Constraining Mixed Warm Dark Matter with Milky Way Satellite Galaxies

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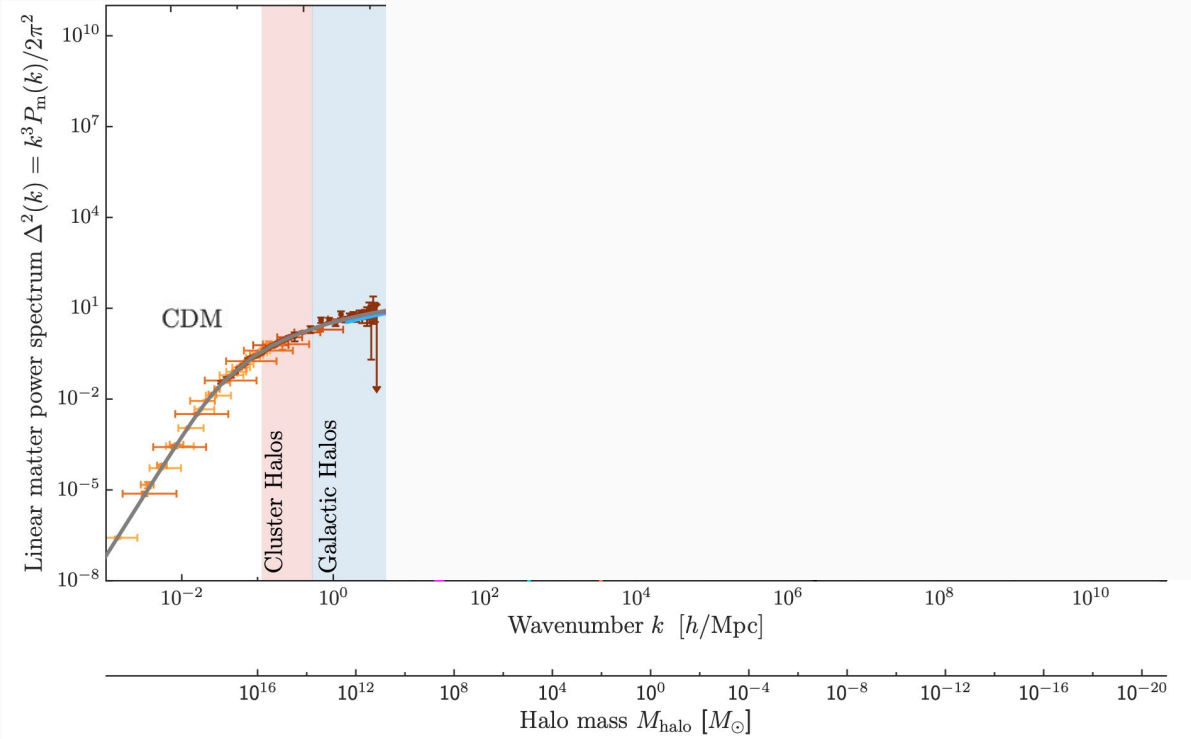
University of Chicago

Matter Power Spectrum - Large Scales

- At scales of ≳1 Mpc, observations show good agreement with CDM



Bechtol+23
(2203.07354)

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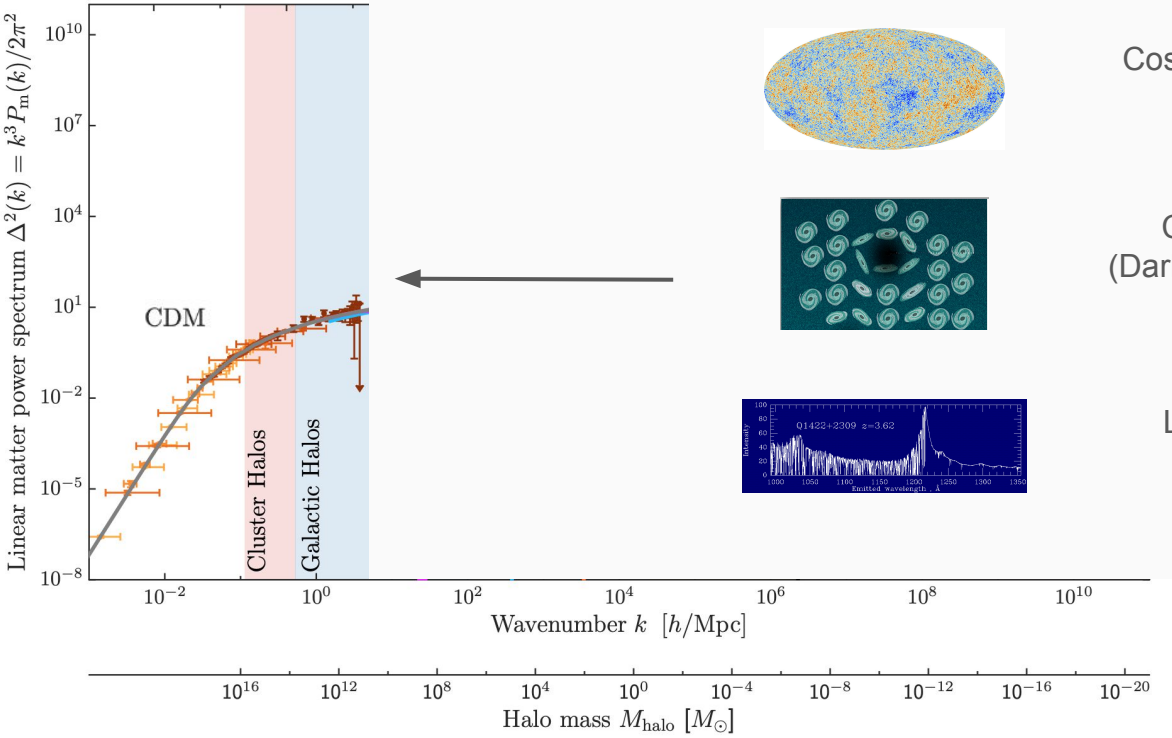


