Astrophysical Constraints on Warm Dark Matter

UCLA Dark Matter 2023

Kev Abazajian
University of California, Irvine

March 30, 2023

How much small scale structure is there?

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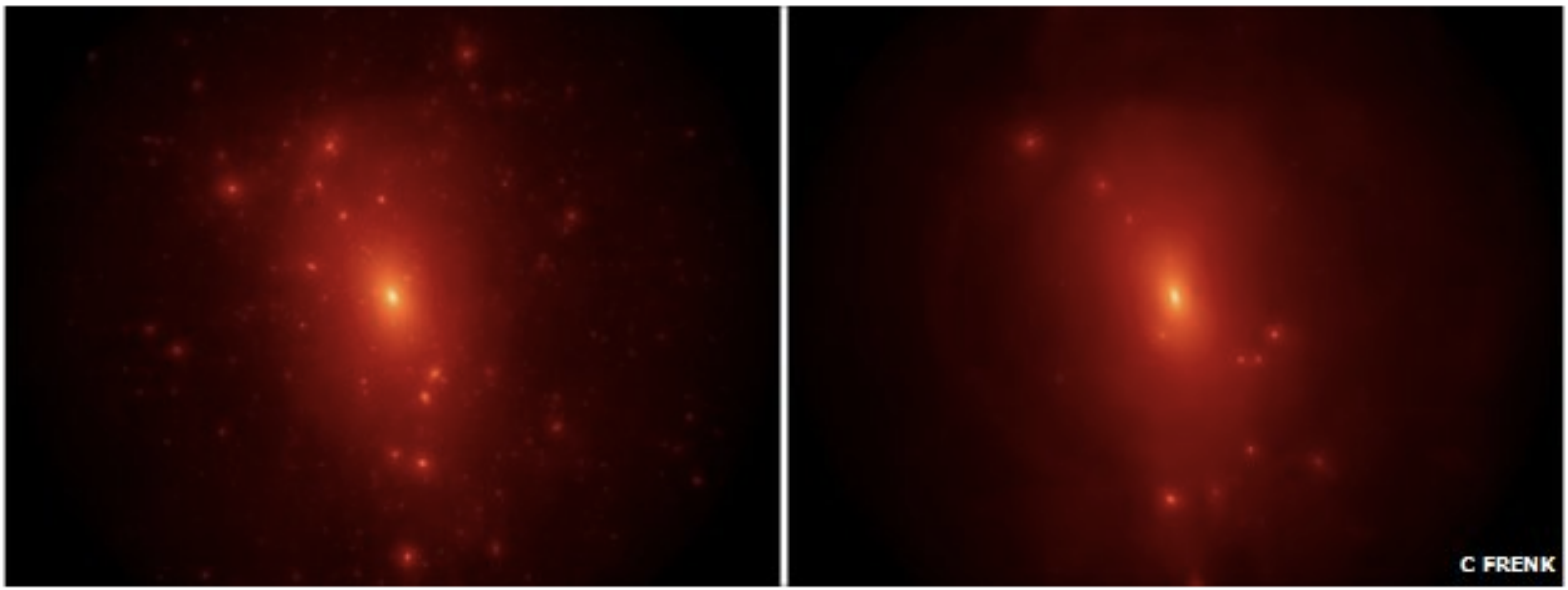
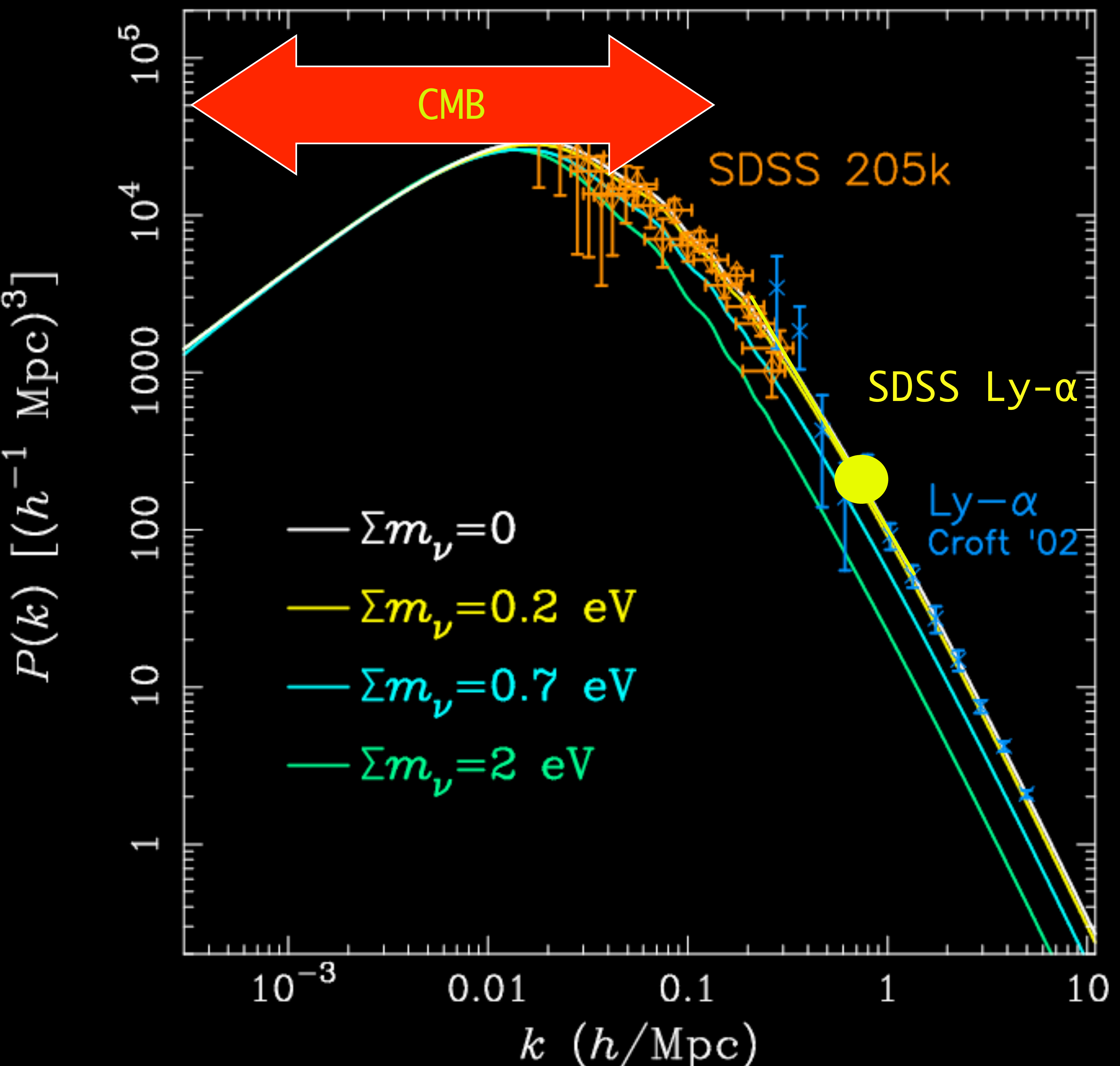


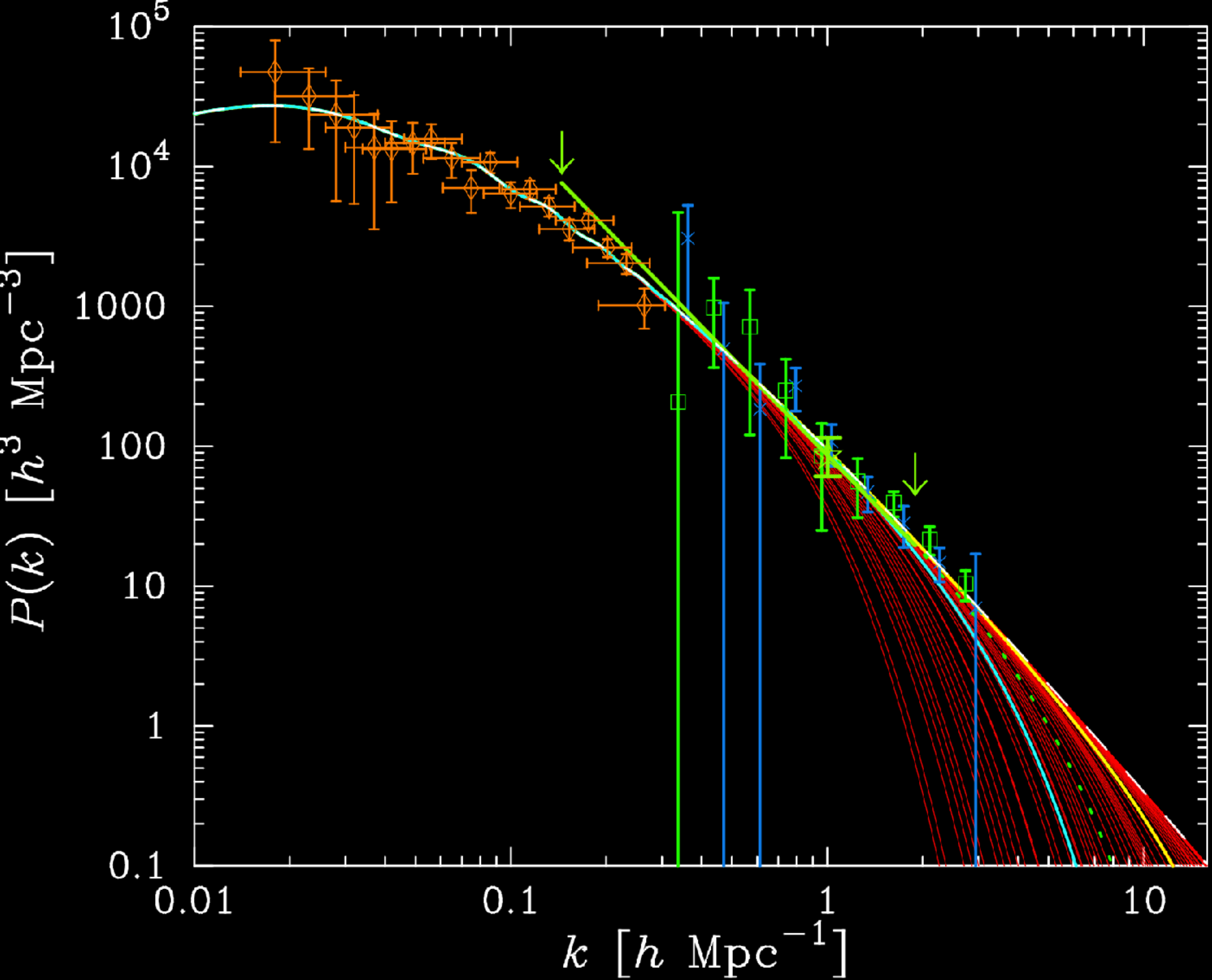
Dwarf galaxies around the Milky Way are less dense than they should be if they held cold dark matter

Measuring Large Scale Structure $P(k)$



Perturbation Evolution

Is there evidence for a small-scale cutoff, and *how warm is too warm?*



Abazajian astro-ph/0511630

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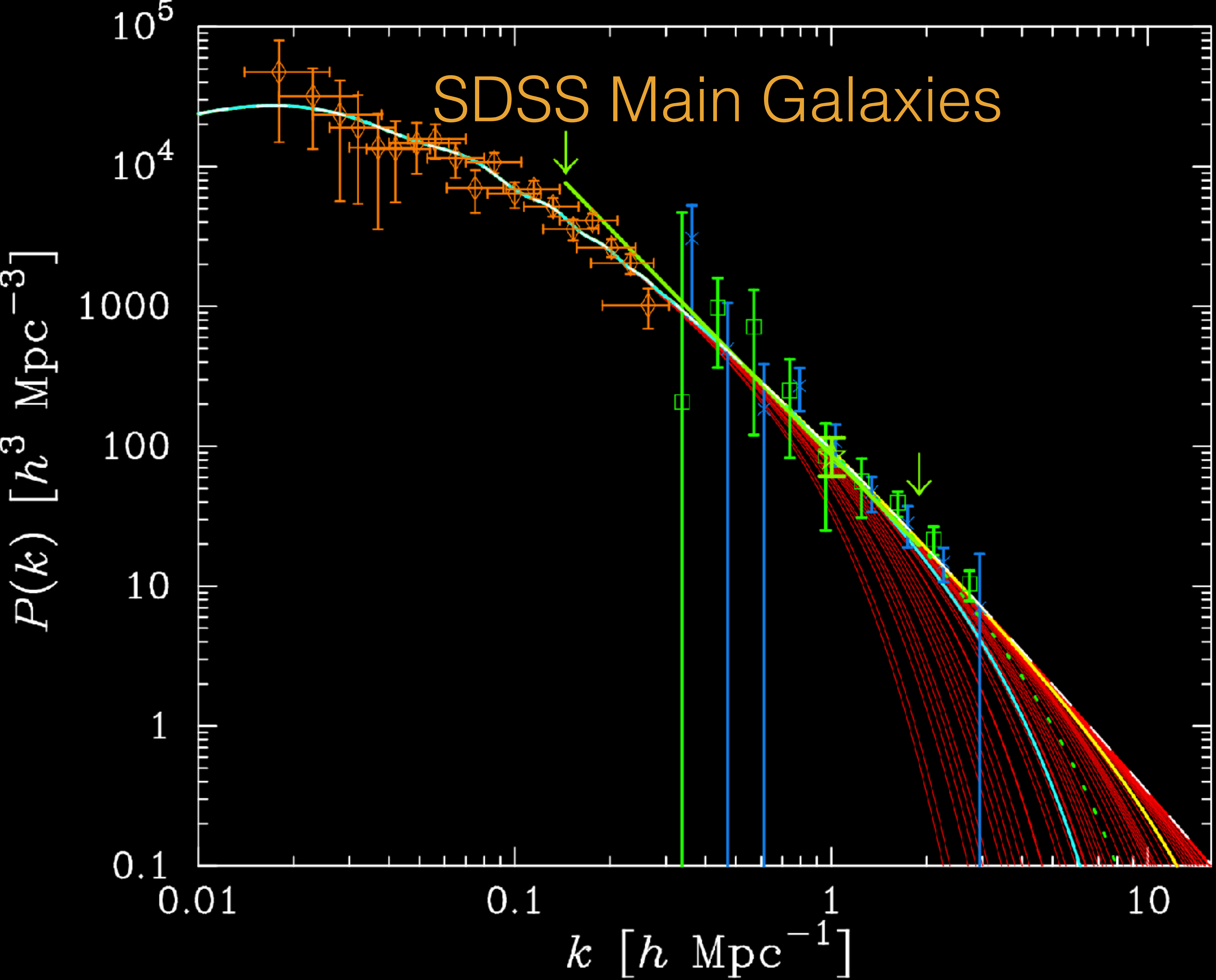

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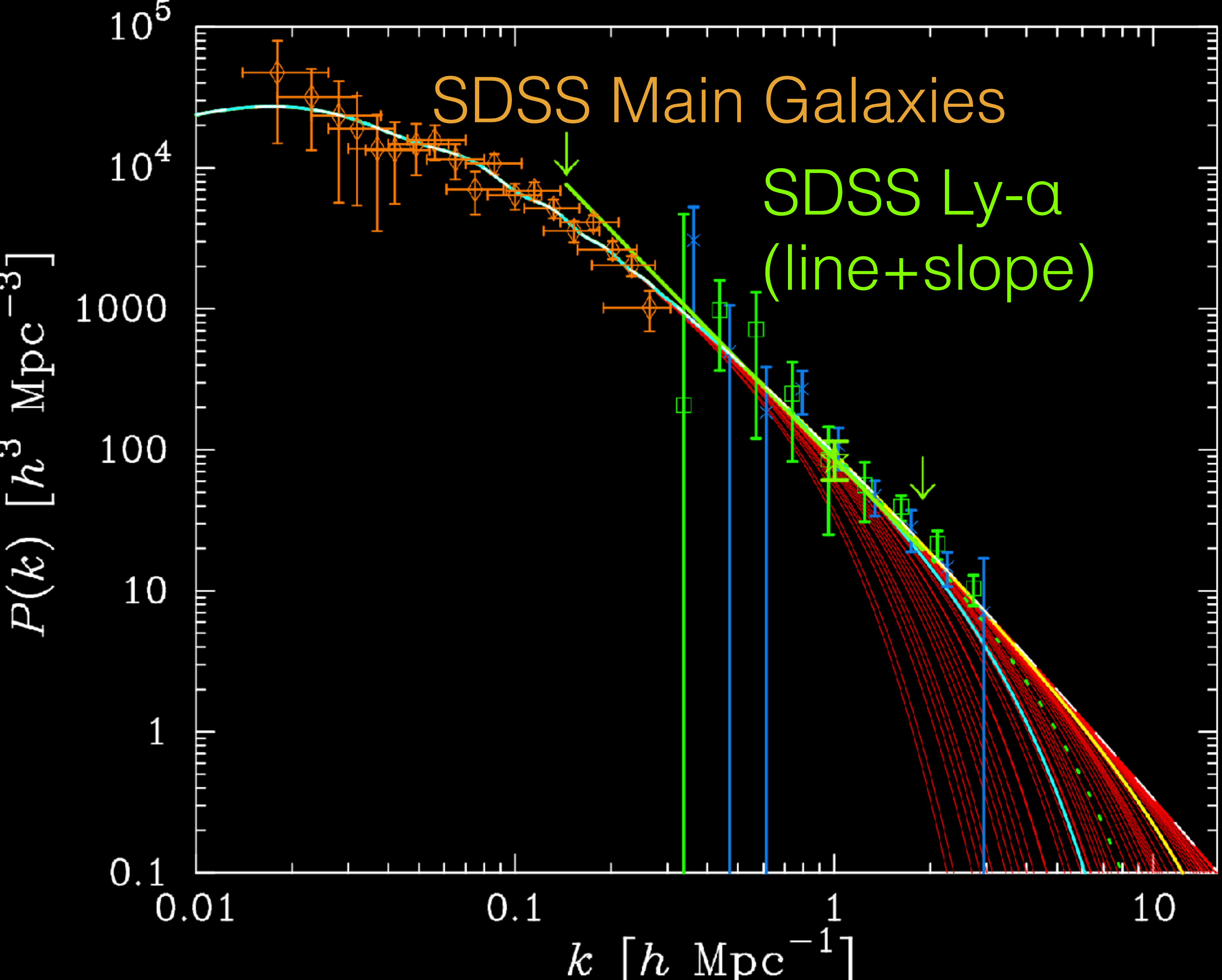

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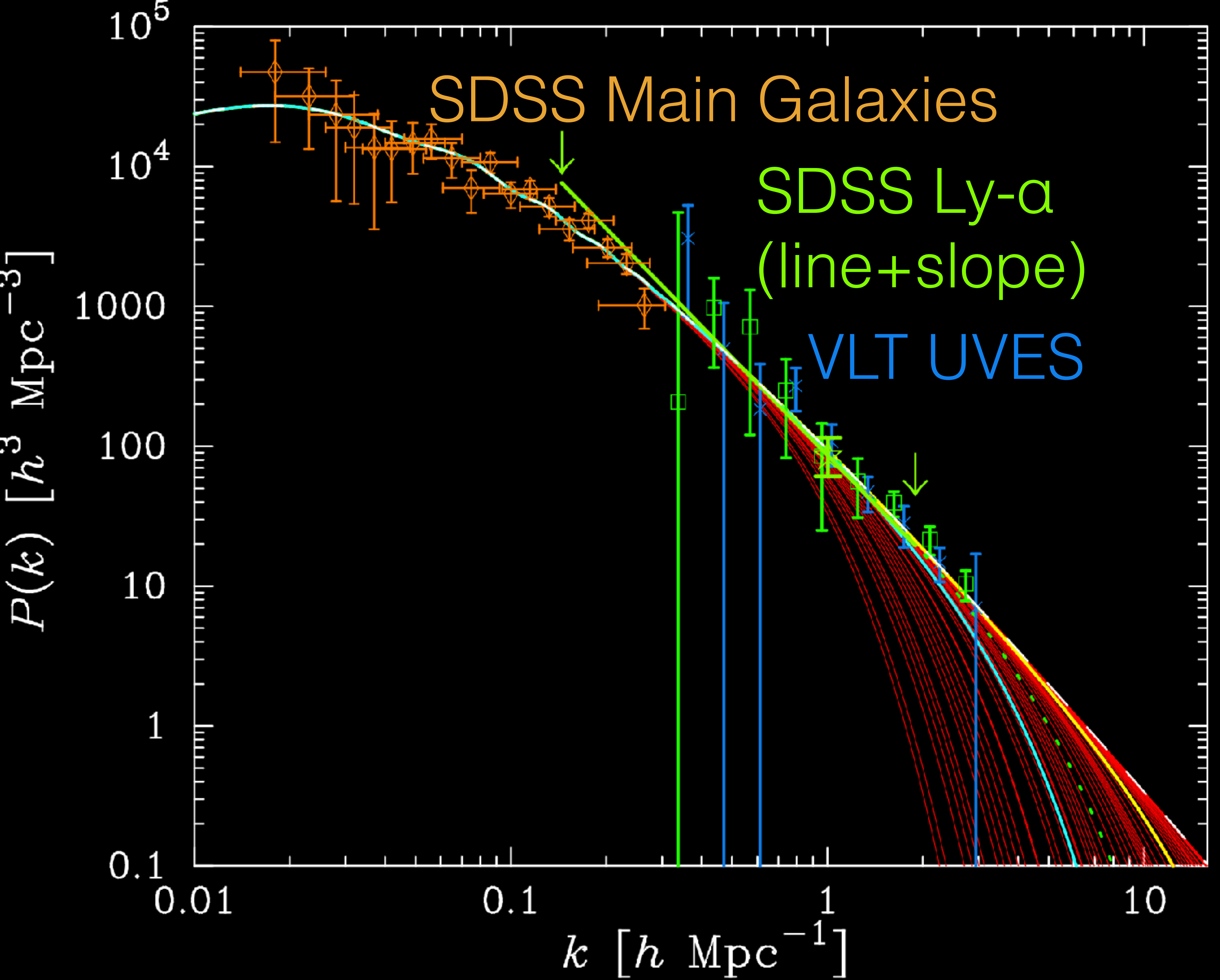

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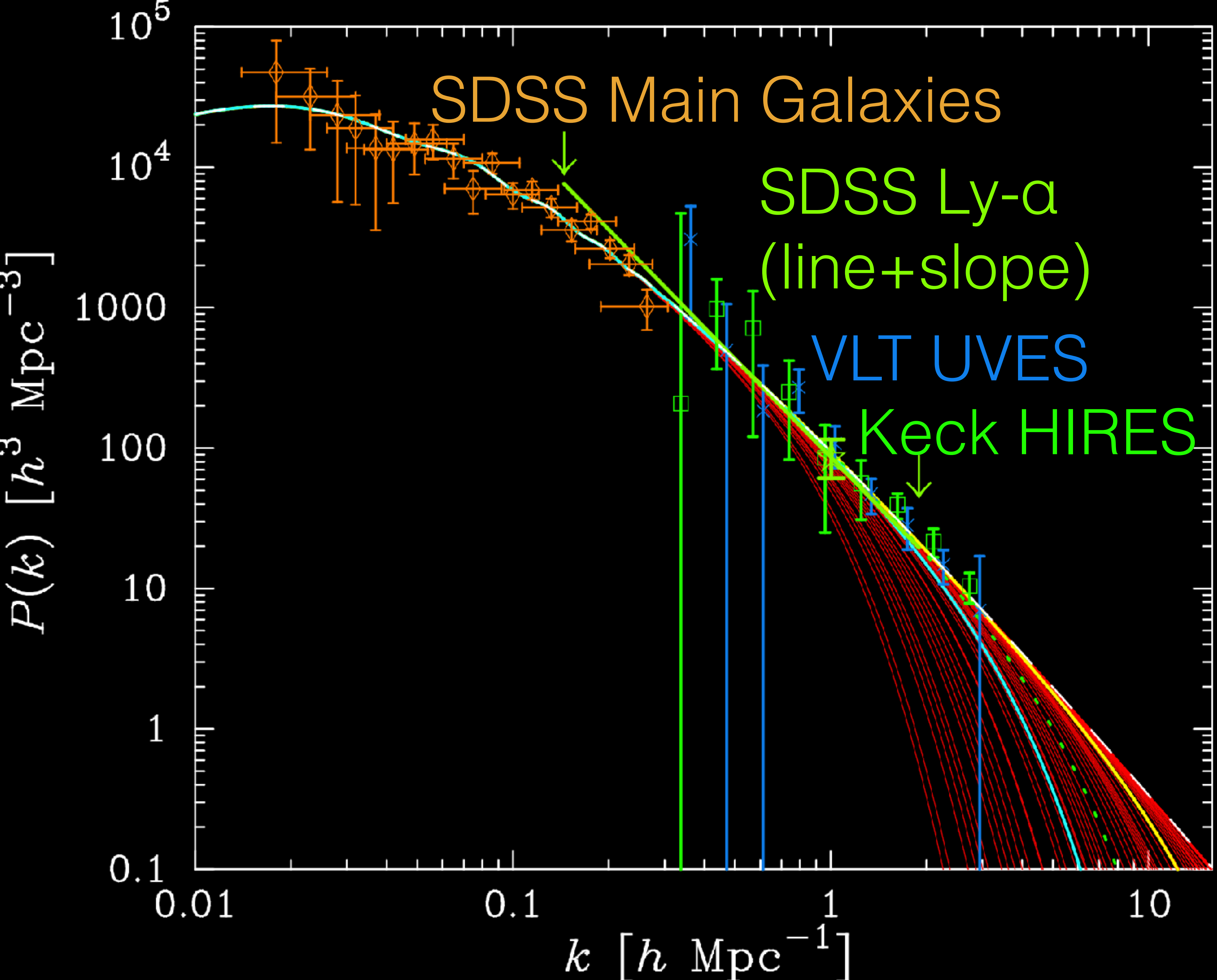

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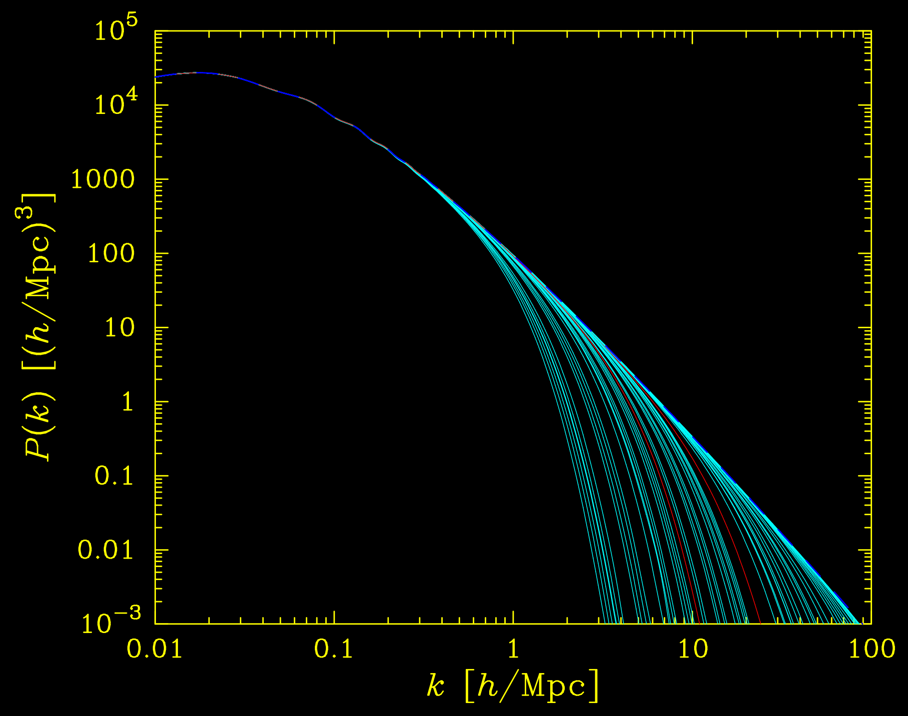
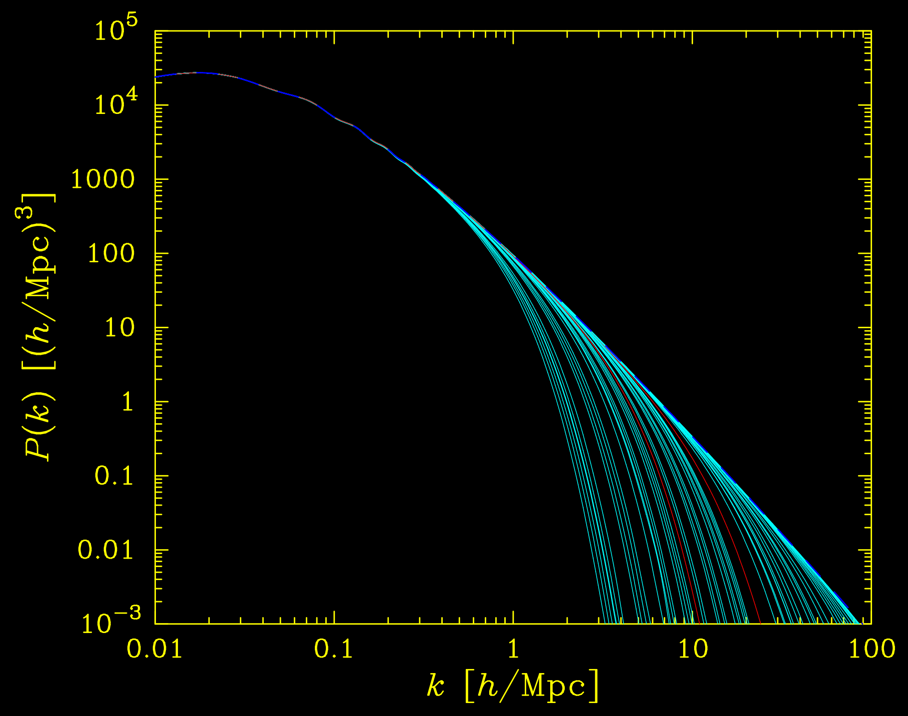


10^5
10^4
1000
100
10
1
0.1
0.01
10^{-3}
0.01
0.1
1
10
100
k [h/Mpc]
$P(k)$ [$(h/\mathrm{Mpc})^3$]

Canonical "Cold" Dark Matter...



