Cosmological searches for a non-cold dark matter component

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Mixed Dark Matter

1) Motivation

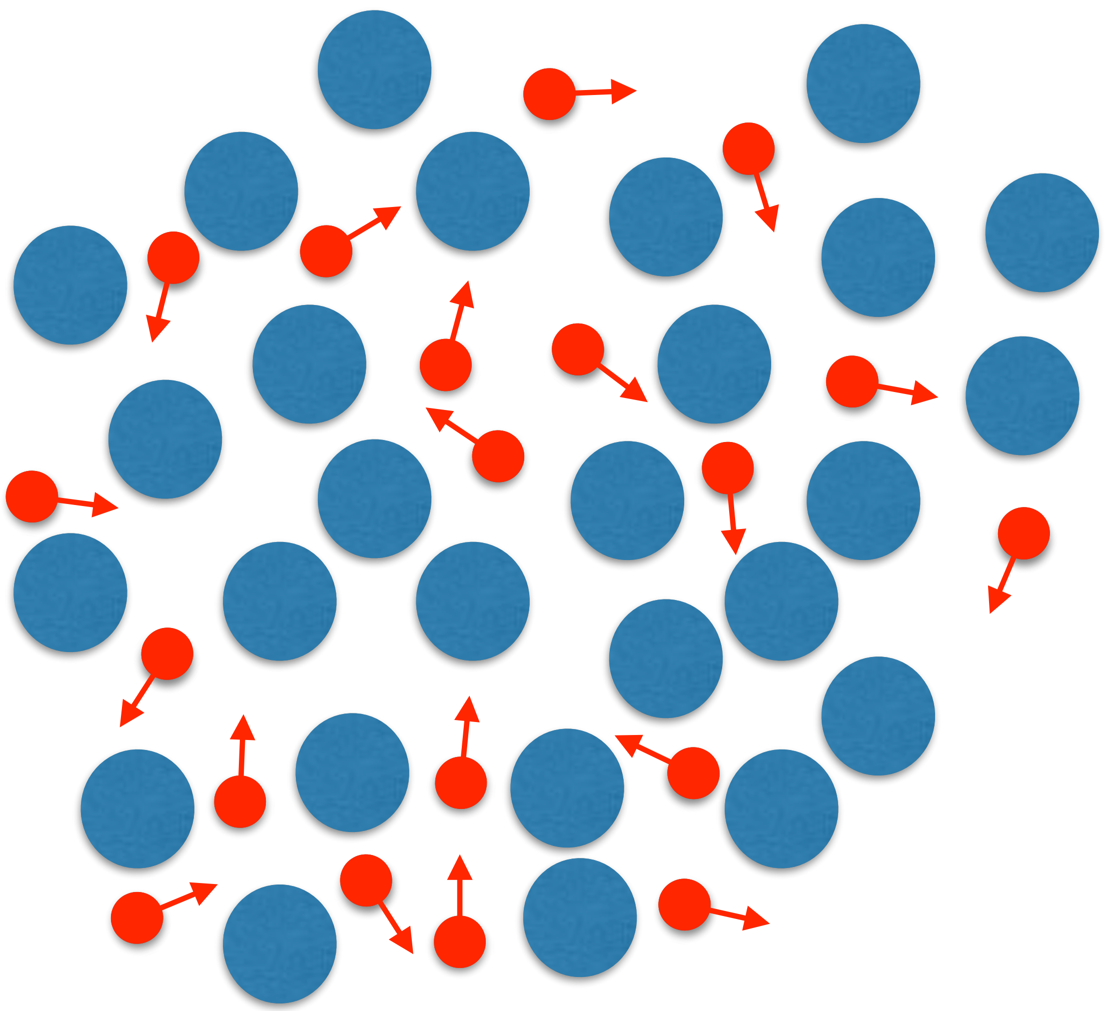
2) Probes:

a) CMB
b) Weak Lensing
c) Dwarf Satellites

3) Constraints:

a) Planck
b) KIDS
c) SDSS

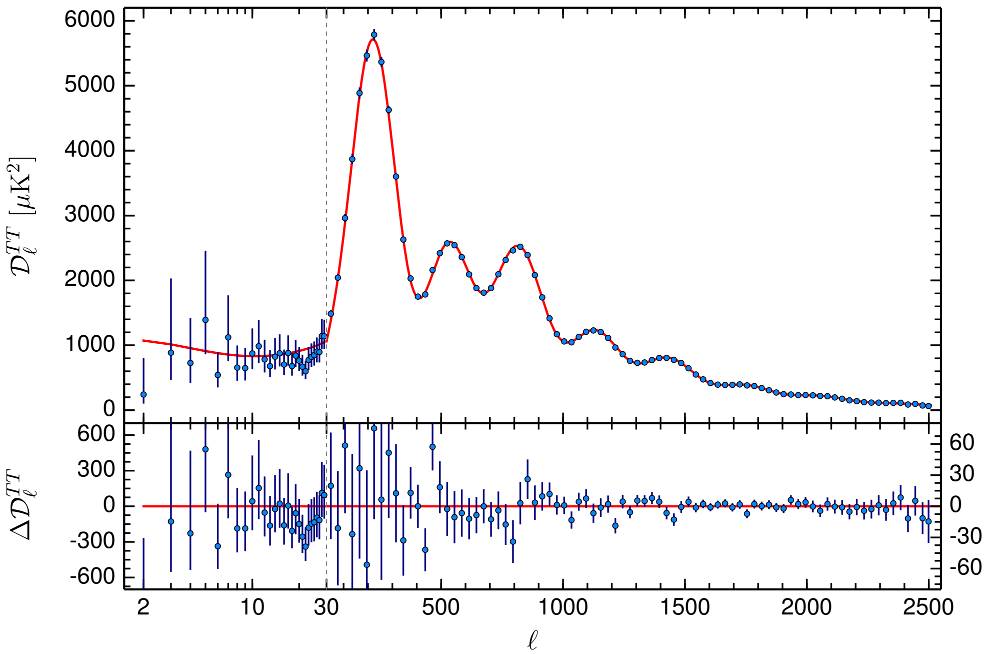
4) Conclusions & Outlook



Motivation

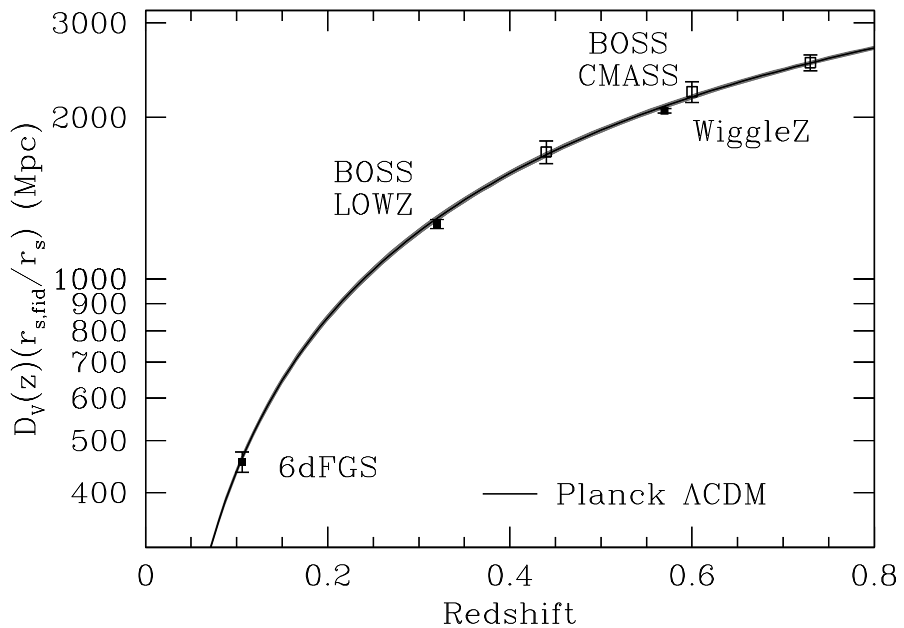
Precision Cosmological observations of the large scale structure of the universe perfectly agree with a totally cold dark matter component