Cosmic Microwave Background (Planck)

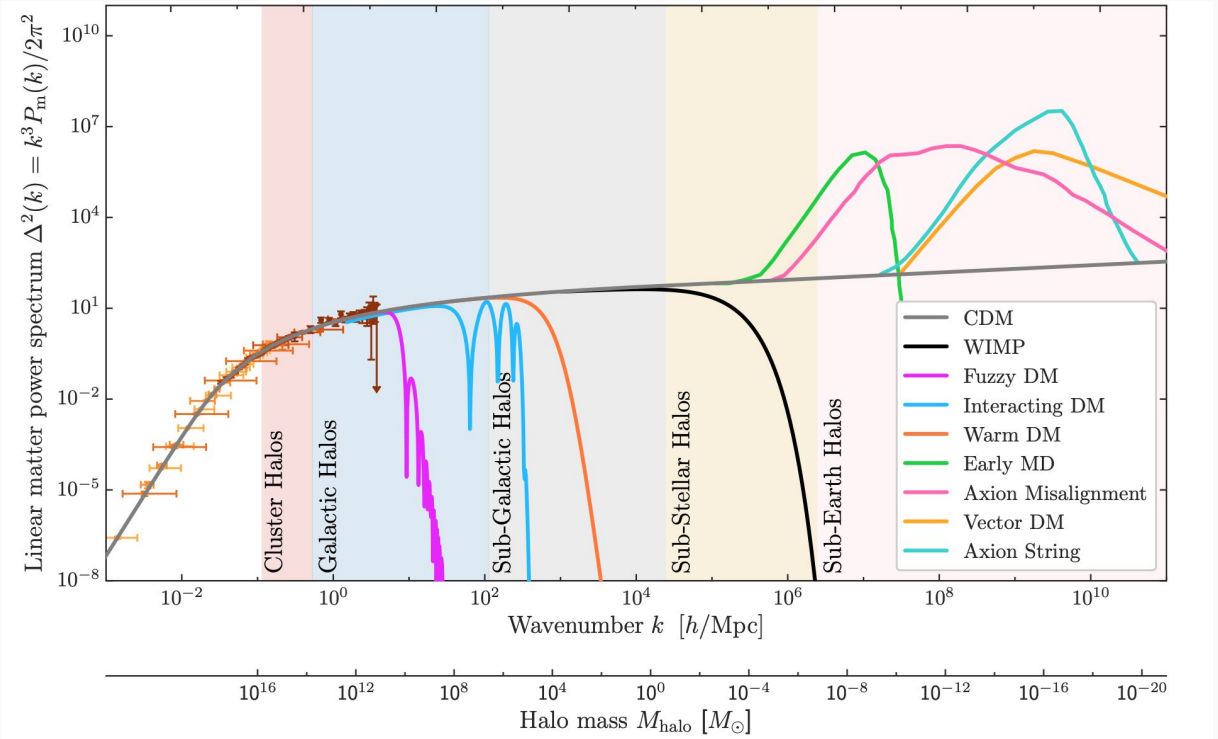
Cosmic Shear (Dark Energy Survey)

Lyman-Alpha (eBOSS)

Bechtol+23 (2203.07354)

Matter Power Spectrum - Small Scales

- However, smaller scales allow alternate dark matter models



Bechtol+23
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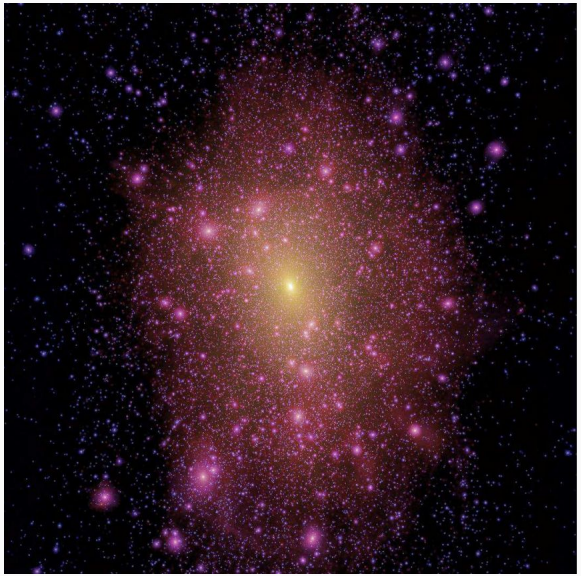
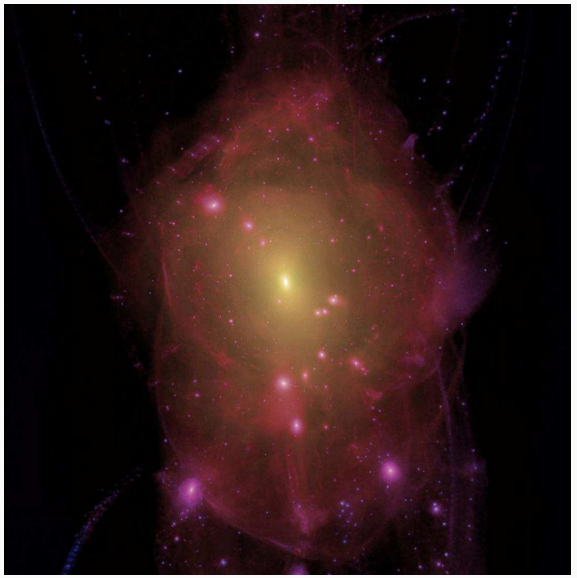
Warm Dark Matter (WDM) subhaloes

