Progress on Old and New Themes in cosmology

Hints for decaying dark matter from S_8 measurements

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Based on arXiv:2008.09615 with
Riccardo Murgia, Vivian Poulin and Julien Lavalle

10/12/20

The S_8 tension

$$\boxed{S_8 = \sigma_8 \sqrt{\frac{\Omega_m}{0.3}}} \quad \text{where} \quad \sigma_8 = \sqrt{\int \frac{k^3}{2\pi} P(k) W_R^2(k) d\ln k} \quad \text{at} \quad R = 8 \text{ Mpc}/h$$

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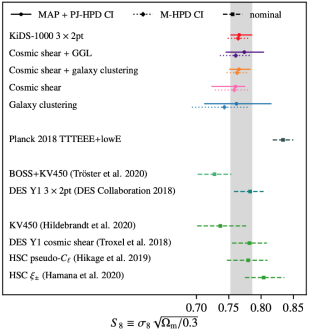
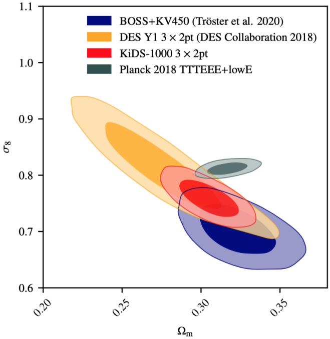
$2-3\sigma$ tension between Weak Lensing and CMB (assuming ΛCDM)





From 2008.11285

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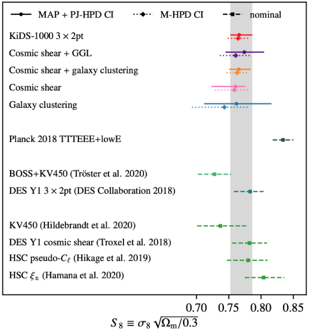

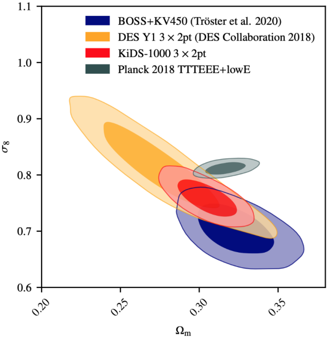

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BOSS+KIDS+2dfLenS analysis revealed tension is mainly **driven by σ_8**

Framework of the 2-body decay

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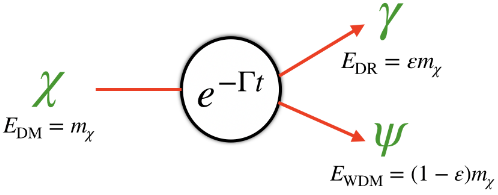
- We explore DM decays to massless (**Dark Radiation**) and massive (**Warm Dark Matter**) particles, $\chi(\text{DM}) \rightarrow \gamma(\text{DR}) + \psi(\text{WDM})$



Two extra parameters:
$\boldsymbol{\Gamma}$ and $\boldsymbol{\varepsilon}$

Current status of the 2-body decay?

1402.2972

Full treatment of perts.,
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Evolution of perturbations: full description

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- Effects on $P(k)$ and C ? → Track **linear perturbations** for the daughter particles: δ_D, θ_D and σ_D
- Boltzmann hierarchy of eqs. dictate the evolution of the **p.s.d. multipoles** $\Delta f\,(q, k, \tau)$

DR treatment is easy, momentum d.o.f. are integrated out

For WDM, one needs to follow the evolution of the full p.s.d. Computationally expensive → $O(\mathbf{10^8})$ **ODEs to solve !**

Evolution of perturbations: fluid approximation for the WDM

Based on a **fluid** description for massive neutrinos (1104.2935)

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The eqs. (valid at $k\tau$ 1) read

$$\dot{\delta}_{\rm D} = -3H(c_{\rm syn}^2 - w)\delta_{\rm D} - (1+w)\left(\theta_{\rm D} + \frac{\dot{h}}{2}\right) + a\Gamma(1-\varepsilon)\frac{\bar{\rho}_{\rm DM}}{\bar{\rho}_{\rm D}}(\delta_{\rm DM} - \delta_{\rm D})$$

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where

$$c_a^2(\tau) = w\left[5 - \frac{p_{\rm D}}{\bar{P}_{\rm D}} - \frac{\bar{\rho}_{\rm DM}}{\bar{\rho}_{\rm D}}\frac{a\Gamma}{3wH}\frac{\varepsilon^2}{1-\varepsilon}\right]\left[3(1+w) - \frac{\bar{\rho}_{\rm DM}}{\bar{\rho}_{\rm D}}\frac{a\Gamma}{H}(1-\varepsilon)\right]^{-1}$$

and

$$c_{\rm syn}^2(k,\tau) = c_a^2(\tau)\left[1 + (1-2\varepsilon)T(k/k_{\rm fs})\right]$$

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Accurate at the $O(0.1\%)$ level in C , and at $O(1\%)$ level in $P(k)$

CPU time reduced from 1 day to 1 minute!