CMB



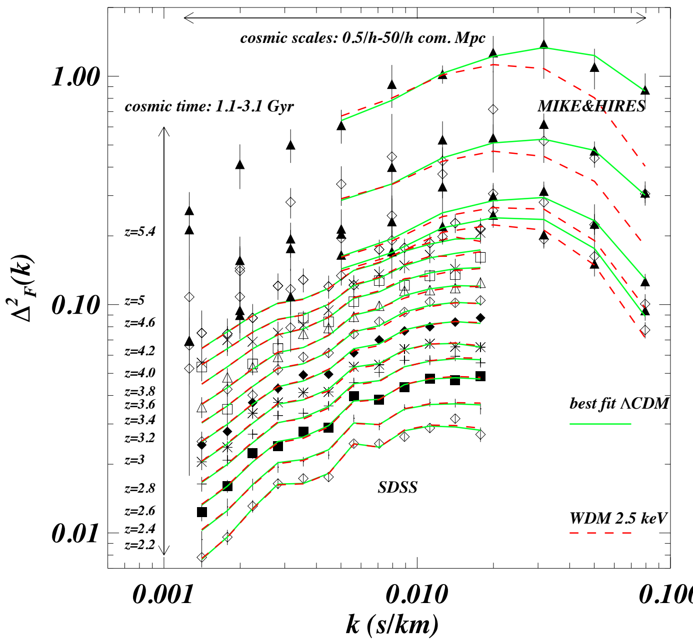
1502.01589

BAO



1312.4877

Lyman alpha



1306.2314 1702.01764

Motivation

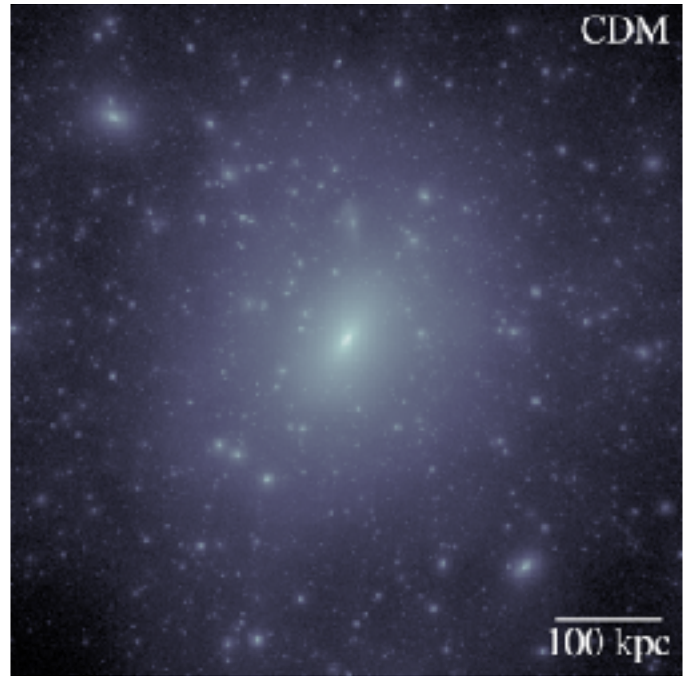
Small scale crisis:

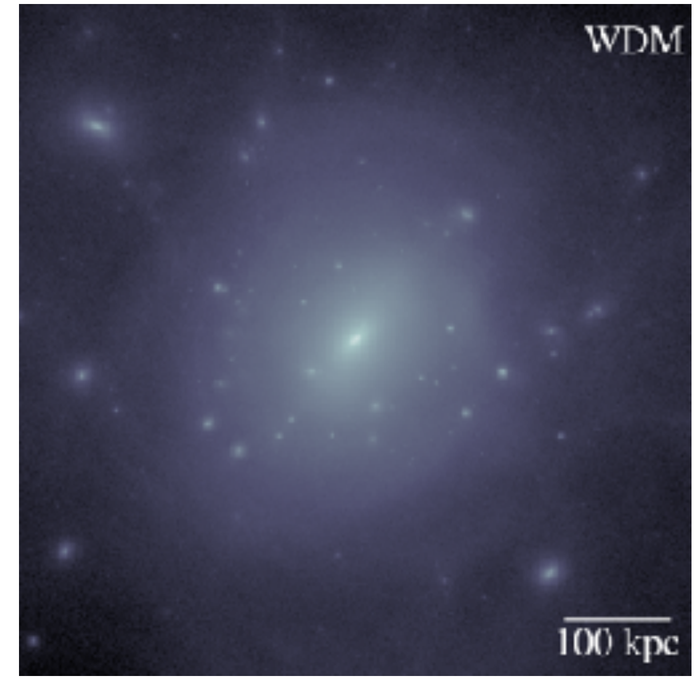
Too big to fail

Missing satellites

Core/cusp

$m_\chi = 2\,\mathrm{keV}$





See review of Bullock & Boylan-Kolchin arXiv:1707.04256

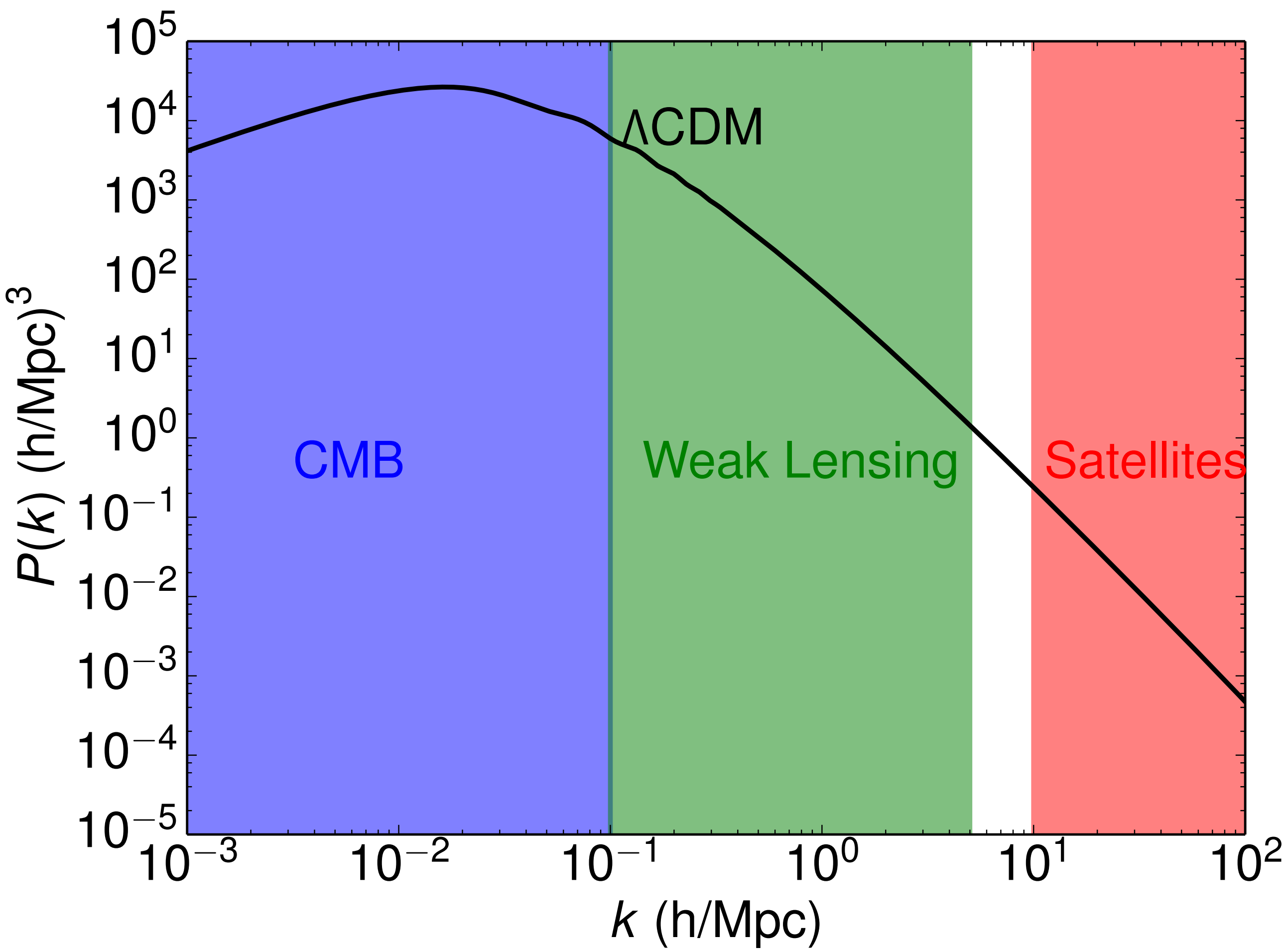
Very well motivated theoretical candidates with a free-streaming nature:

- Sterile Neutrinos — Dodelson & Widrow arXiv:9303287
- Gravitinos — Pagels & Primark (1982)
- Majorons — Lattanzi & Valle arXiv:0705.2406
- WIMP DM and pseudo-Goldstones — Weinberg, Okada, Chacko, Yanagida, Ibarra, Rius ...