- WDM models have free streaming effects that suppress small scale structure



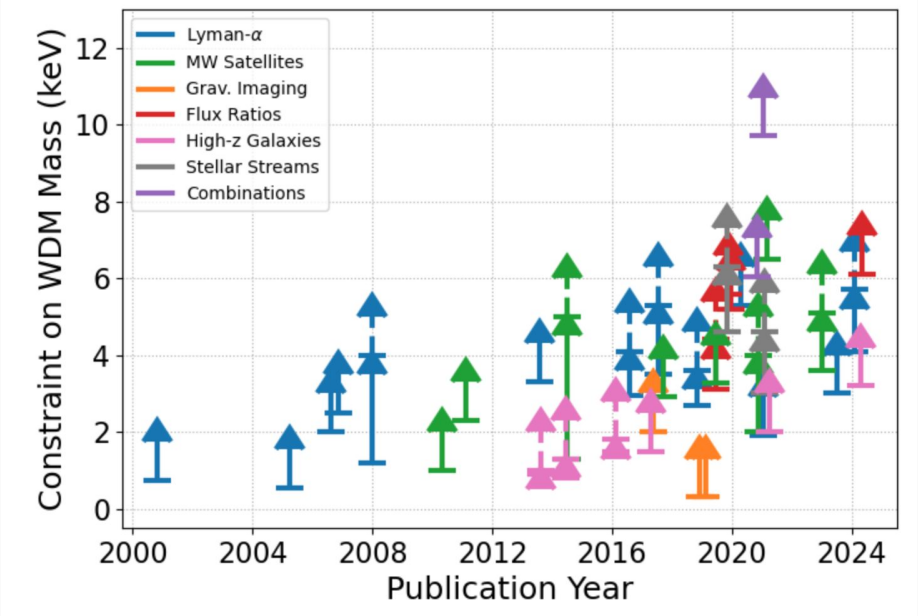
Cold Dark Matter
(CDM)



Warm Dark Matter
(WDM)

Lovell+14
(1308.1399)

Mixed Warm Dark Matter (WDM+CDM)

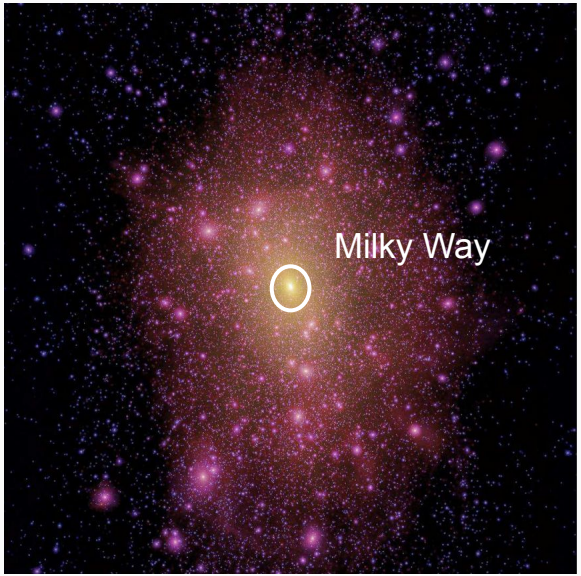


- Observations have placed strict constraints on scenarios composed of 100% warm dark matter.
- We consider a situation where dark matter is made from 2 different species:
  - f_{WDM} : Warm dark matter
  - $1 - f_{WDM}$: Cold dark matter
- Mixed scenario also considered by Anderhalden+12, Parimbelli+21

Credit: Drlica-Wagner, Ethan Nadler

Warm Dark Matter (WDM) subhaloes

- However, we cannot see the DM subhaloes



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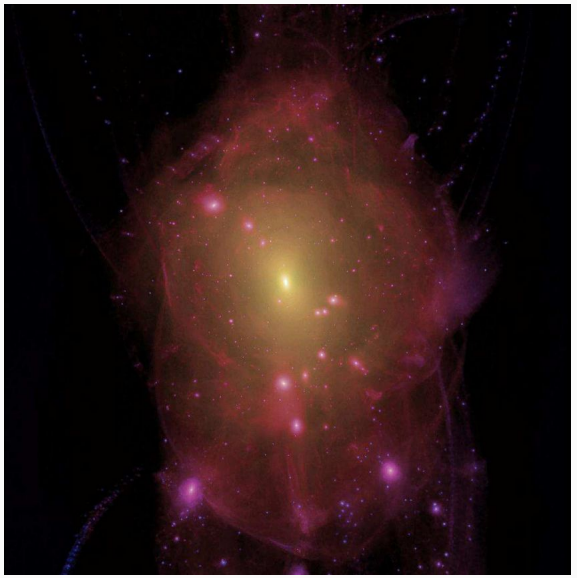

Warm Dark Matter
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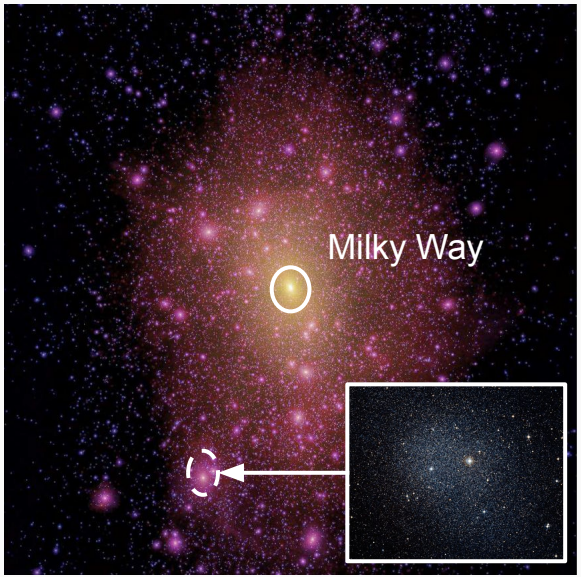
Warm Dark Matter (WDM) subhaloes

- Warm dark matter suppresses the number of Milky Way satellites!



