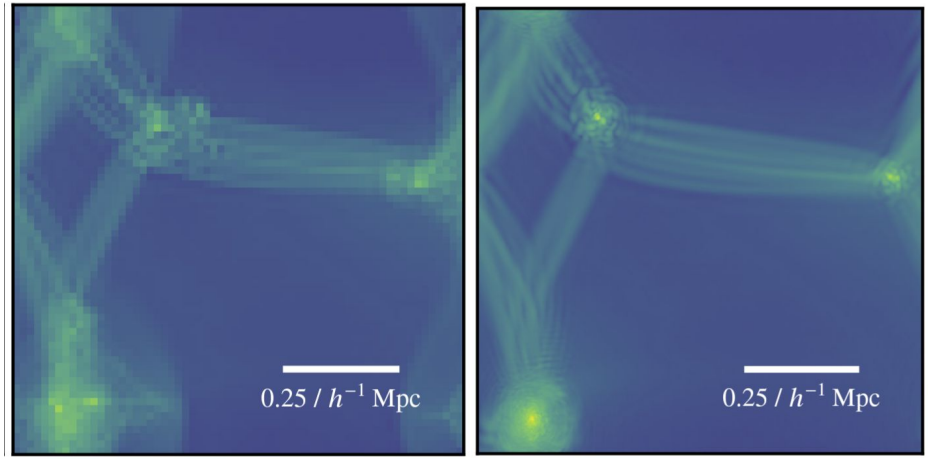
Alternative Dark Matter

Spurious haloes of WDM



Paduroiu 2022

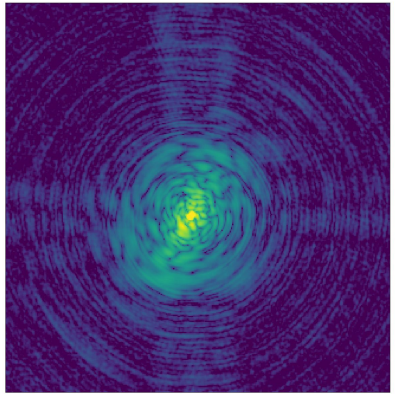
High resolution of FDM



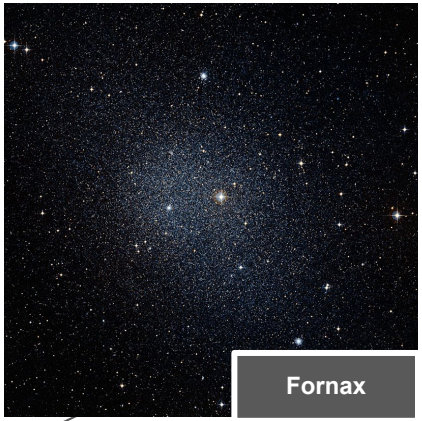
May 2021

Research Strategy

FDM Simulation



Local Universe



Study the Nature of Dark Matter

The Diversity of Core Halo Structure in the Fuzzy Dark Matter Model

(Chan, Elisa, Chiba,. et al, 2022, MRNAS, 511, 943)