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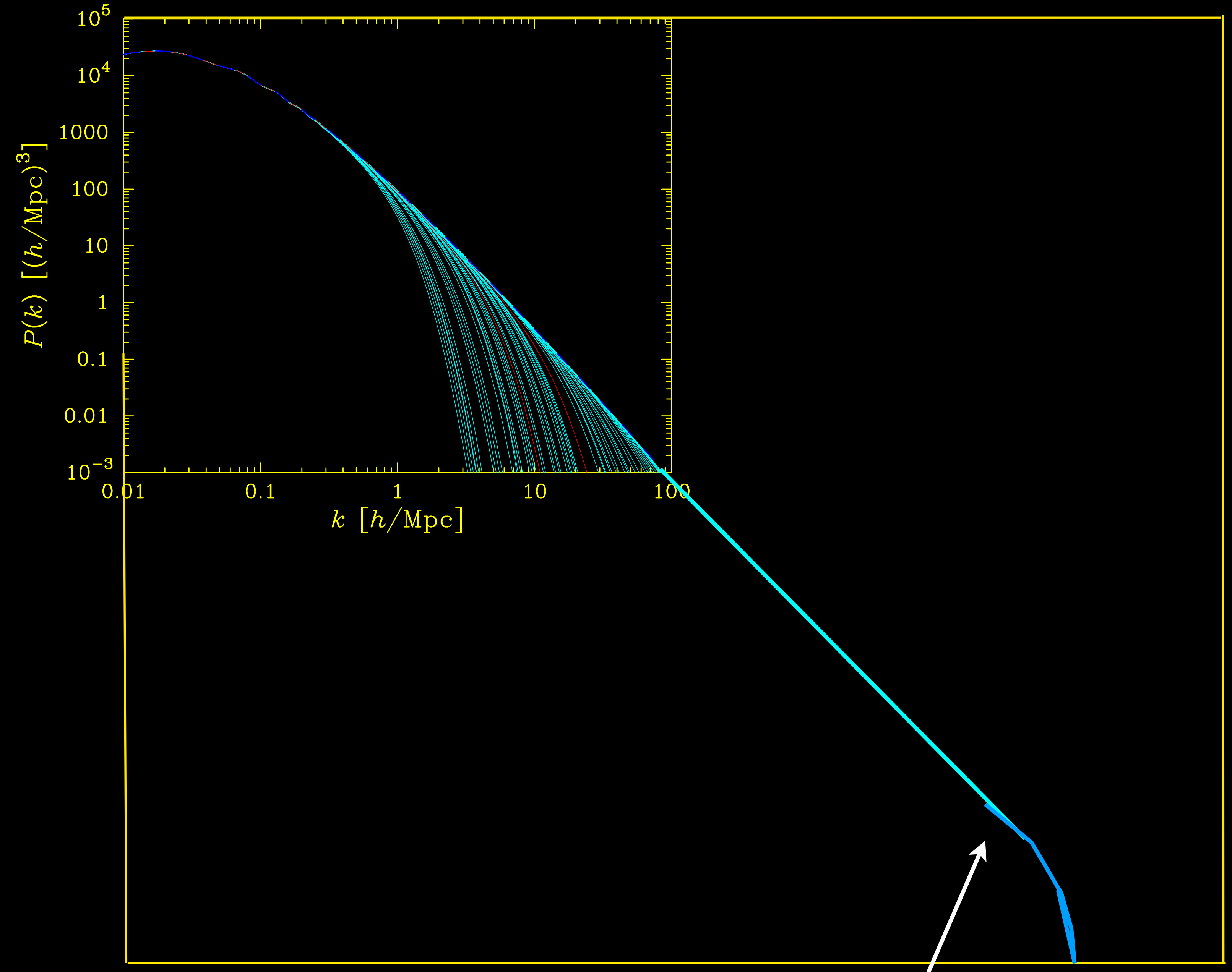
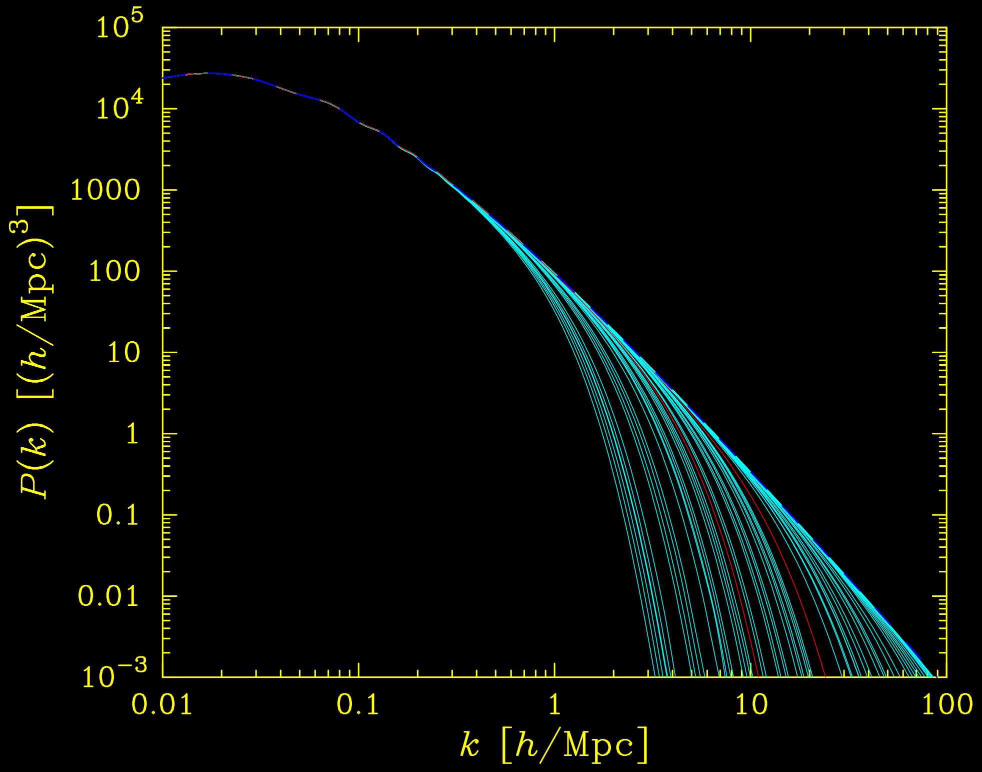


WIMP CDM
$k_c \sim 10^6\ h\,/\mathrm{Mpc}$
(Zaldarriaga & Loeb 2006)

Simulating the Universe's Structure



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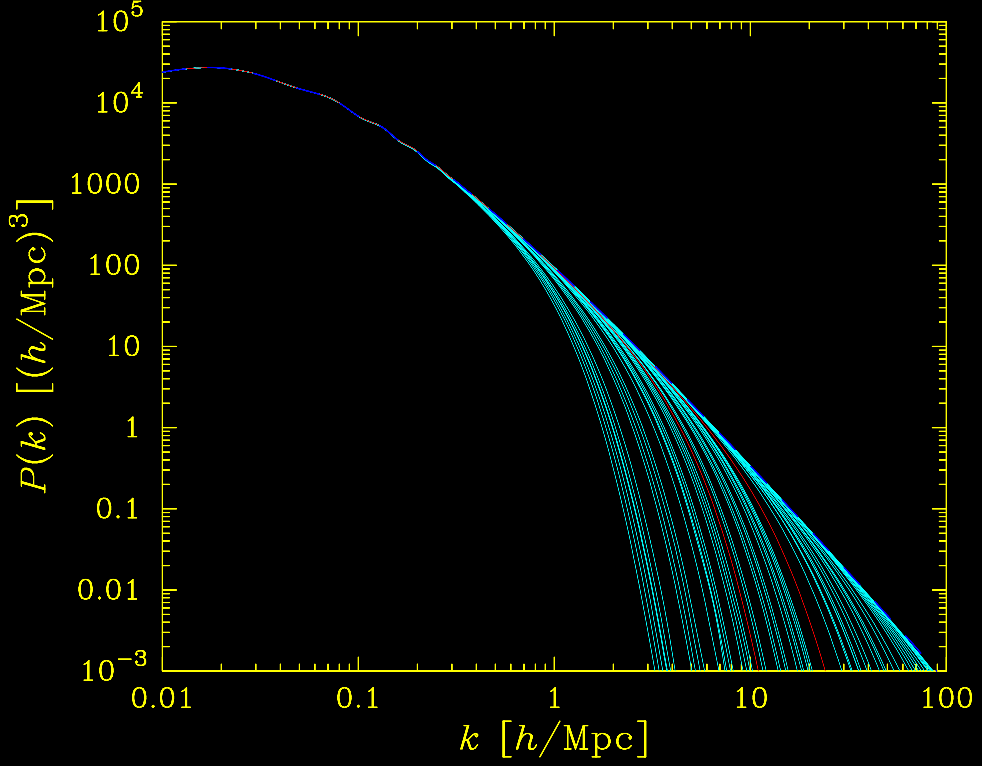
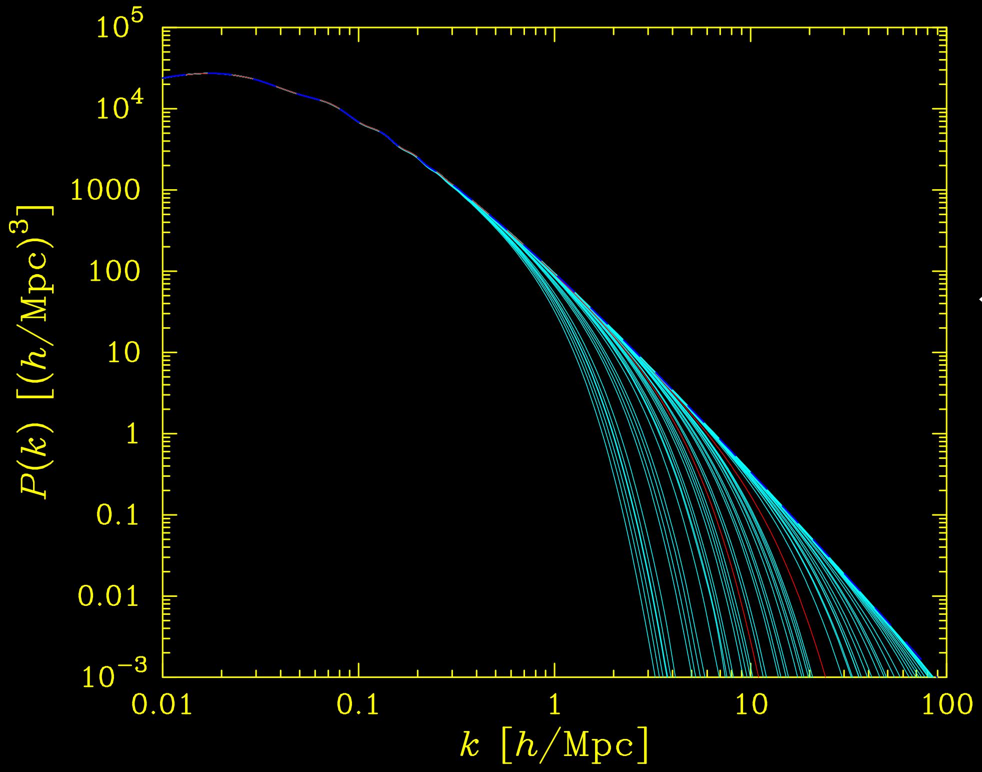


This is a description of the statistical distribution of the density fluctuations in the *linear regime*…

Simulating the Universe's Structure



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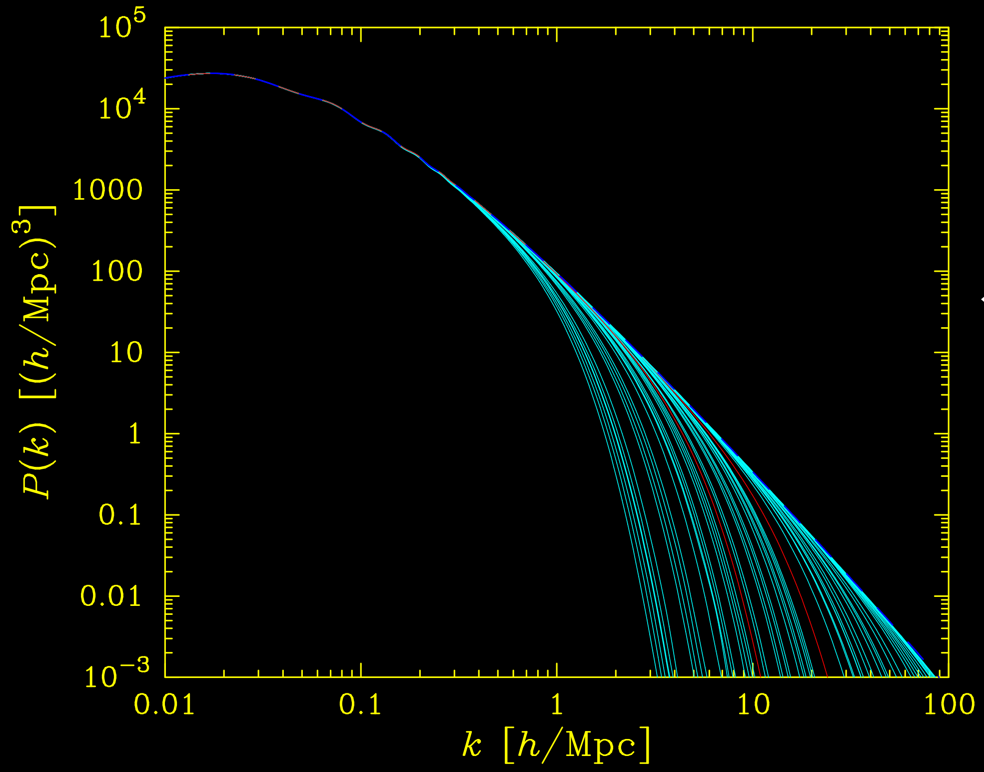

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It is realized by giving a "push" to a grid of particles with that statistical distribution…

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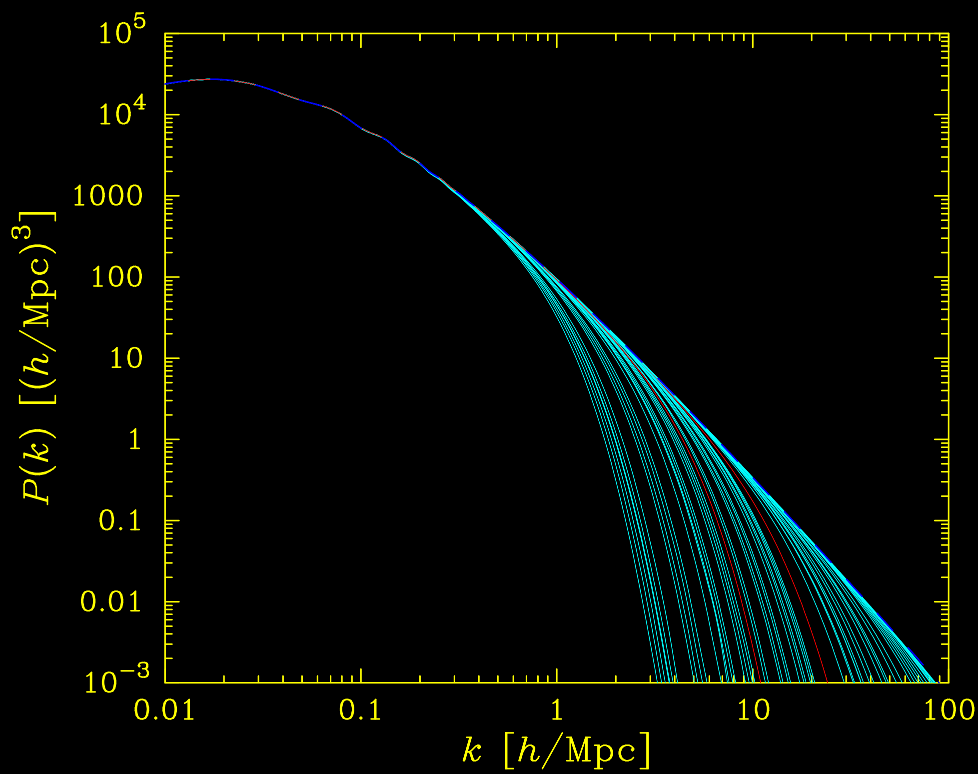

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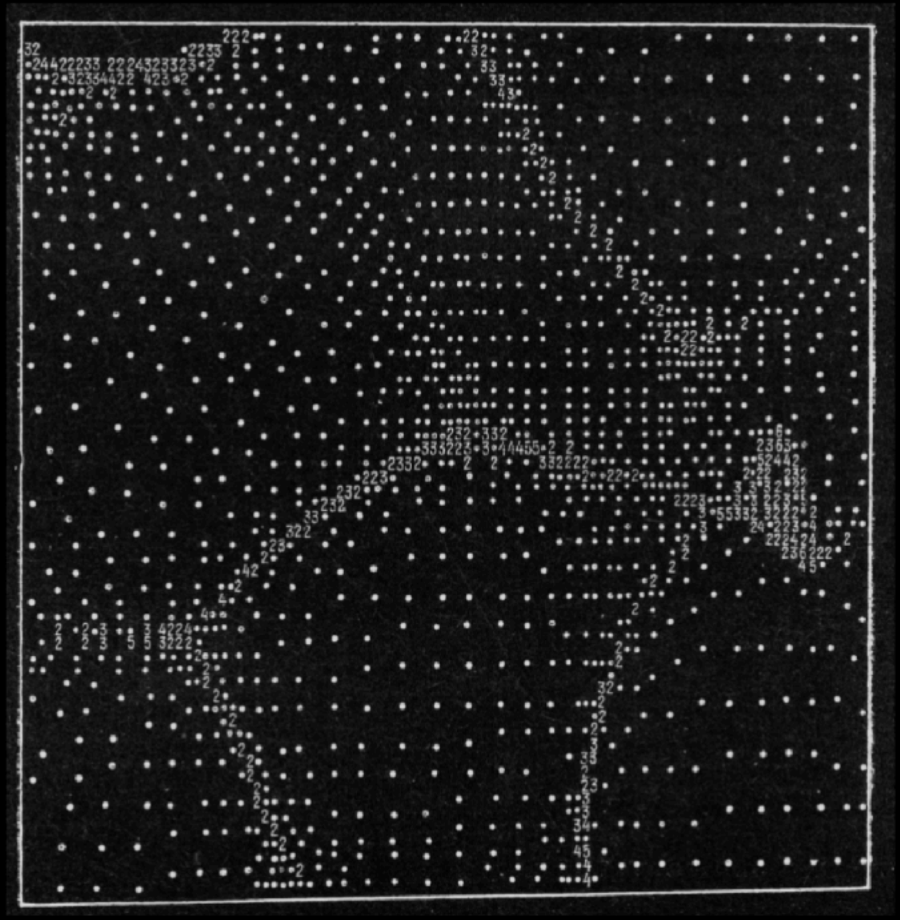

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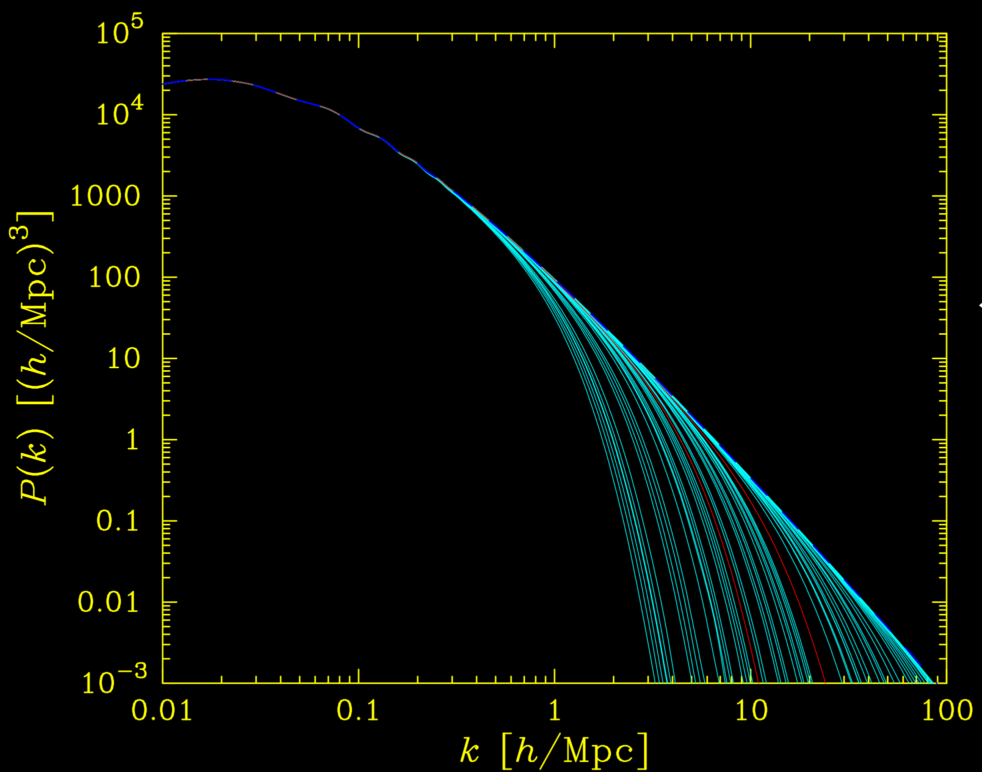
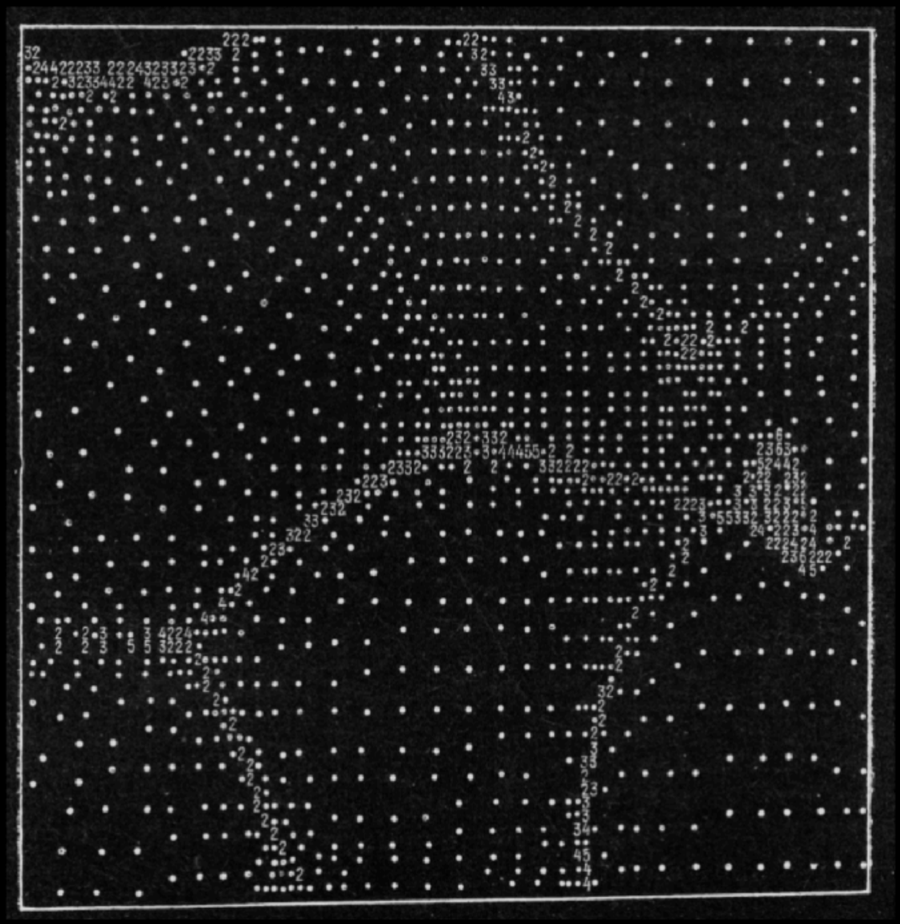


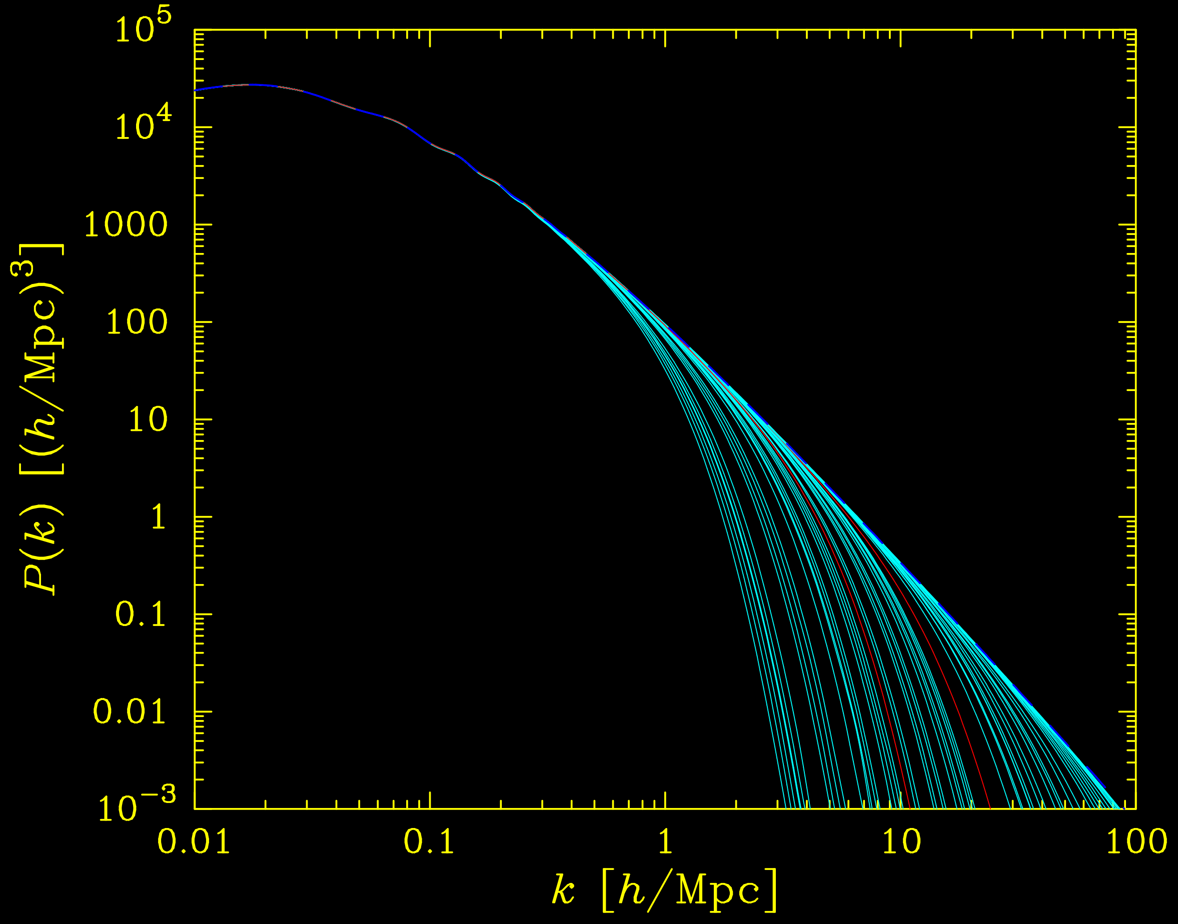
This is a description of the statistical distribution of the density fluctuations in the *linear regime*…

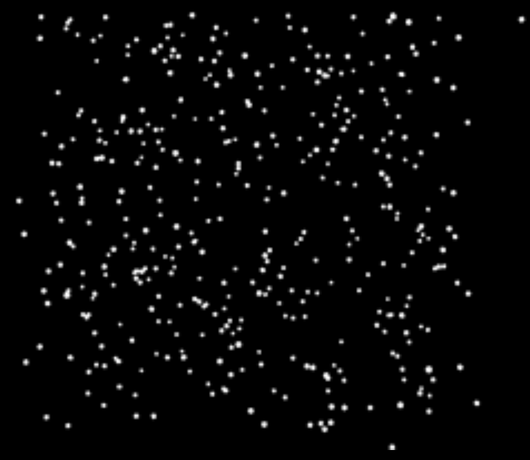
It is realized by giving a "push" to a grid of particles with that statistical distribution…

…and then gravity is allowed to do its duty.