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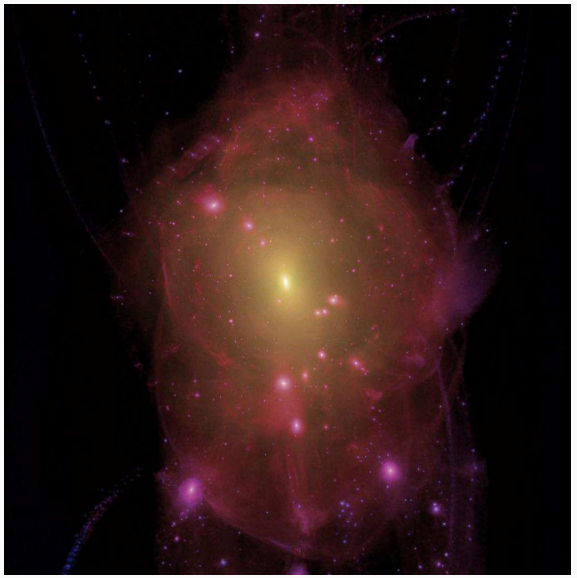

Warm Dark Matter
(WDM)

Lovell+14
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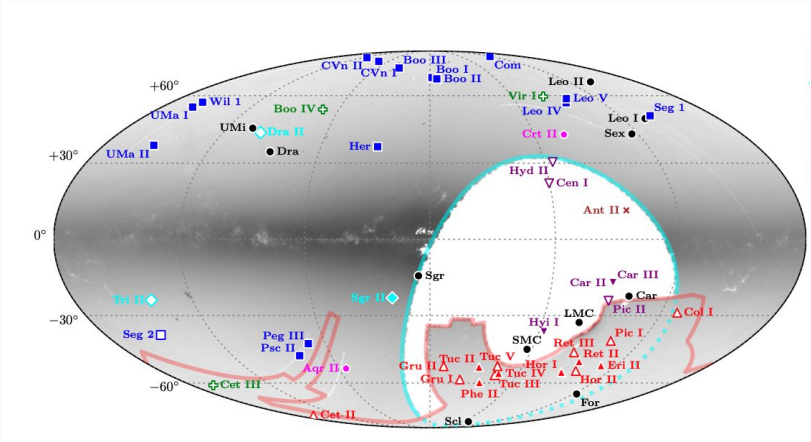
Connecting WDM haloes to Milky Way satellites

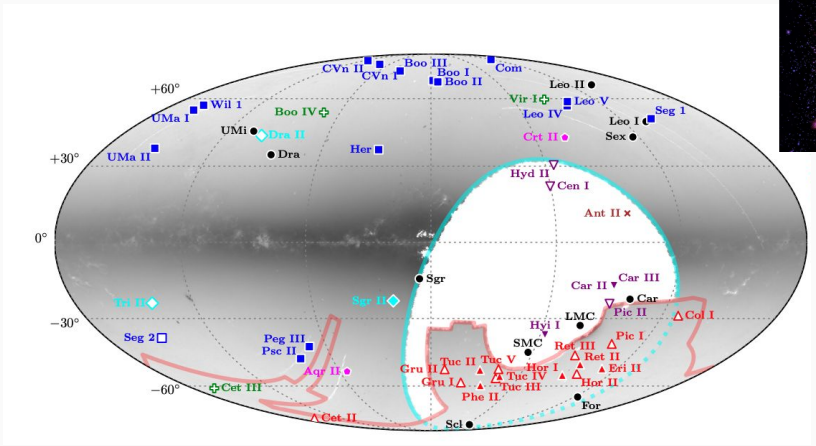
- We start with the known satellites found in Dark Energy Survey (DES) and Pan-STARRS-1 (PS1)

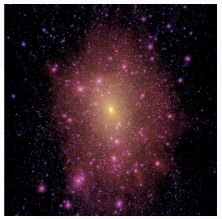


Known Satellites

Connecting WDM haloes to Milky Way satellites

- We then “paint” galaxies onto subhalos and compared it to the known satellites





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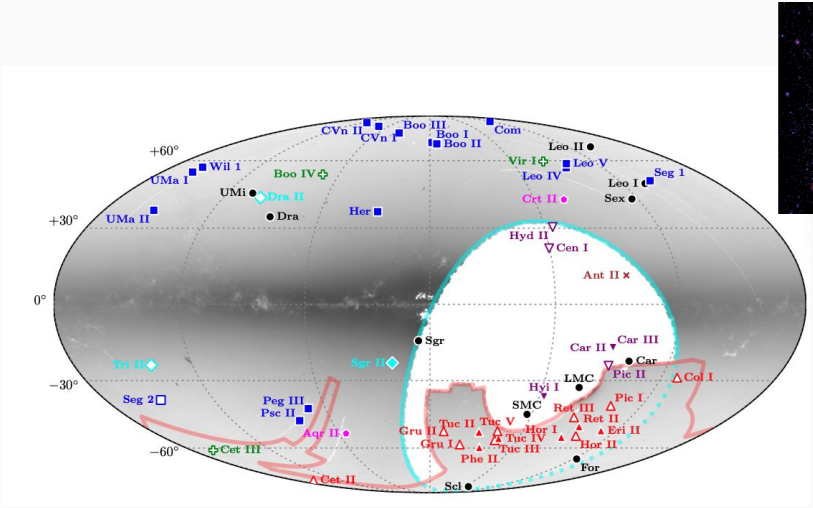
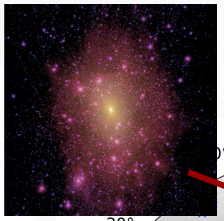
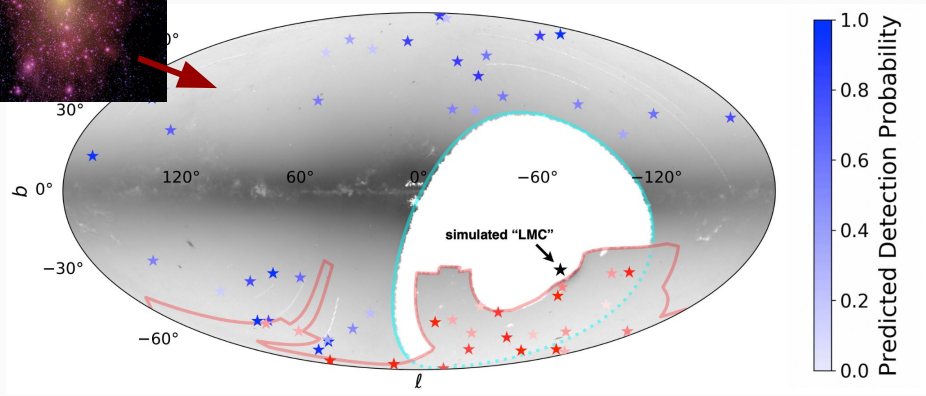