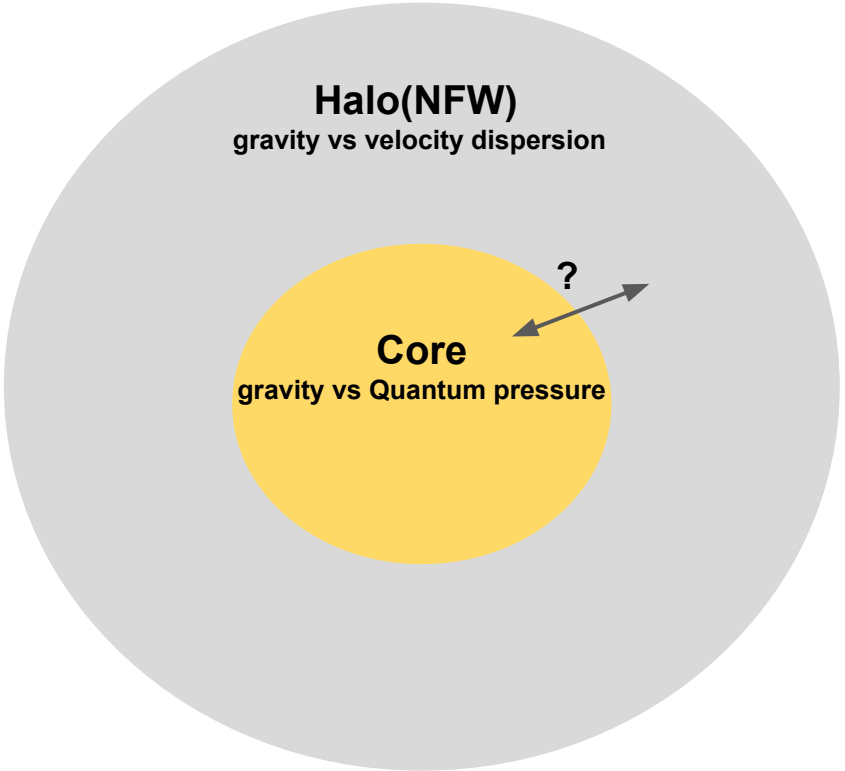
Core-Halo Structure

1) **Density Profile**

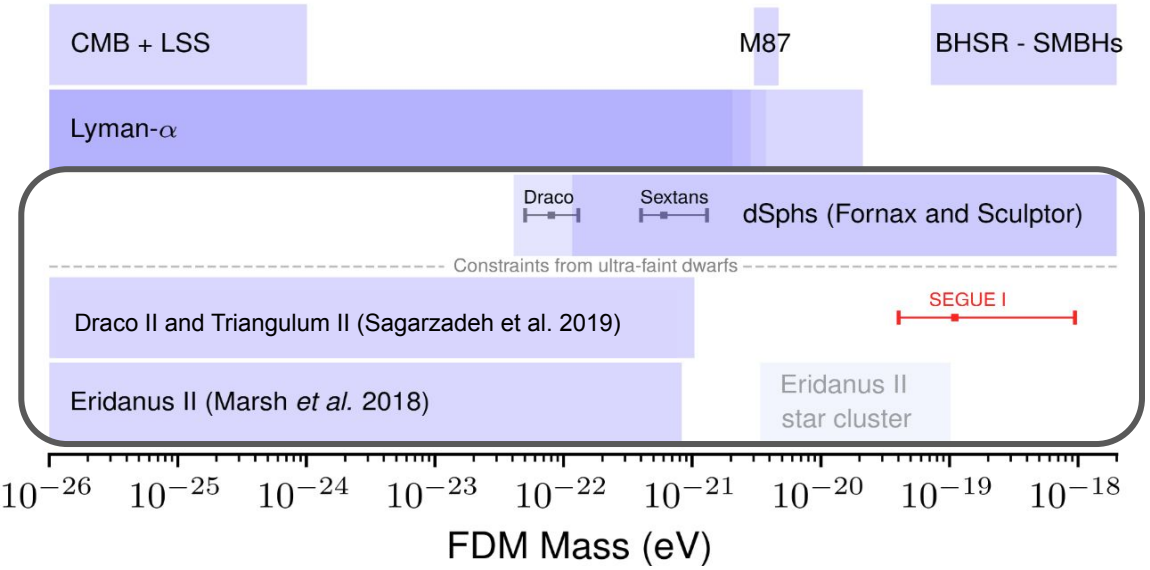
$$\rho = \rho_{\rm core} + \rho_{\rm NFW}$$

2) **Core-halo mass relation**

$$M_{\rm c} \propto M_{\rm h}^{\alpha}$$

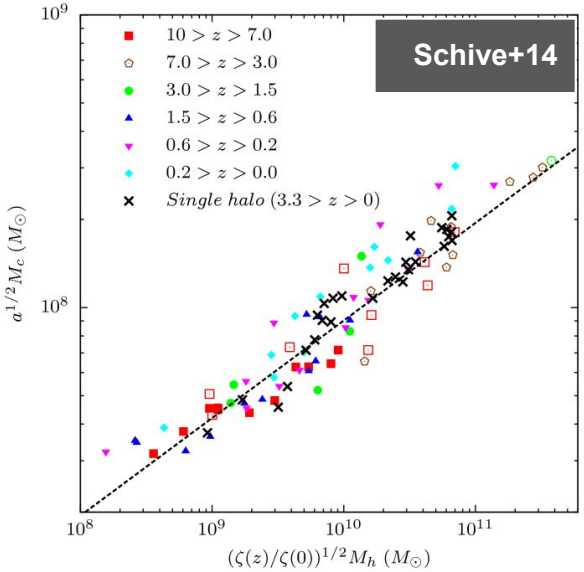


Observational Constraints (Excluded Bound)



K. Hayashi, E. Ferreira, **J. Chan.** 2021

Core-halo relation



No agreement between groups!