Suppression of small scale power
⇒ Suppression of Small Halos





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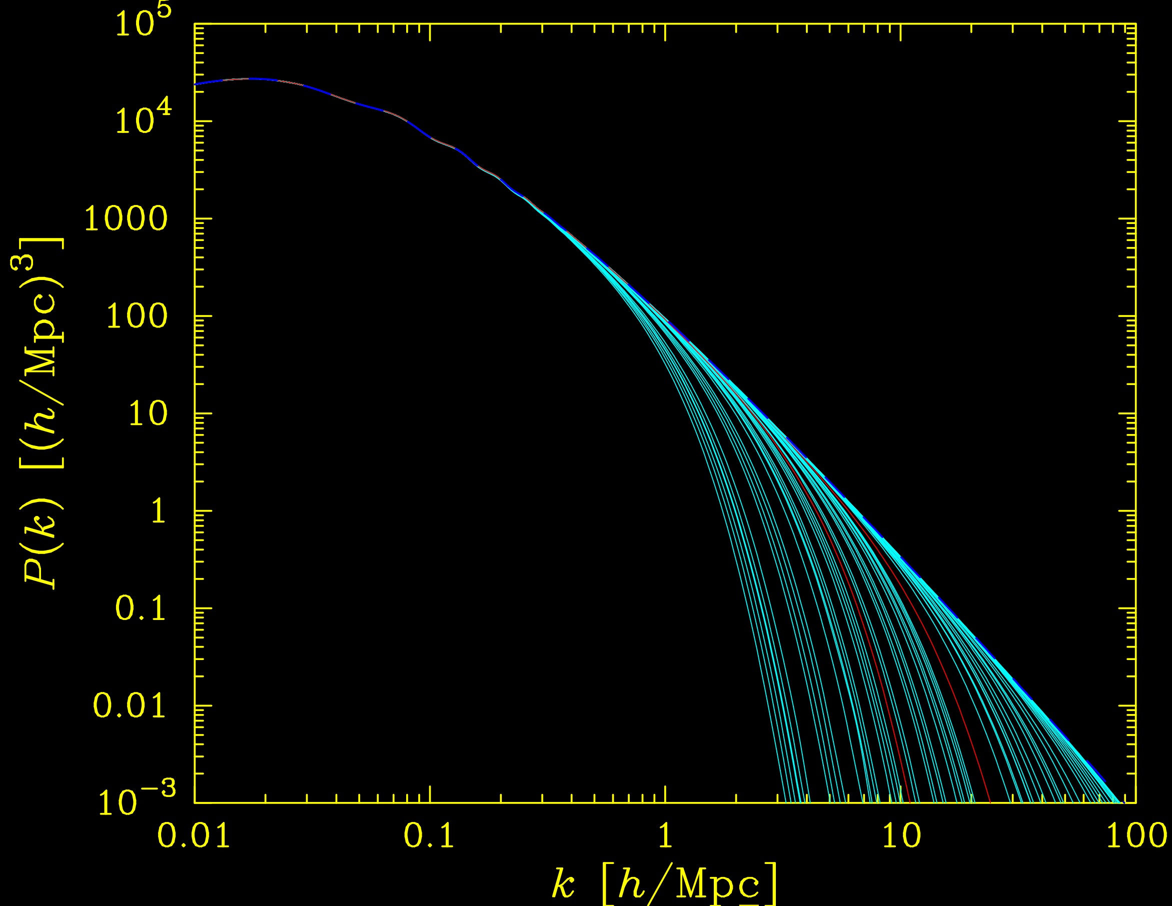

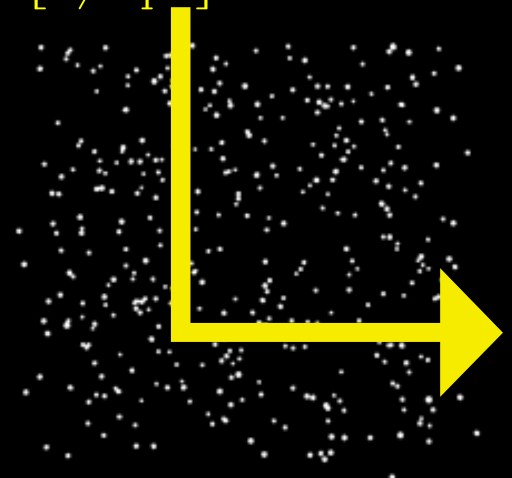

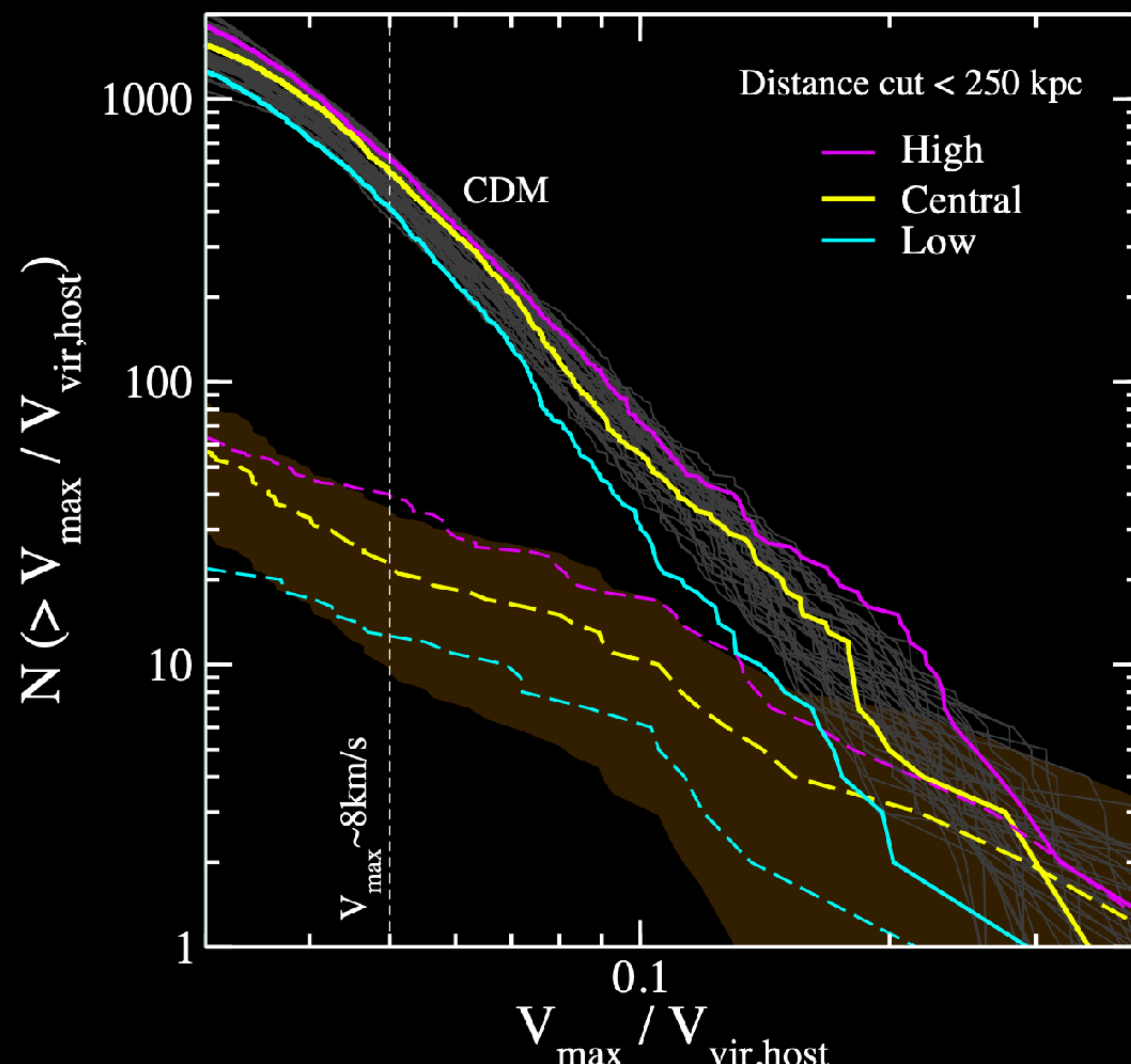

Thermal WDM

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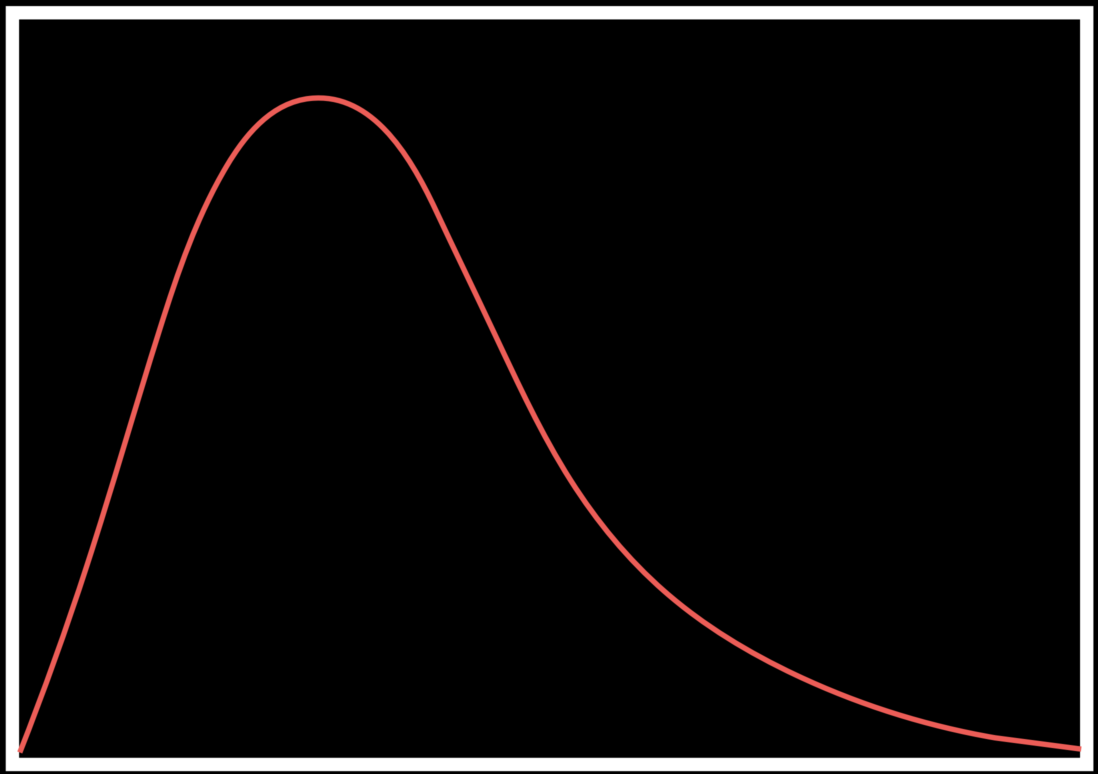

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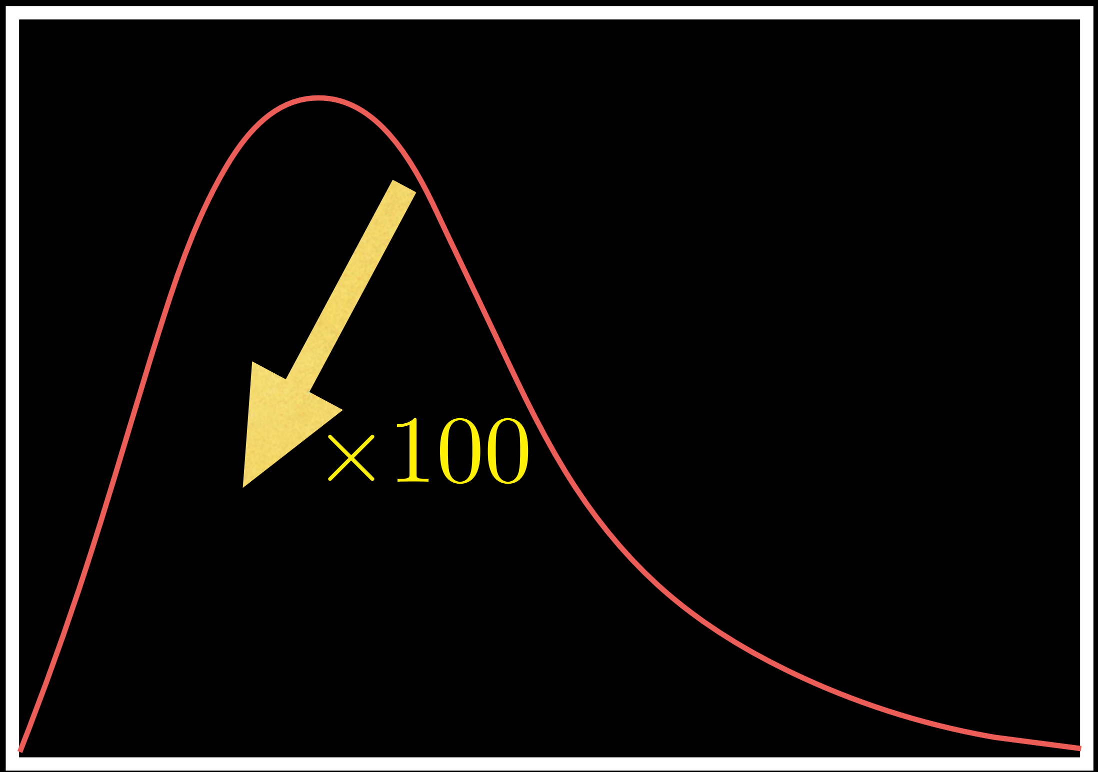

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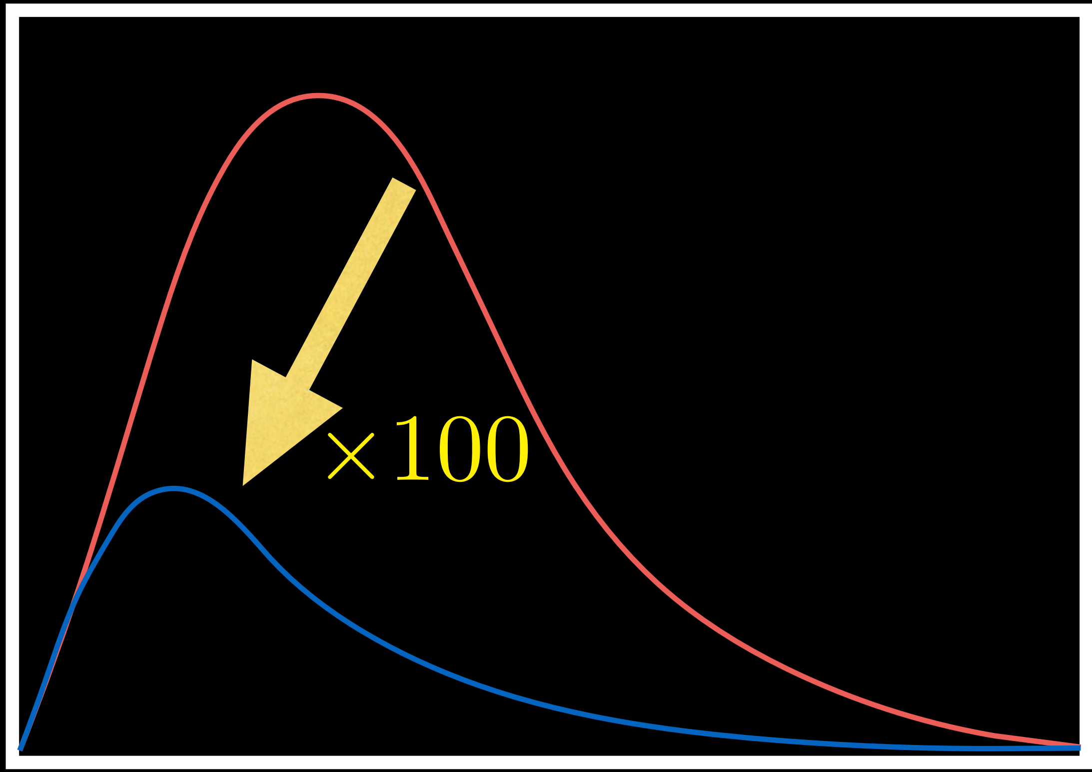

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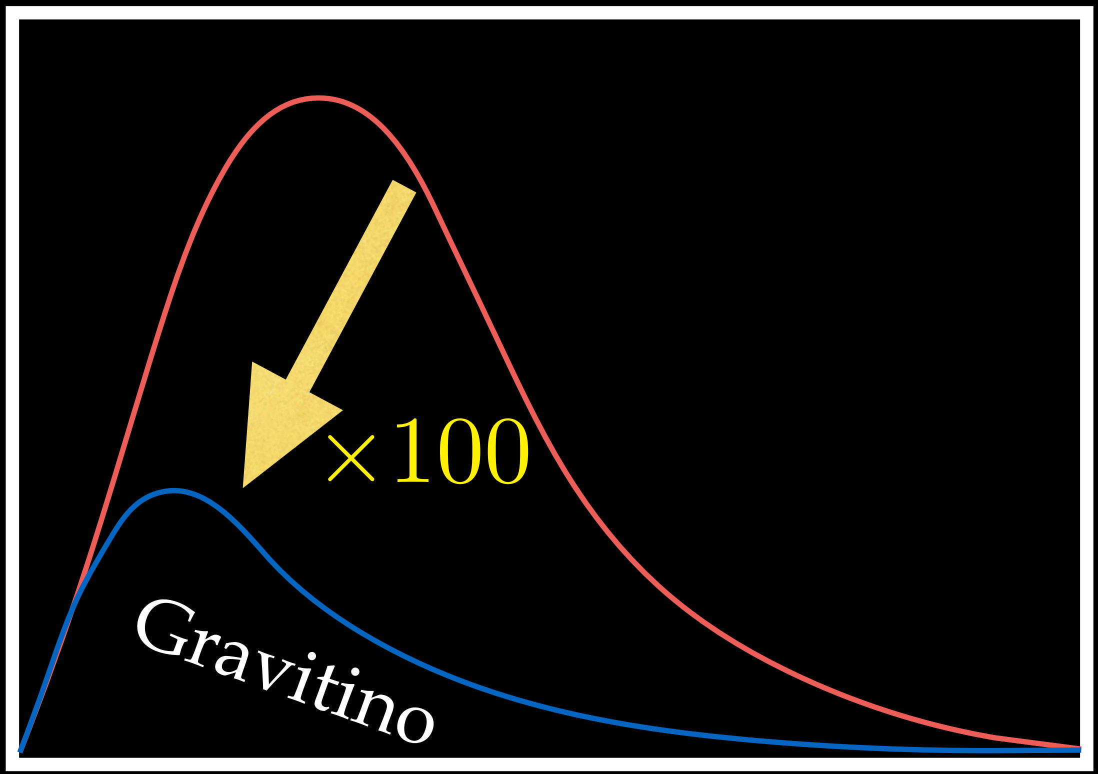

Sterile WDM

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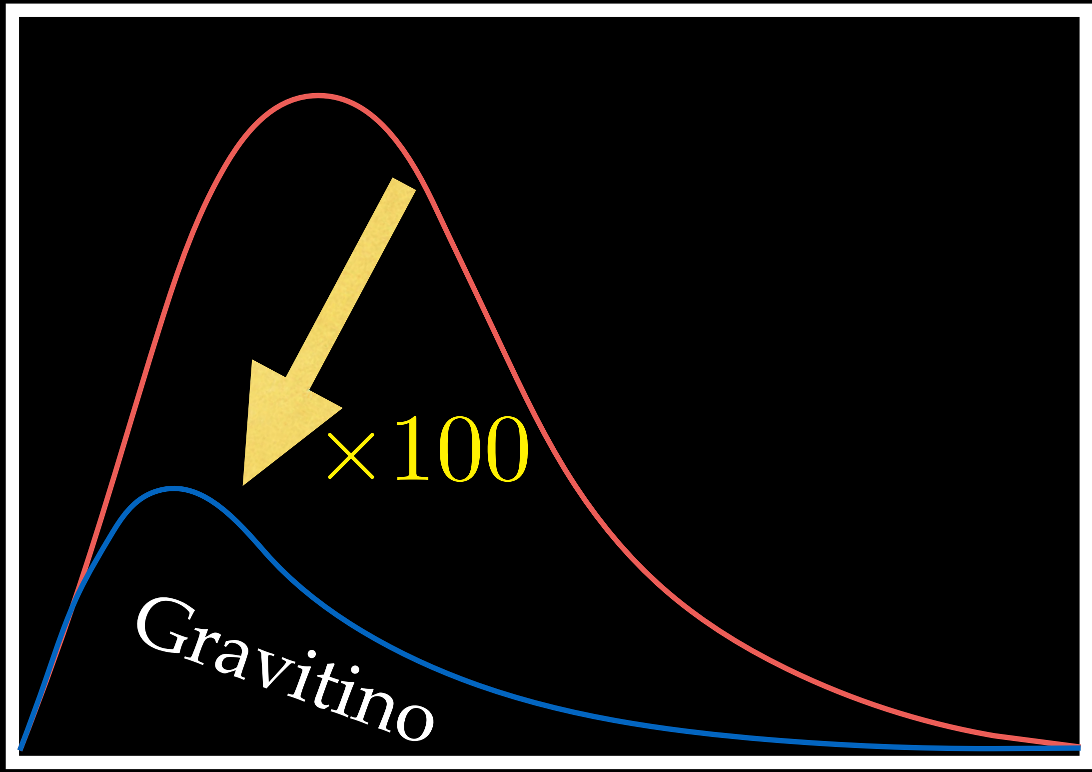
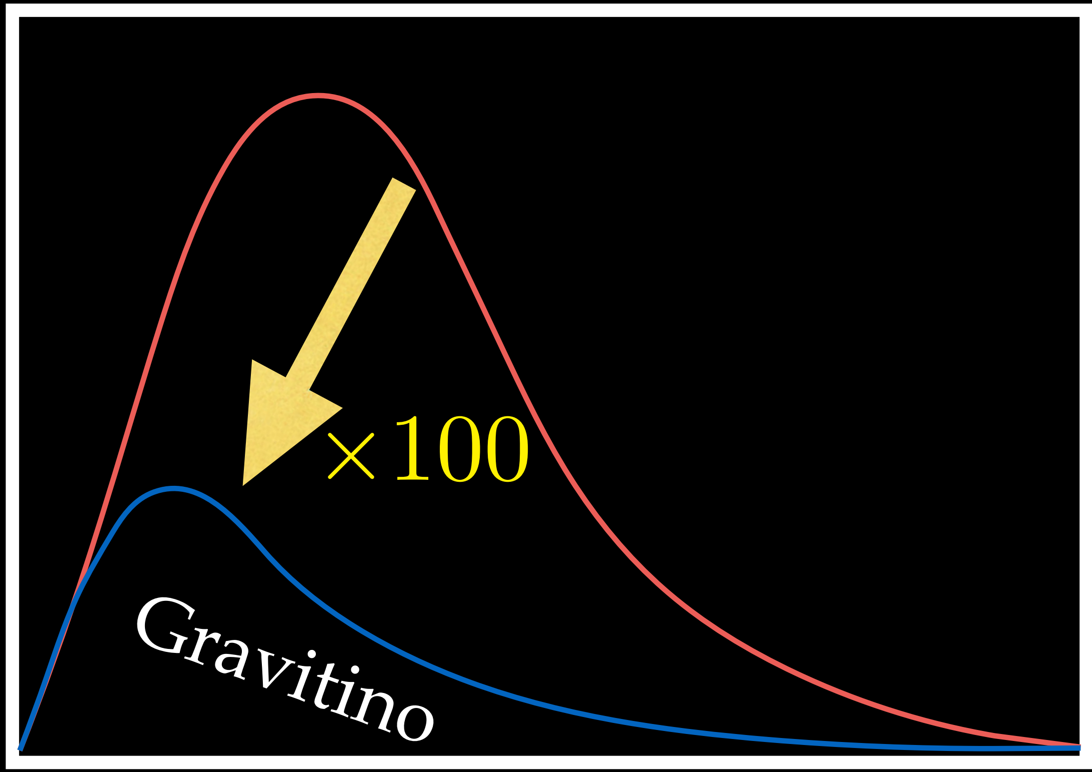


Sterile WDM vs. Thermal WDM



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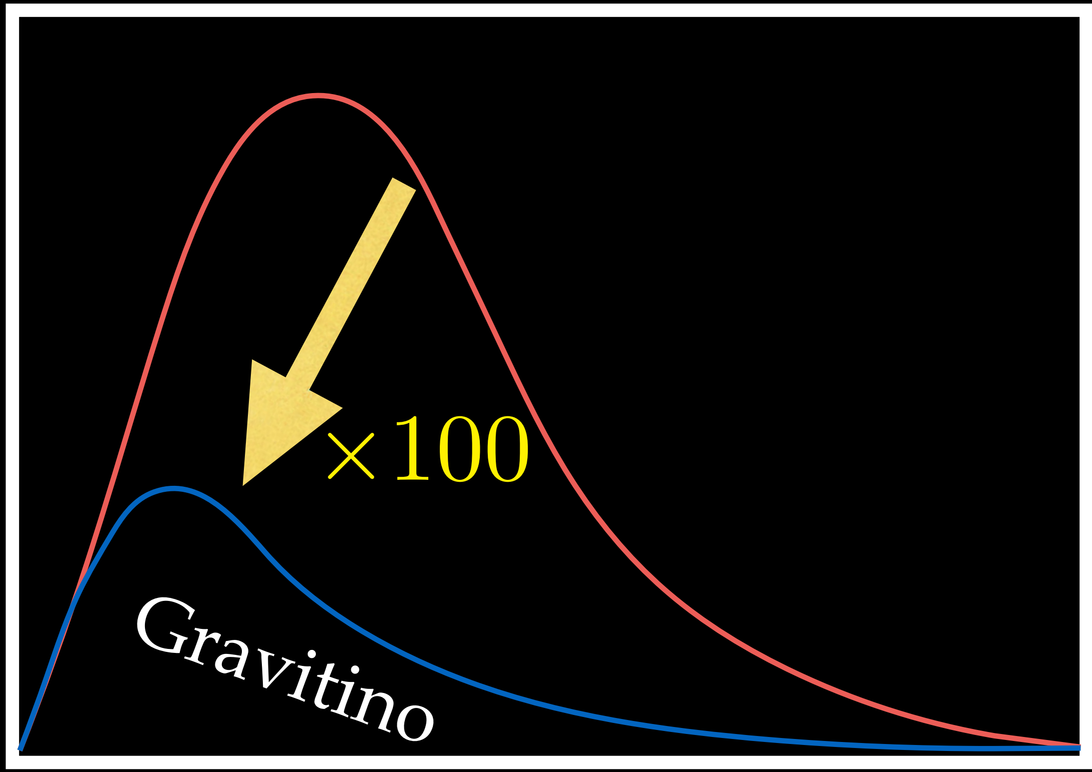

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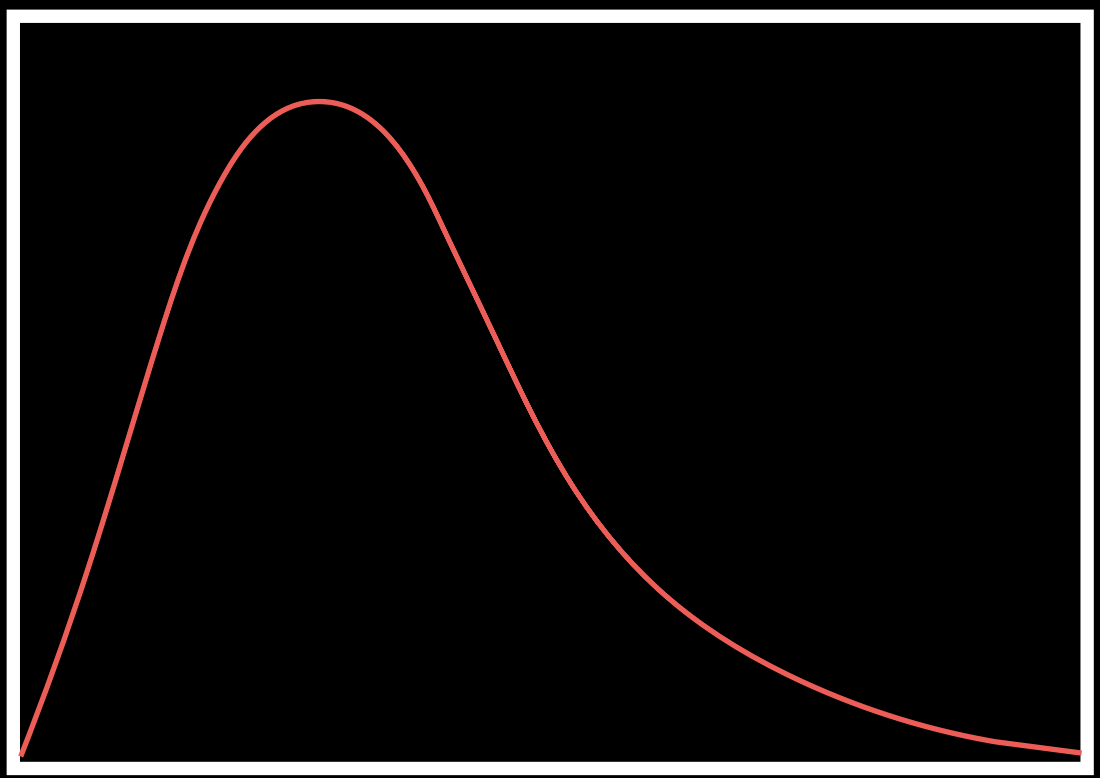

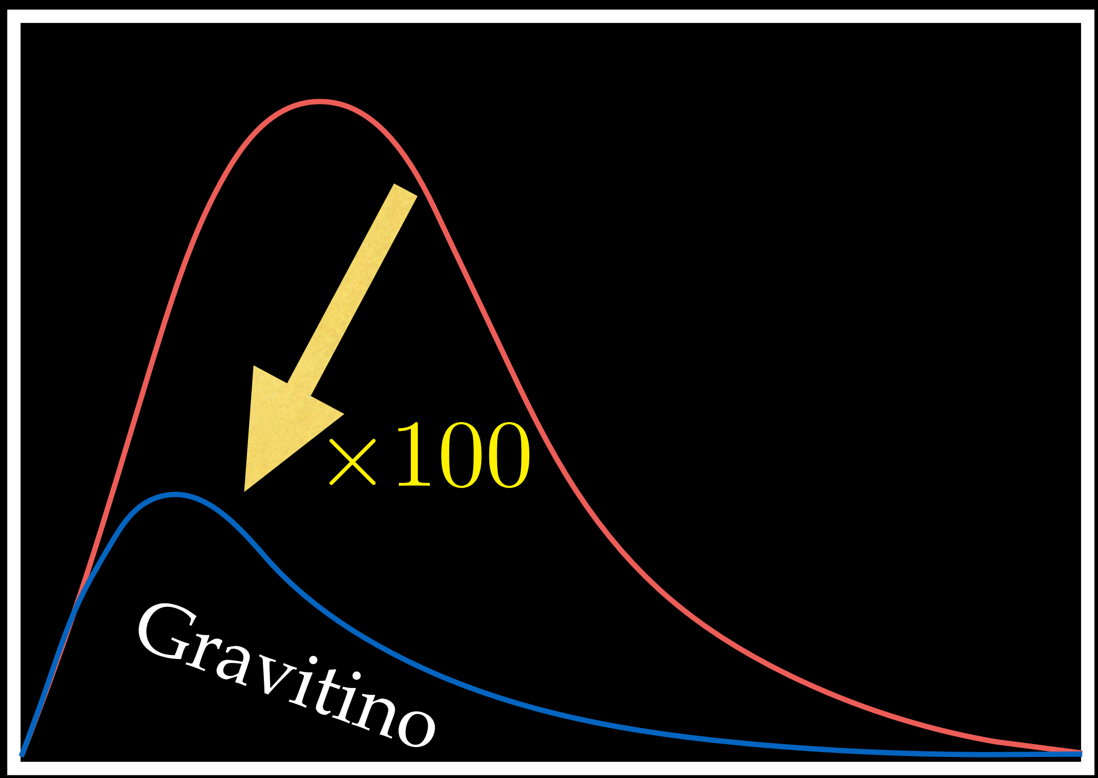

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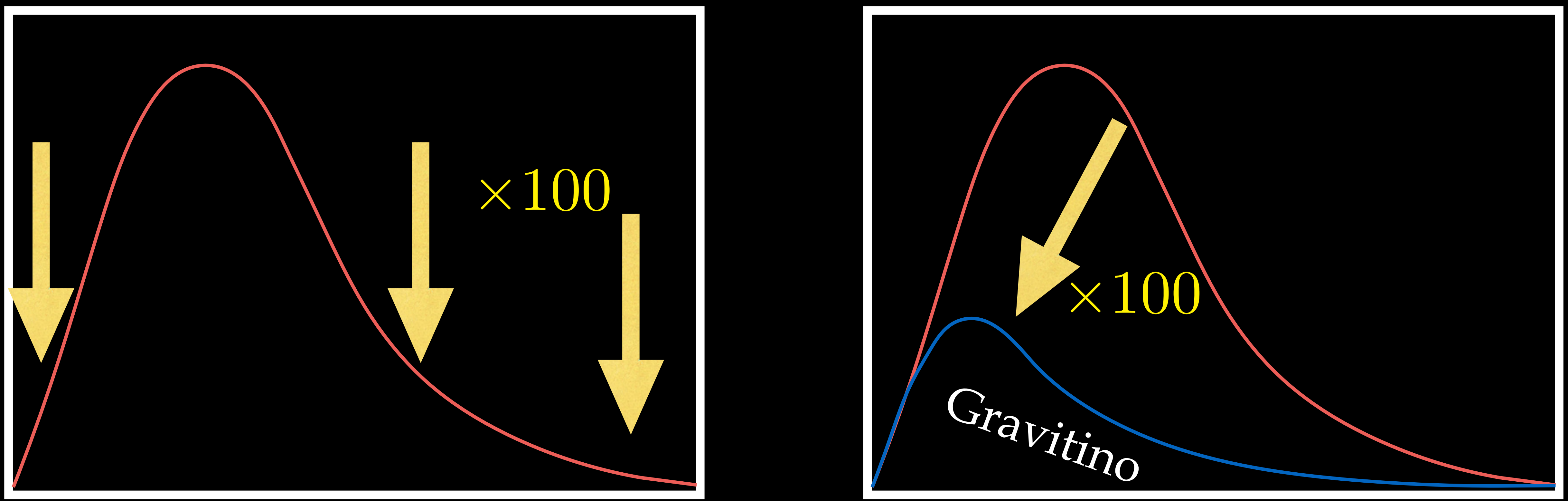

