Progress on Old and New Themes in cosmology

Hints for decaying dark matter from S_8 measurements

Guillermo Franco Abellán

Based on arXiv:2008.09615 with

Riccardo Murgia, Vivian Poulin and Julien Lavalle

10/12/20

The S_8 tension

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

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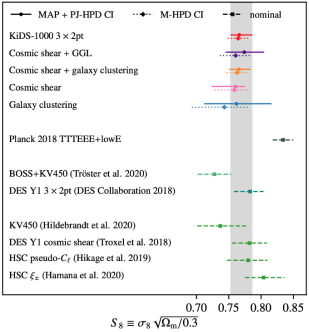
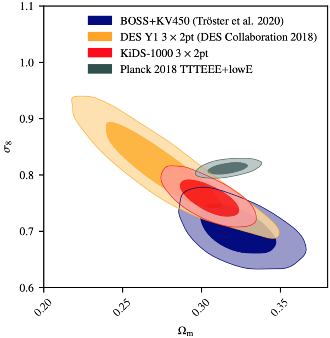
2–3σ tension between Weak Lensing and CMB (assuming ΛCDM)





From 2008.11285

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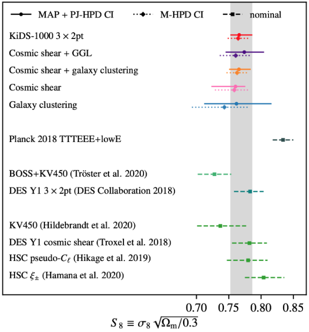

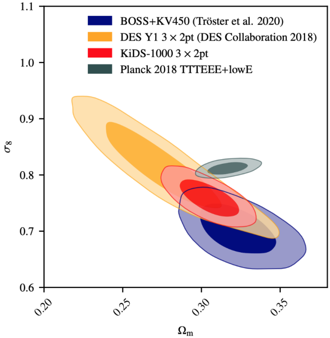

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BOSS+KIDS+2dfLenS analysis revealed tension is mainly **driven by σ_8**

Framework of the 2-body decay

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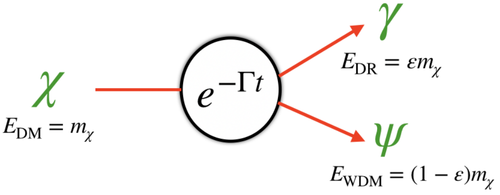
- We explore DM decays to massless (**Dark Radiation**) and massive (**Warm Dark Matter**) particles, $\chi(\mathrm{DM}) \to \gamma(\mathrm{DR}) + \psi(\mathrm{WDM})$



Two extra parameters:
$\mathbf{\Gamma}$ and ε

Current status of the 2-body decay?

Evolution of perturbations and cosmological constraints in decaying dark matter models with arbitrary decay mass products

Shohei Aoyama,[1] Toyokazu Sekiguchi,[1,2] Kiyotomo Ichiki[3] and Naoshi Sugiyama[1,3,4]

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Full treatment of perts.,
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1903.06220

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CMB constraints on late-universe decaying dark matter as a solution to the H_0 tension

Steven J. Clark,[*] Kyriakos Vattis,[†] and Savvas M. Koushiappas[‡]
Department of Physics, Brown University, Providence, RI 02912-1843, USA and Brown Theoretical Physics Center, Brown University, Providence, RI 02912-1843, USA

2006.03678

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Evolution of perturbations: full description

- Effects on $P(k)$ and C_ℓ? $\rightarrow$ Track **linear perturbations** for the daughter particles: $\delta_{\rm D}$, $\theta_{\rm D}$ and $\sigma_{\rm D}$

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- Effects on $P(k)$ and C_ℓ? $\rightarrow$ Track **linear perturbations** for the daughter particles: $\delta_{\rm D}$, $\theta_{\rm D}$ and $\sigma_{\rm D}$

- Boltzmann hierarchy of eqs. dictate the evolution of the **p.s.d. multipoles** $\Delta f_\ell(q,k,\tau)$