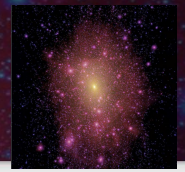
Known Satellites



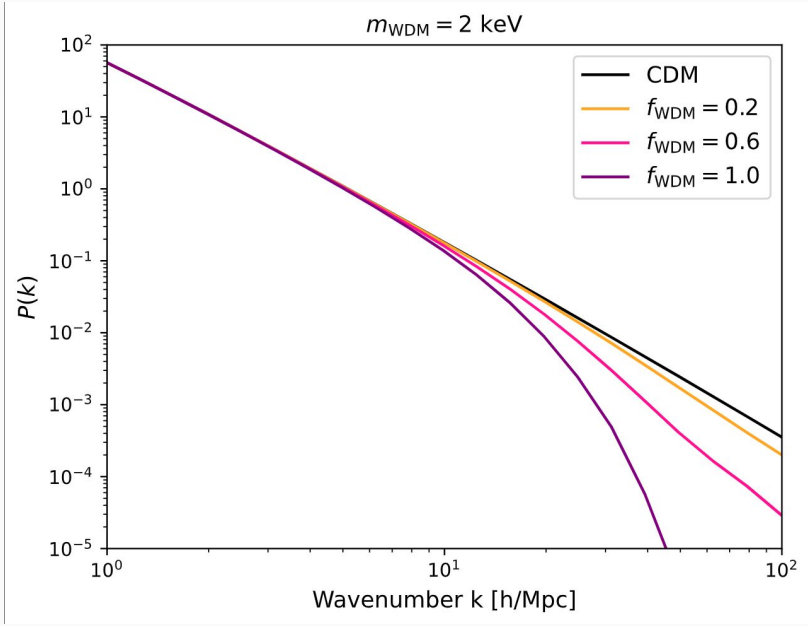


Simulated Satellites

Generating Mixed Warm Dark Matter subhalos



- We need to generate subhalo populations for the Mixed WDM models
- Start with the Matter Power Spectrum from CLASS (Lesgourgues+11)

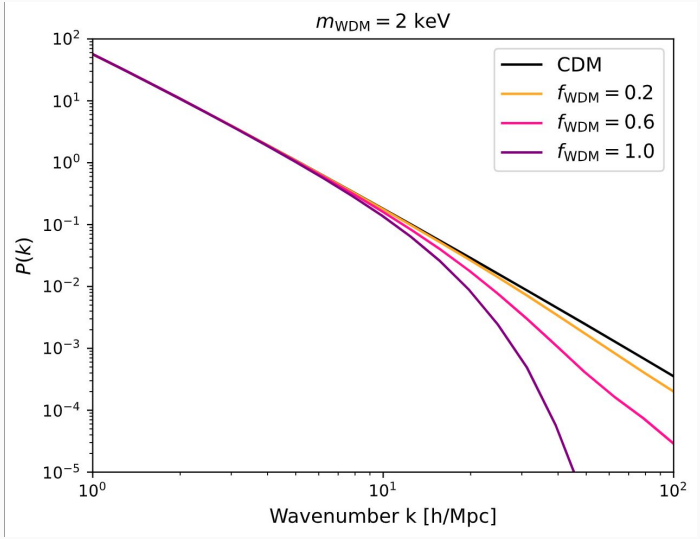


CLASS Mixed WDM Matter Power Spectrum

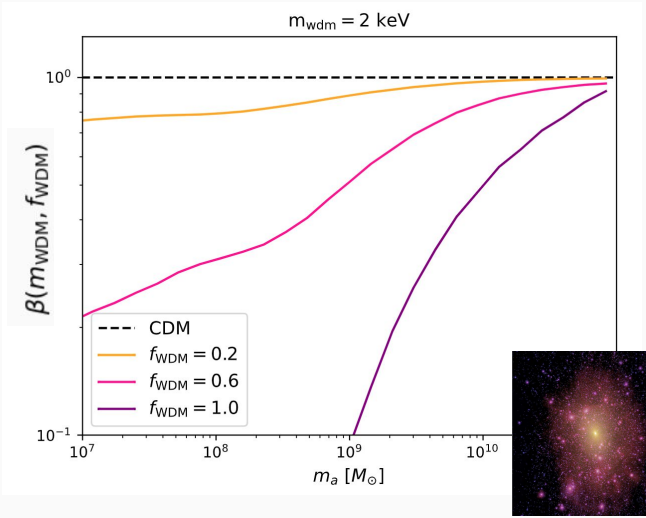
Generating Mixed Warm Dark Matter subhalos

$$\beta = \left(\frac{dN_{\rm sub}}{dM}\right)_{\rm MWDM} \Big/ \left(\frac{dN_{\rm sub}}{dM}\right)_{\rm CDM}$$

- We generate the subhalo suppression function using the extended Press-Schechter Formalism with the semi-analytical *sashimi* (Dekker+21)



sashimi
(Dekker+21)