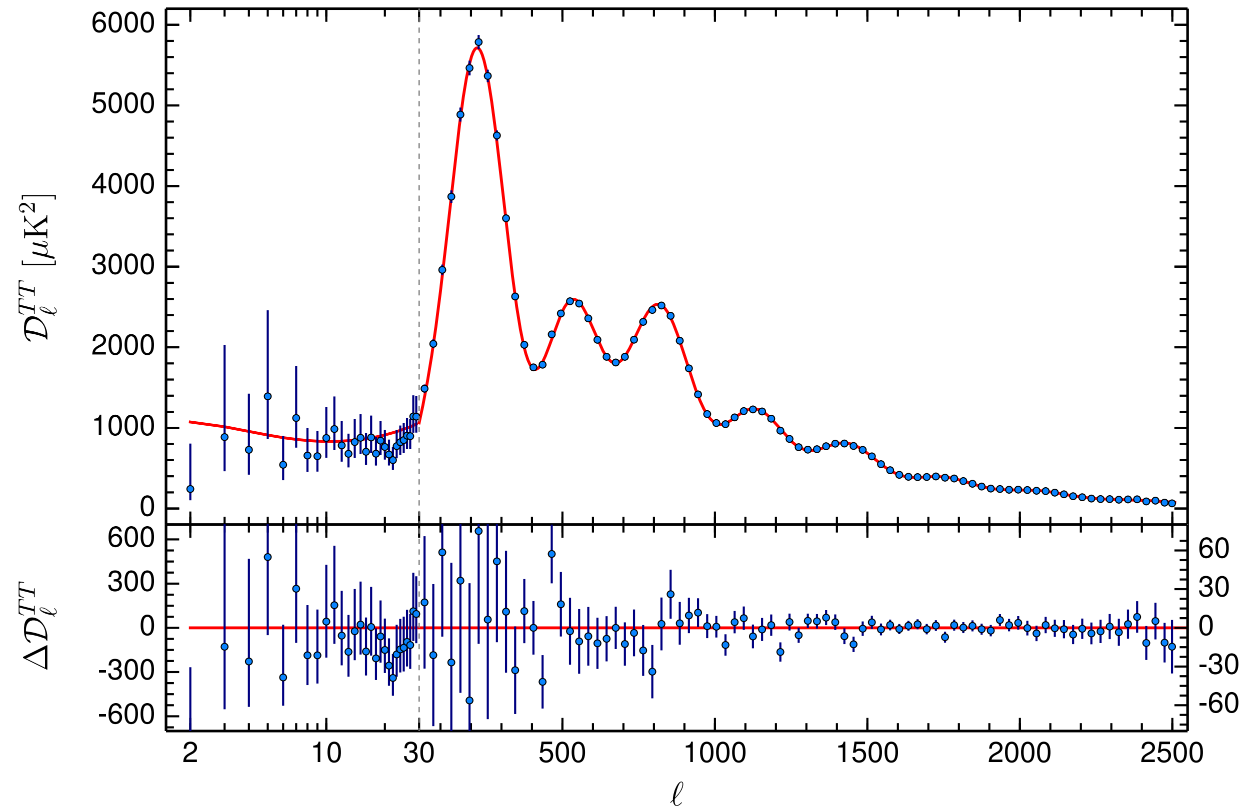
Previous studies: 0501562 Viel et al., 0812.0010 Boyarsky et al., 1701.03128 Diamanti et al.

Our approach

Analyze the Mixed Dark Matter scenario at all scales



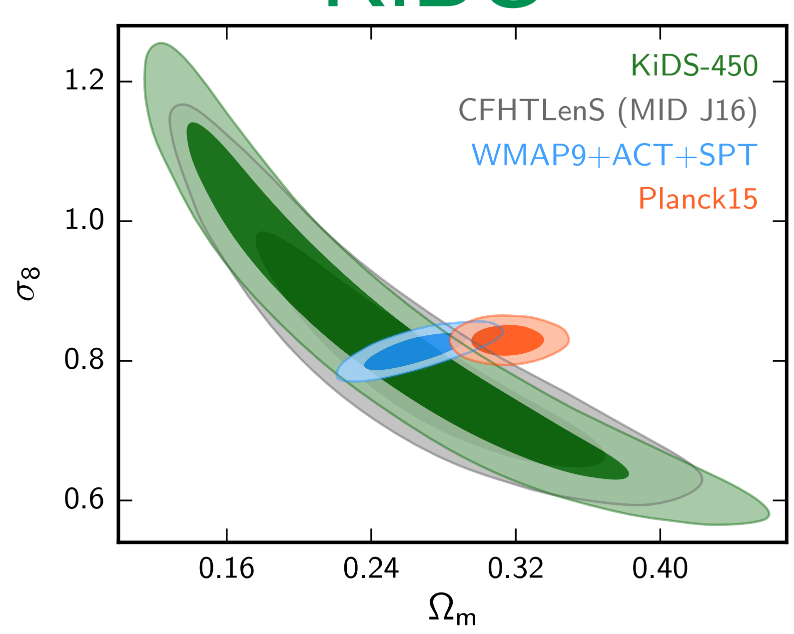
Planck TT+lowP



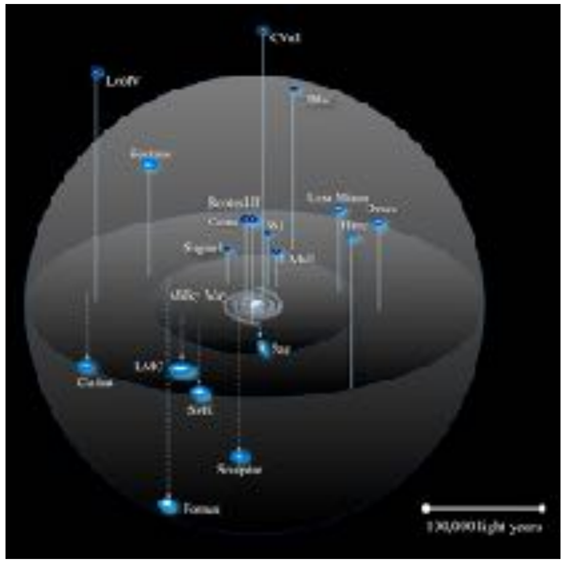
Analysis: MCMC

- CLASS
- Monte Python
- Camb
- CosmoMC

KIDS



SDSS



Mixed Dark Matter

Defining properties
$$\begin{cases} f_X = \dfrac{\omega_X}{\omega_{DM}} \\ T_X \end{cases}$$

CMB spectra fixes: $\omega_{DM} = \omega_X + \omega_{cdm}$

Thermal Relics: $\omega_X \simeq \left(\dfrac{T_X}{T_\nu}\right)^3 \left(\dfrac{m_X}{94\ \mathrm{eV}}\right)$ $\quad \dfrac{T_X}{T_\nu} = \left(\dfrac{10.75}{g_\star(T_D)}\right)^{1/3}$

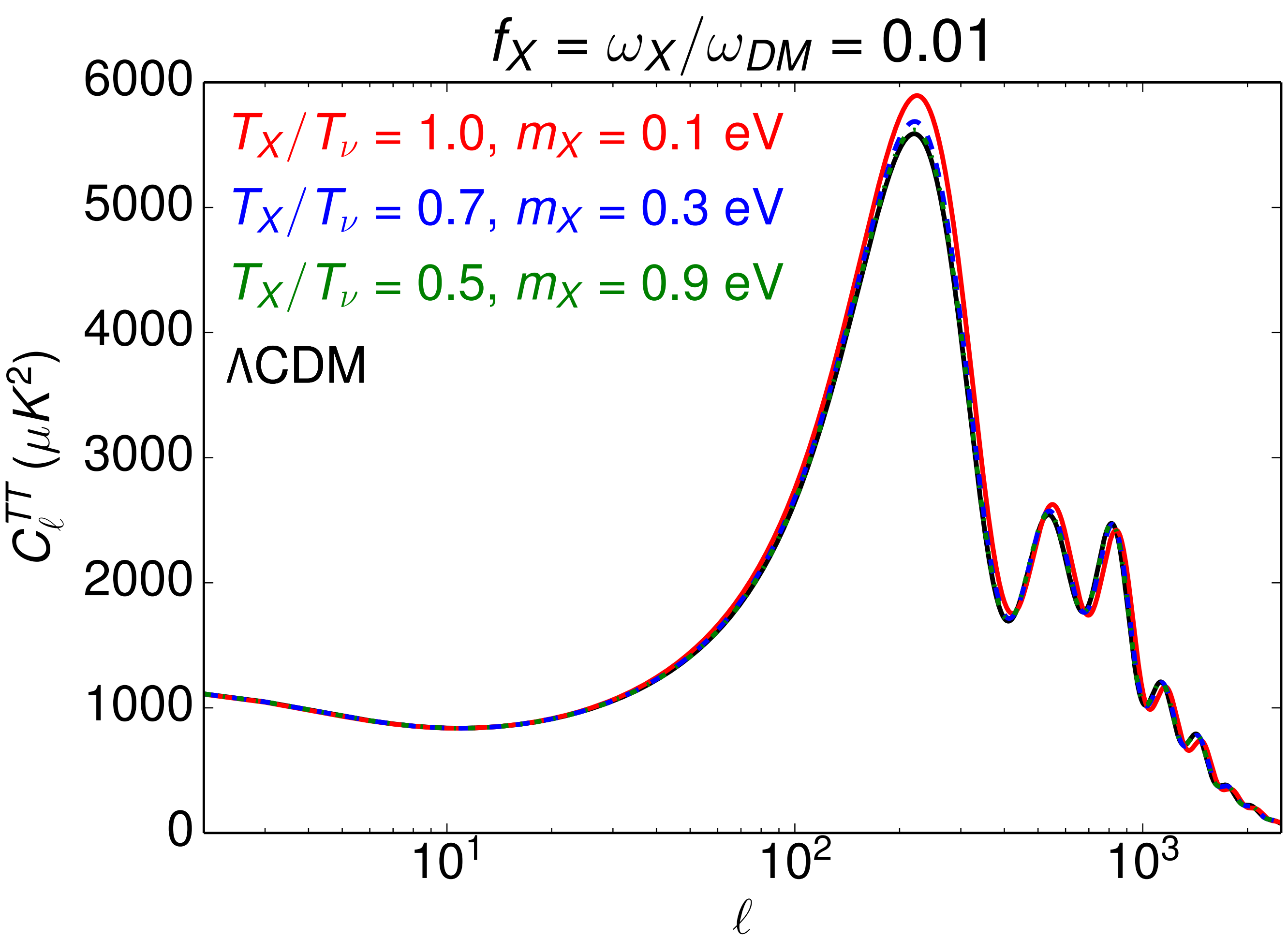
Parameter Space in this study:

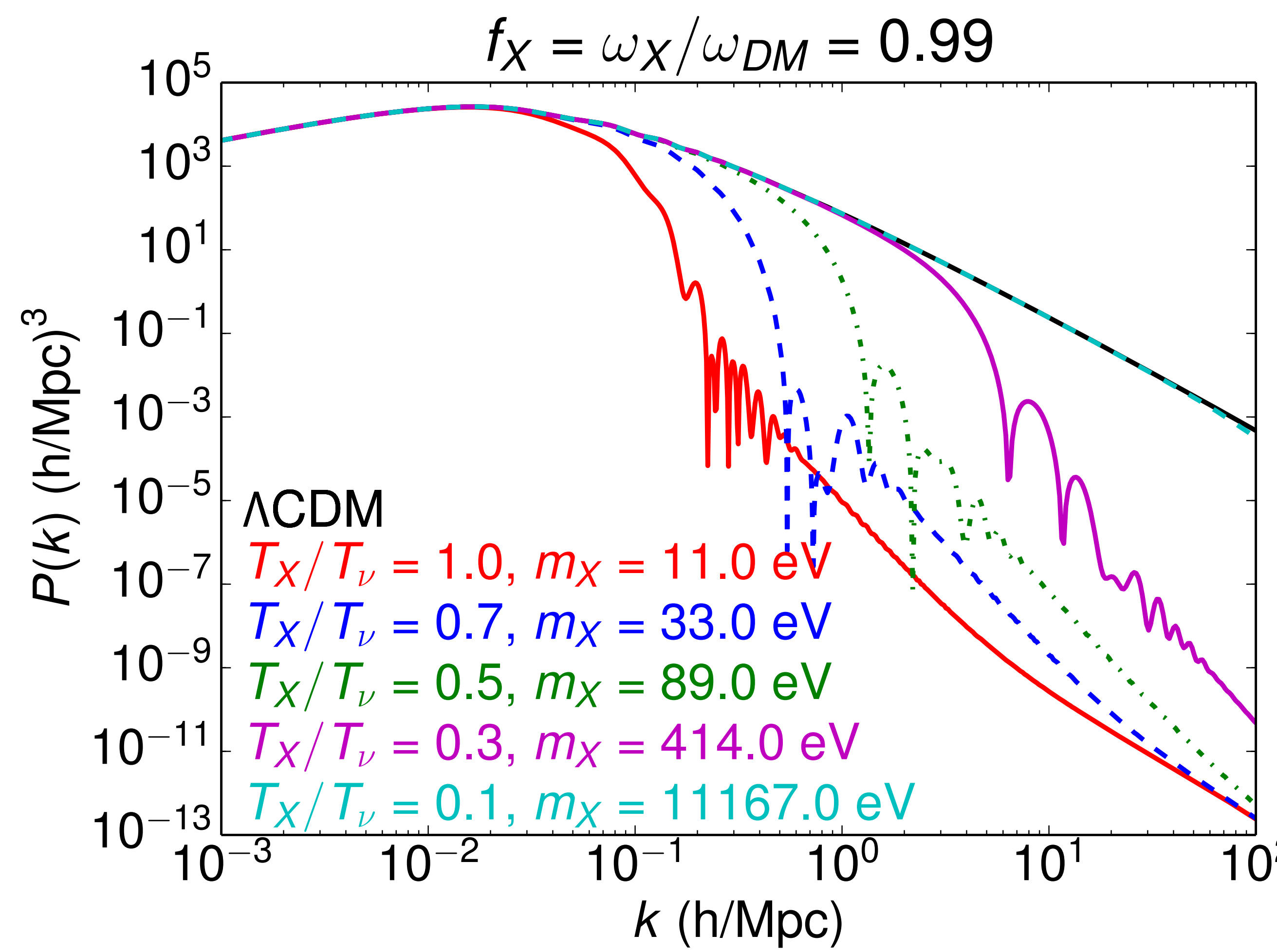
$$-1.5 \leq \log_{10}(T_X/T_\nu) \leq 0$$
$$0 \leq f_X \leq 1$$

Derived →

$$m_X \simeq 94 \times f_X \times \omega_{\mathrm{DM}} \times \left(\frac{T_X}{T_\nu}\right)^3 \ \mathrm{eV}$$
$$0 < m_X < 5\,\mathrm{MeV}$$