Schrodinger-Poisson system

$$i\hbar\partial_t\psi = \left[-\frac{\hbar^2}{2ma^2}\nabla^2 + \frac{m\Phi}{a}\right]\psi \qquad \nabla^2\Phi = 4\pi G m|\psi|^2$$

Operator Splitting Method

1st Step $$i\hbar\partial_t\psi = -\frac{\hbar^2}{2ma^2}\nabla^2\psi$$

2nd Step $$i\hbar\partial_t\psi = -\frac{m\Phi}{a}\psi$$

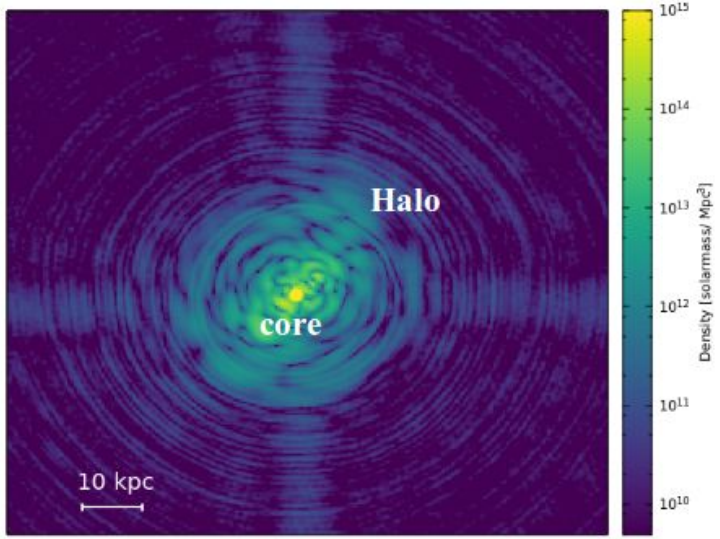
3rd Step $$i\hbar\partial_t\psi = -\frac{\hbar^2}{2ma^2}\nabla^2\psi$$

Time step criteria

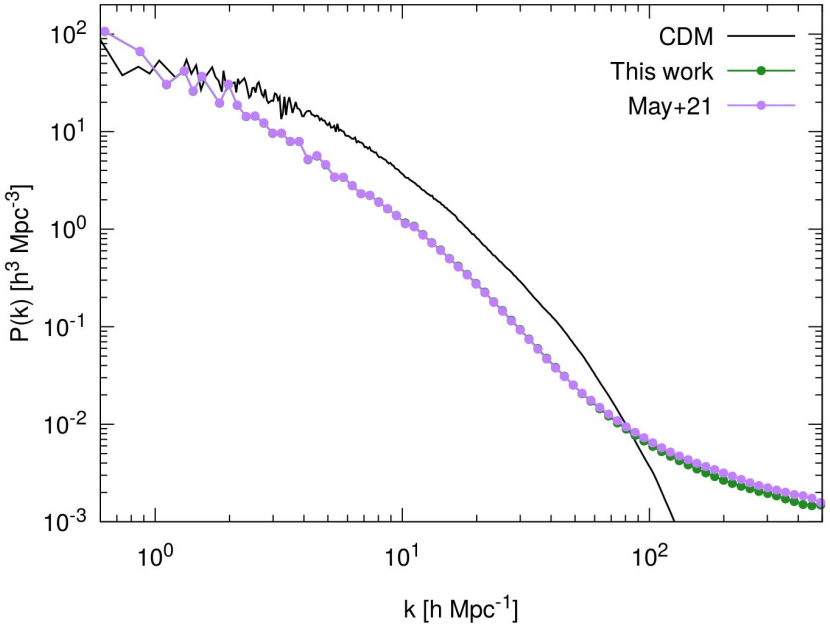
$$\Delta t \sim \Delta x^2$$

Simulation

Simulation


Halo
core
10 kpc
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
Density [solarmass/ Mpc^3]

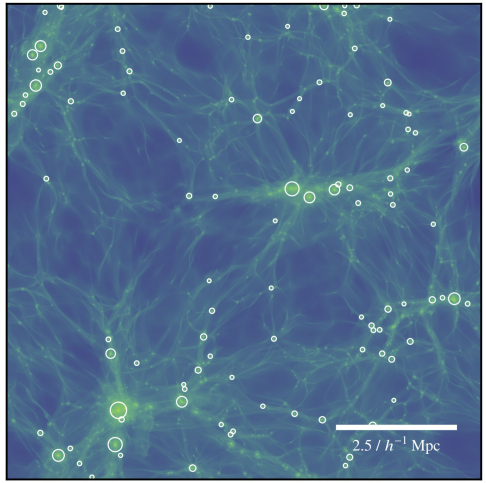
Code Comparison



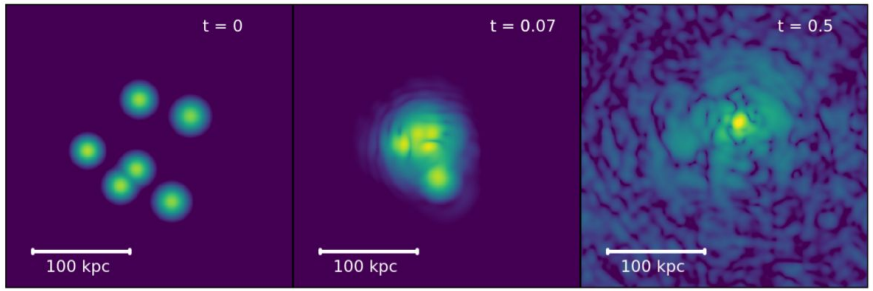
Independently developed!

