Structure Formation beyond SIDM: Closer Look at 3 particle models

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elusives
neutrinos, dark matter & dark energy physics

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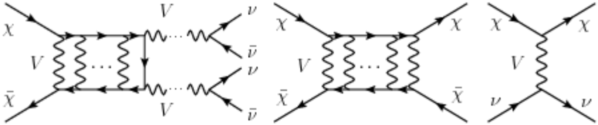
Is dark matter with long-range interactions a solution to all small-scale problems of Λ CDM cosmology?

L. v.d. Aarssen, T. Bringmann, C. Pfrommer (2012)

$$\mathscr{L} \supset g_\chi \bar{\chi} \gamma^\mu \chi V_\mu + g_\nu \bar{\nu} \gamma^\mu \nu V_\mu$$



Able to alleviate Cusp and Core, MS and TBTF

- velocity-dependent self-interaction (Sommerfeld effect)
- Late kinetic decoupling: $M_{\text{ao}}^{\text{cut}} \sim 10^8 \left(1\,\text{keV}/T_{\text{kd}}\right)^3 M_\odot$

Matter Power Spectrum
in Hidden Neutrino Interacting Dark Matter Models:
A Closer Look at the Collision Term

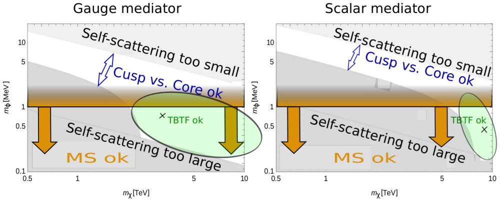
TB, L. Covi, A. Kamada, H. Murayama, T. Takahashi, N. Yoshida (Feb. 2016)

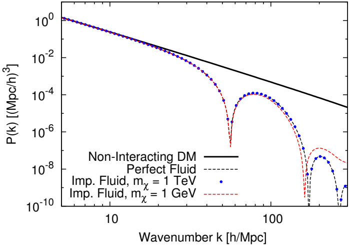
- derived *t*-averaged form of Collision Term

  inspired by Gondolo+, Kasahara thesis
- focused on 3 particle model
- S,V,PS or PV mediator can alleviate MS

  Complementary to classification of late KD operators, Bringmann+
- Map into linear Matter Power Spectrum
- Provide validity check of DM perfect fluid approximation

  Complementary to ETHOS





Q: Possible to distinguish between scalar and vector mediator in case where dark sector is 'closed' (sterile neutrino)?

- Closed dark system escapes strong CMB/direct detection constraints
- Interesting: Impact of DAO on CMB ?

  talk of M. Archidiacono
- Second late period of annihilation induced by sommerfeld enhancement close to a resonance? (!)

  Bachelor thesis by M. Wiesner, S. Sandner in Aug. 2016 Göttingen

Sommerfeld Enhanced Annihilation

$$\langle \sigma v_{\rm rel} \rangle_{T_\chi} = \frac{(m_\chi/T_\chi)^{3/2}}{2\sqrt{\pi}} \int_0^\infty (\sigma v)_0 S(v) v^2 e^{-(m_\chi/T_\chi)v^2/4} \mathrm{d}v$$

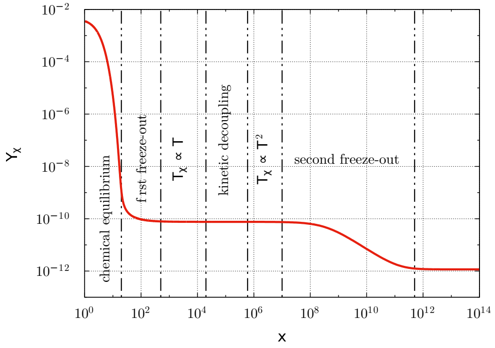
$$\Gamma \equiv \frac{\langle \sigma v_{\rm rel} \rangle_{T_\chi} Y_\chi}{H/s}$$

s-wave:

	$\Gamma \propto$			
	before m-rd-eq.		after m-rd-eq.	
$S(v)$	before kd	after kd	before kd	after kd
const.	x^{-1}	x^{-1}	$x^{-3/2}$	$x^{-3/2}$
$\sim 1/v$	$r^{-1/2}x^{-1/2}$	$r^{-1}(x_l^{\rm kd})^{-1/2}$	$r^{-1/2}x^{-1}$	$r^{-1}(x_l^{\rm kd})^{-1/2}x^{-1/2}$
$\sim 1/v^2$	r^{-1}	$r^{-2}(x_l^{\rm kd})^{-1}x$	$r^{-1}x^{-1/2}$	$r^{-2}(x_l^{\rm kd})^{-1}x^{1/2}$

Γ never grows for p-wave annihilation!