Effects

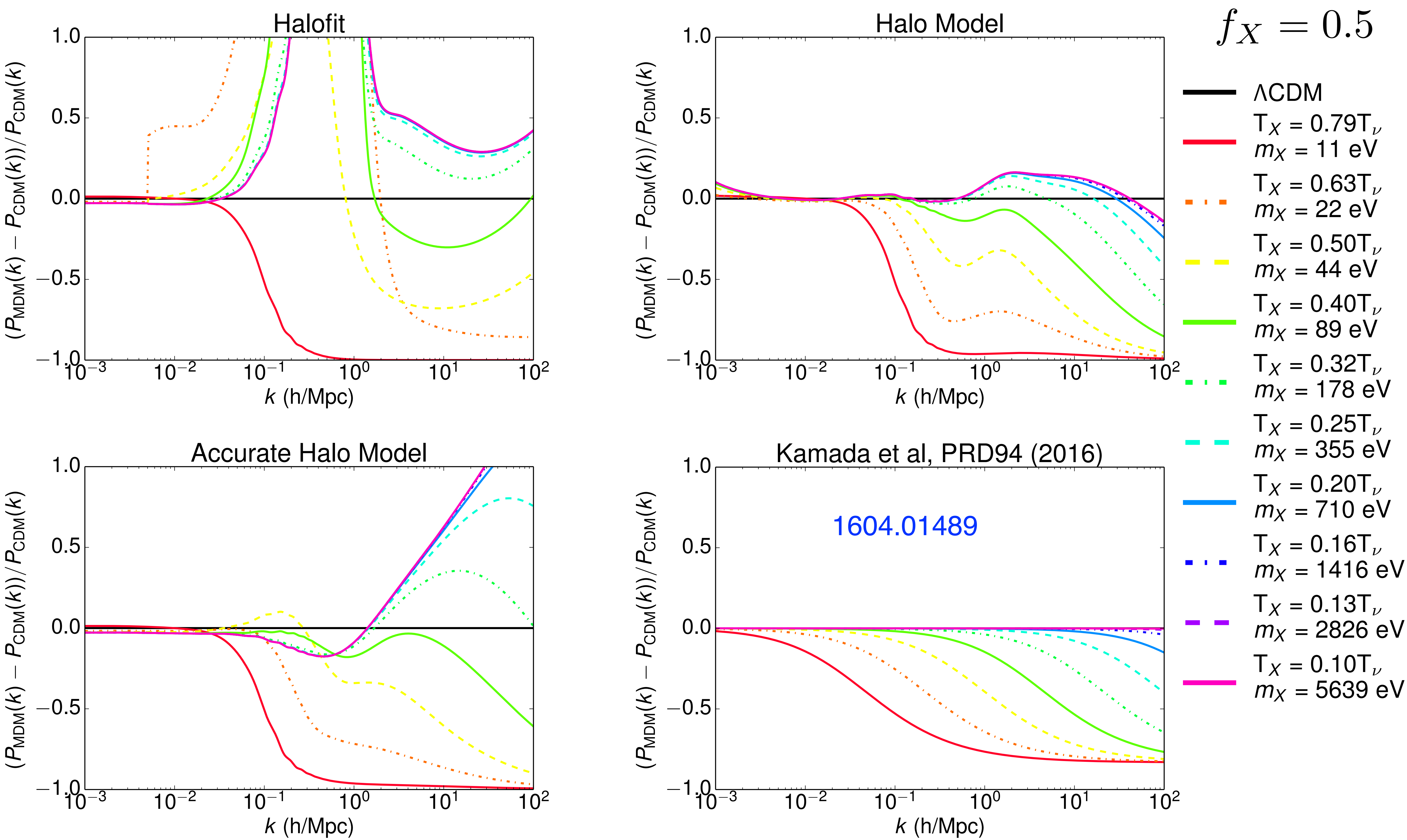




Small f_X: constraints from $\Delta N_{\rm eff}$

Large f_X: constraints from suppressed Matter power spectrum

Non-Linear Theory



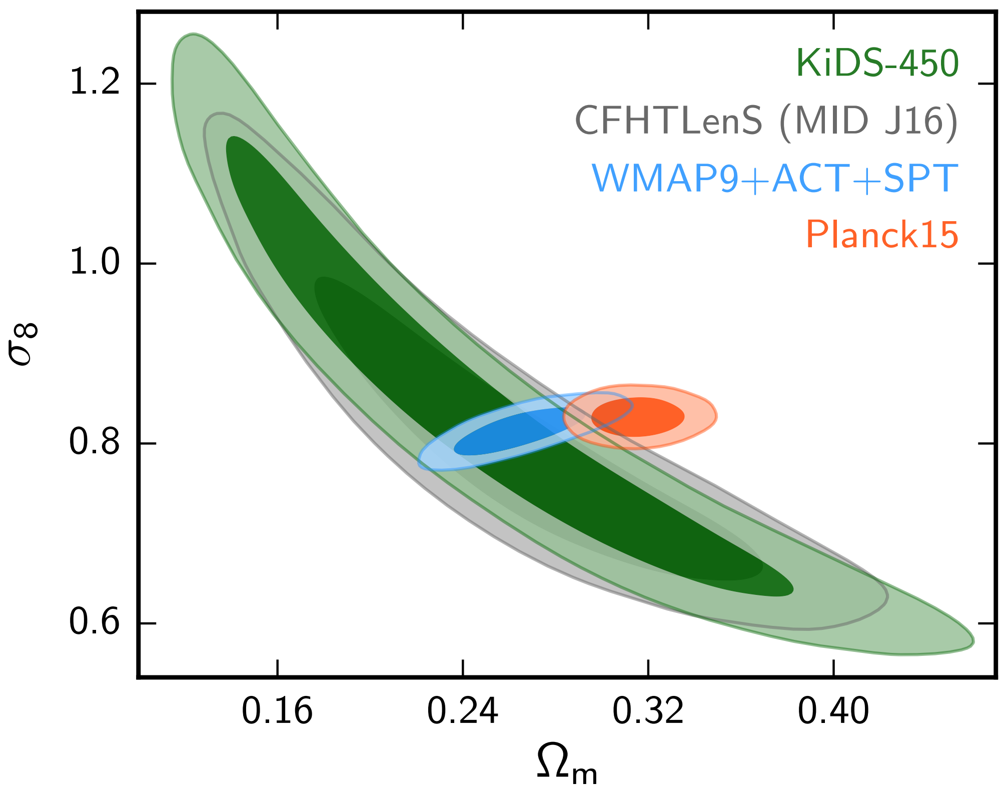
KIDS-450

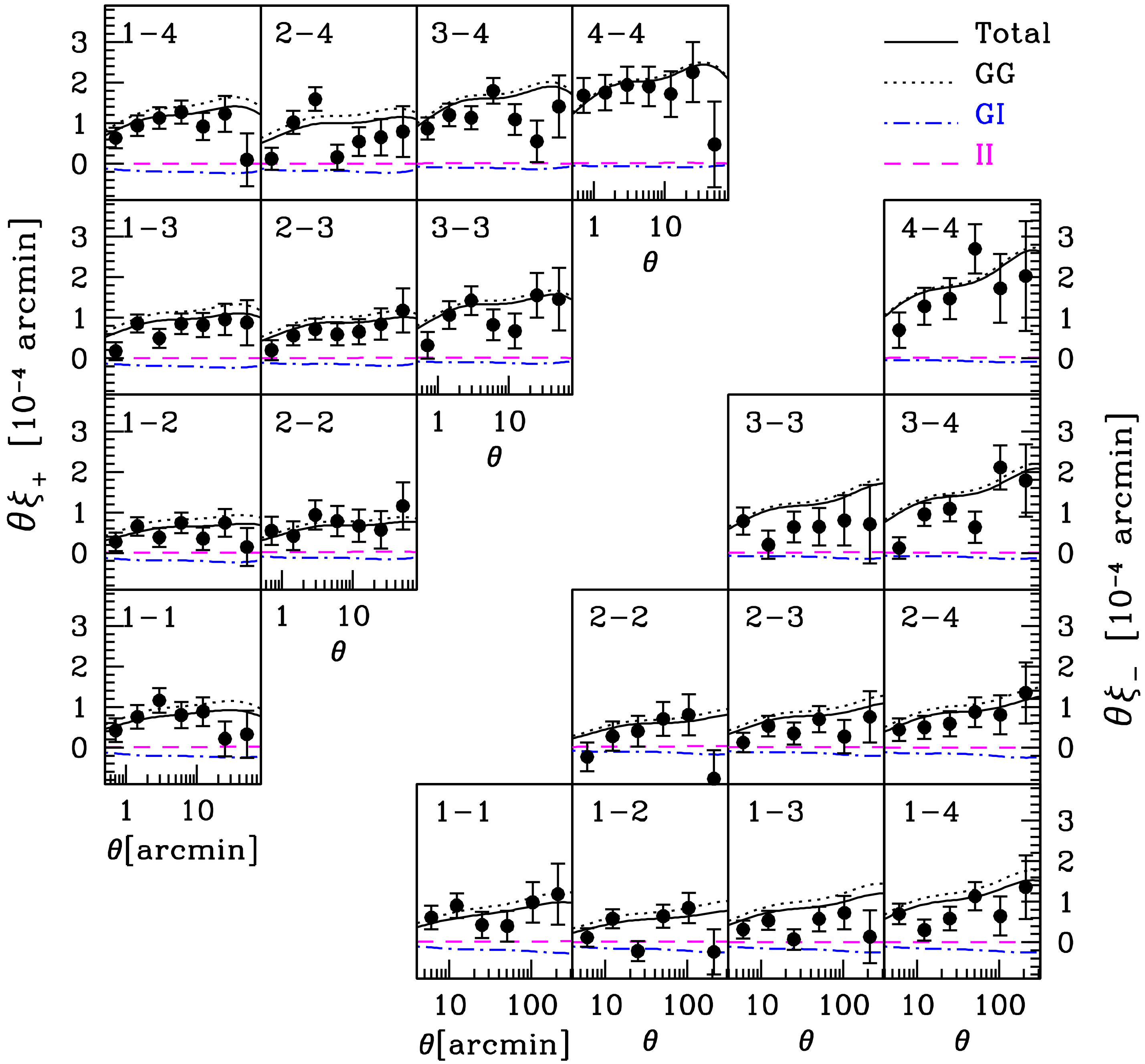
- 2-point shear correlation
- sky coverage 450 deg2
- 0.1 < z < 0.9
- discrepancy with Planck

Kuijken et al. 1507.00738

Hildebrandt et al. 1606.05338

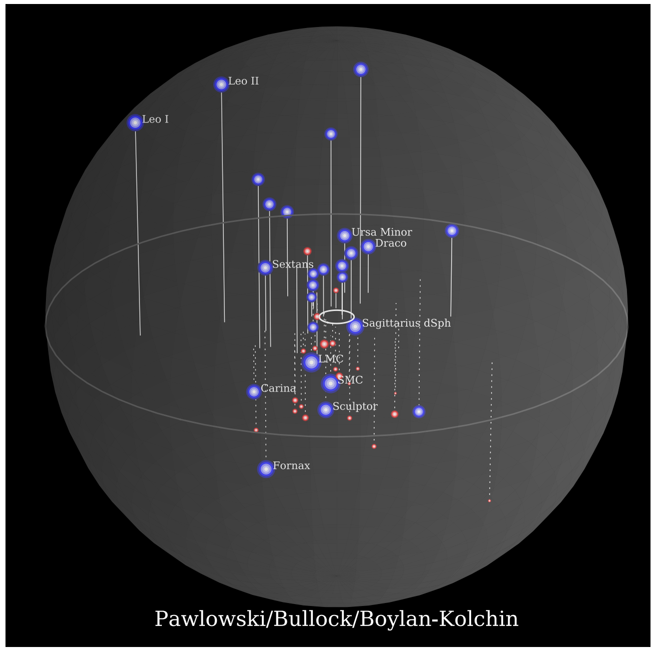
Although see Efstathiou & Lemos 1707.00483
and KIDS+GAMMA 1706.05004
and DES results 1708.01530