  ◇ **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 $\rightarrow$ $\mathcal{O}(\mathbf{10^8})$ **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 $k\tau \gg 1$) read

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

$$\dot{\theta}_{\rm D} = -\mathcal{H}(1-3c_a^2)\theta_{\rm D} + \frac{c_{\rm syn}^2}{1+w}k^2\delta_{\rm D} - k^2\sigma_{\rm D} - a\Gamma(1-\varepsilon)\frac{\bar{\rho}_{\rm DM}}{\bar{\rho}_{\rm D}}\frac{1+c_a^2}{1+w}\theta_{\rm D}$$

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where

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

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Accurate at the $\mathcal{O}(0.1\%)$ level in C_ℓ, and at $\mathcal{O}(1\%)$ level in $P(k)$

CPU time reduced from ~ 1 day to ~ 1 minute!

Physical effects of the WDM daughter

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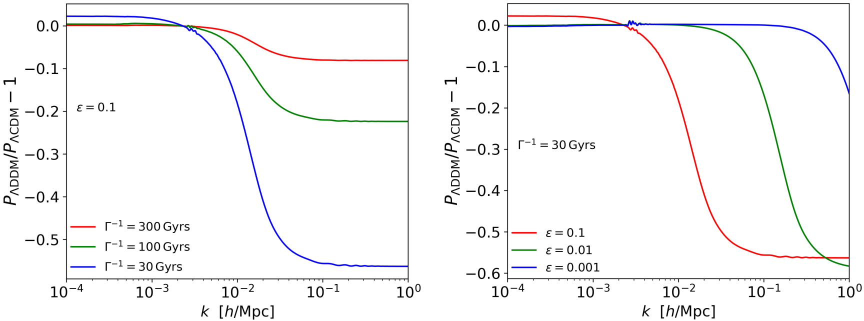
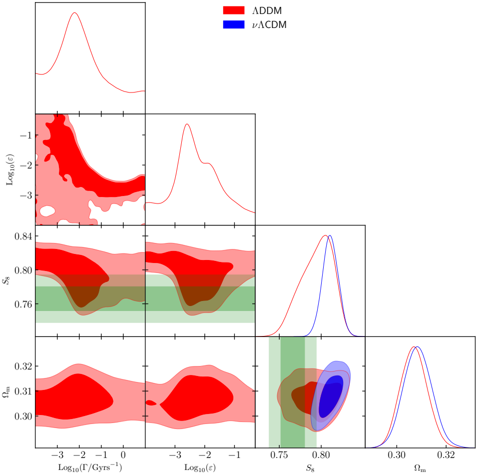
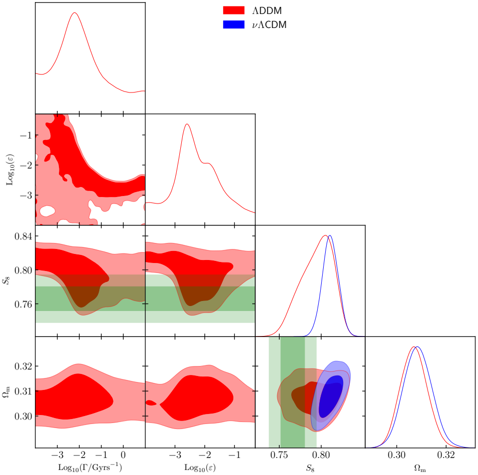
- $\boldsymbol{\Gamma}$ controls the **depth** of the power suppression
- ε controls the **cut-off** scale $(k_{\rm fs})$





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

[1] $S_8 = 0.766^{+0.020}_{-0.014}$ from KIDS+BOSS+2dfLenS



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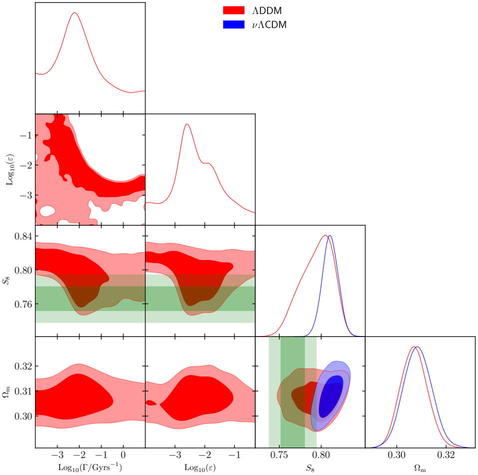
Resolving the S_8 tension with the 2-body decay