The Second Freeze-out (SFO)

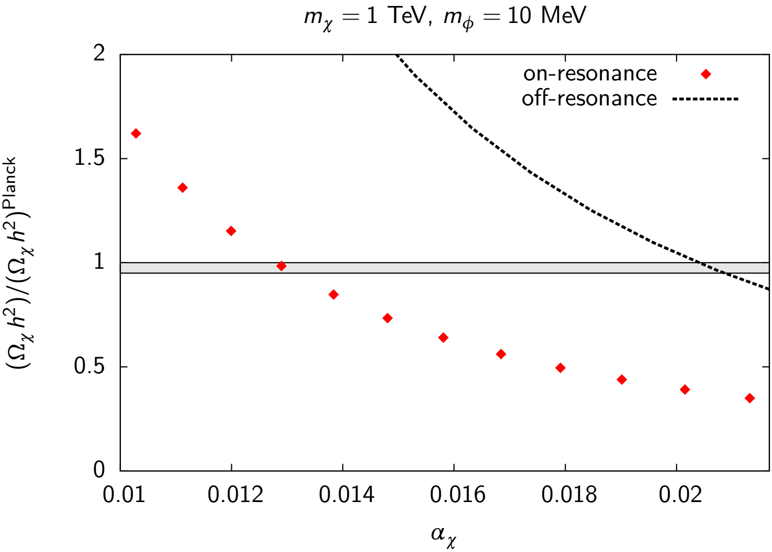


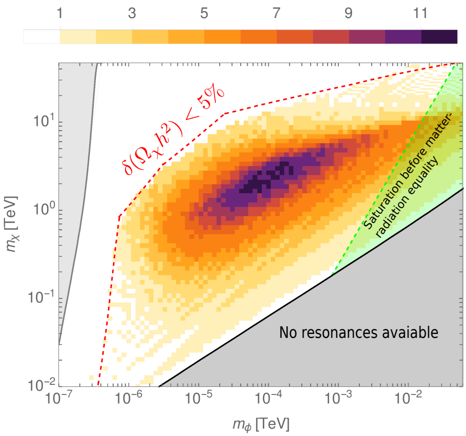
- SFO amplitude set by saturation
- Solving for relic density after kd goes beyond the Standard Gondolo,Gelmini treatment

  see Bringmann+ 2013, TB TB MG+ 2017 for formal description

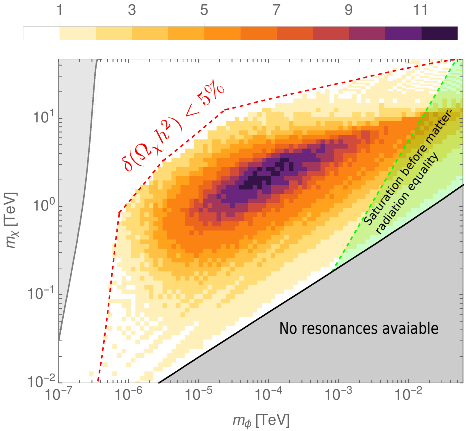
- Coupled system of differential equations: $n_\chi, T_\chi, \rho_\phi, \rho_\nu, H$

For simplicity, we consider equal charge case: $\alpha_\nu = \alpha_\chi$.
Fixing (m_χ, m_ϕ), the relic abundance is degenerated in α_χ.



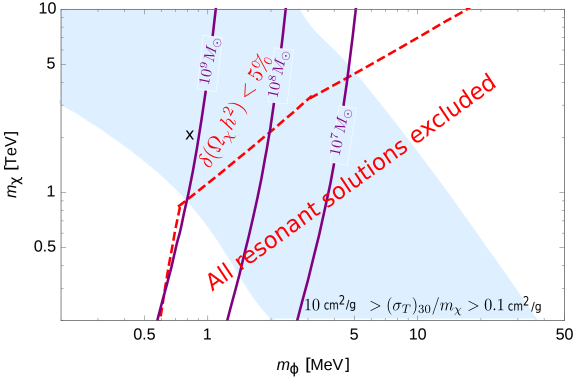


- up to 11 resonances lead to correct relic density (23 possible α_χ)
- for $m_\phi \lesssim 1$ GeV, SFO typically happens in matter-dominated epoch
- typical amplitude of SFO for $m_\phi \lesssim 1$: 5% - factor of a few



Amplitude of SFO can be constraint using

- Size of sound horizon at rec.: $r_s(z^\star) = \int_0^{1/(1+z^\star)} \frac{da}{a^2 H \sqrt{3(1+R)}}$
- Angular distance diameter: $D_A(z^\star) = \int_{1/(1+z^\star)}^{1} \frac{da}{a^2 H}$
- Angular size of sound horizon:
$100 \times \theta^\star \equiv r_s(z^\star)/D_A(z^\star) = 1.04105 \pm 0.00046$ (Planck 2015)



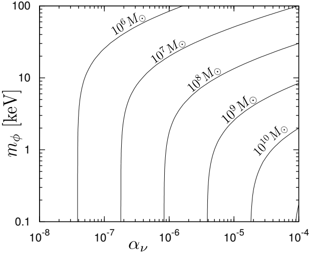
- SFO happens in 'golden region' after recombination
- $\delta(\Omega_\chi h^2) \lesssim 5\%$ ok within 3 σ deviation from $100\theta^\star$
- SFO in 'golden region' mimics decaying DM that has been regarded to explain H_0 tension
- Critical point: we rely on homogeneous solution of Boltzmann equation for relic abundance
- work in progress...

Summary

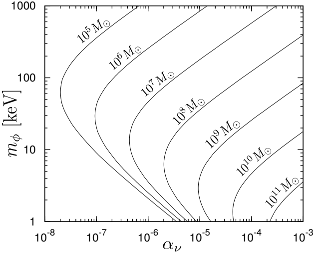
- S,V,PS,PV:
  all operators can lead to suppressed power spectrum on dwarf-galactic scales
- s-wave Sommerfeld effect on-resonance leads to a second late period of annihilation
- SFO of 'golden' parameter region seems to be interesting in connection with H_0

Backup 1

Cut-off masses for $m_\chi = 0.1$ GeV:



Pseudoscalar



Pseudovector