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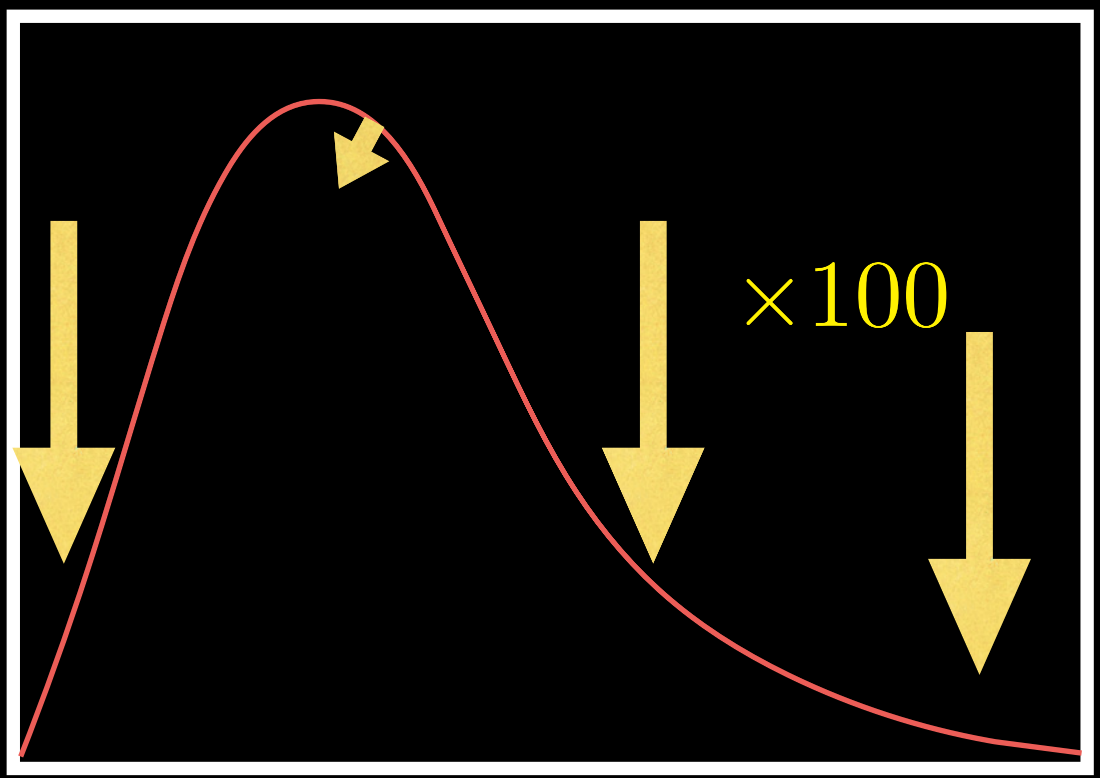

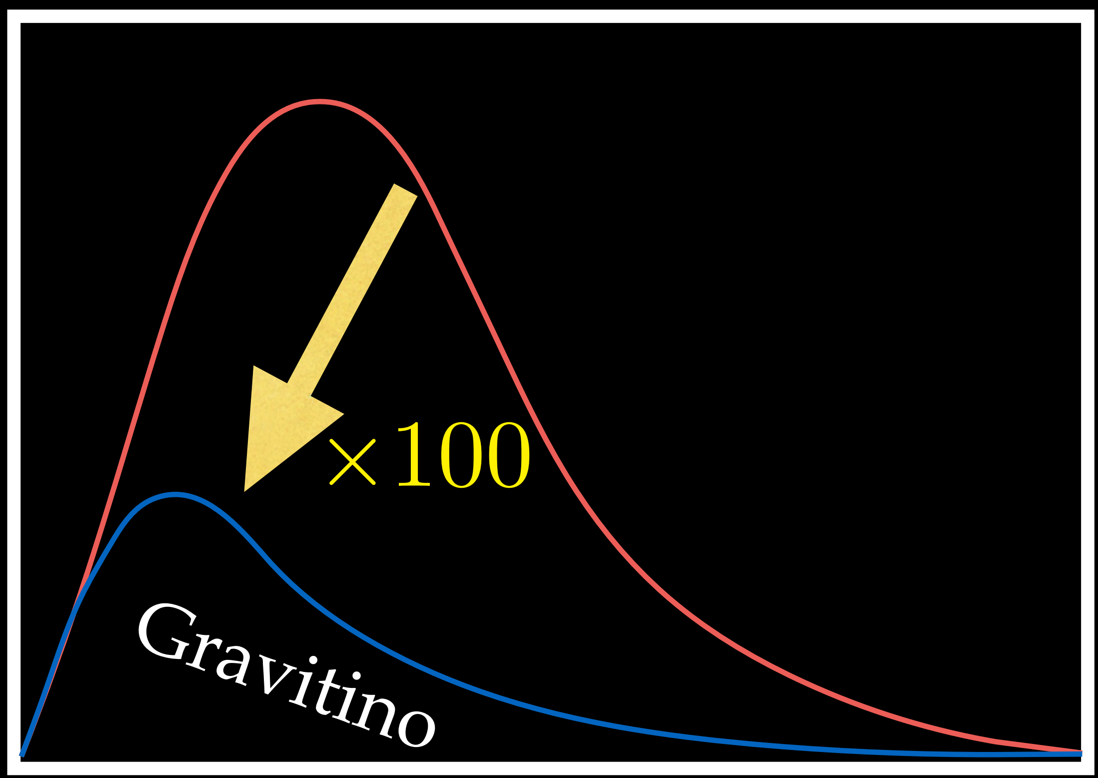

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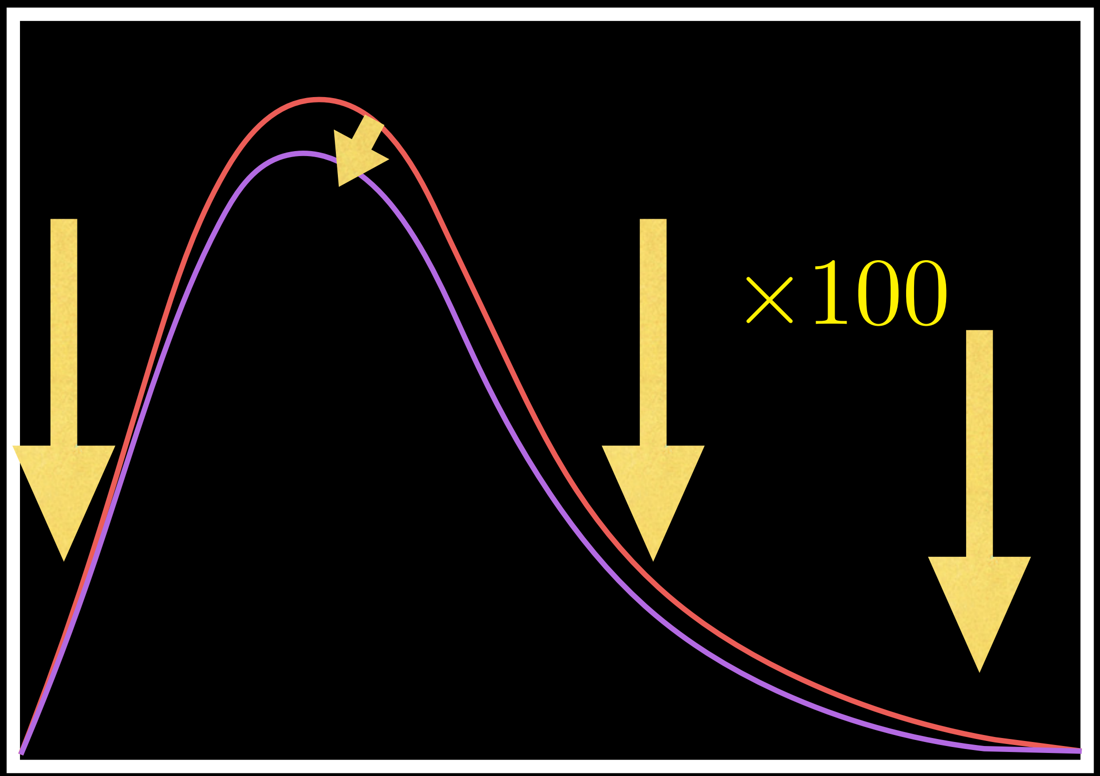

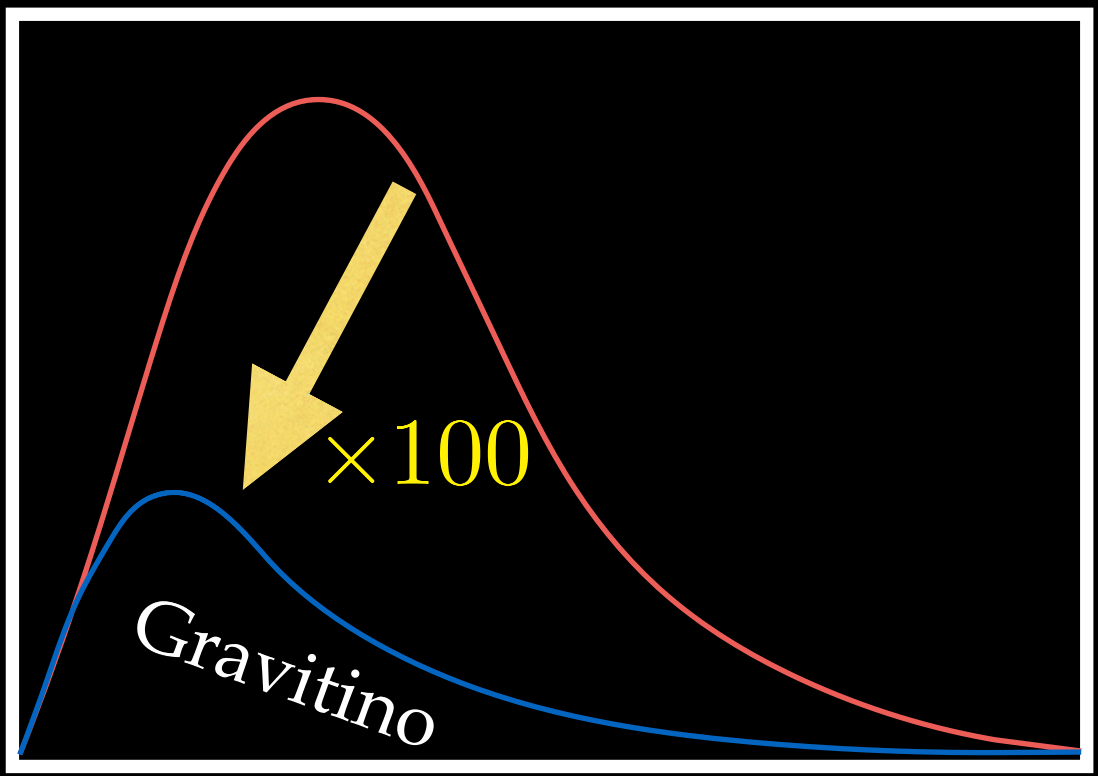

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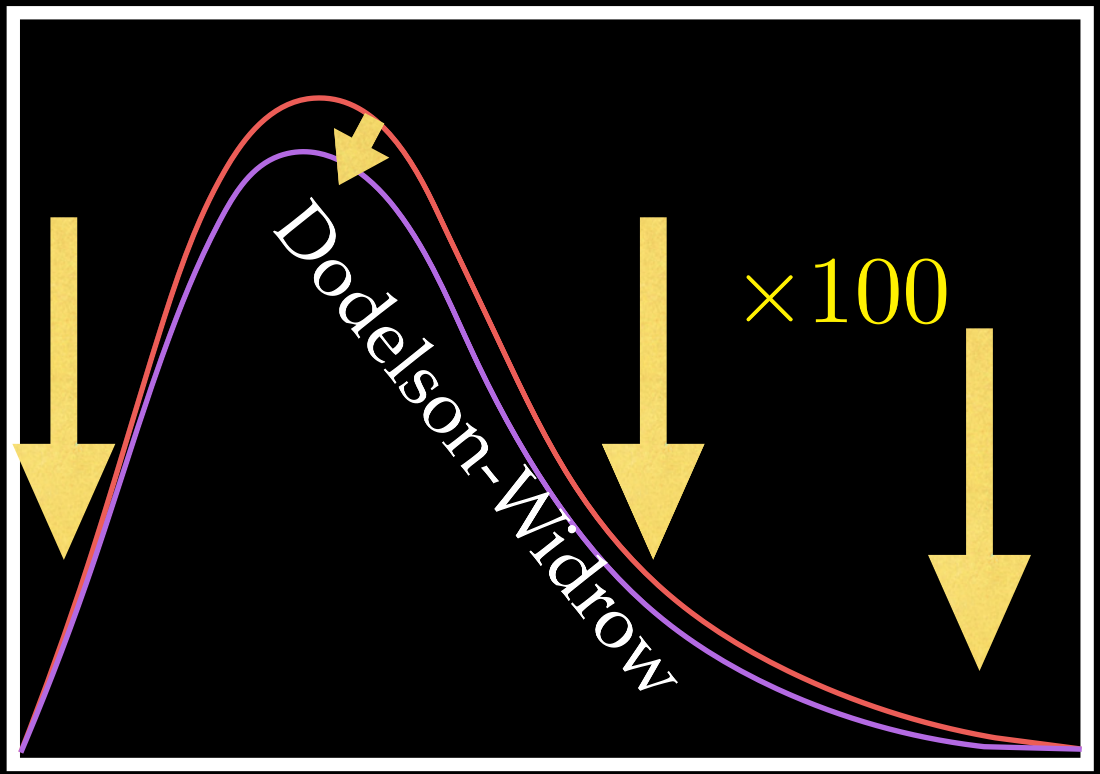

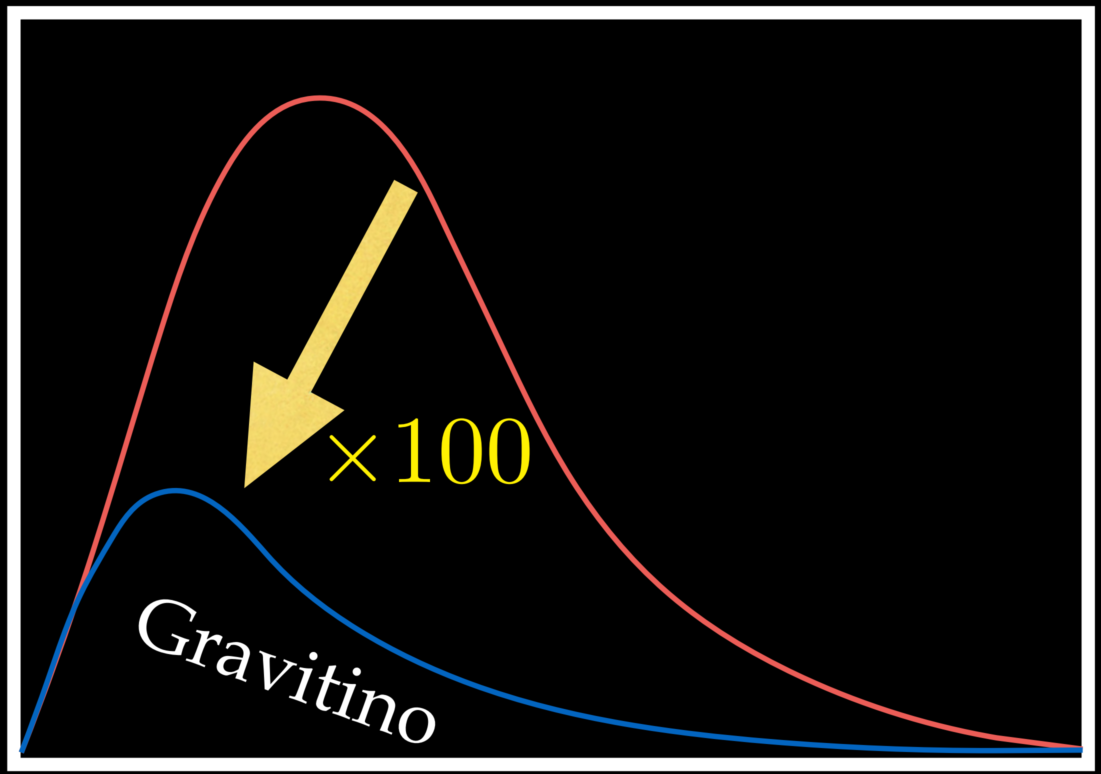

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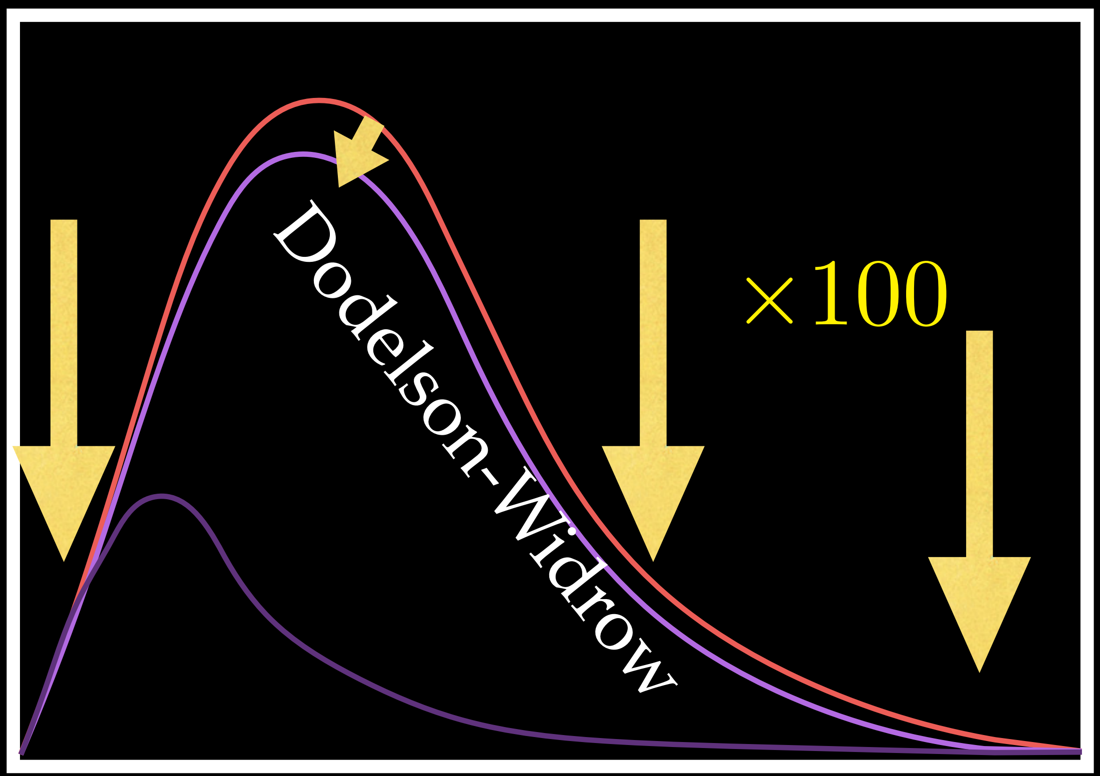

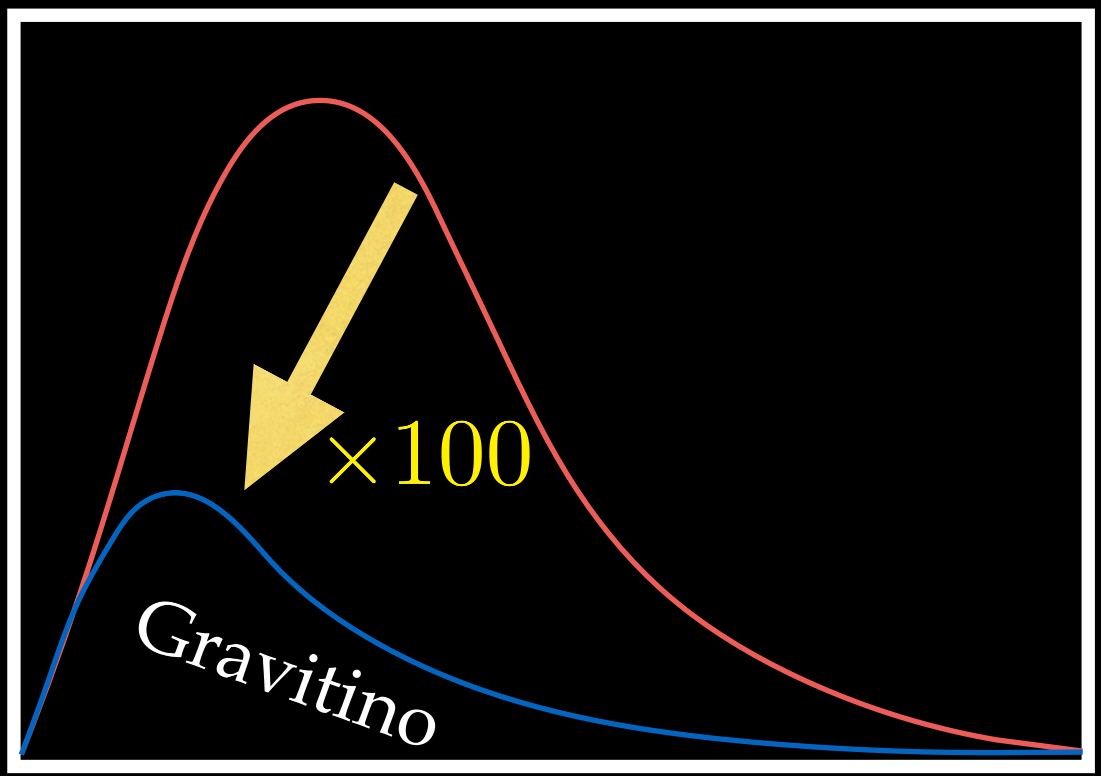

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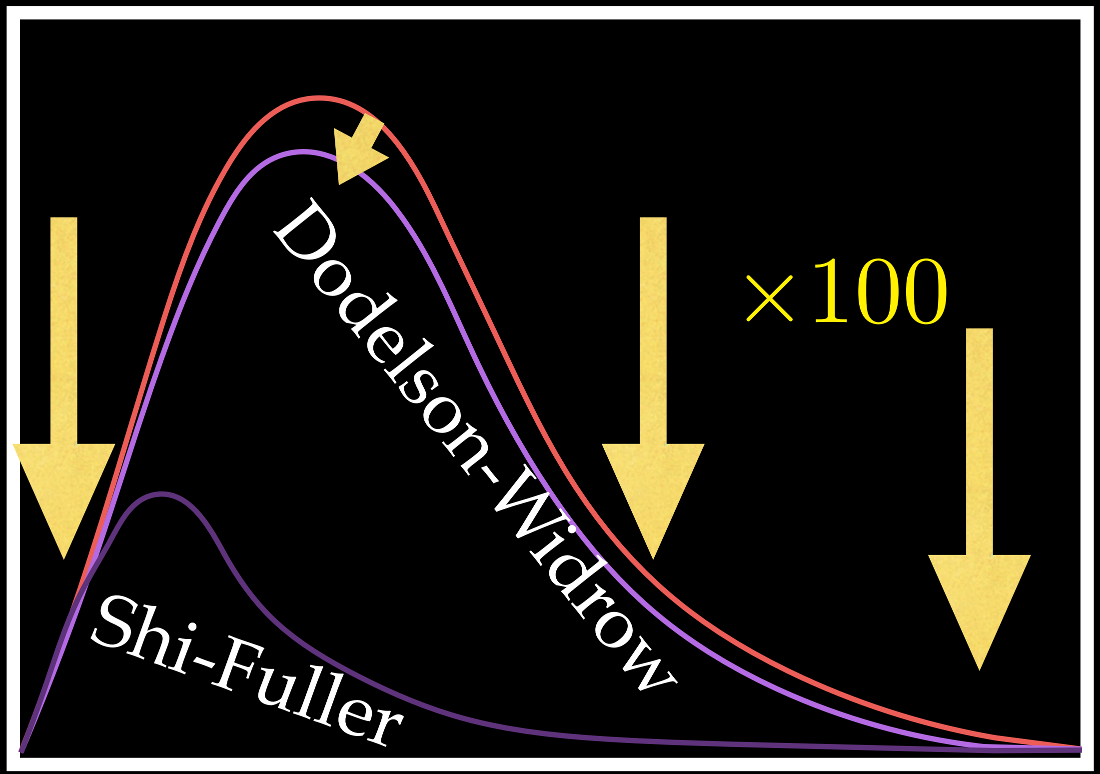