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	$\nu\Lambda$CDM	ΛDDM
$\chi^2_{\rm CMB}$	1015.9	1015.2
$\chi^2_{S_8}$	5.64	0.002

$\longrightarrow \Delta\chi^2_{\rm min} \simeq -5.5$

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

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Best-fit cosmology and comparison with massive neutrinos

- In the best-fit cosmology, $\Omega_{\rm wdm}/\Omega_{\rm m} \sim 18\%$

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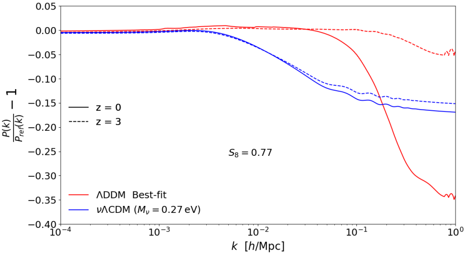

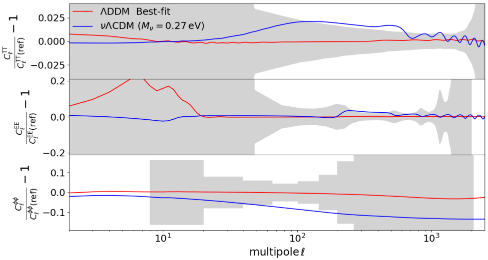

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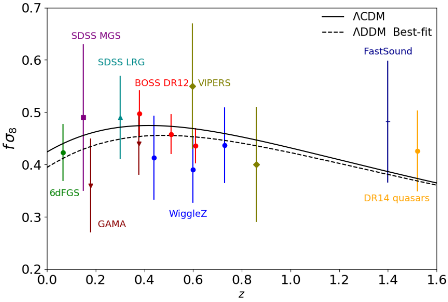

Accurate measurements of $f\sigma_8$ at $0 \lesssim z \lesssim 1$ will further test the 2-body decay

Conclusions

- 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)
- Future growth factor measurements can further test this scenario

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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*)

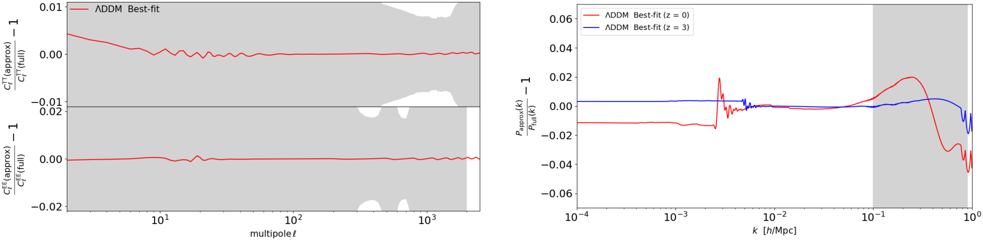
$$\begin{aligned}
\frac{\partial}{\partial\tau}(\Delta f_0) &= -\frac{\mathbf{q}k}{\boldsymbol{\mathcal{E}}}\Delta f_1 + q\frac{\partial\bar{f}}{\partial q}\frac{\dot{h}}{6} + a\frac{\Gamma\bar{N}_{\mathrm{M}}(\tau)}{4\pi q^3\mathcal{H}}\delta(\tau-\tau_q)\delta_{\mathrm{M}},\\
\frac{\partial}{\partial\tau}(\Delta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

where $q = a(\tau_q)p_{\max}$. In the relat. limit $\mathbf{q}/\boldsymbol{\mathcal{E}} = 1$, 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 $\sim 0.65\%$, smaller than the $\sim 1.8\%$ error of the measurement from BOSS+KIDS+2dfLenS