Good agreement!

Simulation Set Up



	(This Work)	(May+21)
	Soliton merger	Large-box cosmological
L	0.3 Mpc	10 Mpc/h
N^3	512^3	8640^3
mc^2	10^{-22} eV	7×10^{-23} eV
$z_{\rm f}$	3	3
Δx	0.644 kpc	1.547 =kpc



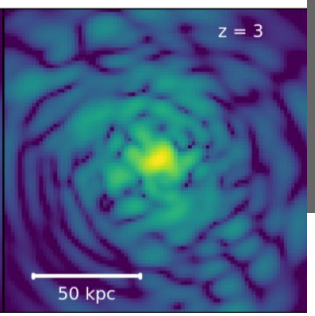
Difficult to simulate FDM!

Simulation

largeキュー

このキューは各カテゴリごとに以下の設定値でジョブを実行できるキューです。

カテゴリ	XC-A	XC-B+	XC-B	XC-MD	XC-Trial
キュー名	large-a	large-bp	large-b	large-md	large-t
最大同時利用可能コア数	20000	3440	1040	800	120
単一ジョブ最大コア数	20000	3440	520	400	120
最大同時投入数	無制限	無制限	無制限	無制限	無制限
最大同時実行数(括弧内は混雑した場合の値)	10(1)	10(1)	10(1)	10(1)	5(1)
継続時間	24 hour	24 hour	24 hour	24 hour	4 hour