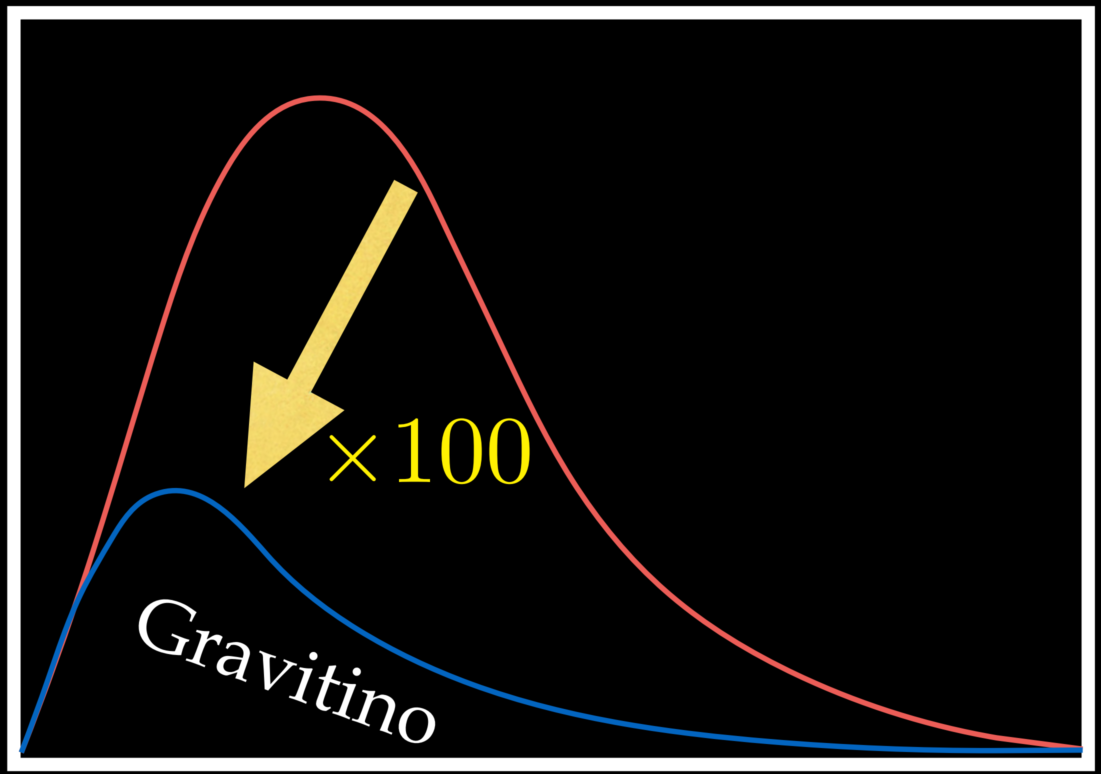

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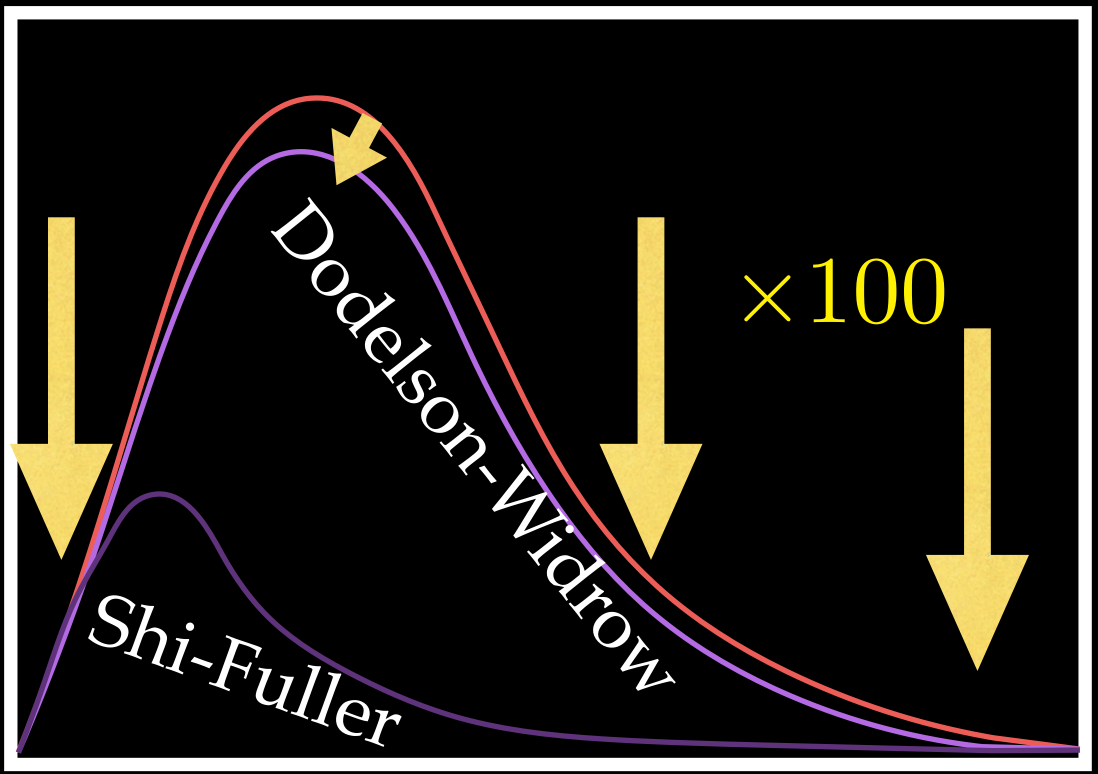
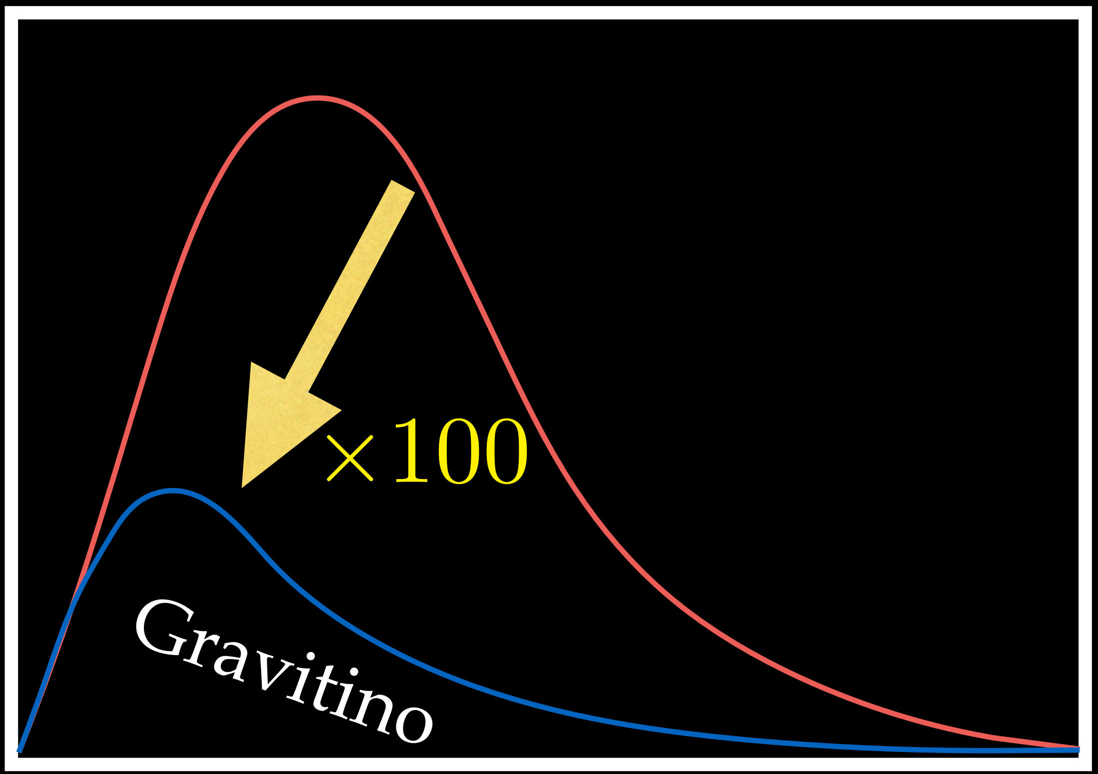
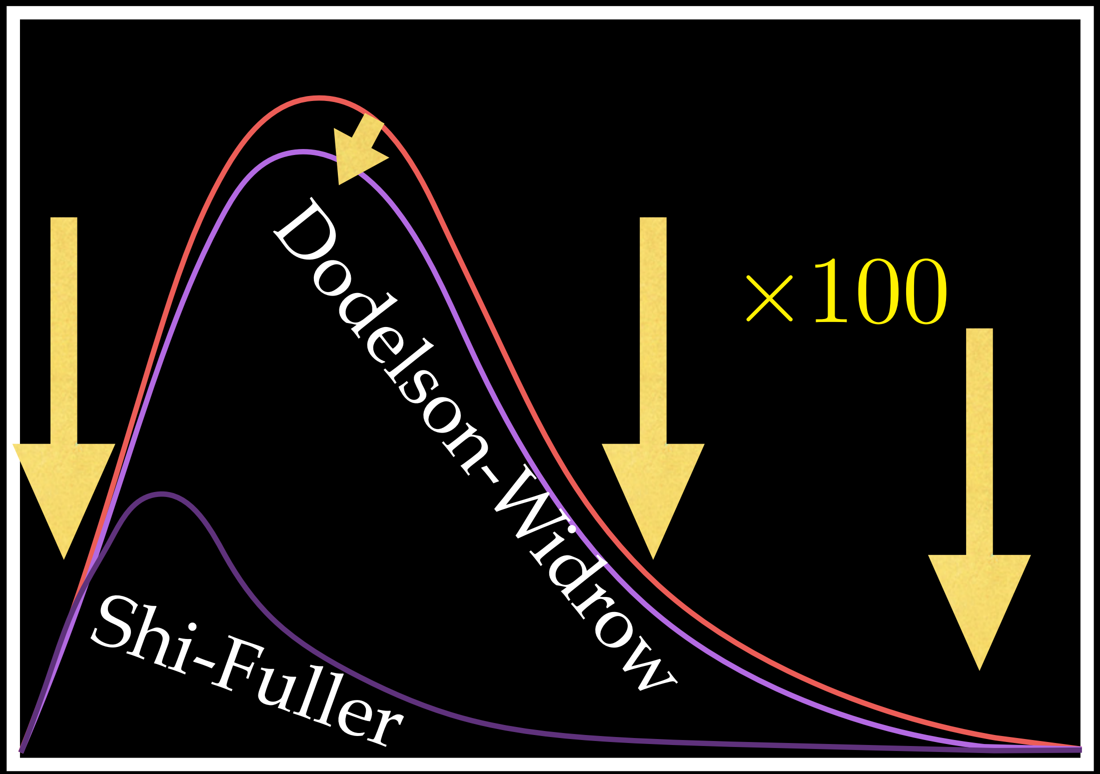
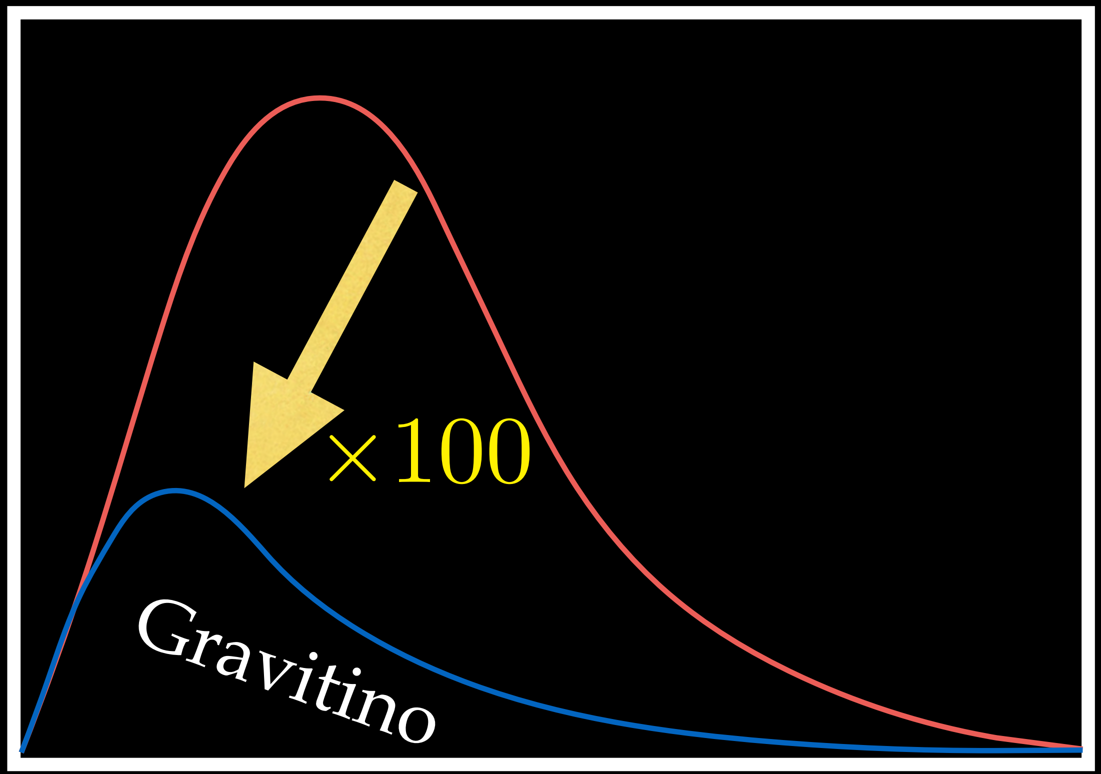




$$m_s\big|_{\text{Dodelson-Widrow,ideal}} \approx 4.46\,\text{keV}\left(\frac{m_{\text{thermal}}}{1\,\text{keV}}\right)^{4/3}$$

Sterile WDM vs. Thermal WDM





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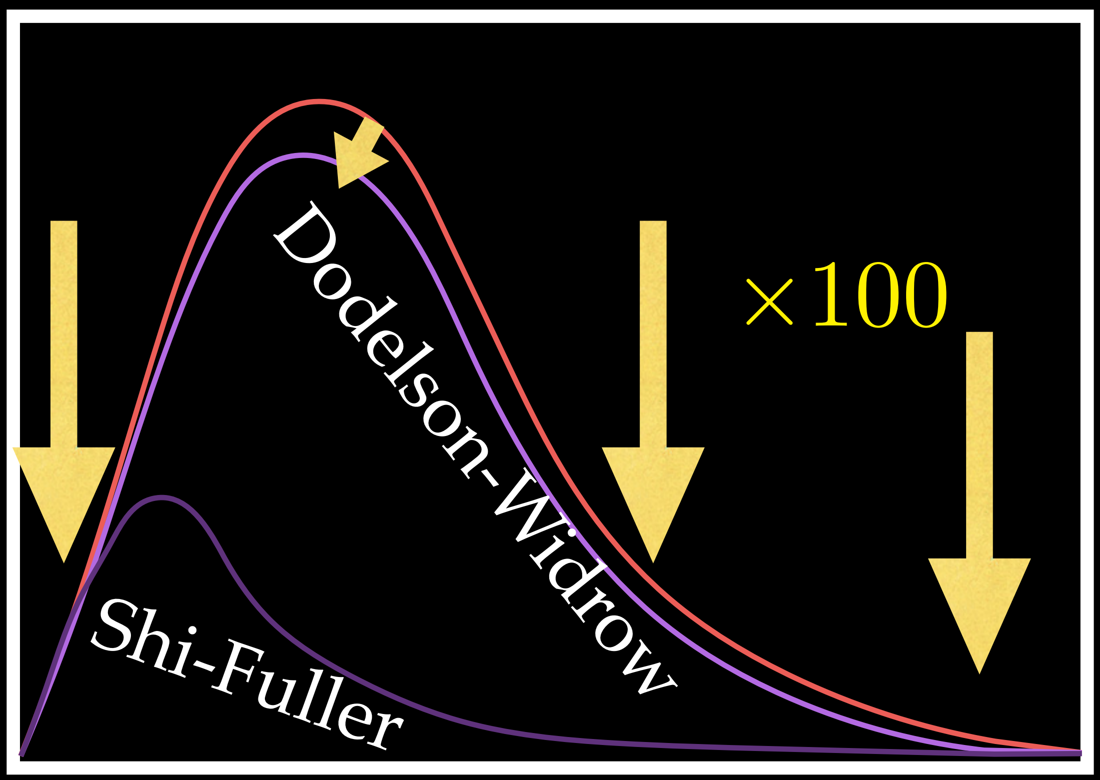

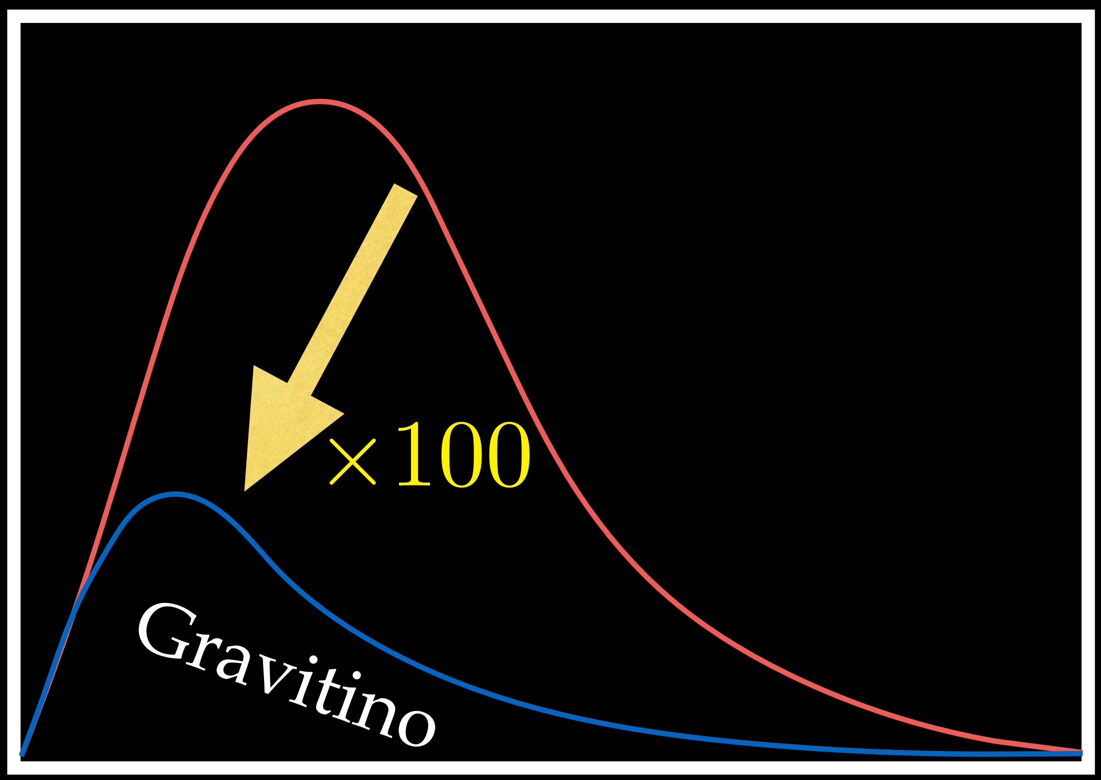

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$$m_s\big|_{\text{Shi-Fuller}} < m_s\big|_{\text{Dodelson-Widrow}}$$

$$m_{\text{thermal}} = 2\,\mathrm{keV} \Rightarrow m_s\big|_{\text{DW,ideal}} \approx 11\,\mathrm{keV} \Rightarrow m_s\big|_{\text{Shi-Fuller}} \approx 7\,\mathrm{keV}$$

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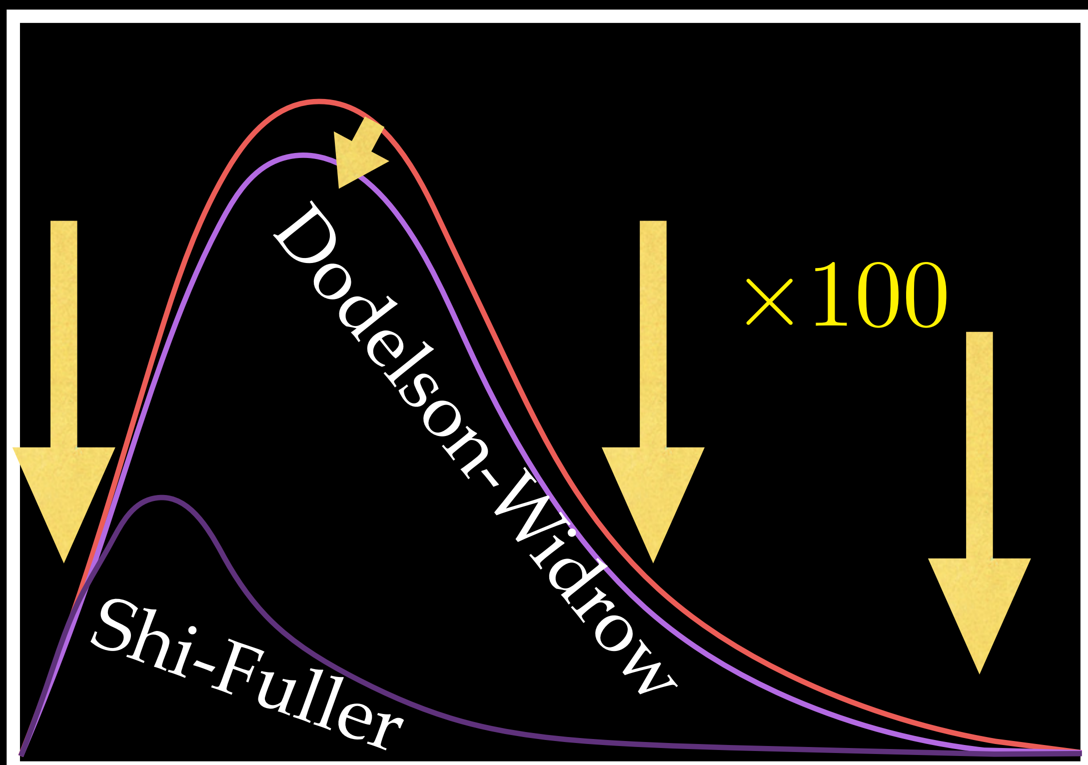

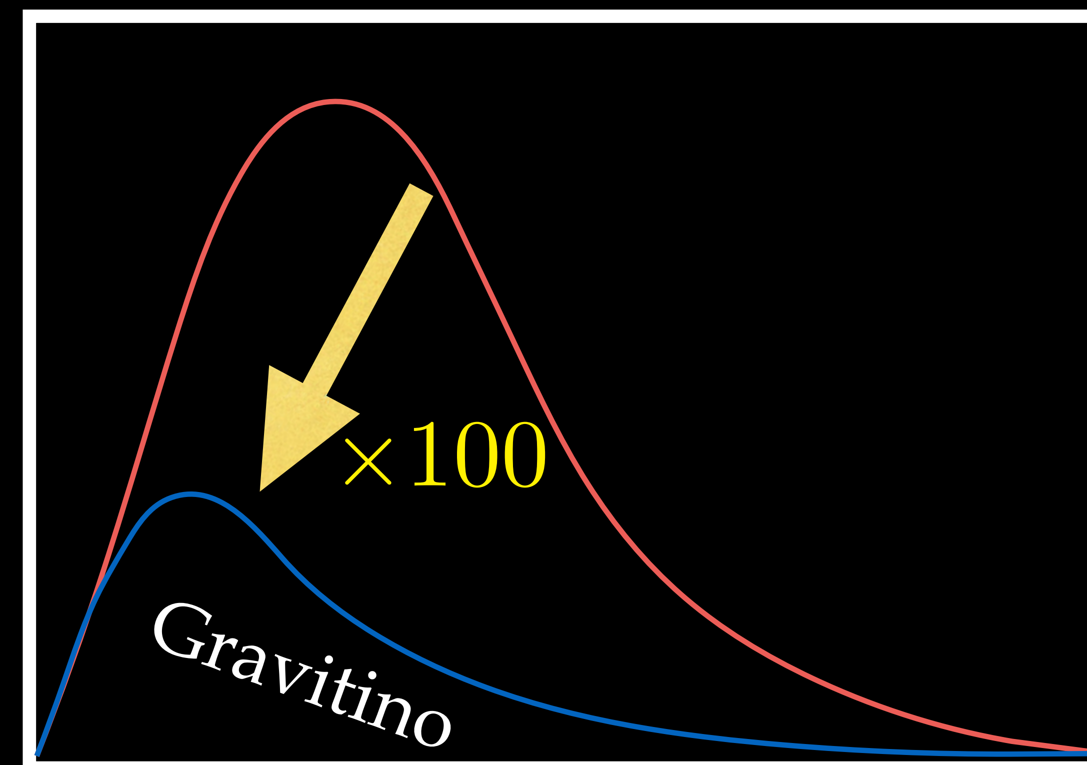

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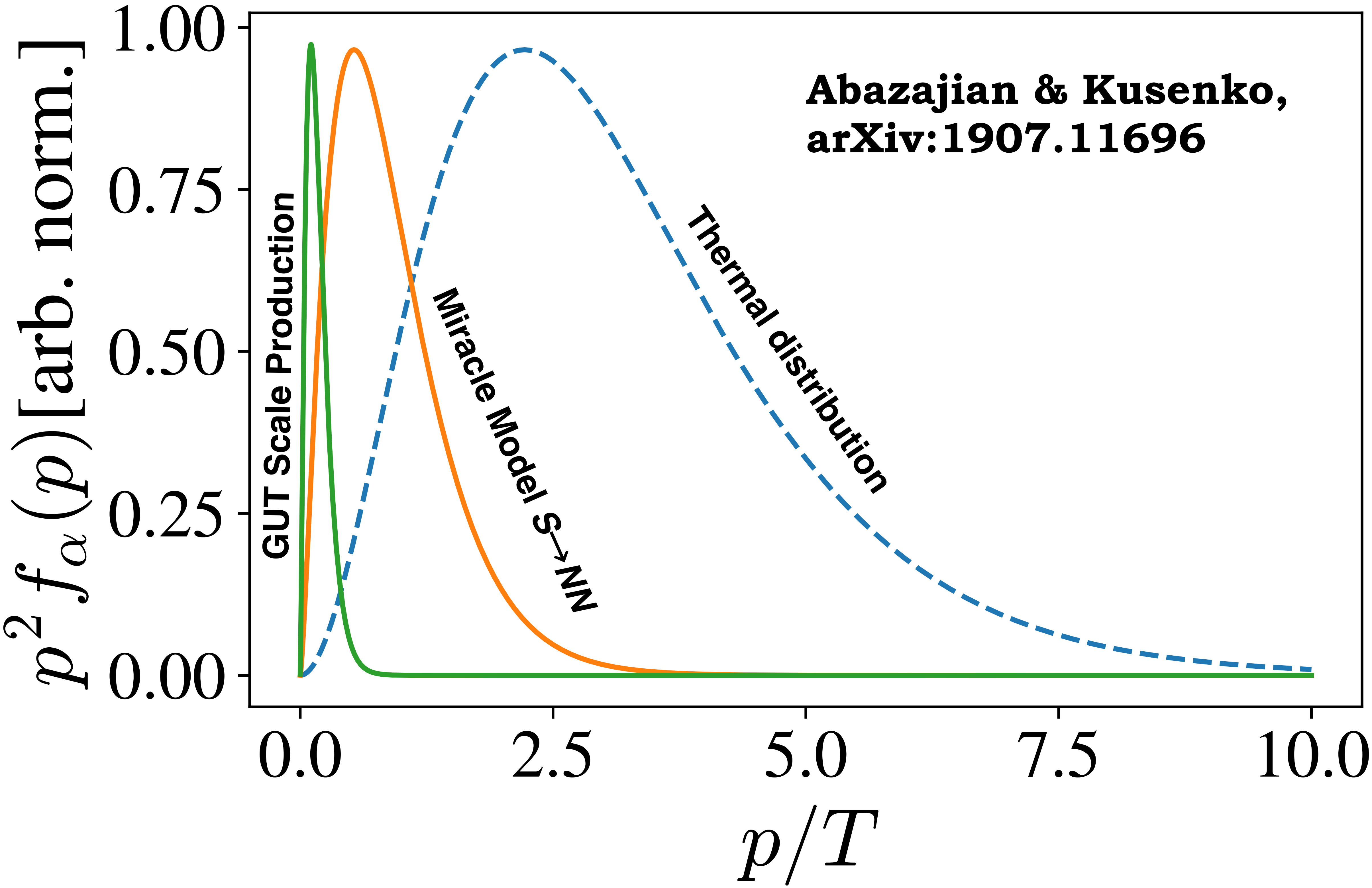
Colombi, Dodelson & Widrow astro-ph/9505029;
Abazajian 2005; arXiv:1705.01837; Venumadhav+ 2016

Varied Momenta Distributions for Different Production Mechanisms



Lyman-α Forest Constraints on WDM

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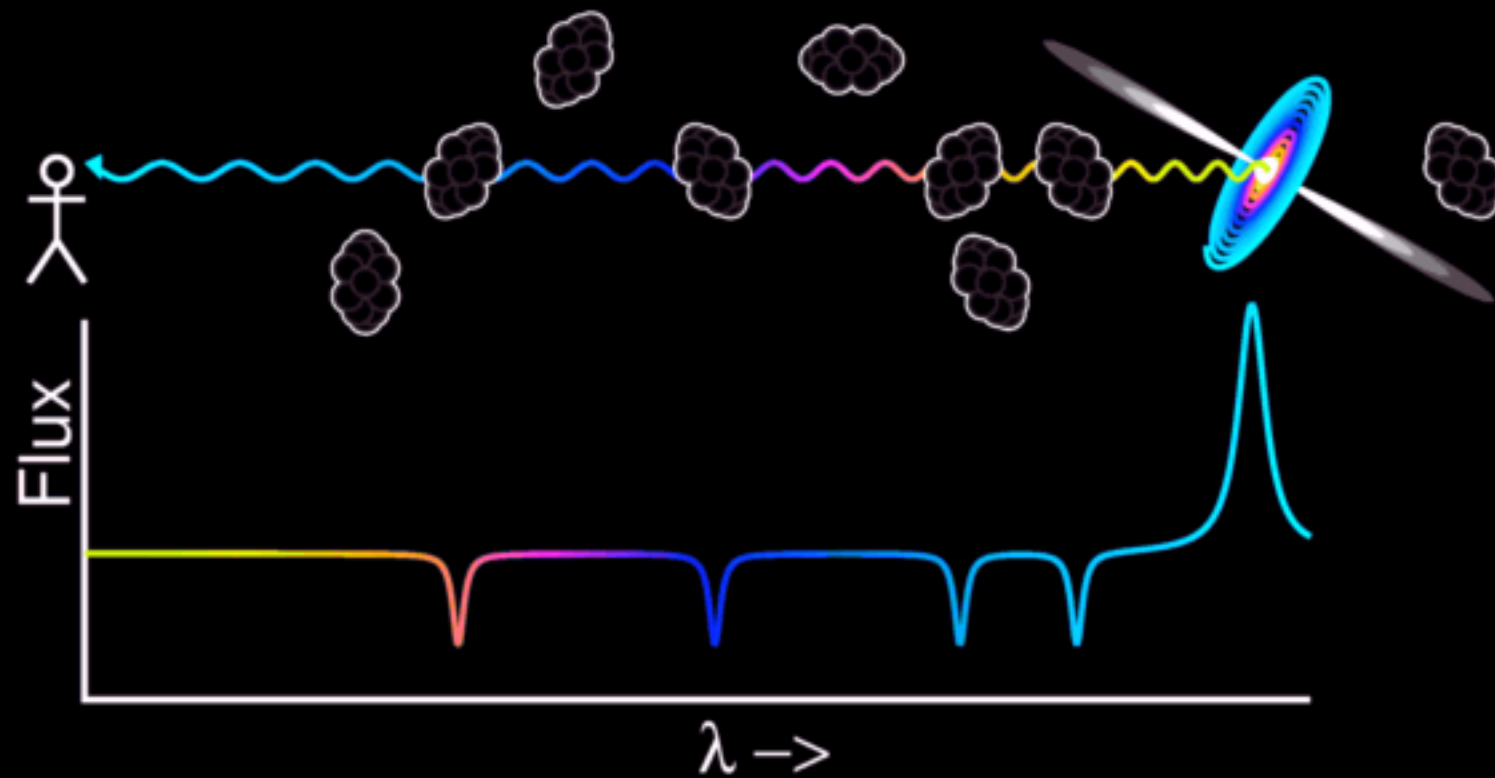

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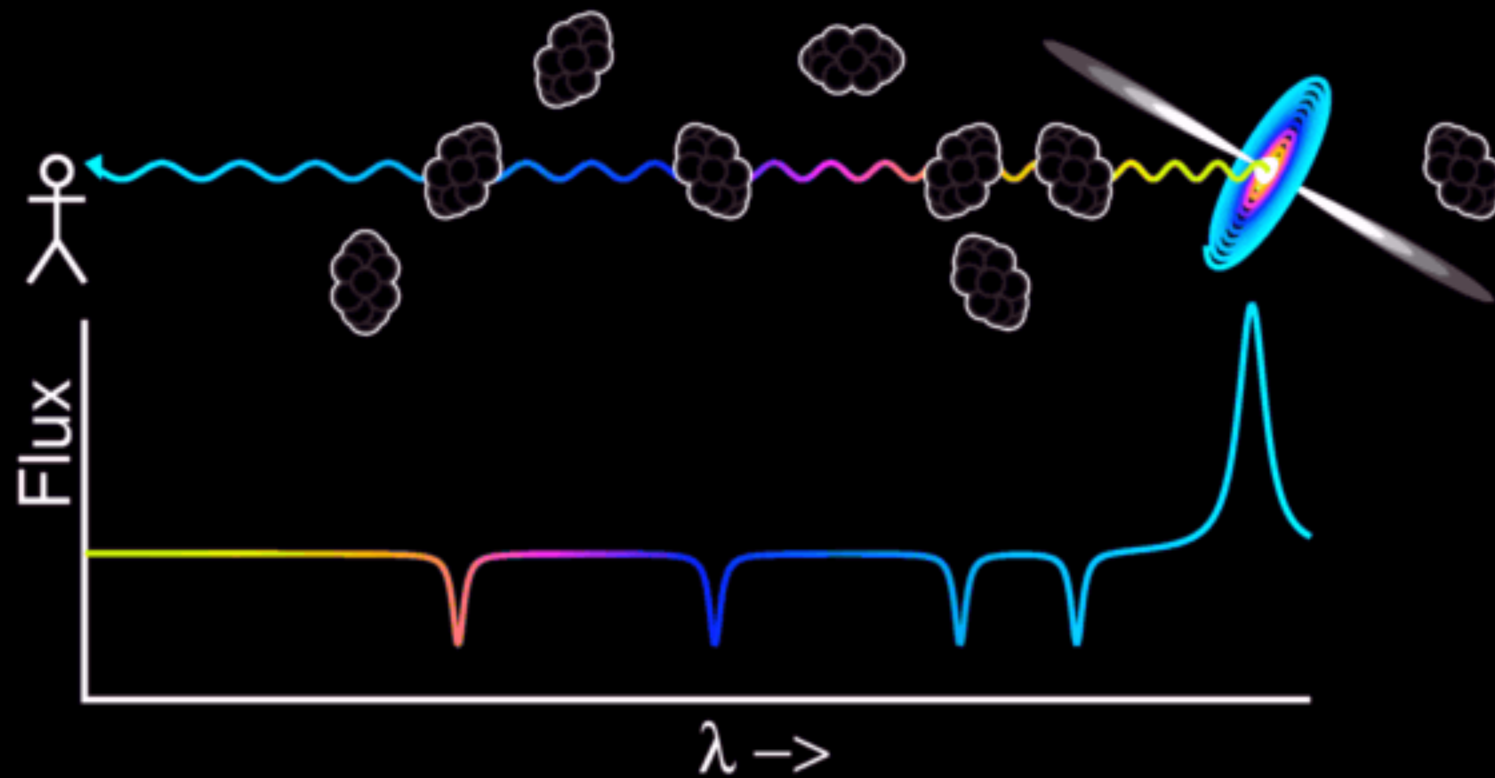
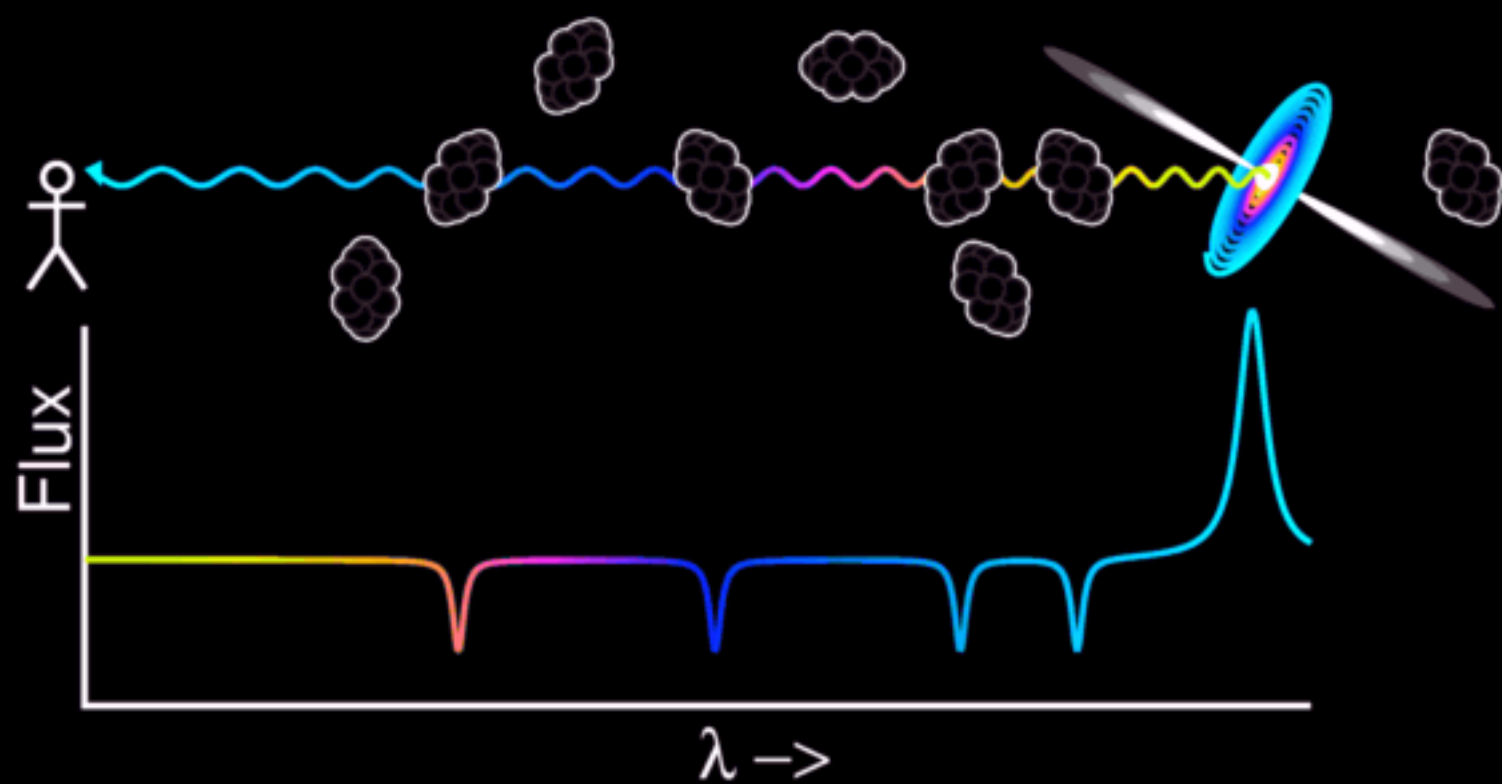