Dwarf Galaxies

Observational Status



$\text{Classical: } 11$

$\text{SDSS: } 15$

$f_{\text{sky}}^{\text{SDSS}} = 0.28$

DES and others:
(candidates)
8+14=22

$$N_{\text{sat}} = 65 \pm 11$$

We modelled it by imposing a half Gaussian likelihood

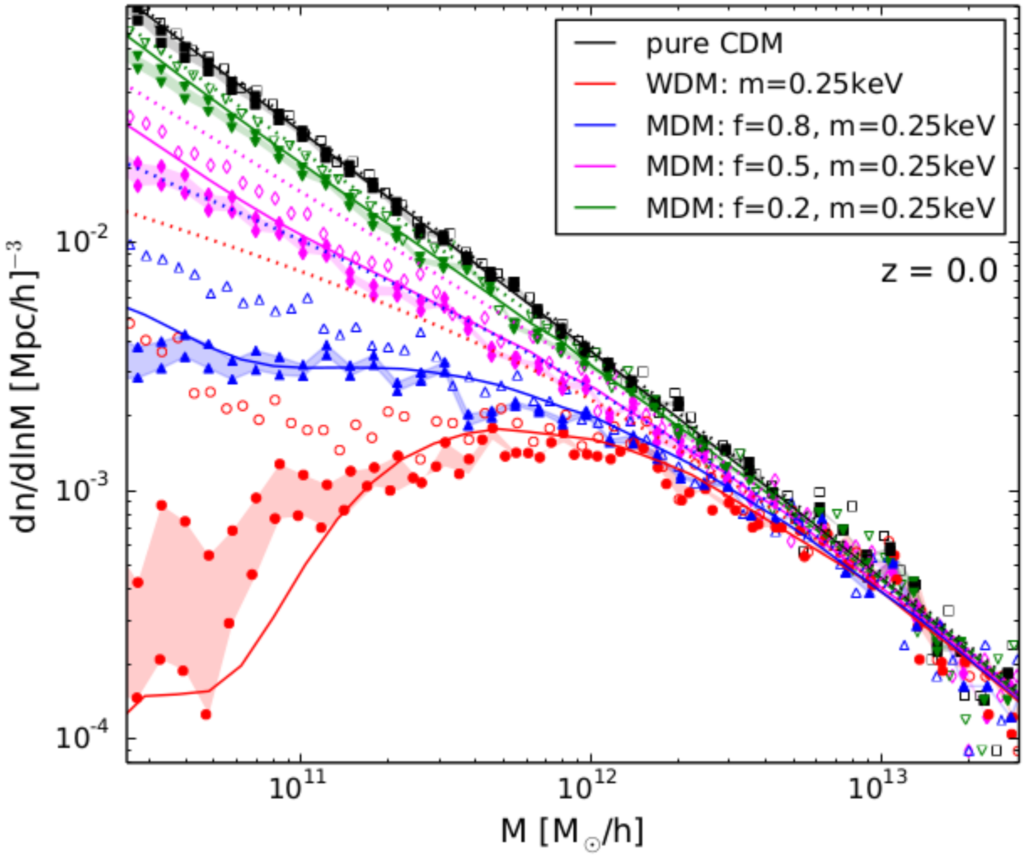
Drlica-Wagner et al. 1508.03622

Theory

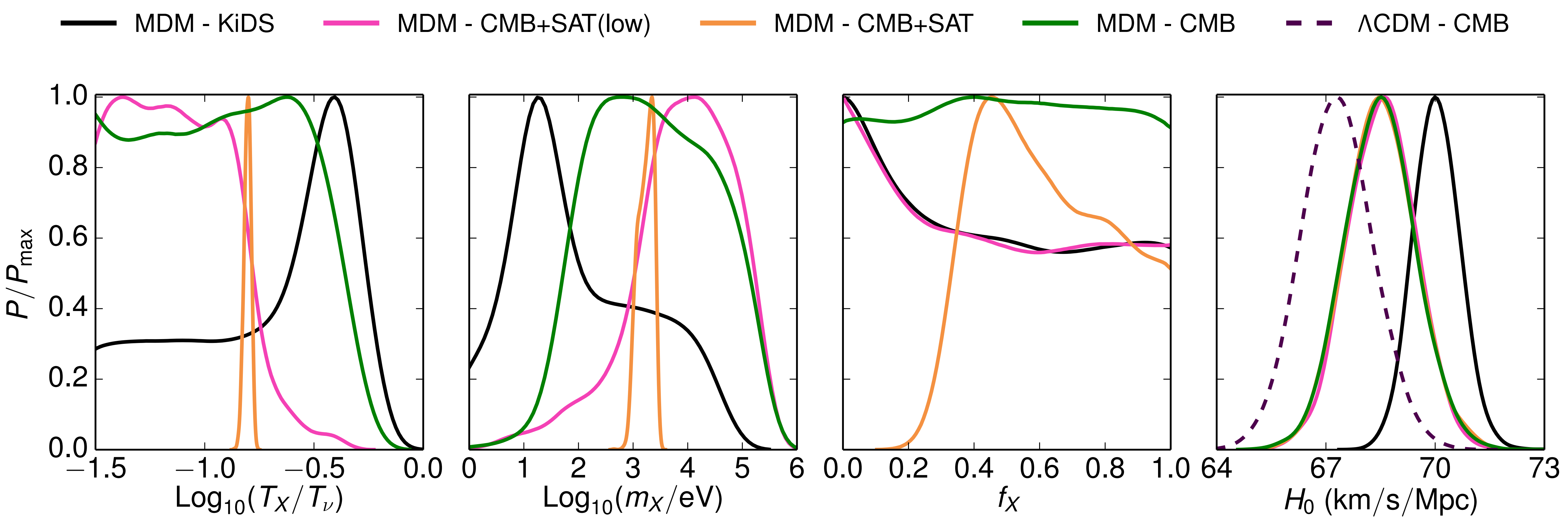
Schneider, 1412.2133 & 1601.07553

- Based on the sharp-k method
- Extended Press-Schechter
- Matching between simulations and formulae
- Further confirmation of the validity of the approach

Murgia et al. arXiv:1704.07838



Results



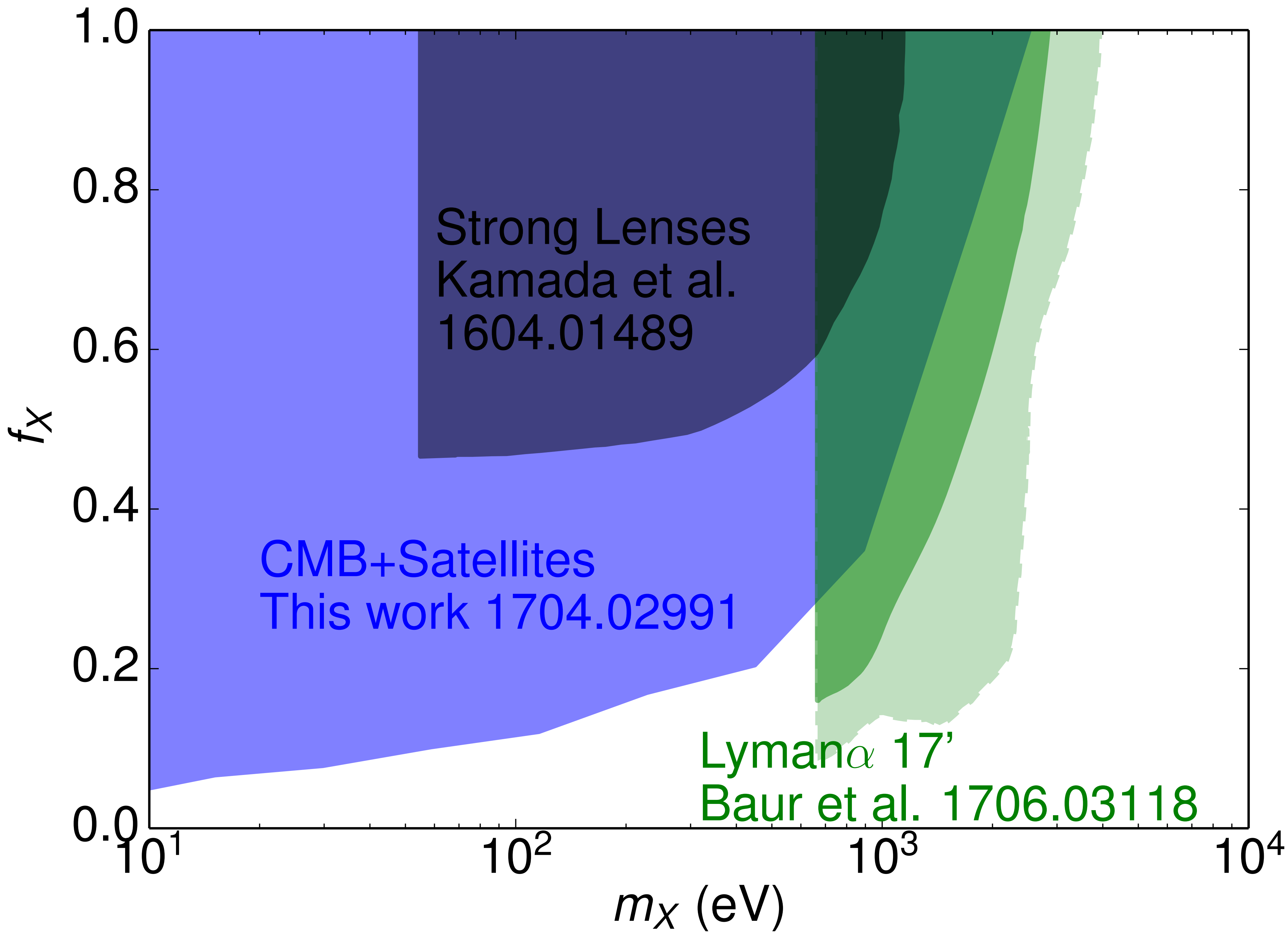
Satellites Gaussian	$0.15 < T_X/T_\nu < 0.17$	0.95 keV$< m_X < 2.9$ keV	$f_X > 0.34$
Satellites Half Gaussian	$T_X/T_\nu < 0.19$	$m_X > 0.09$ keV	$0 \leq f_X \leq 1$