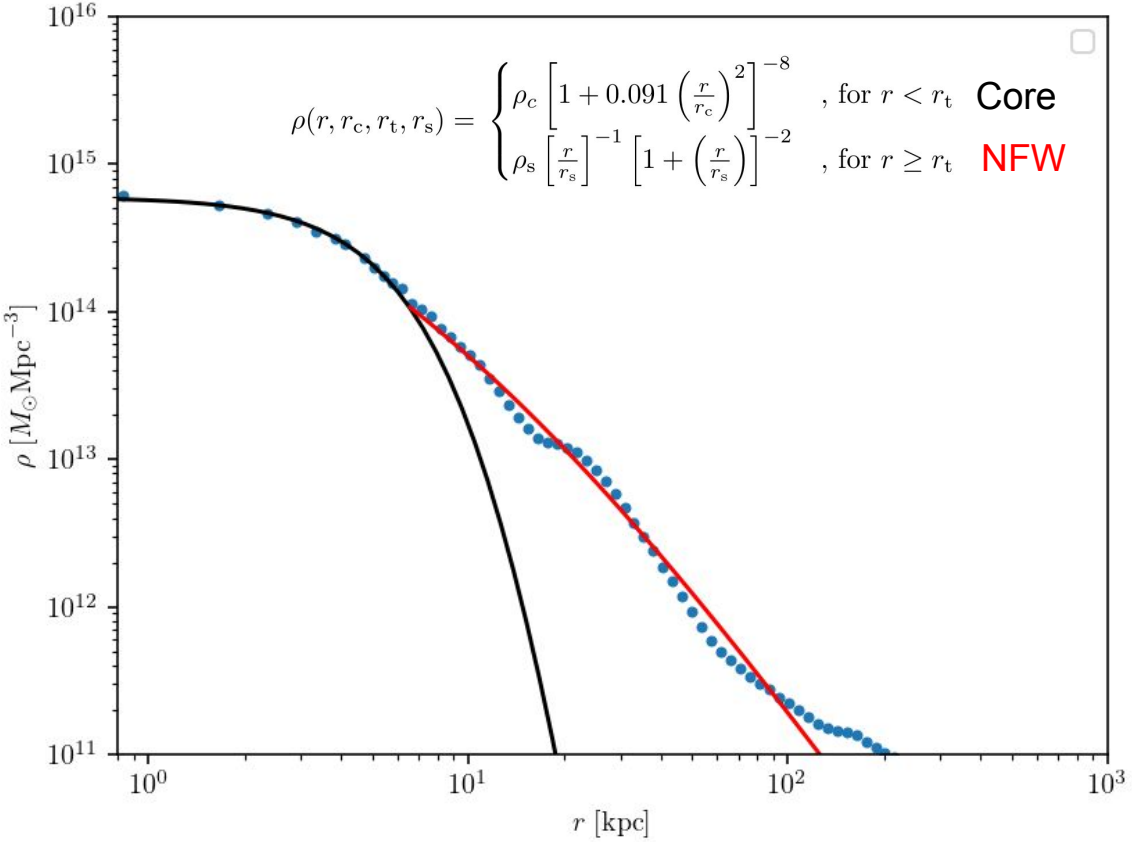


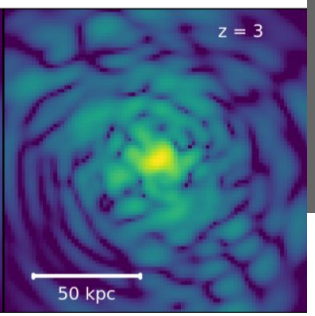
Density profile

$$\rho(r, r_c, r_t, r_s) = \begin{cases} \rho_c \left[1 + 0.091 \left(\frac{r}{r_c}\right)^2\right]^{-8} & , \text{for } r < r_t \\ \rho_s \left[\frac{r}{r_s}\right]^{-1} \left[1 + \left(\frac{r}{r_s}\right)\right]^{-2} & , \text{for } r \geq r_t \end{cases}$$