Lyman-α forest:
m_{th} > 3 keV (WDM) (95% CL)
$m_{s,DW}$ > 16 keV
(Baur et al. 2015)

Lyman-α Forest Constraints on WDM



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Milky Way galaxy counts:
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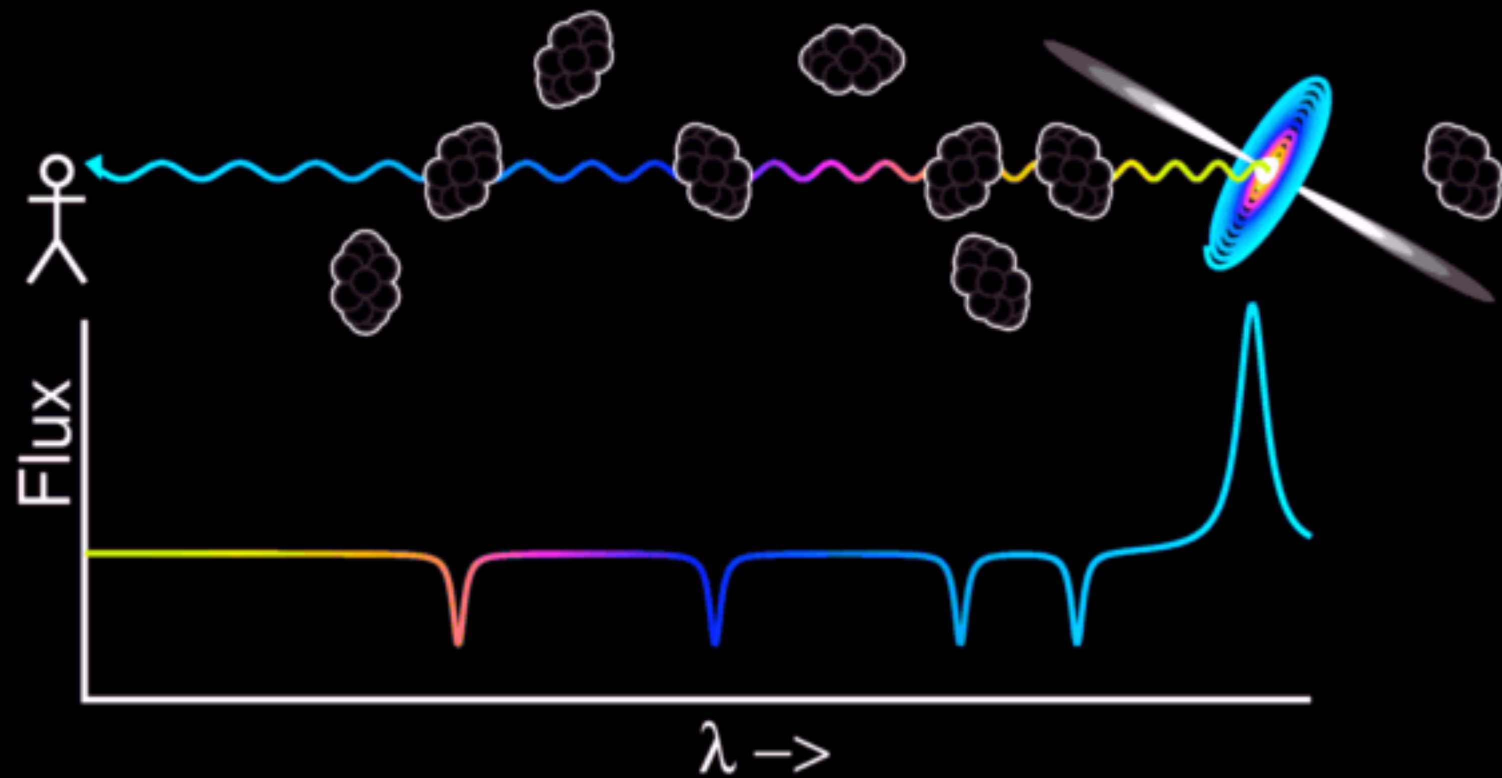

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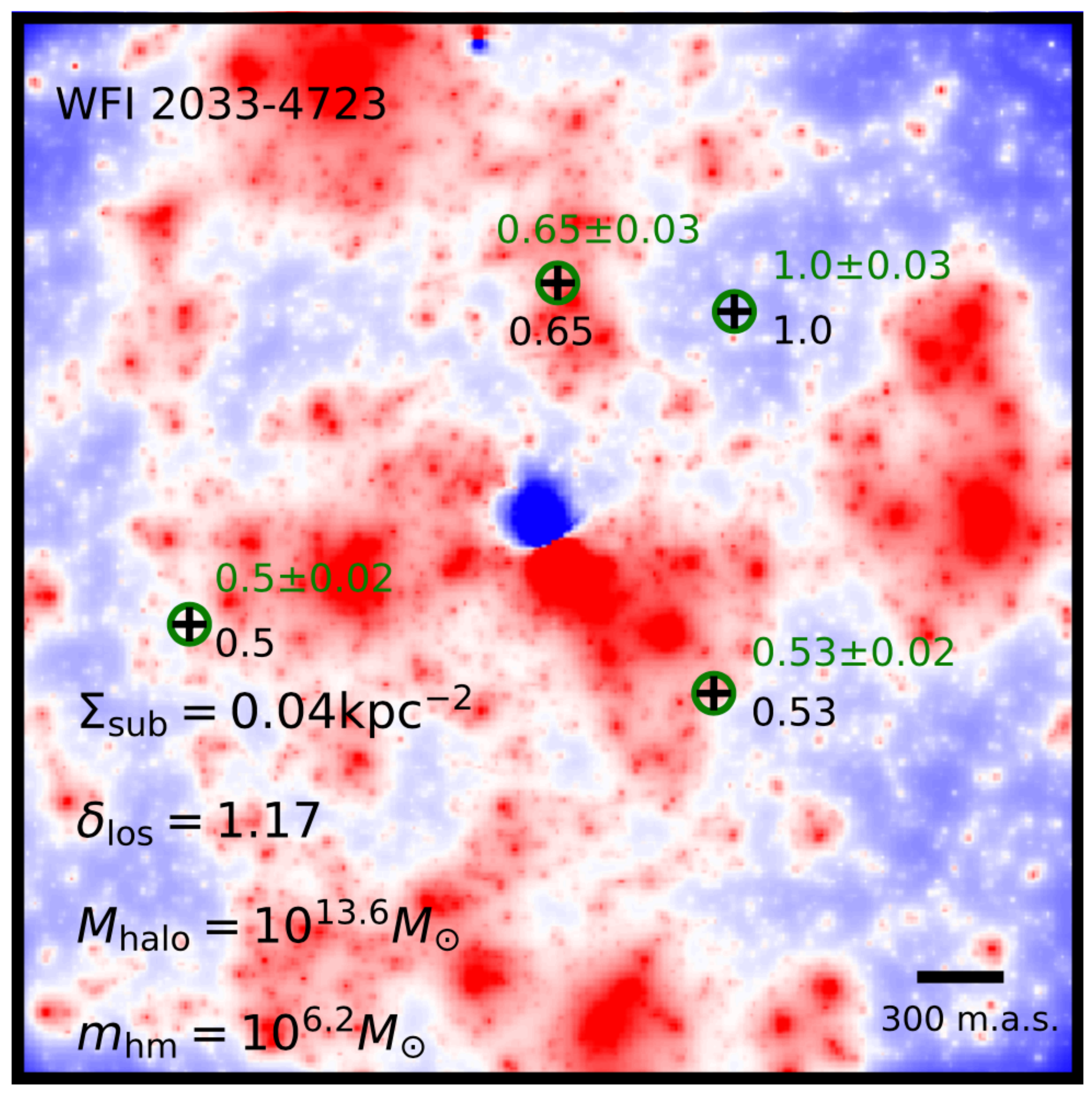
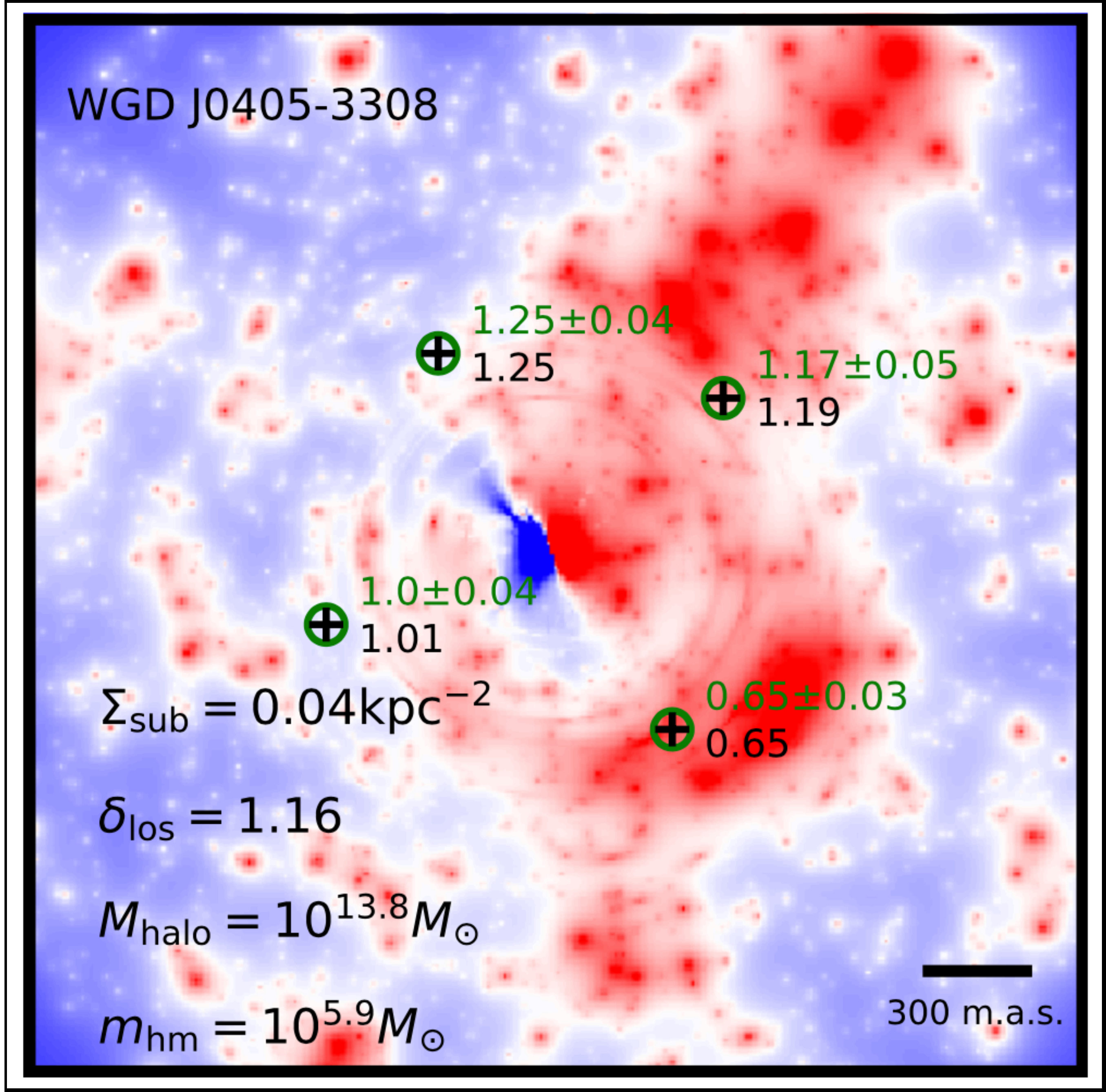
$\lambda_{FS} < 42$ kpc $M_{FS} < 3 \times 10^6$ M$_\odot$ (Abazajian & Koushiappas 2006)

Lensing Constraints on WDM



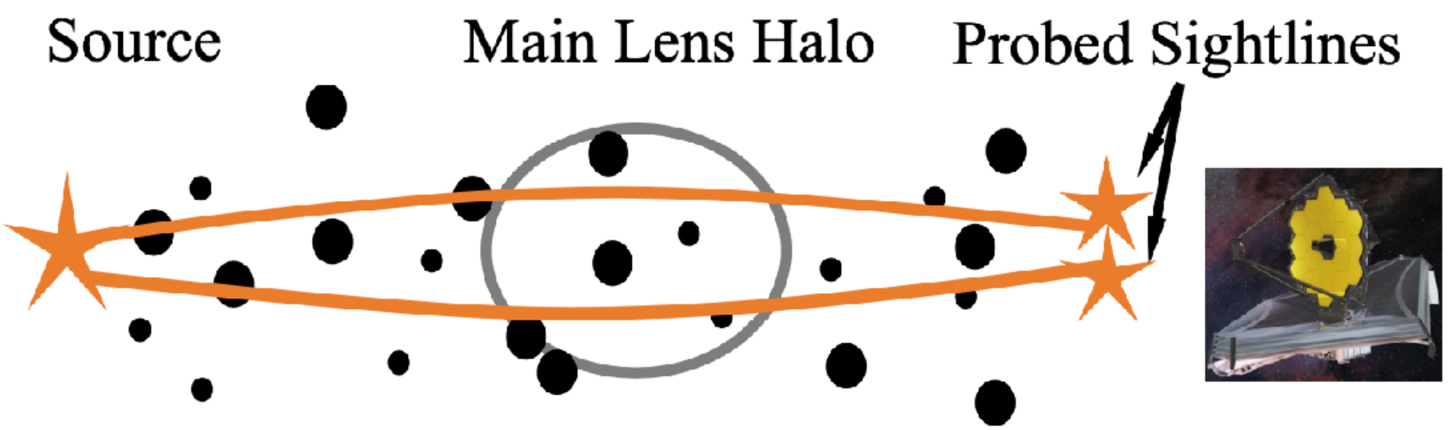


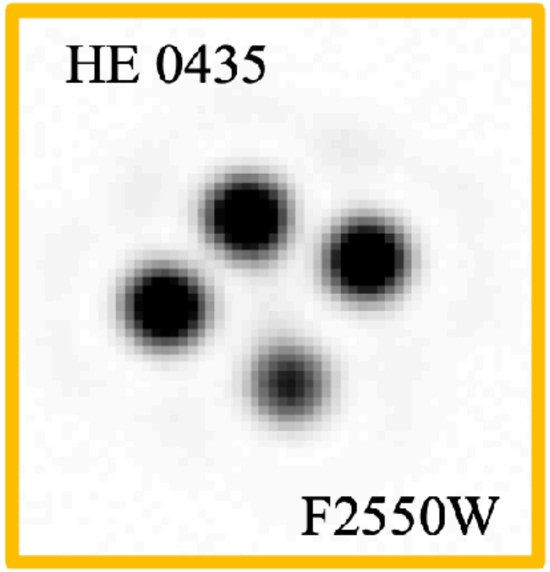
Lensing substructure constraints push:

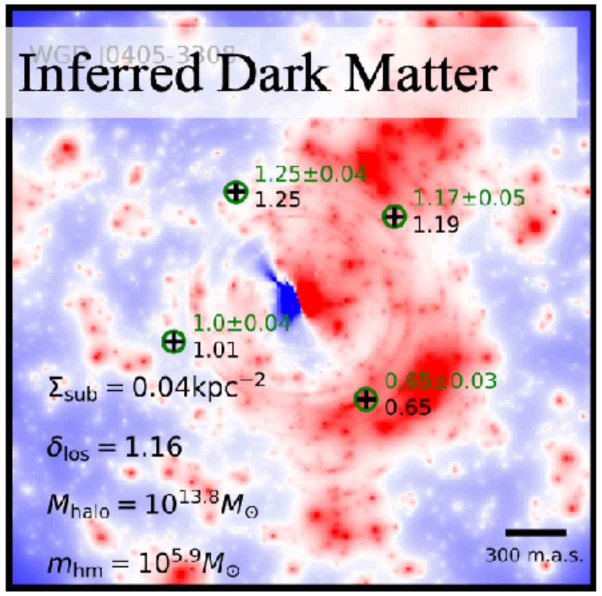
m_{th} > 5.3 keV ($m_{s,DW}$ > 41 keV)

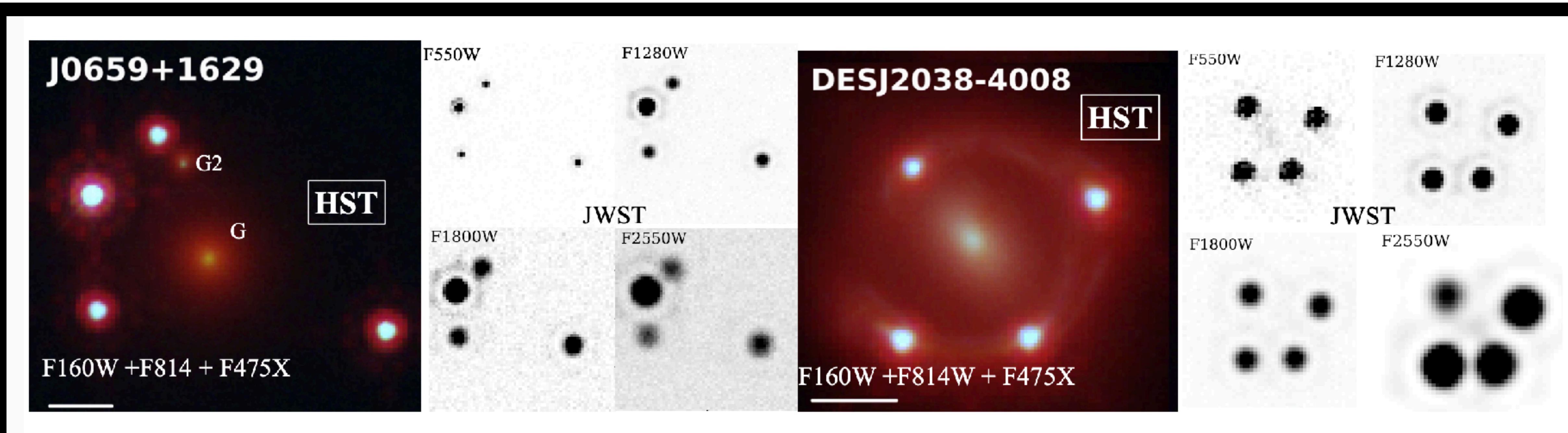
(Gilman+ 2019)

Strong Lensing Tests of WDM: Quadruply-Lensed Systems

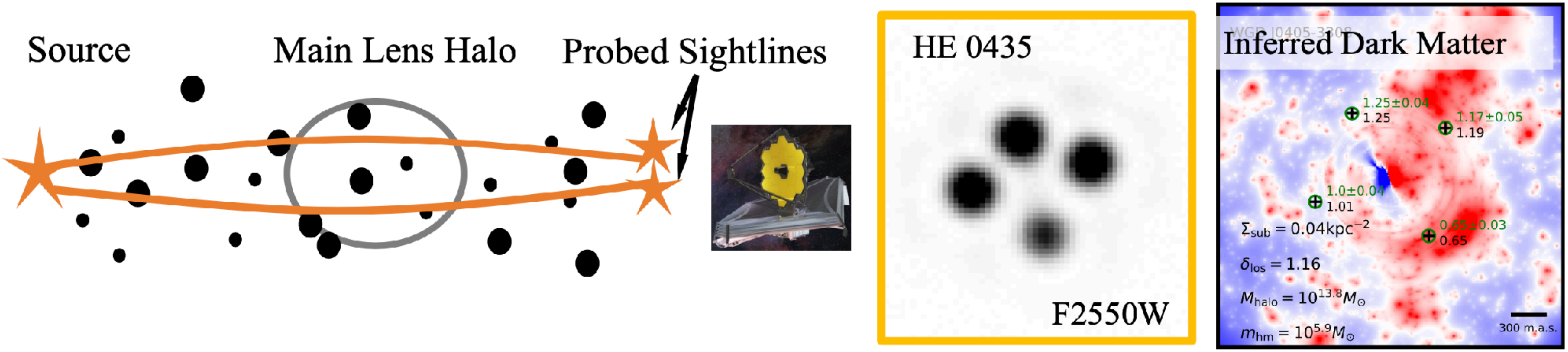


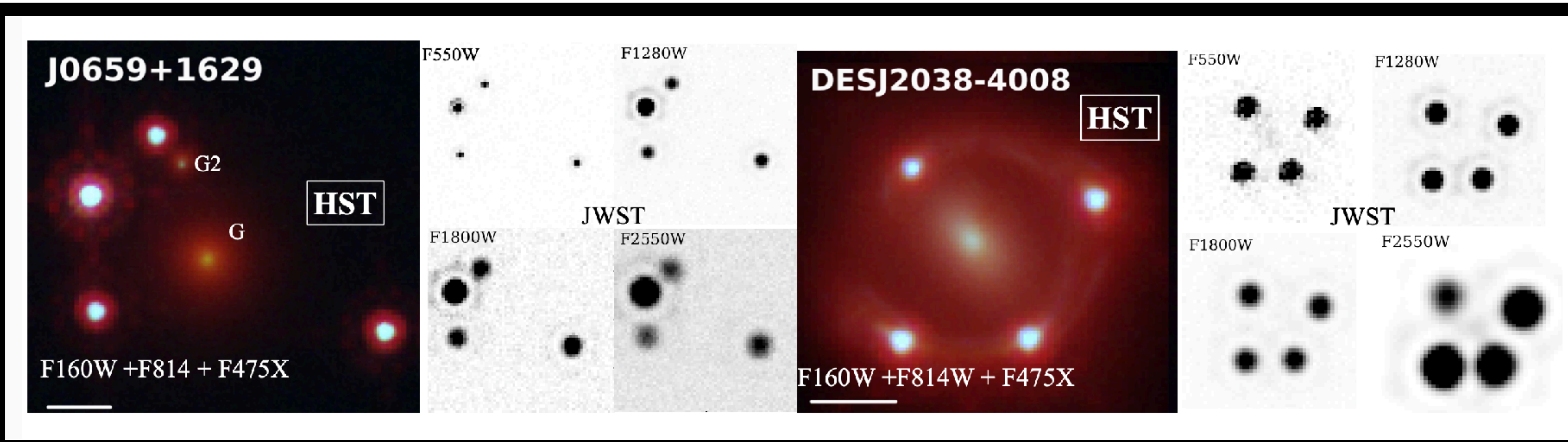






Strong Lensing Tests of WDM: Quadruply-Lensed Systems





JWST Cycle ONE Proposal 2022 (PI Nierenberg): $\boldsymbol{m_{th} > 10}$ ***keV***

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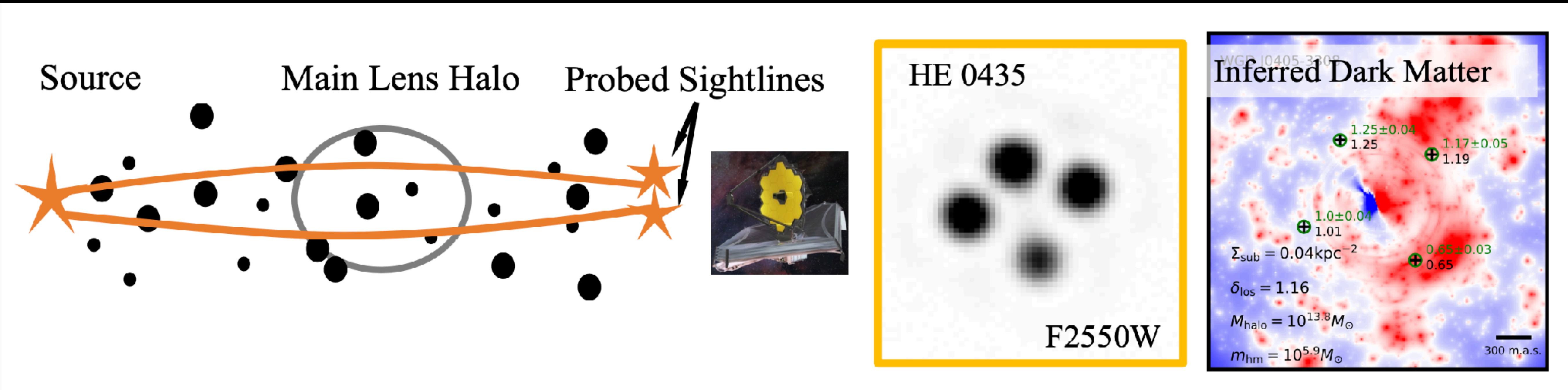

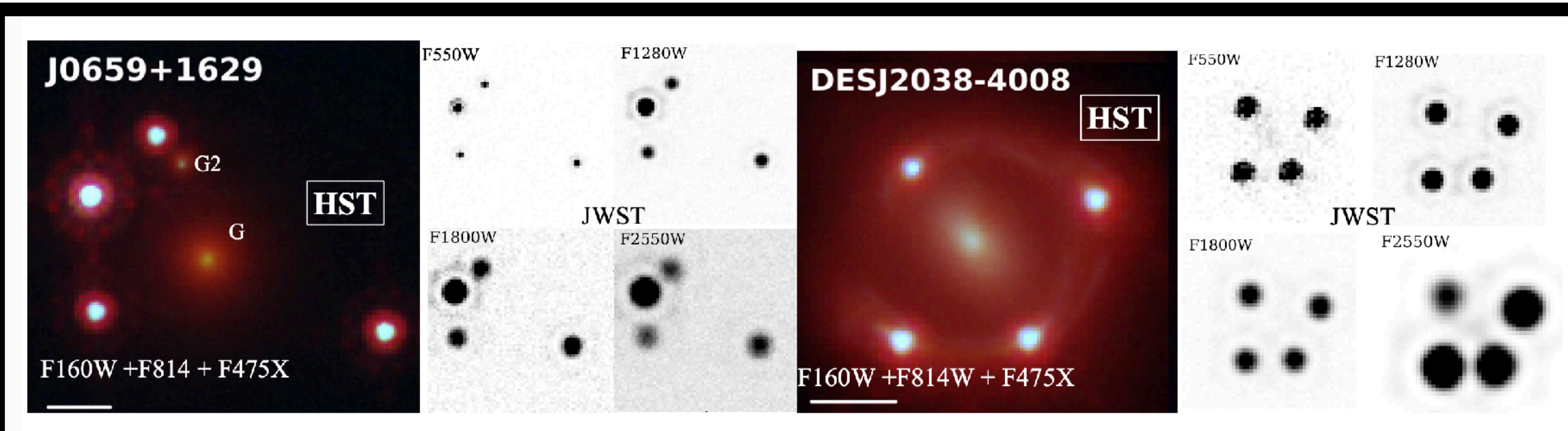

Lensing substructure constraint: m_{th} **> 5.3 keV** (Gilman+ 2019)