KIDS data not completely able resolving the NCDM temperature or mass
BUT prefers small masses/high temperatures

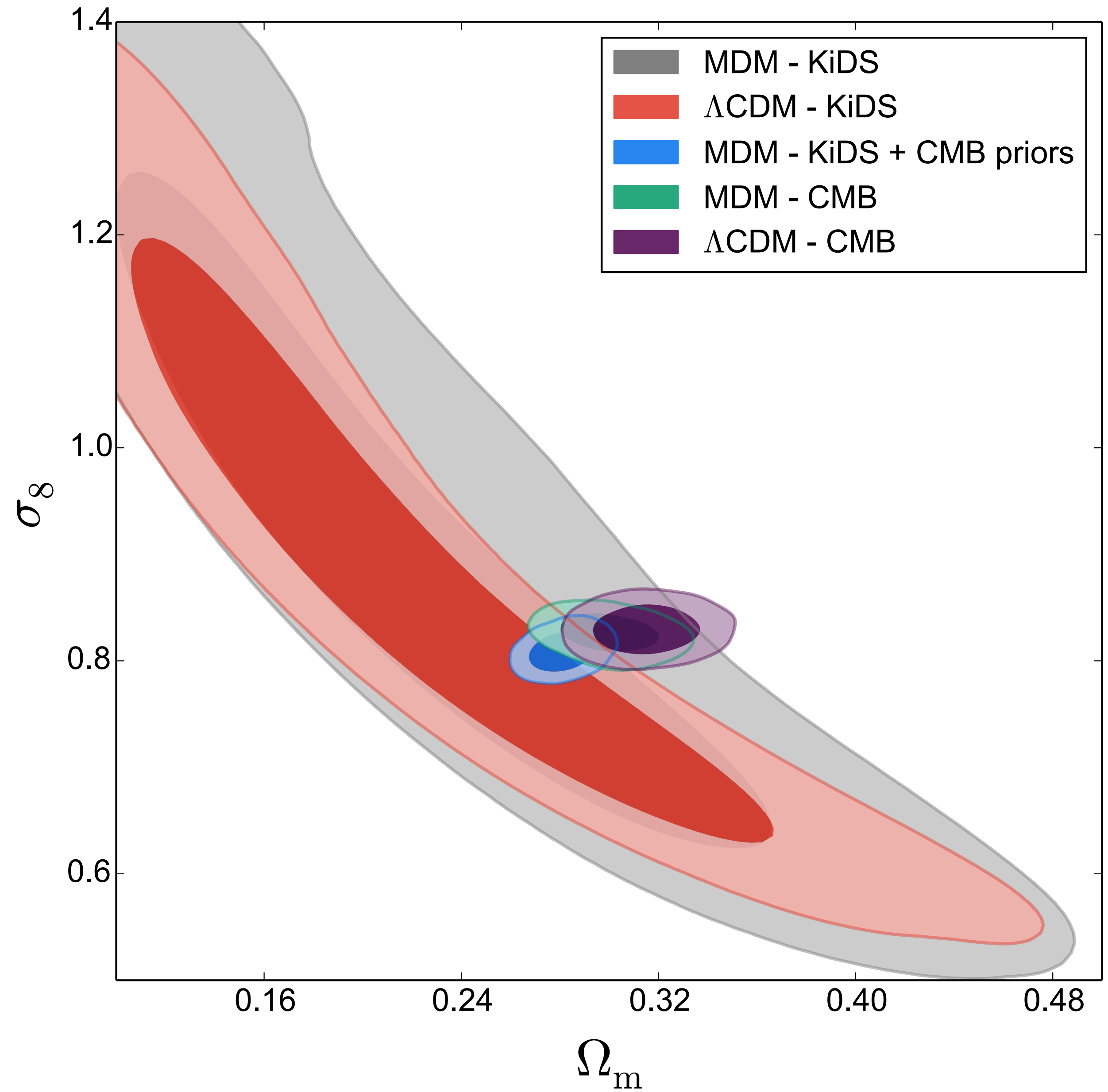
H0 tension slightly alleviated in the Mixed Dark Matter scenario