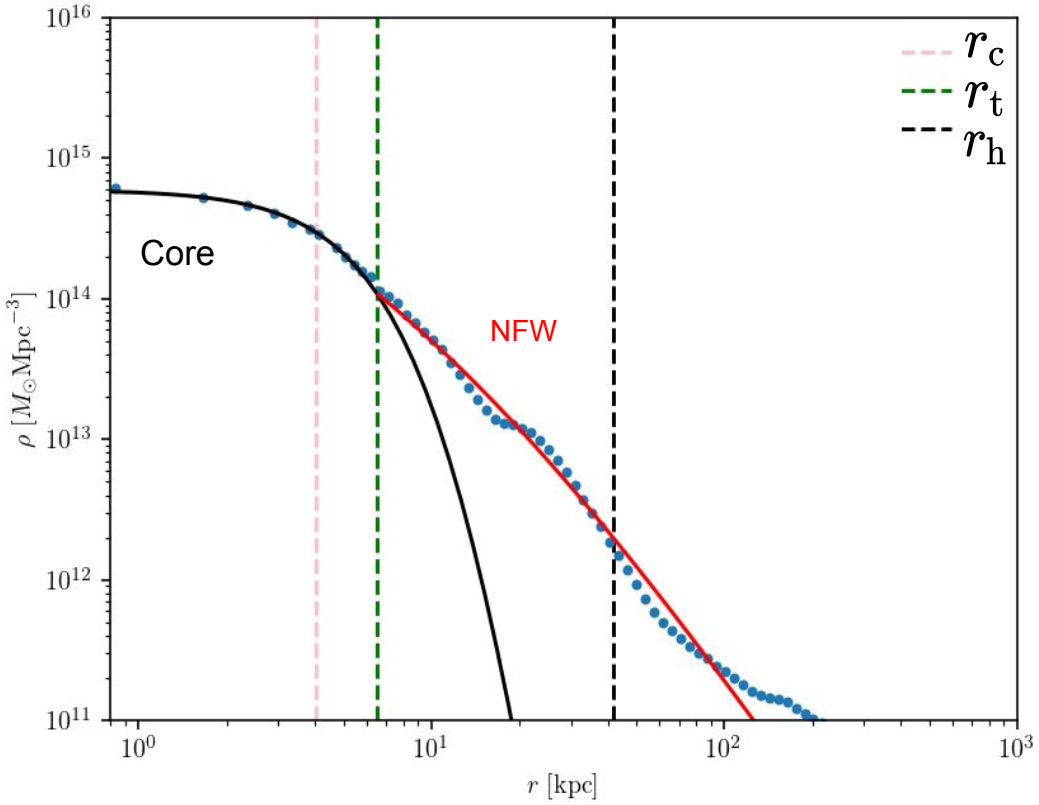
Core

NFW



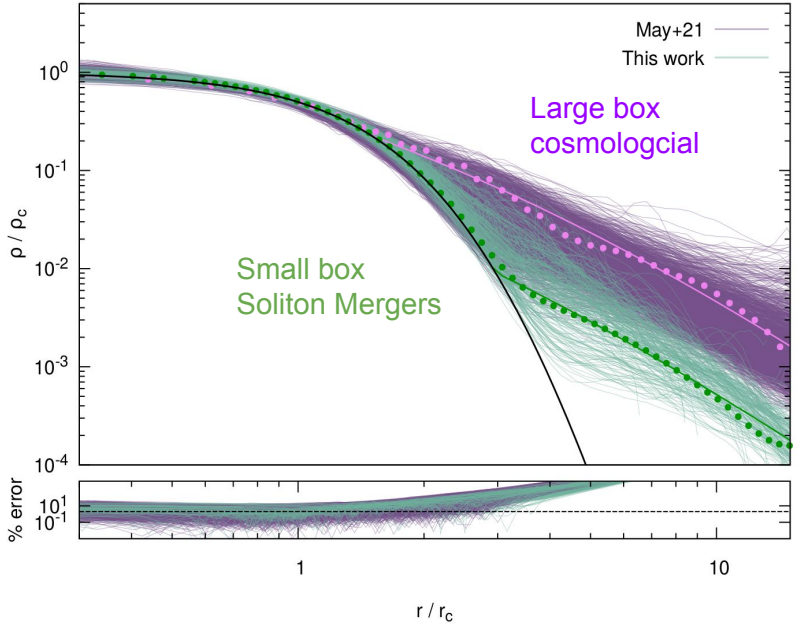


Density profile



Our Results

Density Profile

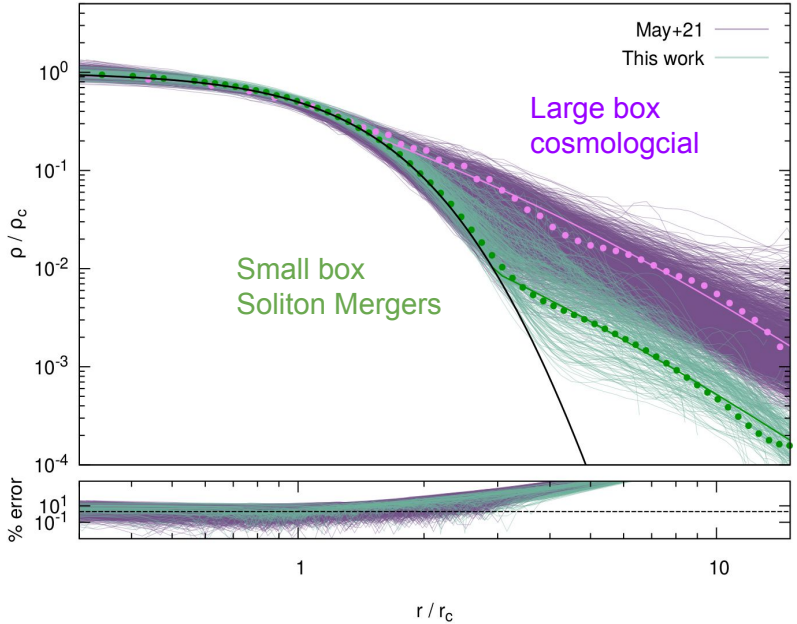


Confirming the core profile

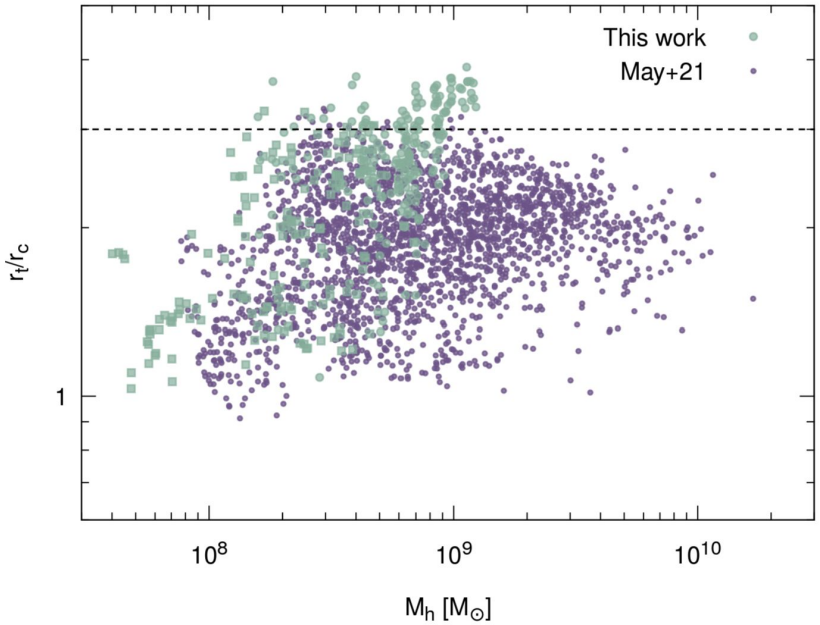
Transition radius