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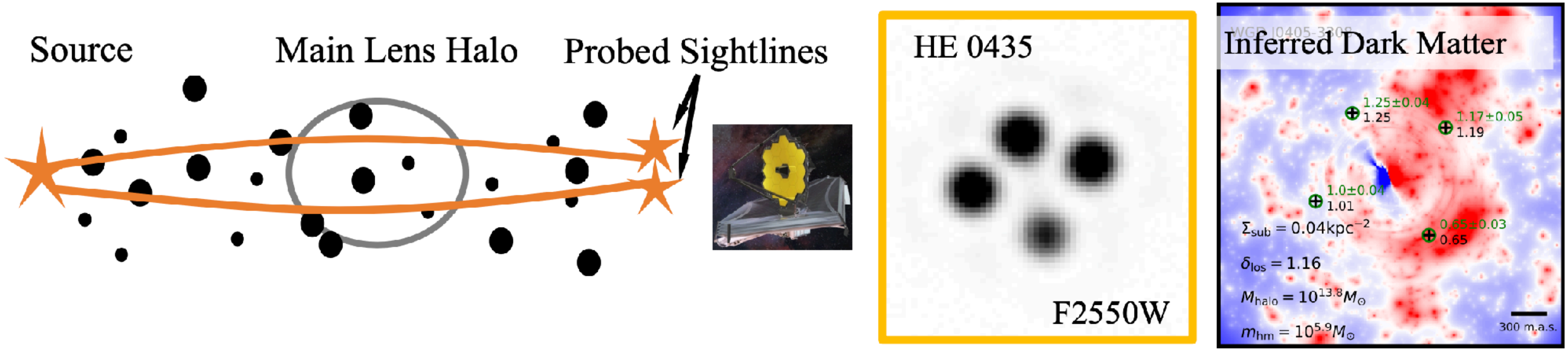
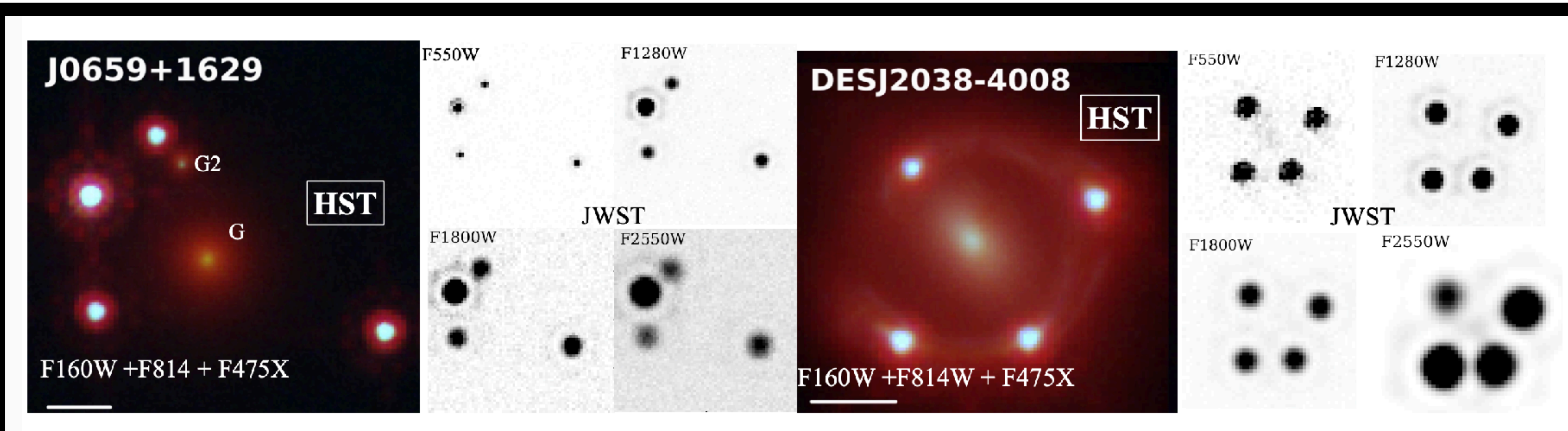




Lensing substructure constraint: m_{th} **> 5.3 keV** (Gilman+ 2019)

Studied in a wide range of sterile neutrino DM models (Zelko+ '22)

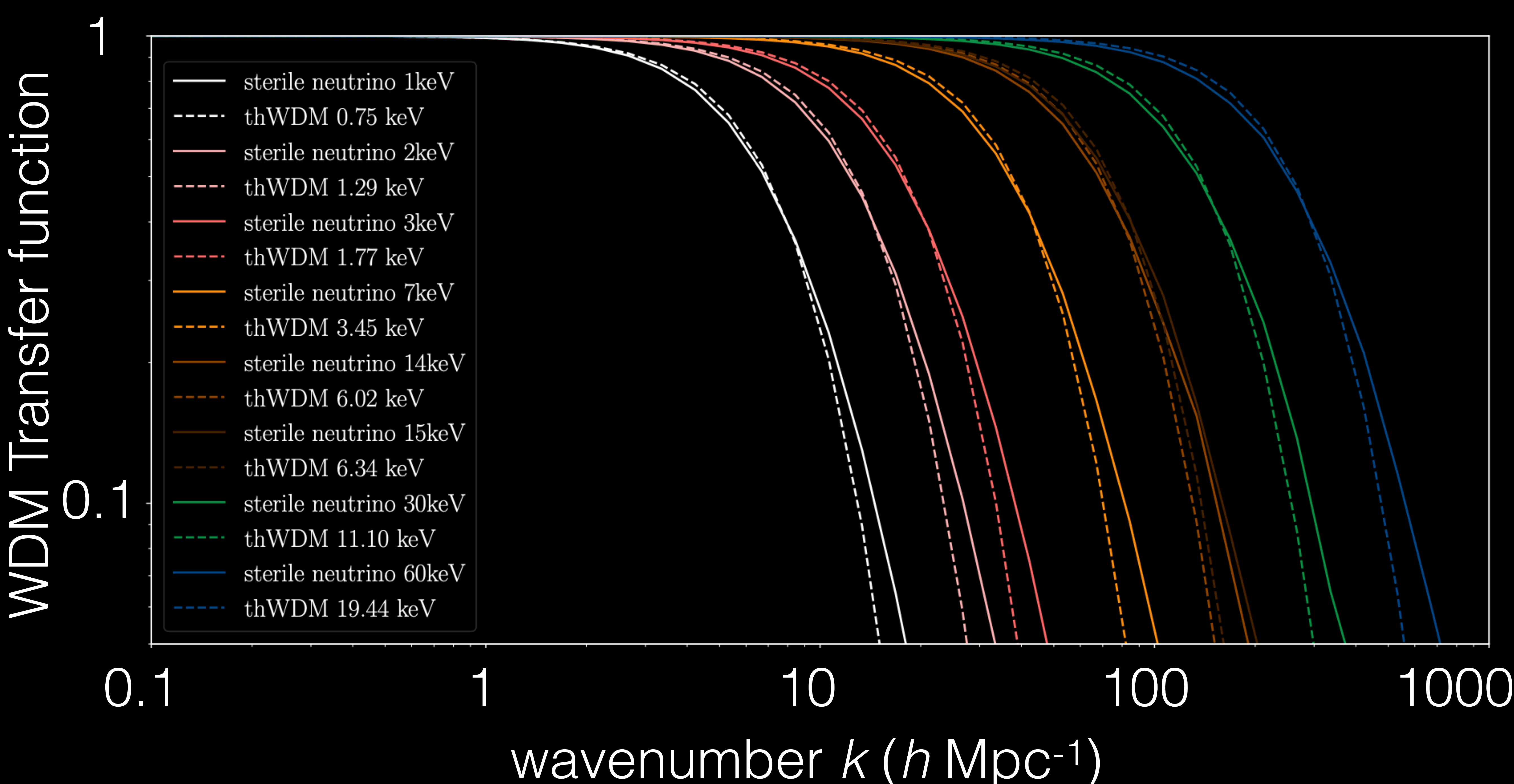
JWST Cycle ONE Proposal 2022 (PI Nierenberg): m_{th} ***> 10 keV***

Lensing Test of Sterile Neutrino DM Models

	Strong Lensing [keV]	Strong Lensing & Galaxy Counts [keV]	Lyman-α [keV]	Lyman-α & Thermo. [keV]
PK	I: 10 II: 9.6	I: 26 II: 24	6.9	12
KTY	I: 2.1 II: 1.9	I: 5.2 II: 4.8	1.3	2.4
νMSM	7.0	16	I: 5.0 II: 5.0	I: 9.0 II: 10
DW	I: 34 II: 31	I: 92 II: 84	21	40
thermal	4.6	9.7	3.3	5.3

(Zelko et al., *PRL*, arXiv:2205.09777)

Lensing Test of Sterile Neutrino DM Models



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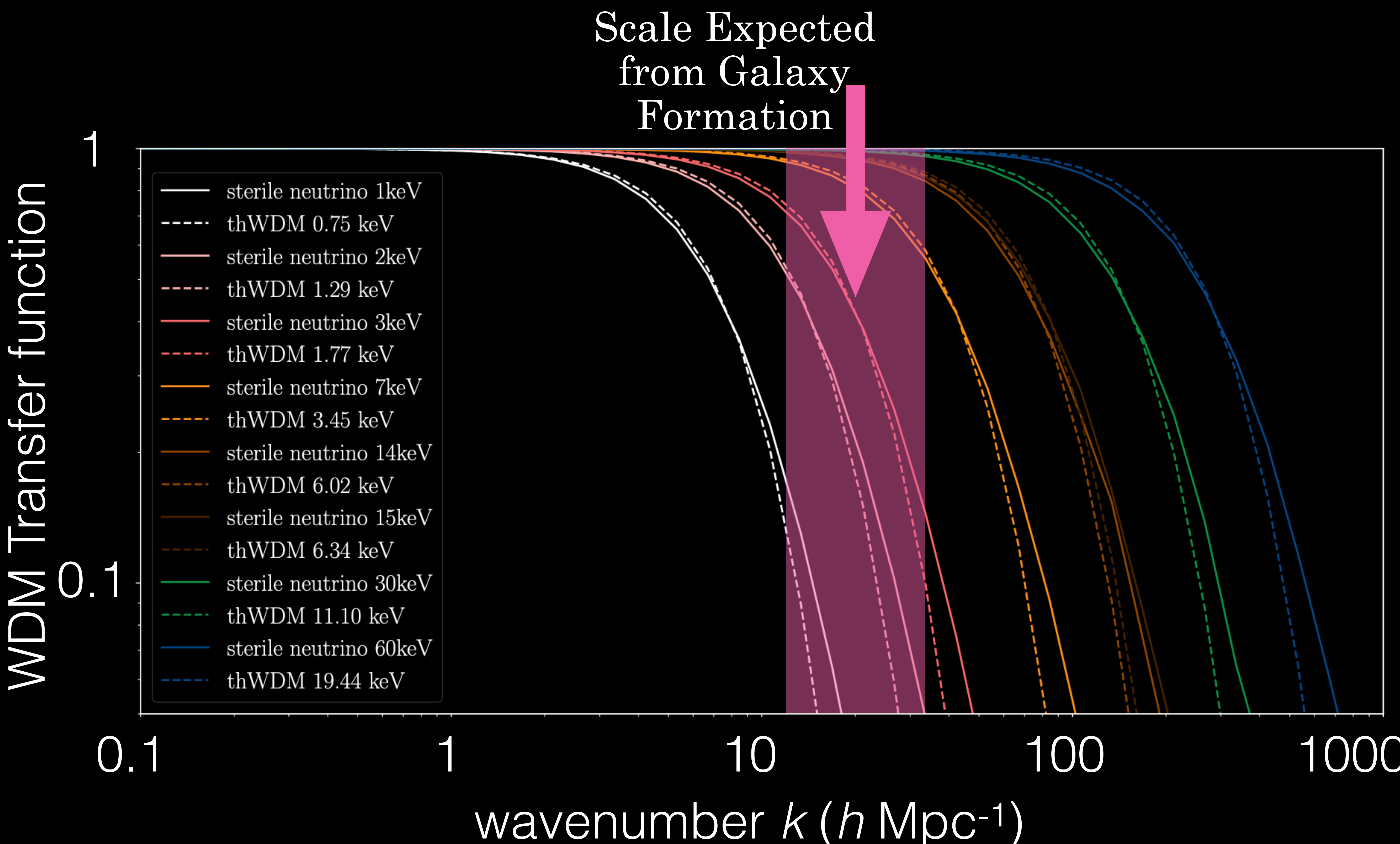

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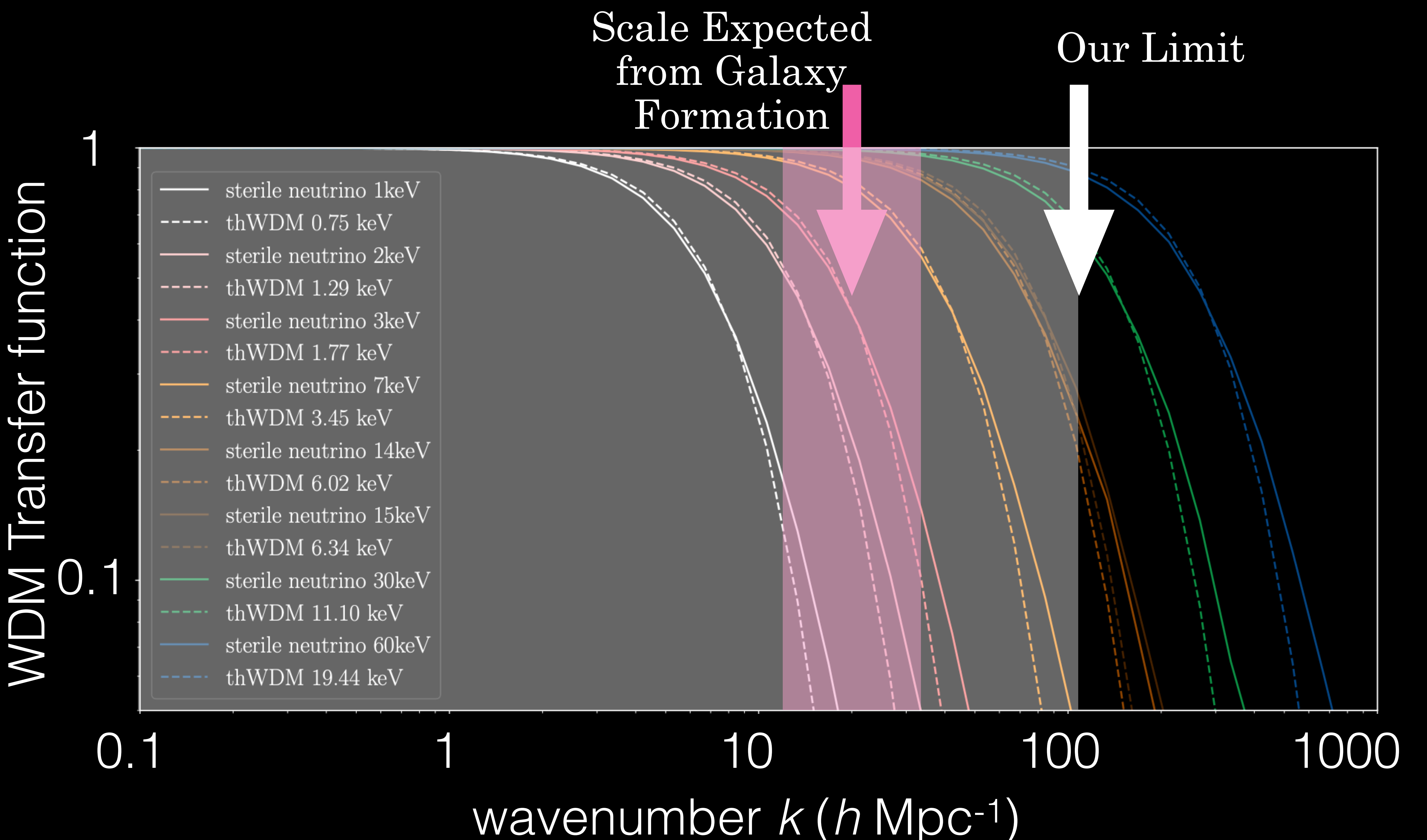

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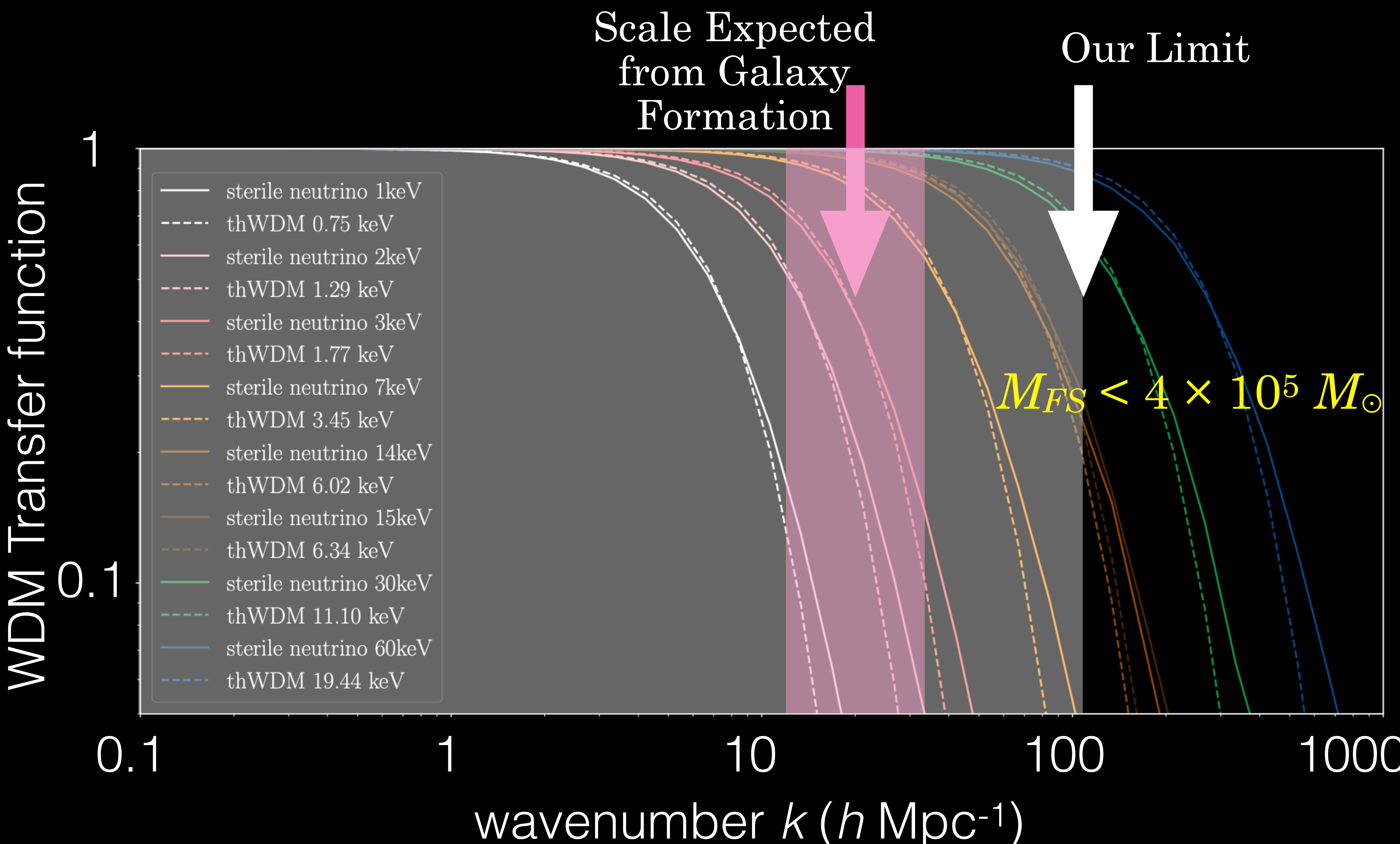

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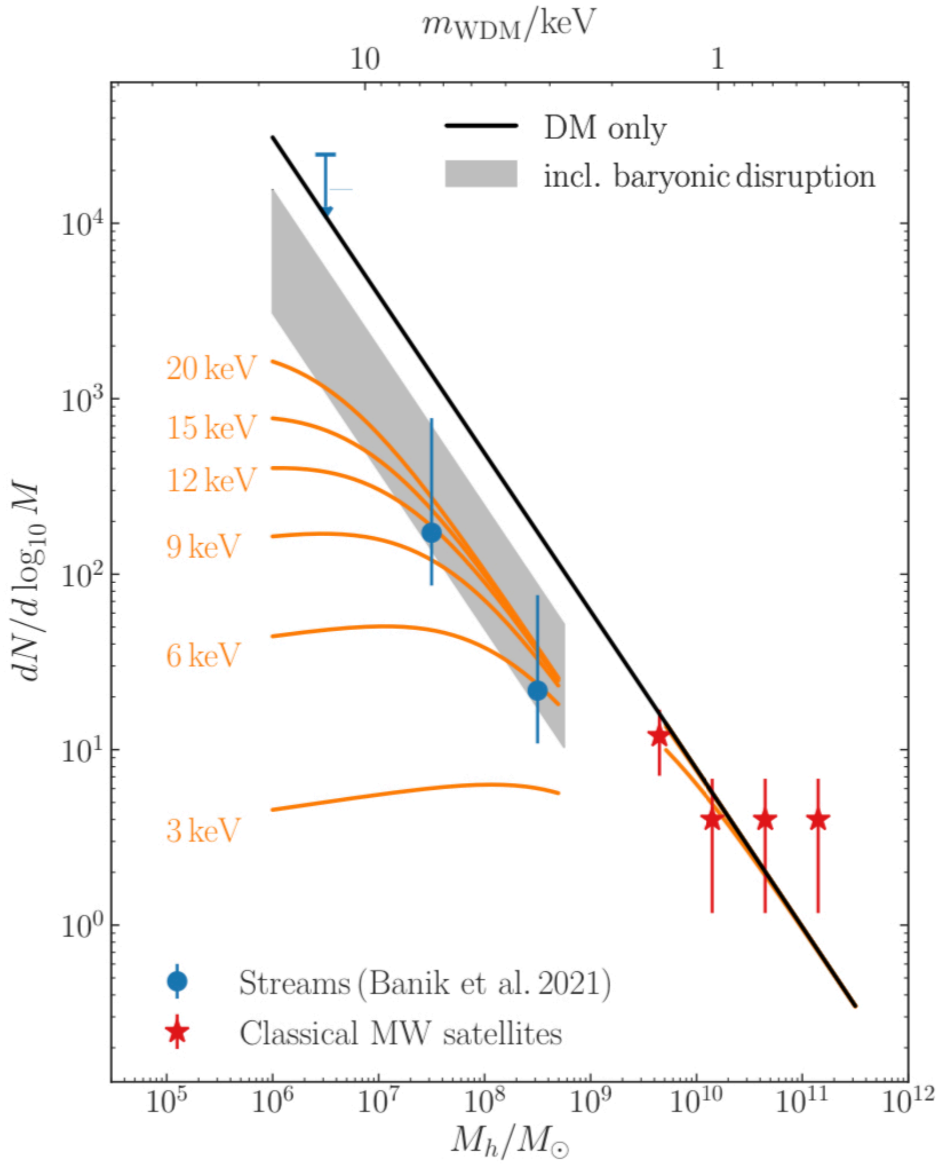
Warm dark matter

(Jo Bovy – yesterday)

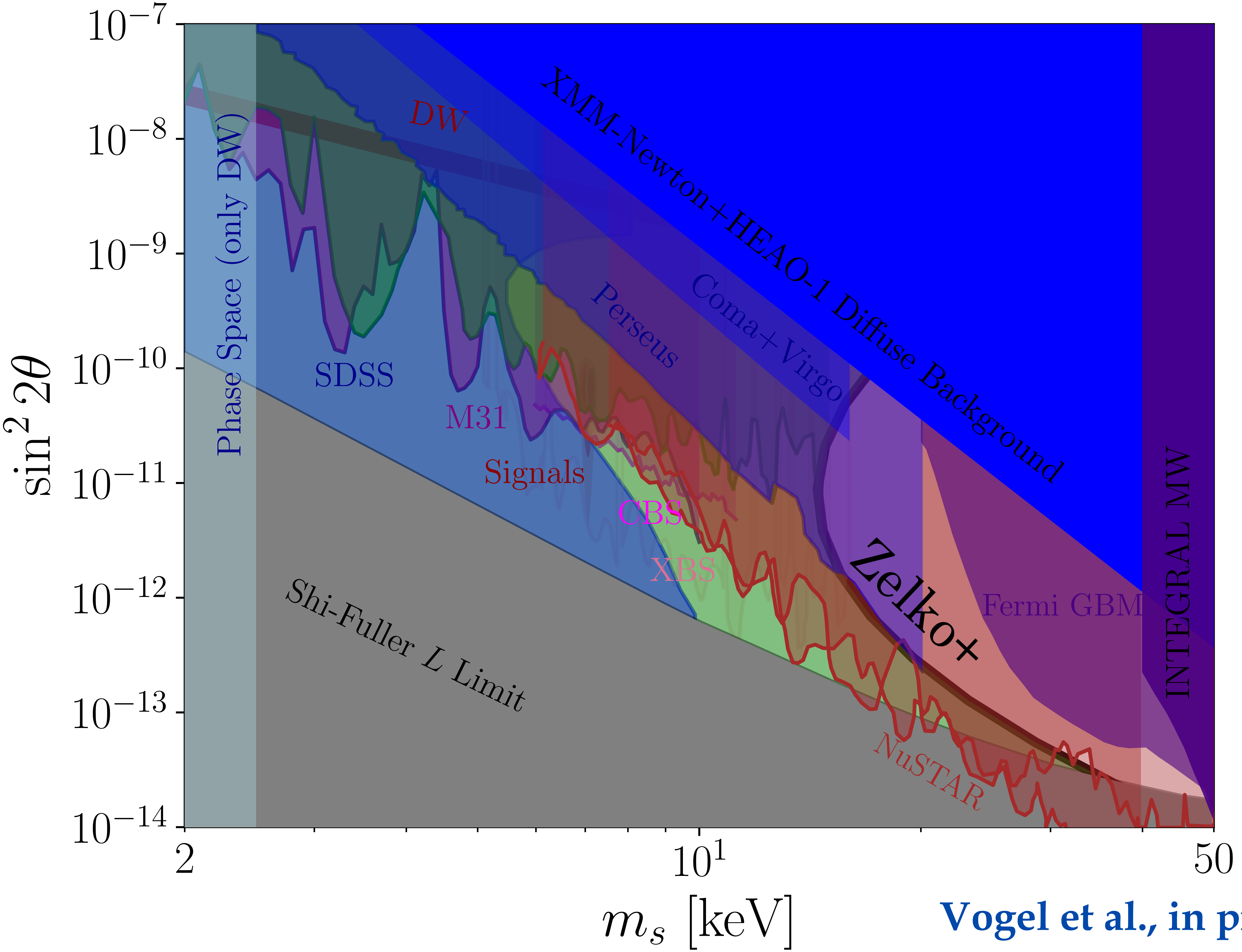


- GD-1+Pal 5:
  - $m_{\rm WDM} > 4.6$ keV
- Including classical satellites:
  - $m_{\rm WDM} > 6.3$ keV
- +lensing+other MW dwarfs:
  - $m_{\rm WDM} > 11$ keV
  - (all 95% confidence)

thermal

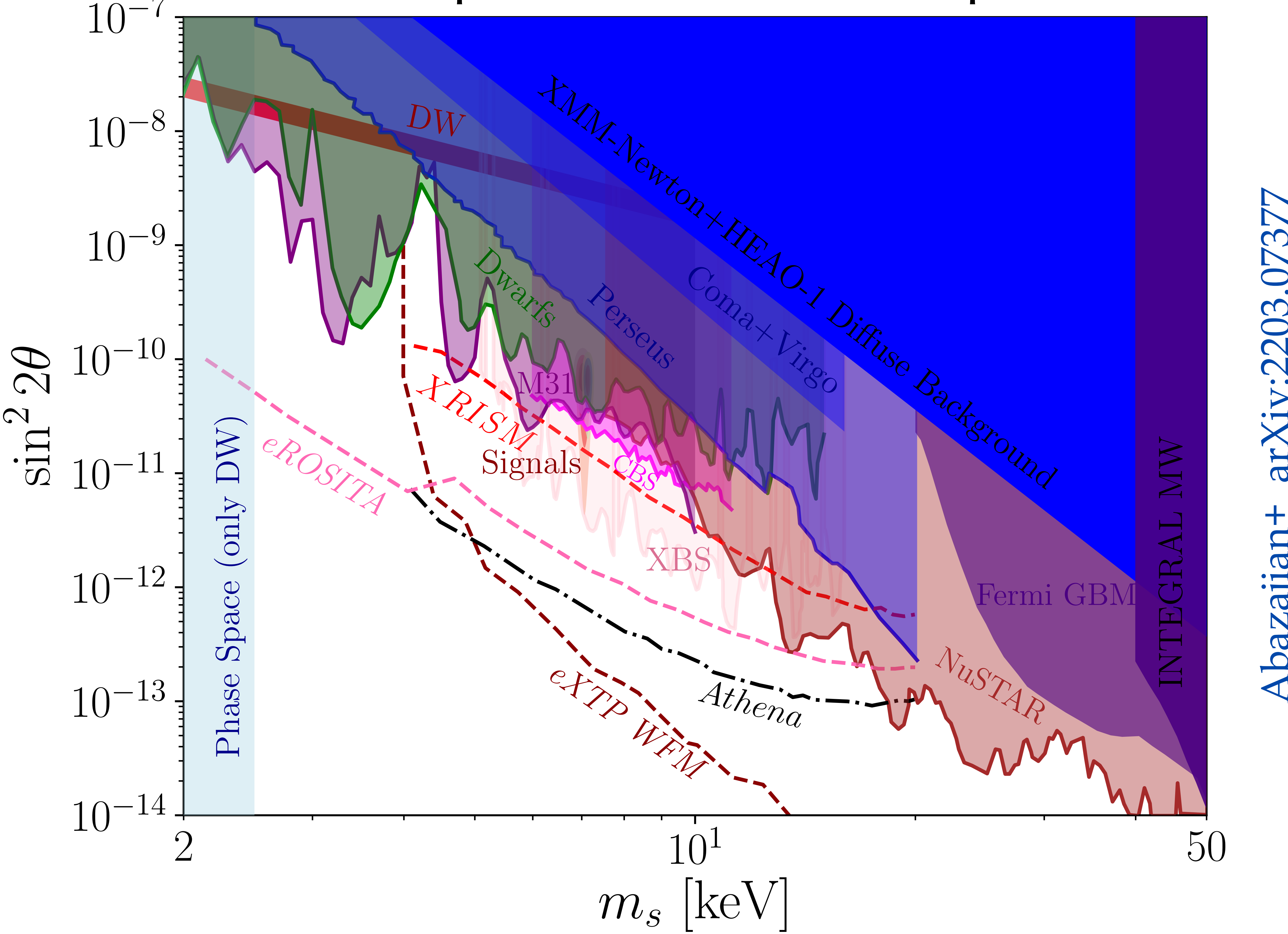
Banik, Bovy, et al. (2021b)

Sterile Neutrino Dark Matter: Shi-Fuller Mechanism Excluded



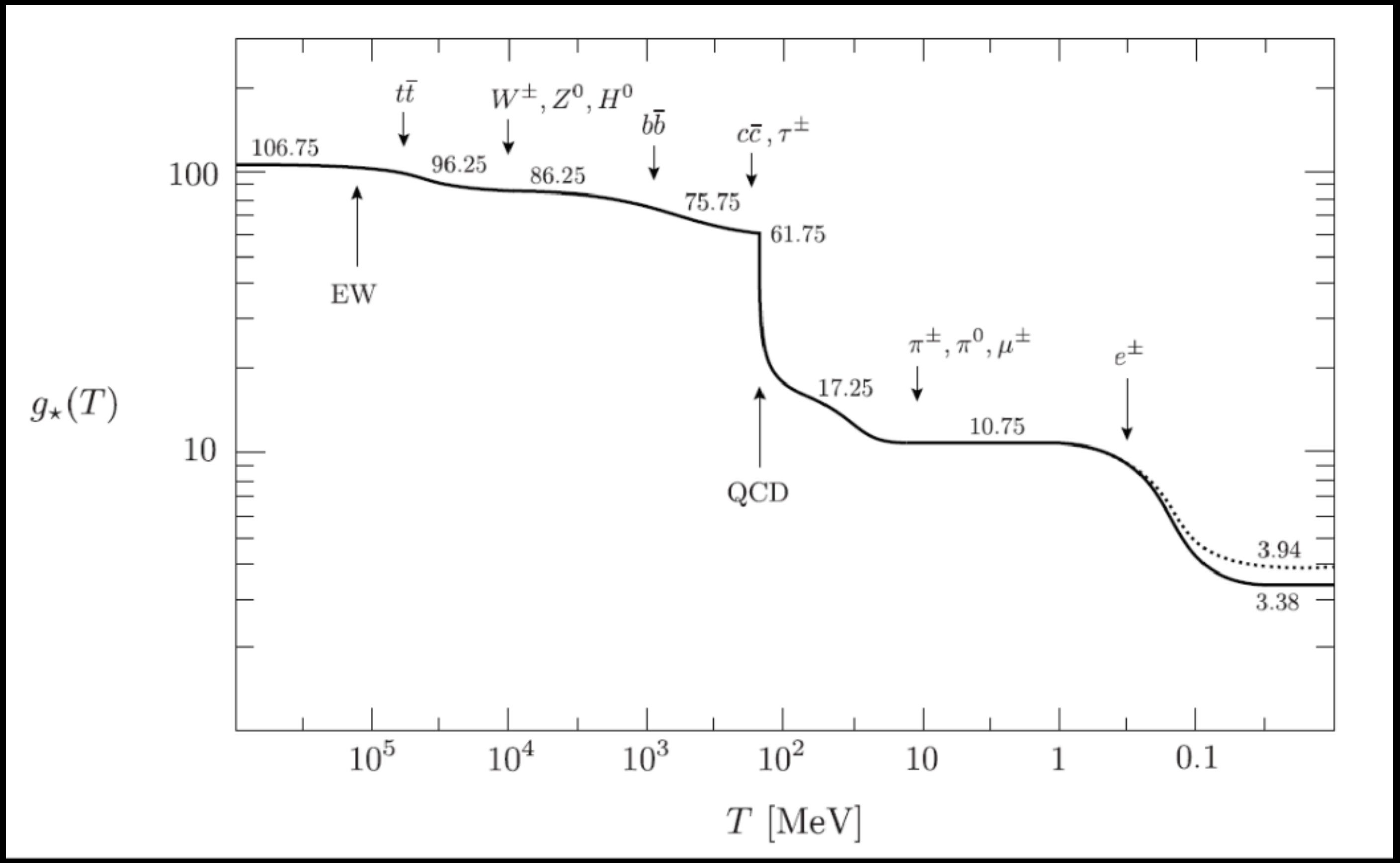
Vogel et al., in prep.