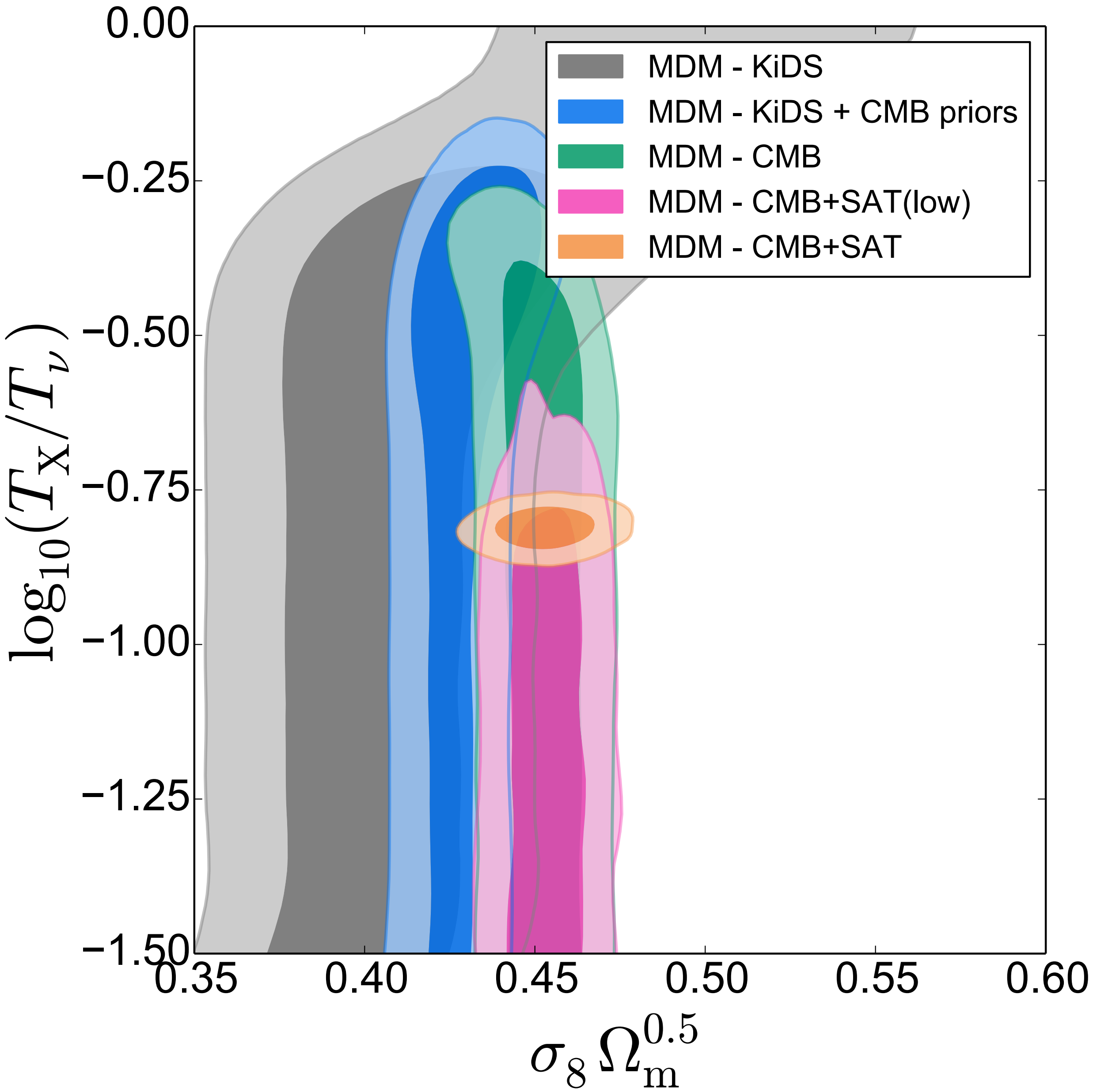
Results

Complementary constraints with others from different data sets



Results



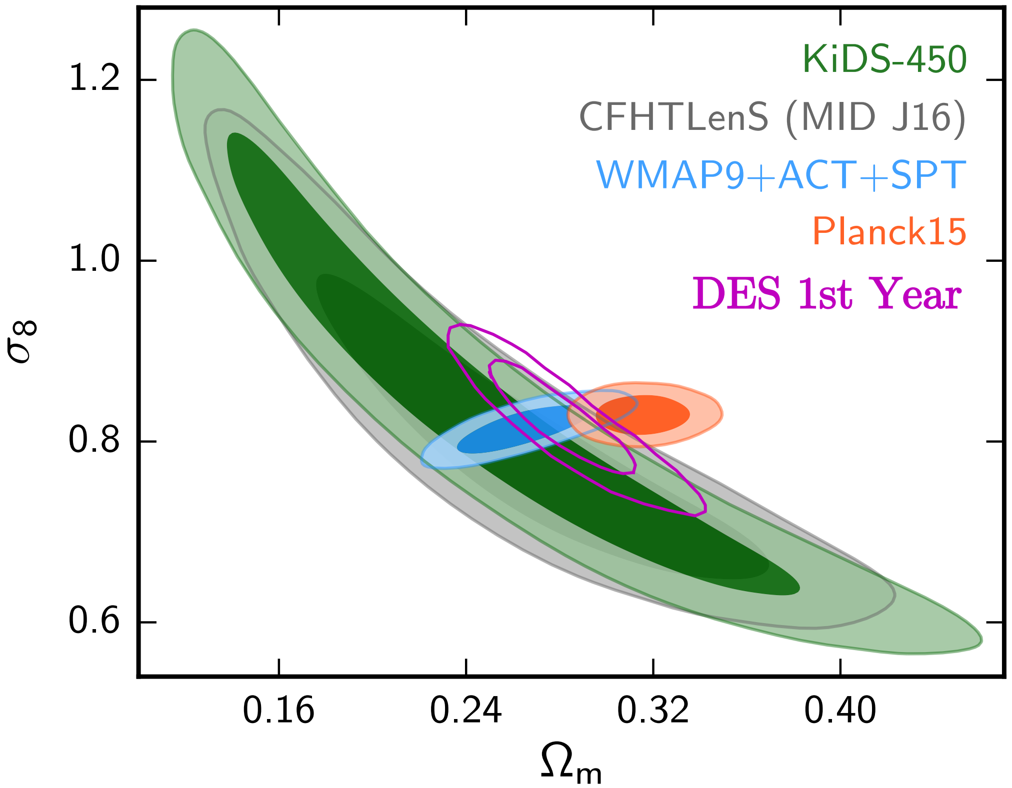


σ_8/Ω_m Tension alleviated within MDM, but not in the region favoured by Satellites data

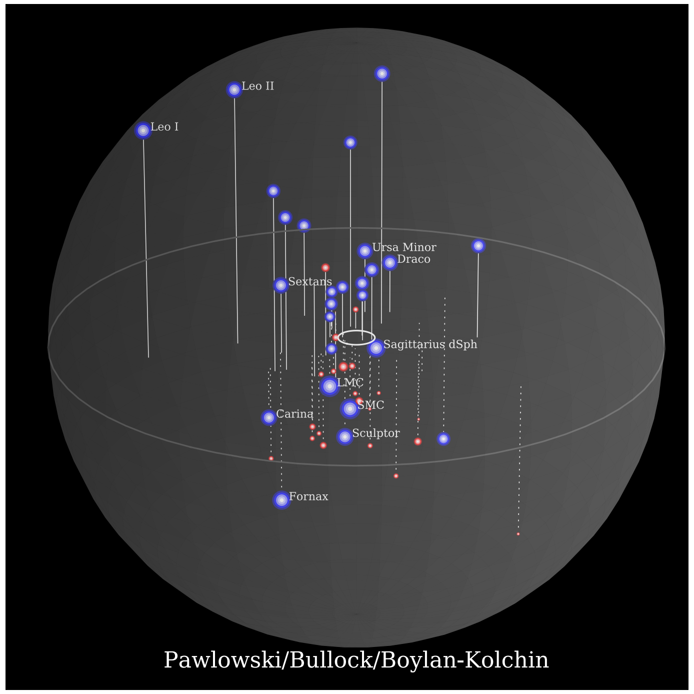
Outlook

DES Cosmology Results

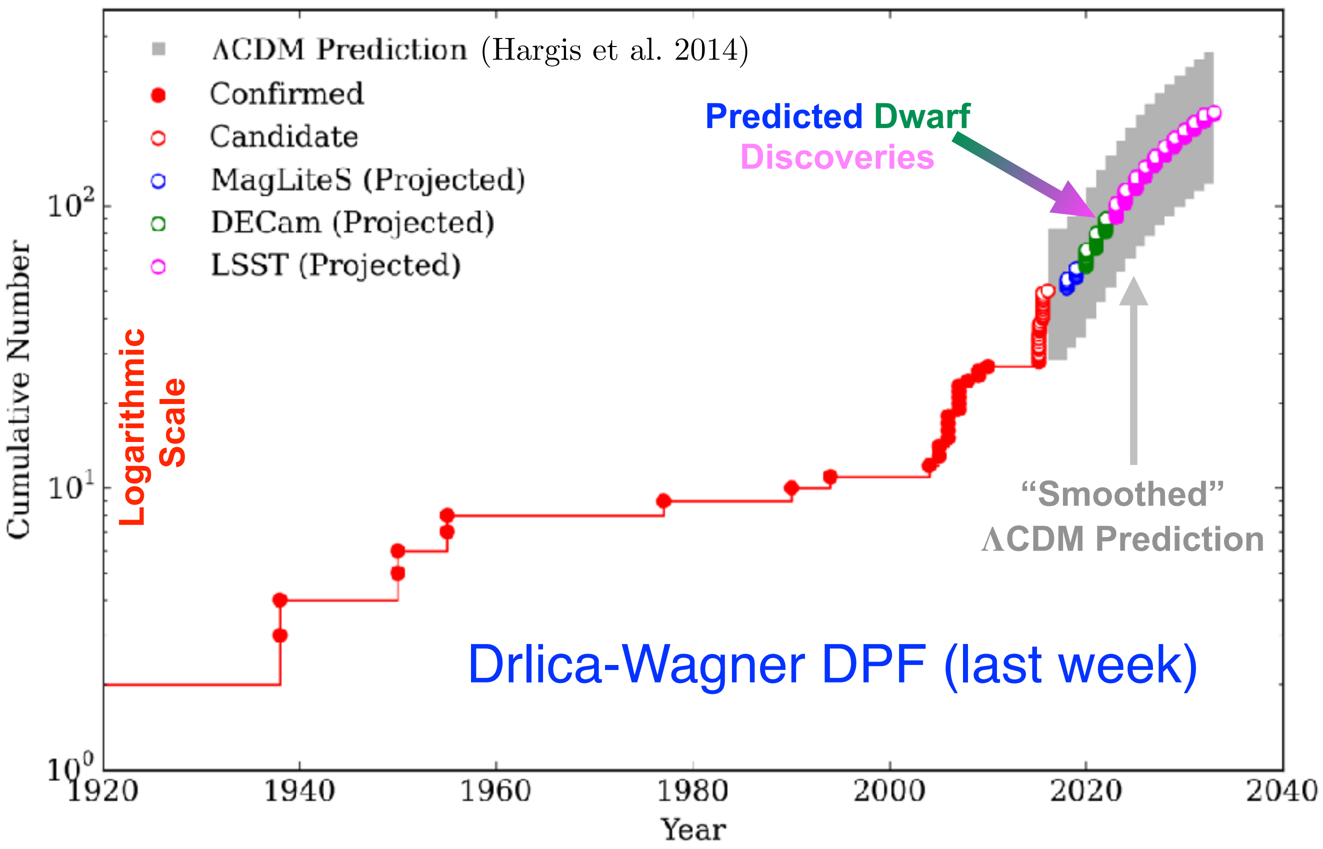
1708.01530



DES satellites



Drlica-Wagner et al. 1508.03622



Conclusions

Mixed Dark Matter tested in the linear and non-linear regimes against the most recent cosmological observations.

Dwarf galaxies counts provide very strong constraints.

The addition of a non-cold dark matter component could account for the Sigma8 discrepancy as measured by KIDS but in a region not favoured by dwarf satellite counts.

Thank you!

Questions welcome!!!

arXiv:1704.02991

Back up: Satellites Counts

Schneider, 1412.2133 & 1601.07553

$$\frac{dN_{\rm sat}}{d\ln M_s} = \frac{1}{C_n}\frac{1}{6\pi^2}\left(\frac{M_h}{M_s}\right)\frac{P(1/R_s)}{R_s^3\sqrt{2\pi(S_s - S_h)}}$$

$$S_i(M) = \frac{1}{2\pi^2}\int_0^\infty k^2 P(k) W^2(k|M) dk$$

$$M_i = \frac{4\pi}{3}\Omega_m \rho_c (cR_i)^3$$

Sharp-k

$$W(k|M) = \begin{cases} 1, & \text{if} \quad k \leq k_s(M) \\ 0, & \text{if} \quad k > k_s(M) \end{cases}$$

Lovell et al. 1104.2929

Back up: Non-Linear MPS

Kamada et al. 1604.01489

$$\frac{P_{\rm MDM}(k)}{P_{\rm CDM}(k)} = T^2(k; r_X, k'_d) = (1 - r_X) + \frac{r_X}{(1 + k/k'_d)^{0.7441}}$$

$$r_X(f_X) = 1 - \exp\left(-a\,\frac{f_X^b}{1 - f_X^c}\right) ,$$

$$k'_d(k_d, f_X) = k_d \cdot f_X^{-5/6} .$$

$$k_d(m_X, z) = \left(\frac{m_X}{\rm keV}\right)^{2.207} D(z)^{1.583}\; 388.8\, h\, {\rm Mpc}^{-1} .$$

Simulation Matching $a = 1.551\,,\quad b = 0.5761\,,\quad c = 1.263\,.$