Our Results

Density Profile

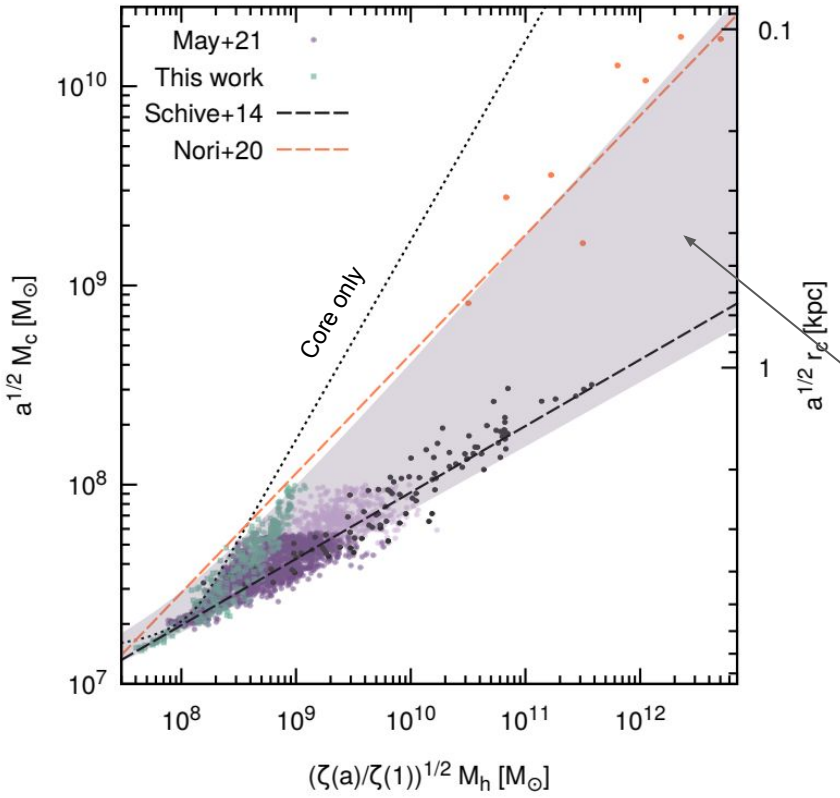


Transition radius



Confirming the core profile

The core-halo relation

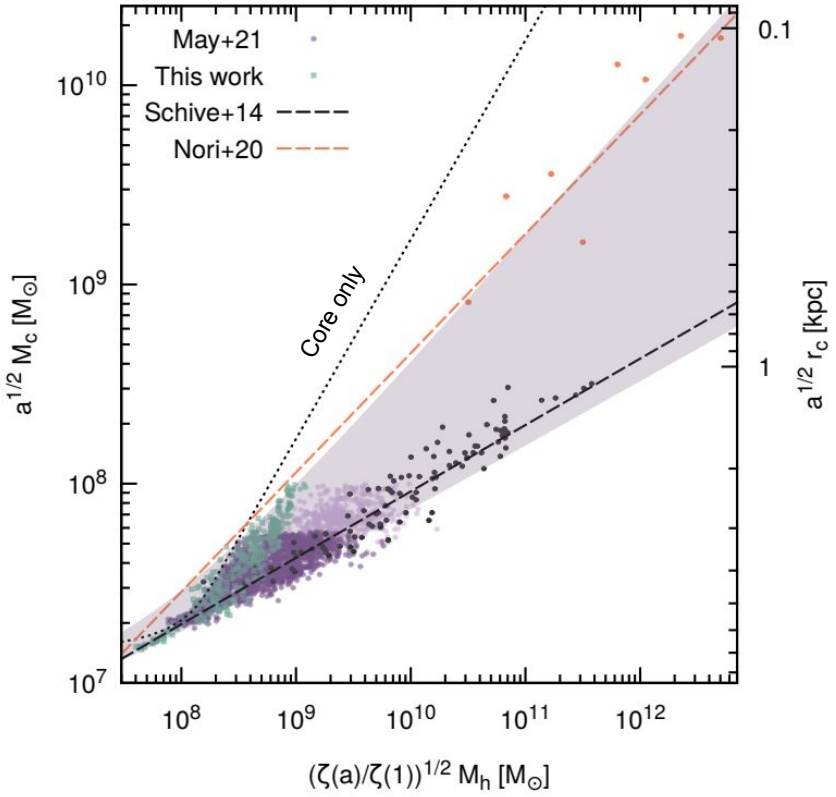


- **Dispersion !**
- **Previous studies only describe part of the core-halo population**