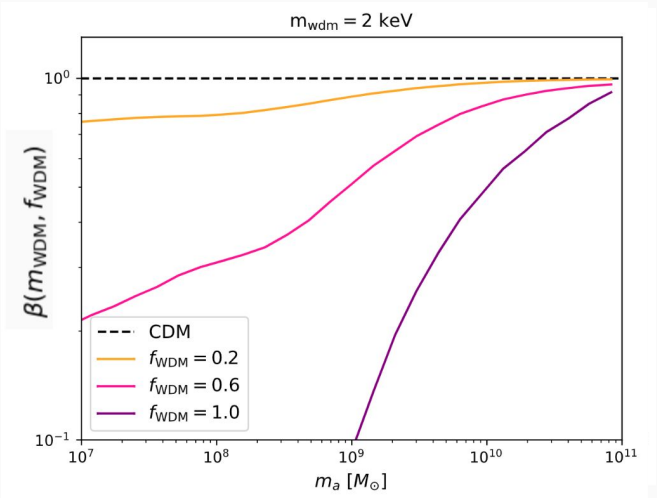


Mixed WDM
Matter Power Spectrum

Mixed WDM
Subhalo Suppression Function

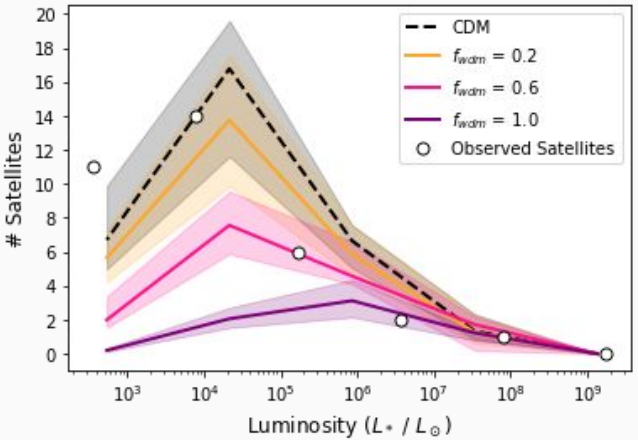
Mixed WDM satellite galaxy populations

- Using formalism developed from Nadler+20, we obtain the satellite luminosity function from the subhalo mass function. We also take account of



Subhalo Suppression function

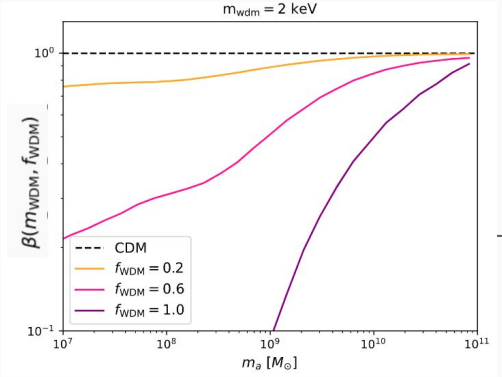
Subhalo-satellite connection (Nadler+20)



Satellite Luminosity Function

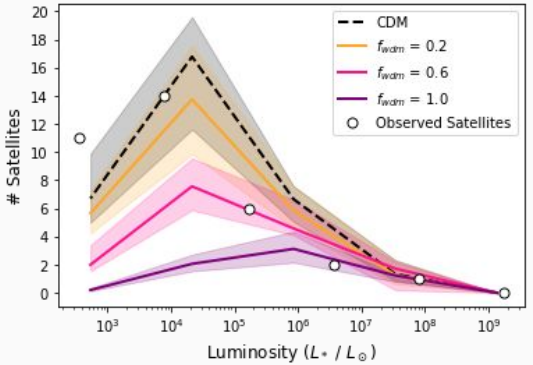
Generating satellite galaxy populations

- Using formalism developed from Nadler+20, we obtain the satellite luminosity function from the subhalo mass function. We also take account of
  - DES & PS1 survey selection function
  - Subhalo disruption due to baryonic effects
  - Impact of the Large Magellanic Cloud



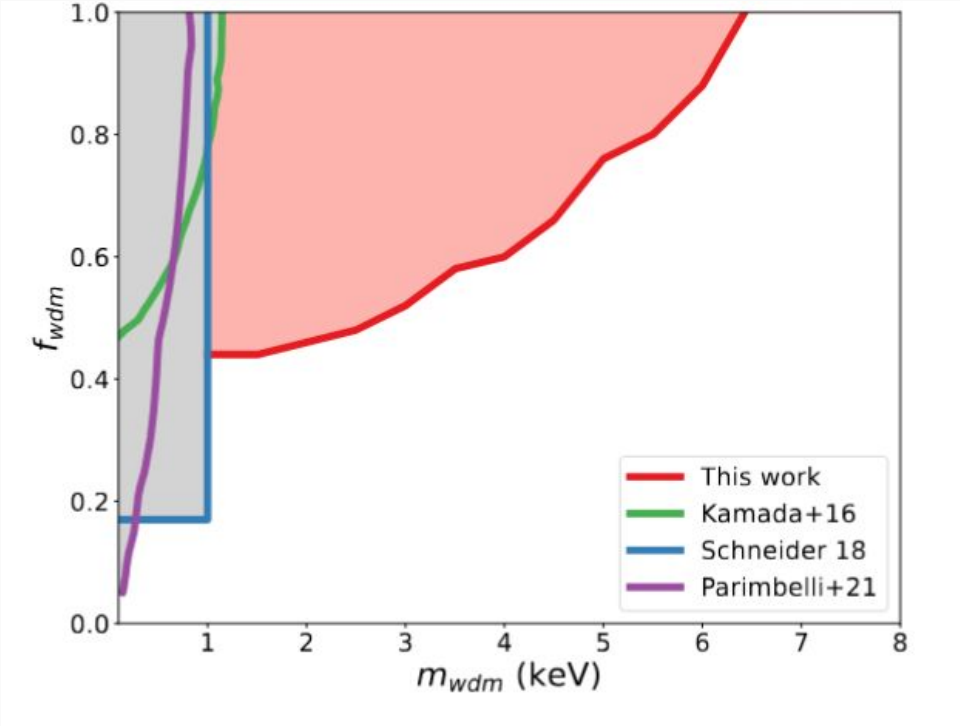
Subhalo Suppression function

Subhalo-satellite connection (Nadler+20)