Sterile Neutrino Dark Matter: Model-Independent Parameter Space



Pushing beyond $m_{\rm th}$ > 10 keV: Accurate Calculations of Standard *Thermal* WDM

Thermal WDM abundance set by degrees of freedom of the plasma…



m [keV]	Spin-1/2 $g_*(T_D)$	Spin-1/2 T_X/T_γ	Spin-3/2 $g_*(T_D)$	Spin-3/2 T_X/T_γ
2	1917	0.1268	3833	0.1007
5	4792	0.09344	9583	0.07416
10	9583	0.07416	19170	0.05886
20	19170	0.05886	38330	0.04672

Vogel & Abazajian 2210.10753

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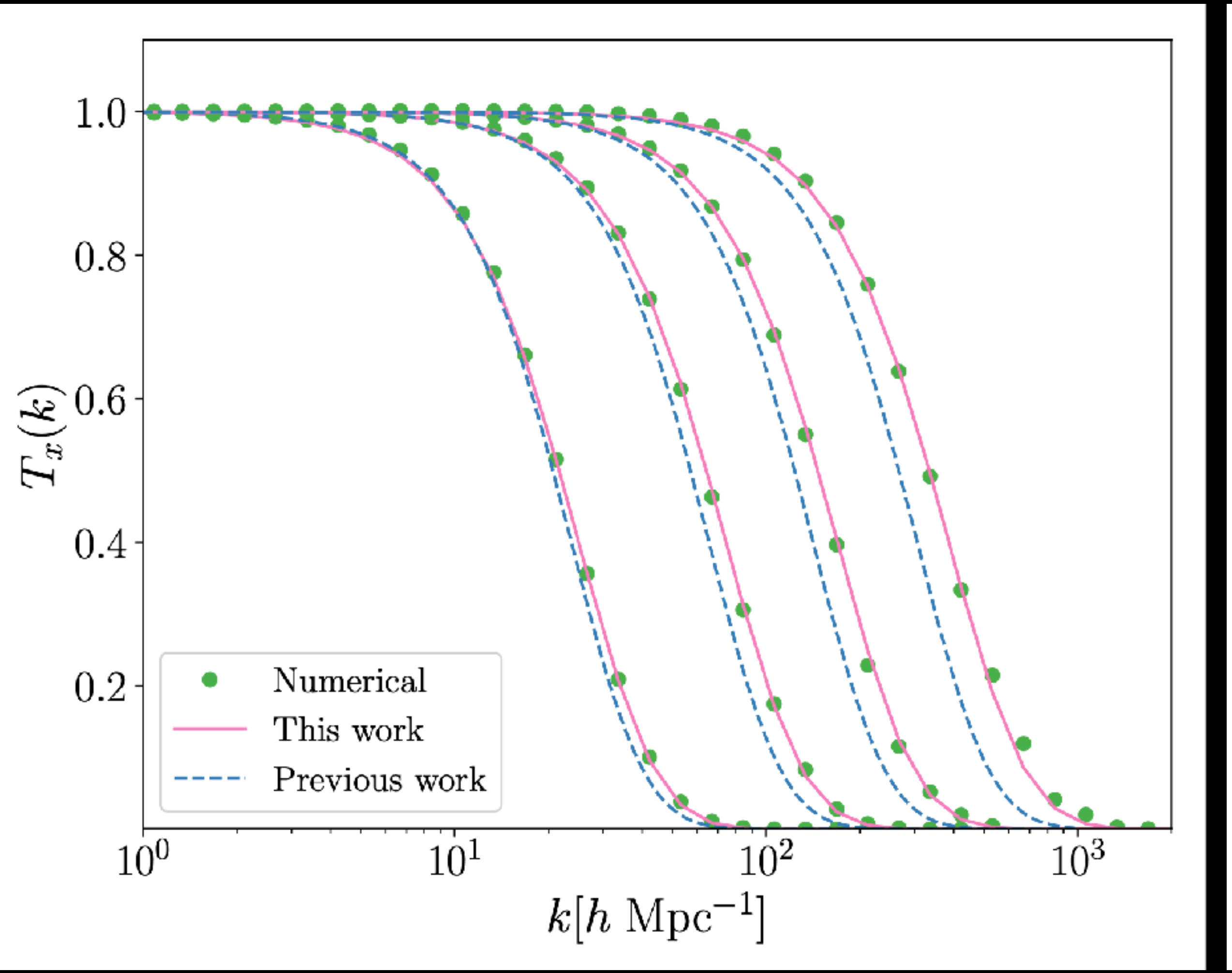
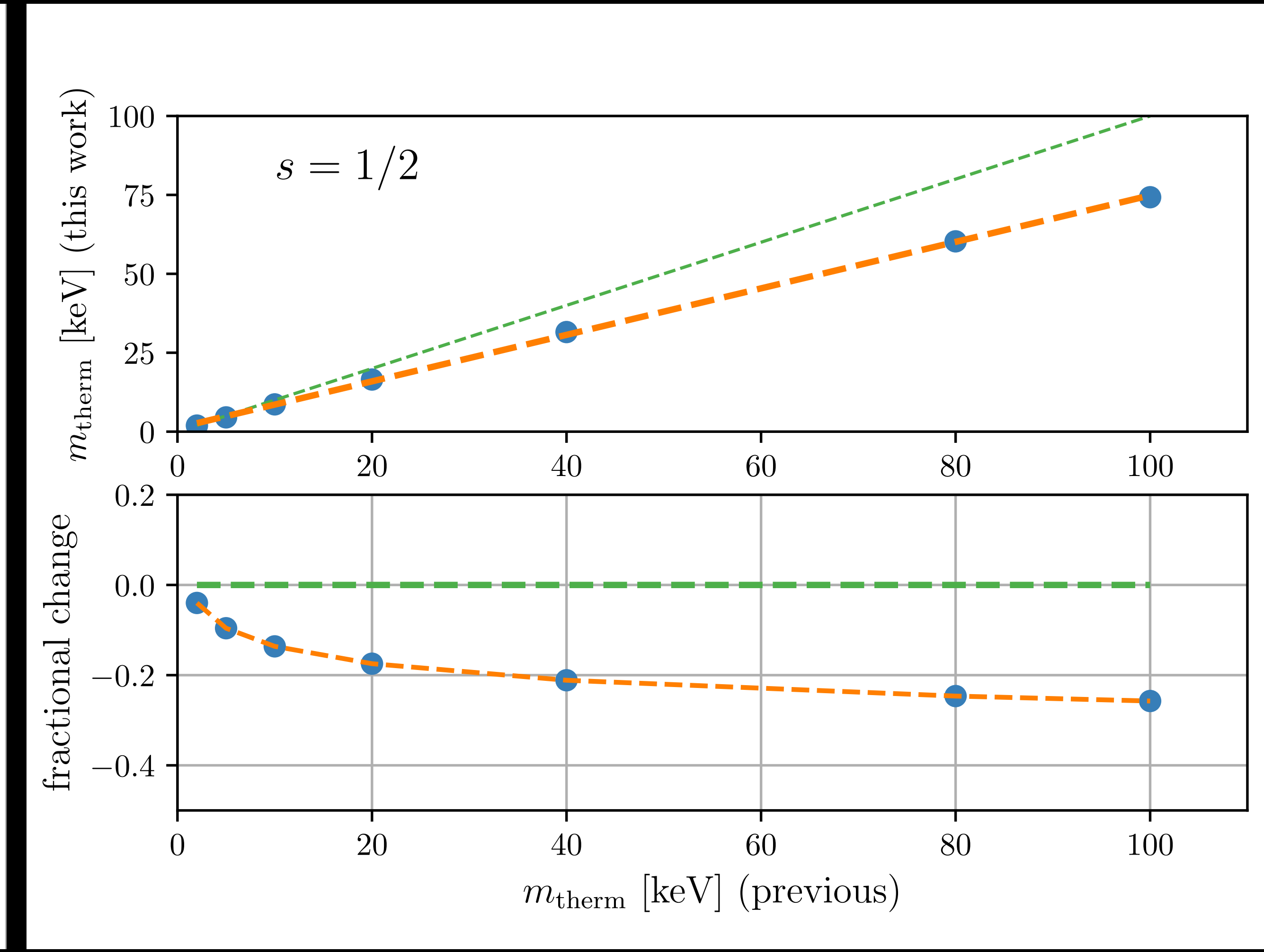


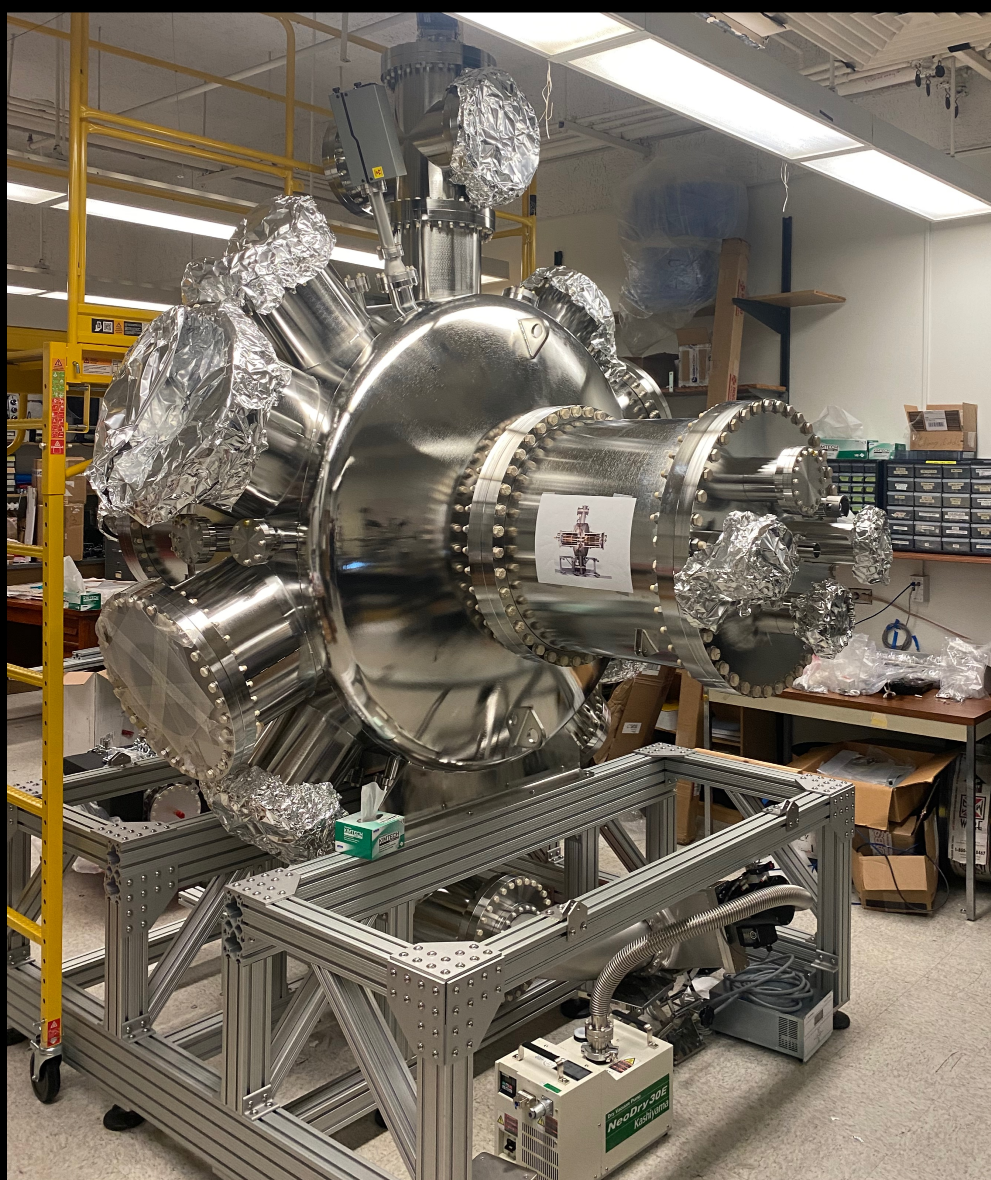


Given exact temperature via dilution, and training on 1 keV < m_{th} < 100 keV, we corrected the particle mass inferred from a given cutoff scale by 20% to 40% from previous WDM fits (e.g. Viel et al. 2005)

Vogel & Abazajian 2210.10753

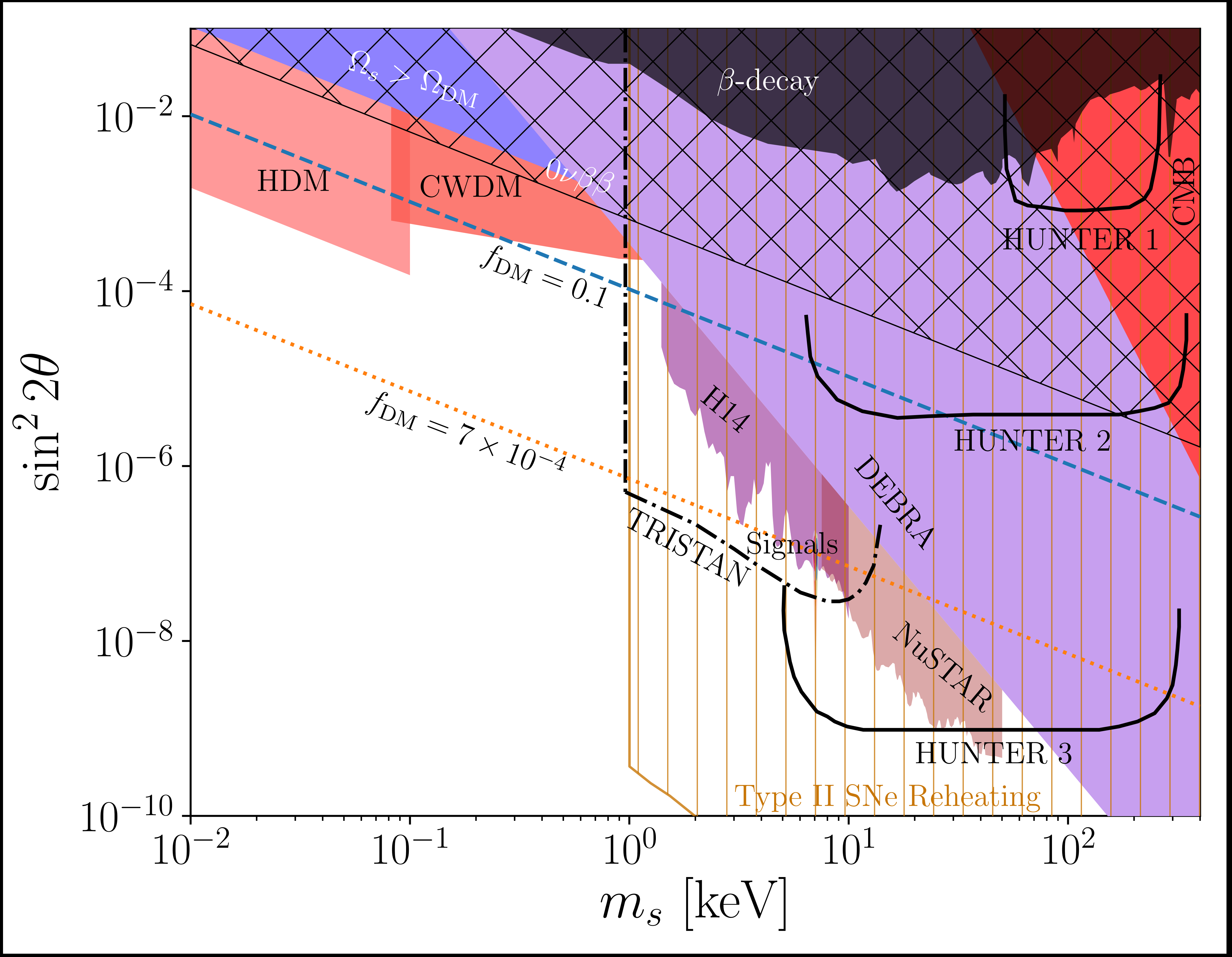
Sterile Neutrino kinematic searches in nuclear β-decay: KATRIN/TRISTAN, HUNTER, MAGNETO-ν

HUNTER



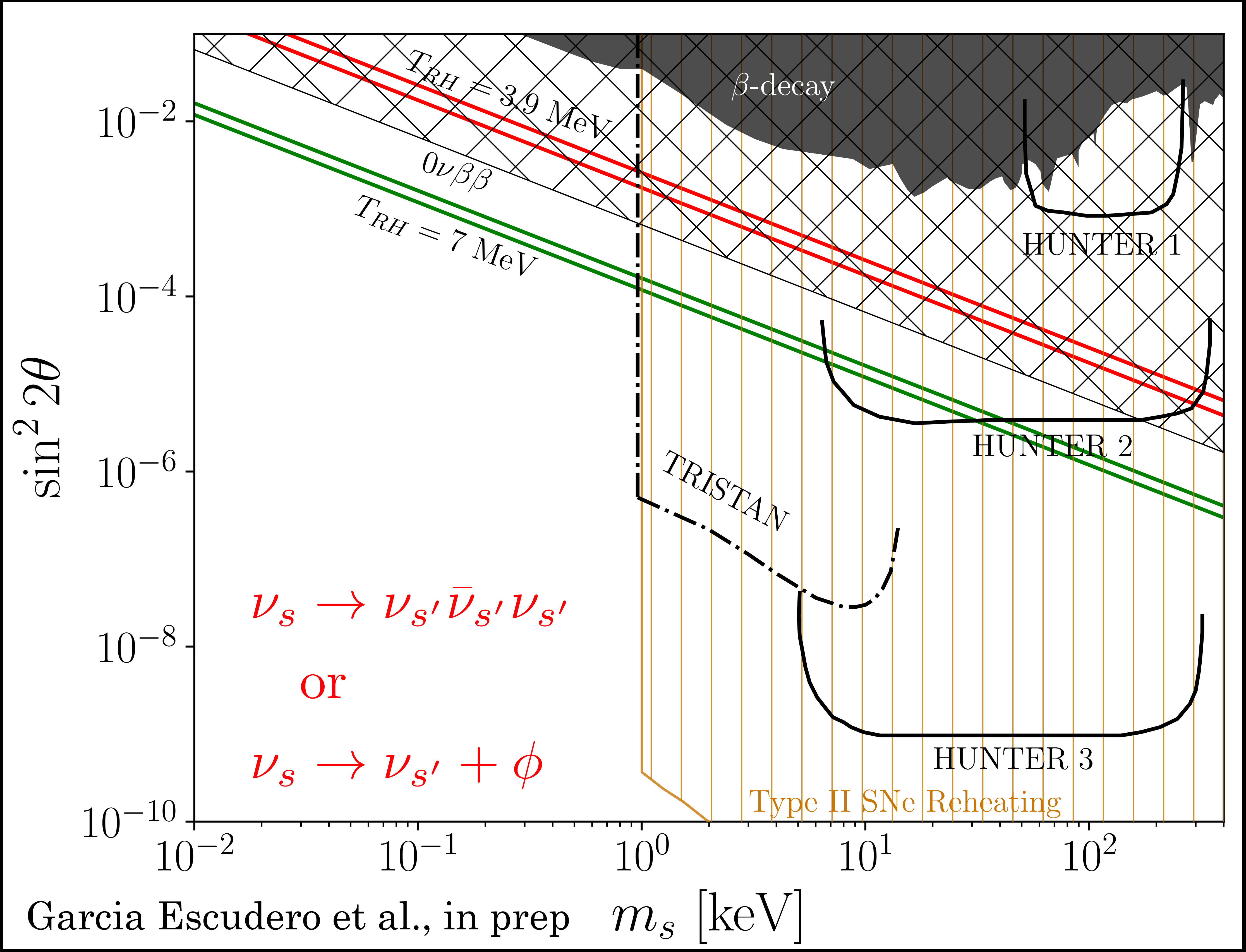
KATRIN/TRISTAN

Visible Sterile ν in the Low-Reheat Universe: Cosmological Constraints & Laboratory Constraints



Abazajian+ arXiv:2203.07377

Visible Sterile ν in the Low-Reheat Universe: Cosmological Signals & Laboratory Constraints



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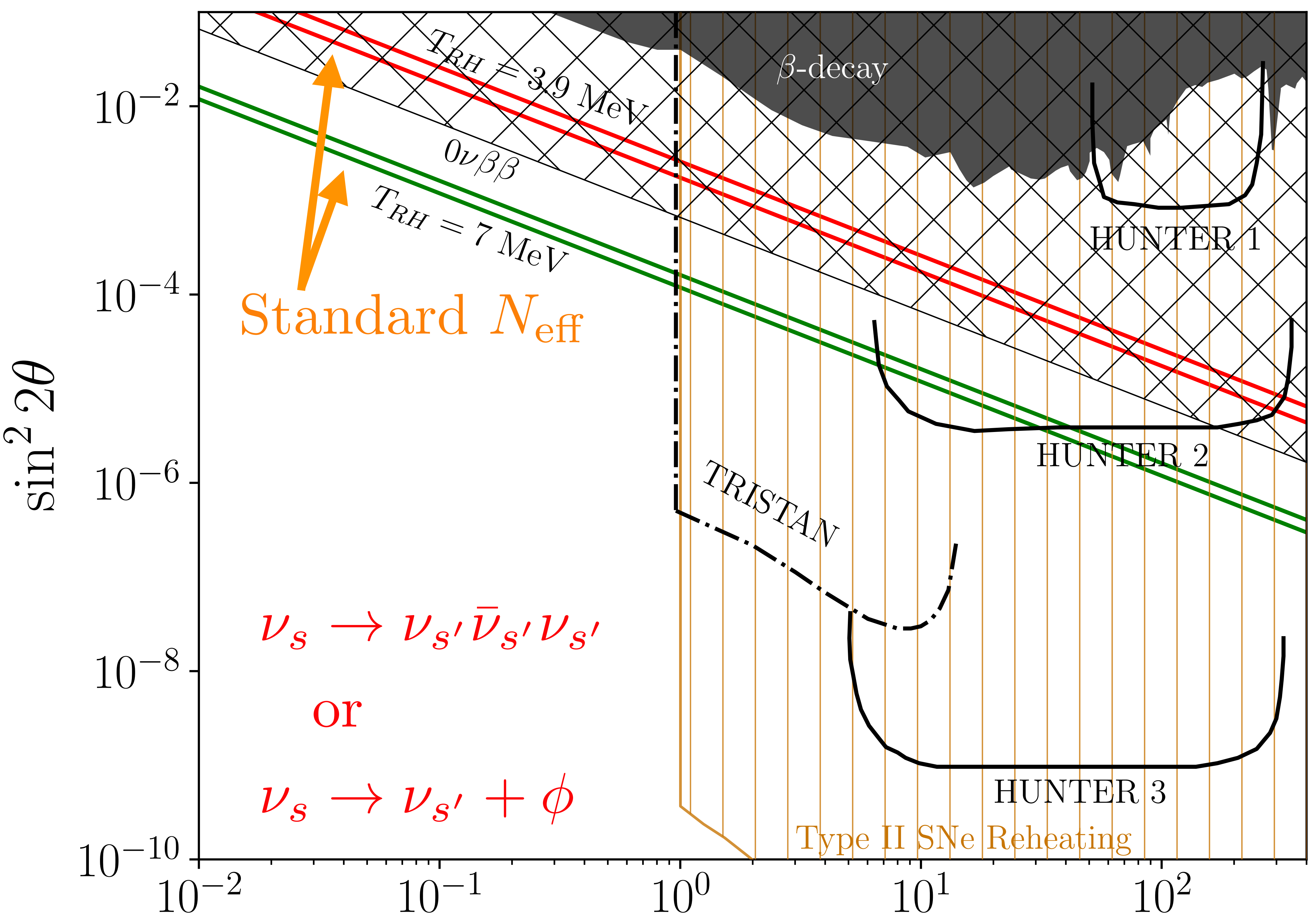

Garcia Escudero et al., in prep

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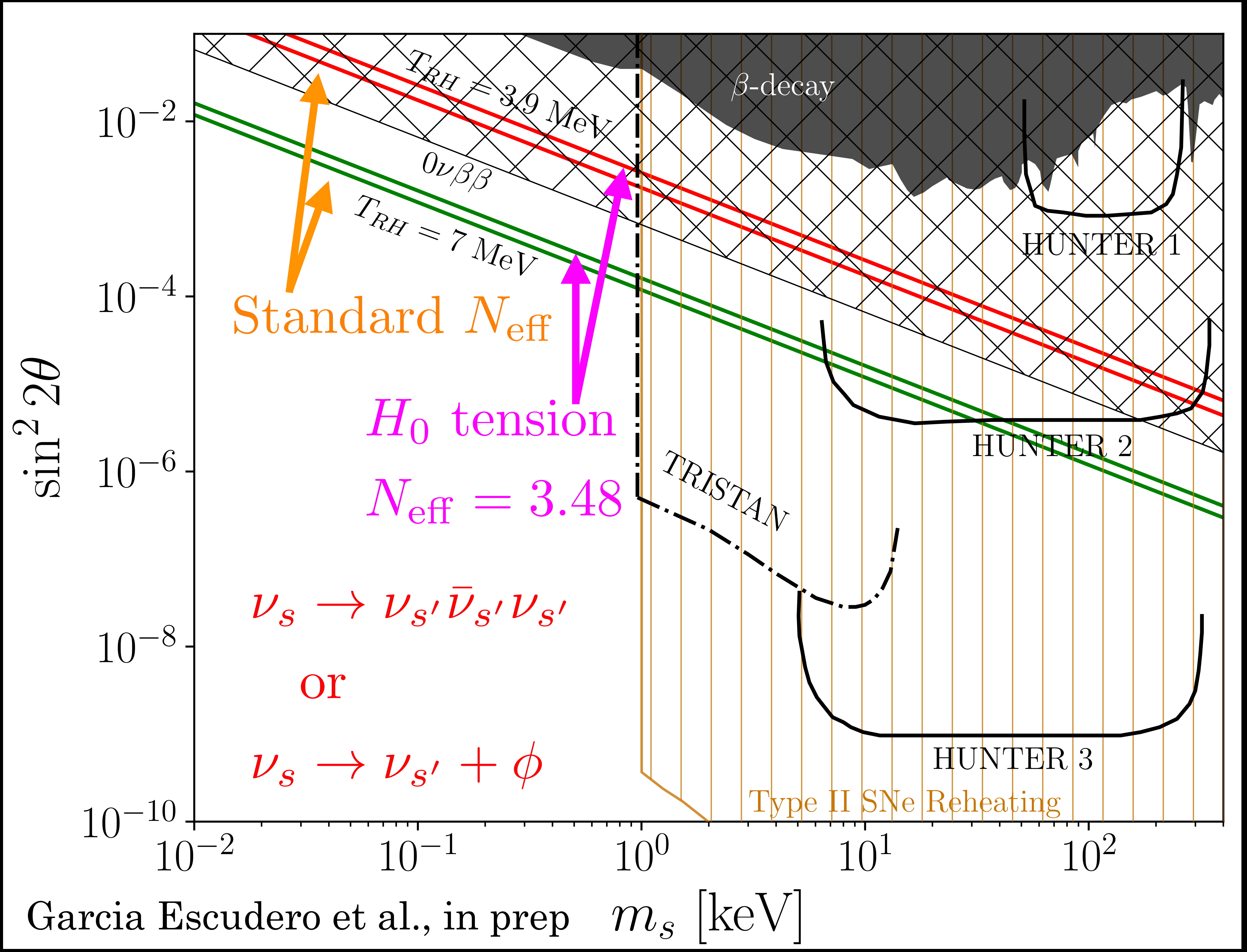

Summary: Warm Dark Matter

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