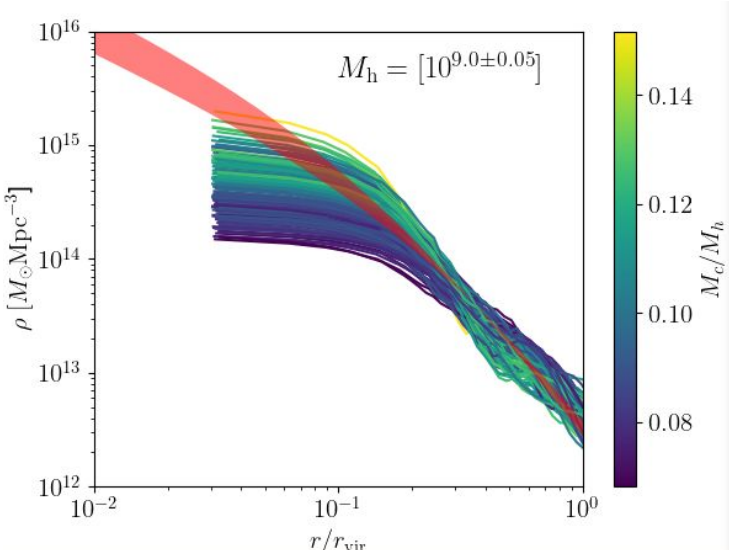
- **New Empirical Equation**

$$M_c = \beta + (M_h/\gamma)^{\alpha}$$

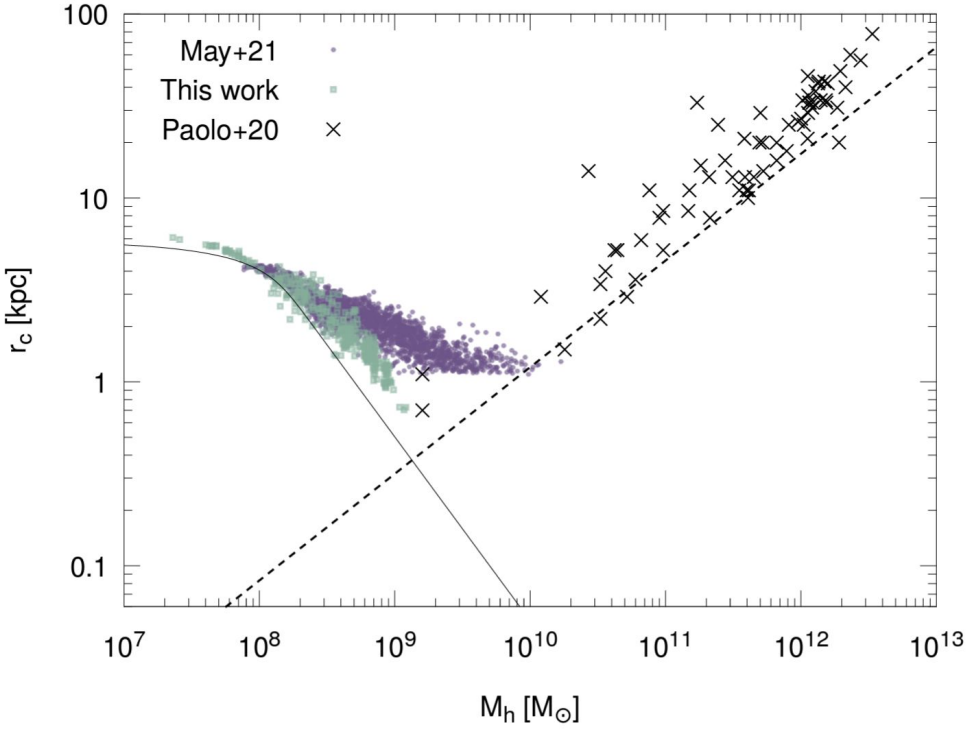
Dispersion in the core-halo relation



Diversity of density profiles

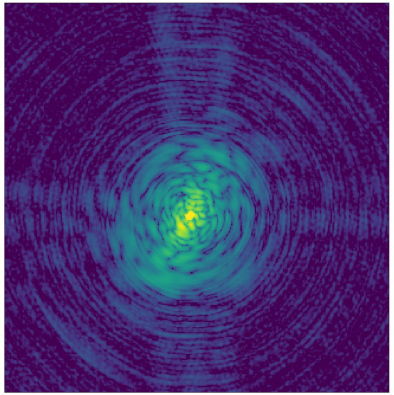


Problem with FDM



Summary & future work

Simulation



Diverse core-halo structure (this work)

Revaluate dwarf data

Diversity of Rotation curve

We need
Zoom-in simulation of MW size halo until z=0

Thank you for listening!

Reference:

- The Diversity of Core Halo Structure in the Fuzzy Dark Matter Model (Chan, Elisa, Chiba,. et al, 2022, MRNAS, 511, 943)

- Narrowing the mass range of Fuzzy Dark Matter with Ultra-faint Dwarfs (Kohei., Elisa., Chan , 2021, ApJ, 912, L3)

- Structure formation in large-volume cosmological simulations of FDM (May., Springel, 2021, MNRAS, 506, 2603)