Satellite Luminosity Function

Constraints on WDM Fractions

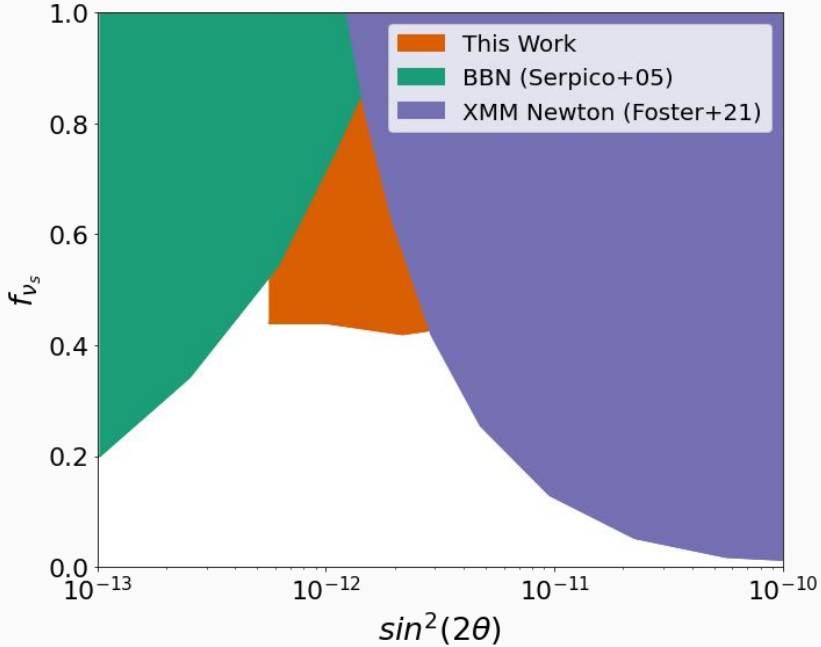


PRELIMINARY

- Exclude regions with posterior odds compared to CDM < 1:20
- Ruled out 100% Pure WDM at mass limit of ~6.5 keV
  - Consistent with constraints from Nadler+21
- Constraints converges to $f_{WDM} \lesssim 0.45$ for low WDM masses.
  - Uncertainty in subhalo-satellite connection parameters
  - Incomplete survey coverage at low masses

Constraints of 7 keV Sterile Neutrinos Fractions

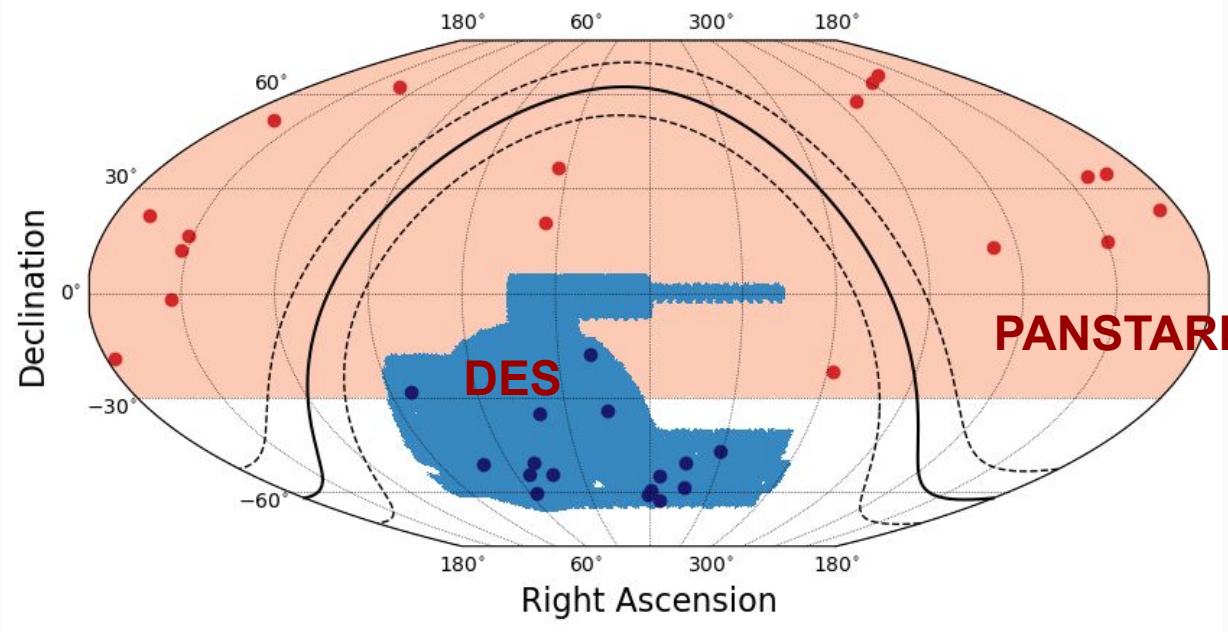
- Excluded $\gtrsim$45% of dark matter being composed of 7 keV sterile neutrinos produced from Shi-Fuller mechanism



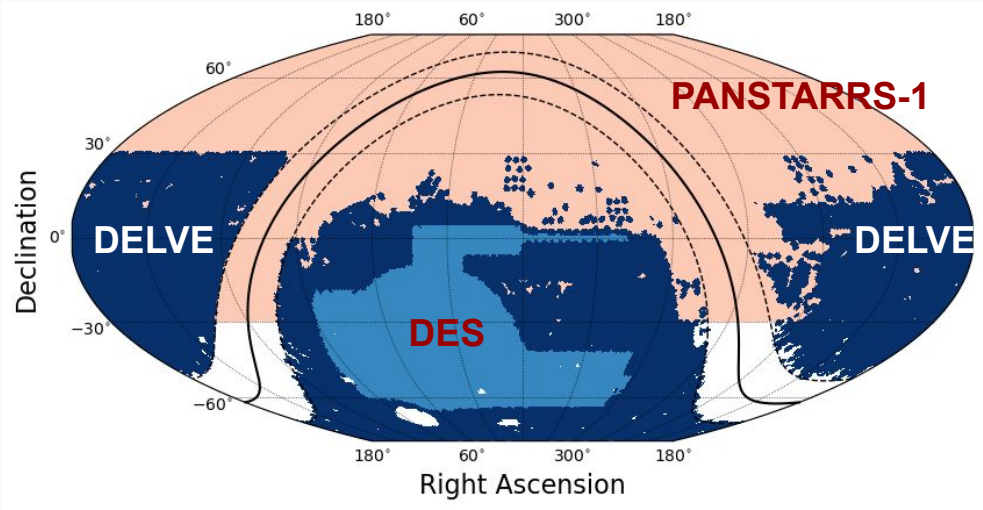
PRELIMINARY

Increasing Satellite Galaxy Survey Volume

- Our constraints are limited by Survey Volume (Survey Area x Survey Depth)