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controls the depth of the power suppression

" controls the cut-o scale (k_{fs})

- Modified version of CLASS
- Run MCMC against Planck, BAO SNIa, $f\sigma_8$ & S_8 [1]

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	CDM	DDM
${}^2_{CMB}$	1015.9	1015.2
${}^2_{S_8}$	5.64	0.002

$\to \quad {}^2_{min} \simeq 5.5$

$\varepsilon \simeq 0.7$ % and ${}^{-1} \simeq 55$ Gyrs

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Best- t cosmology and comparison with massive neutrinos

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Some promising implications

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Accurate measurements of $_8$ at 0 . z . 1 will further test the 2-body decay

First thorough cosmological analysis of the 2-body decay scenario

It fully restores cosmological concordance for S_8 (but not for H_0)

Many interesting implications (DM model building, small-scale crisis, Xenon-1T excess)

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THANKS FOR YOUR ATTENTION

$$f(q,k,\mu,\tau) = \bar{f}(q,\tau) + \Delta f(q,k,\mu,\tau)$$

Expand Δf in multipoles. The Boltzmann eq. leads to the following **hierarchy** (*in synchronous gauge comoving with the mother*)

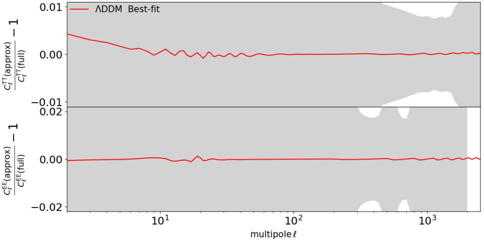
$$\frac{\partial}{\partial\tau}(\Delta f_0) = -\frac{\mathbf{q}k}{\mathcal{E}}\Delta f_1 + q\frac{\partial\bar{f}}{\partial q}\frac{\dot{h}}{6} + a\frac{\Gamma\bar{N}_\mathrm{M}(\tau)}{4\pi q^3 H}\delta(\tau-\tau_q)\delta_\mathrm{M},$$
$$\frac{\partial}{\partial\tau}(\Delta f_1) = \frac{\mathbf{q}k}{3\mathcal{E}}\left[\Delta f_0 - 2\Delta f_2\right],$$
$$\frac{\partial}{\partial\tau}(\Delta f_2) = \frac{\mathbf{q}k}{5\mathcal{E}}\left[2\Delta f_1 - 3\Delta f_3\right] - q\frac{\partial\bar{f}}{\partial q}\frac{(\dot{h}+6\dot{\eta})}{15},$$
$$\frac{\partial}{\partial\tau}(\Delta f_l) = \frac{\mathbf{q}k}{(2l+1)\mathcal{E}}\left[l\Delta f_{l-1} - (l+1)\Delta f_{l+1}\right] \qquad (\text{for } l \geq 3).$$

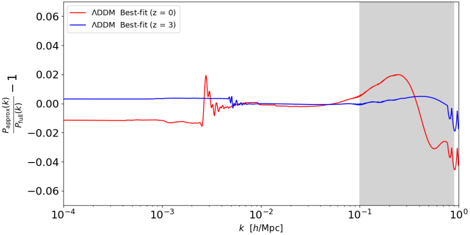
where $q = a(\tau_q)p_{\mathrm{max}}$. In the relat. limit $\mathbf{q}/\mathcal{E} = 1$, so we can take

$F_l \equiv \frac{4\pi}{\rho_c}\int dq\; q^3\Delta f_l$ and **integrate out the dependency on** q

We compare two configurations (at the **best-fit** values)

- **Full**: Solve Boltzmann hierarchy with $N_q = 10^4$
- **Approx**: Solve Boltzmann hierarchy with $N_q = 300$ and switch-on fluid eqs. at $k\tau > 25$





The residual error on S_8 is 0.65%, smaller than the 1.8% error of the measurement from BOSS+KIDS+2dfLenS