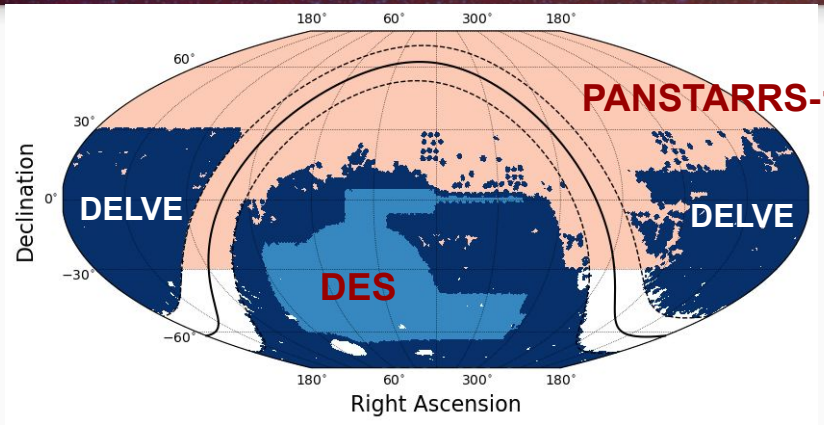


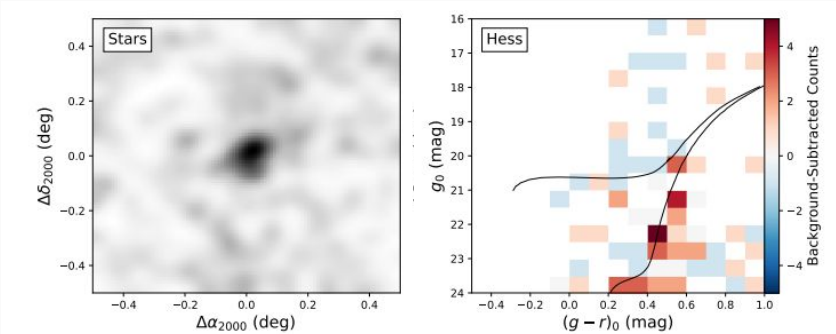
DELVE Survey



- Aims to complete DECam imaging of the southern sky (|b|>10) in the g, r, i, z band
- Combines public DECam data (e.g., DES) with more than 150 nights of new observations
- “Practice Run” before Rubin

DELVE Survey





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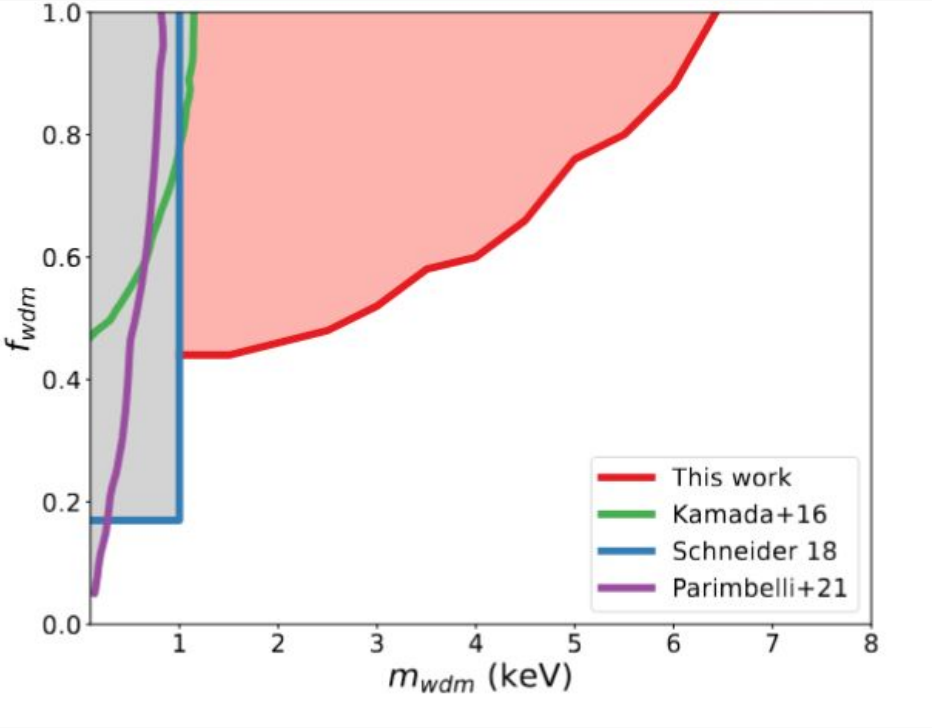
- Combines public DECam data (e.g., DES) with more than 150 nights of new observations
- “Practice Run” before Rubin
- Many new MW satellite systems have already been discovered in DELVE
  - Recently Found Leo VI !

Tan+24 (2408.00865)

Summary (arXiv:2409.XXXXX)



- Obtained subhalo mass function for MWDM scenarios with semi-analytical models
- Used Milky Way satellite galaxies counts to place on MWDM scenarios.
  - Exclude $m_{WDM} \lesssim 6.5$ keV at $f_{WDM} = 1$
  - Plateau at $f_{WDM} \lesssim 0.45$ for $m_{WDM} \lesssim 1$ keV
- Excluded >45% of dark matter composed of resonantly-produced 7 keV Sterile Neutrino