Title: TBA

Date: Jul 20, 2017 05:15 PM

URL: http://pirsa.org/17070030

Abstract:

Dark Matter - neutrino interactions :

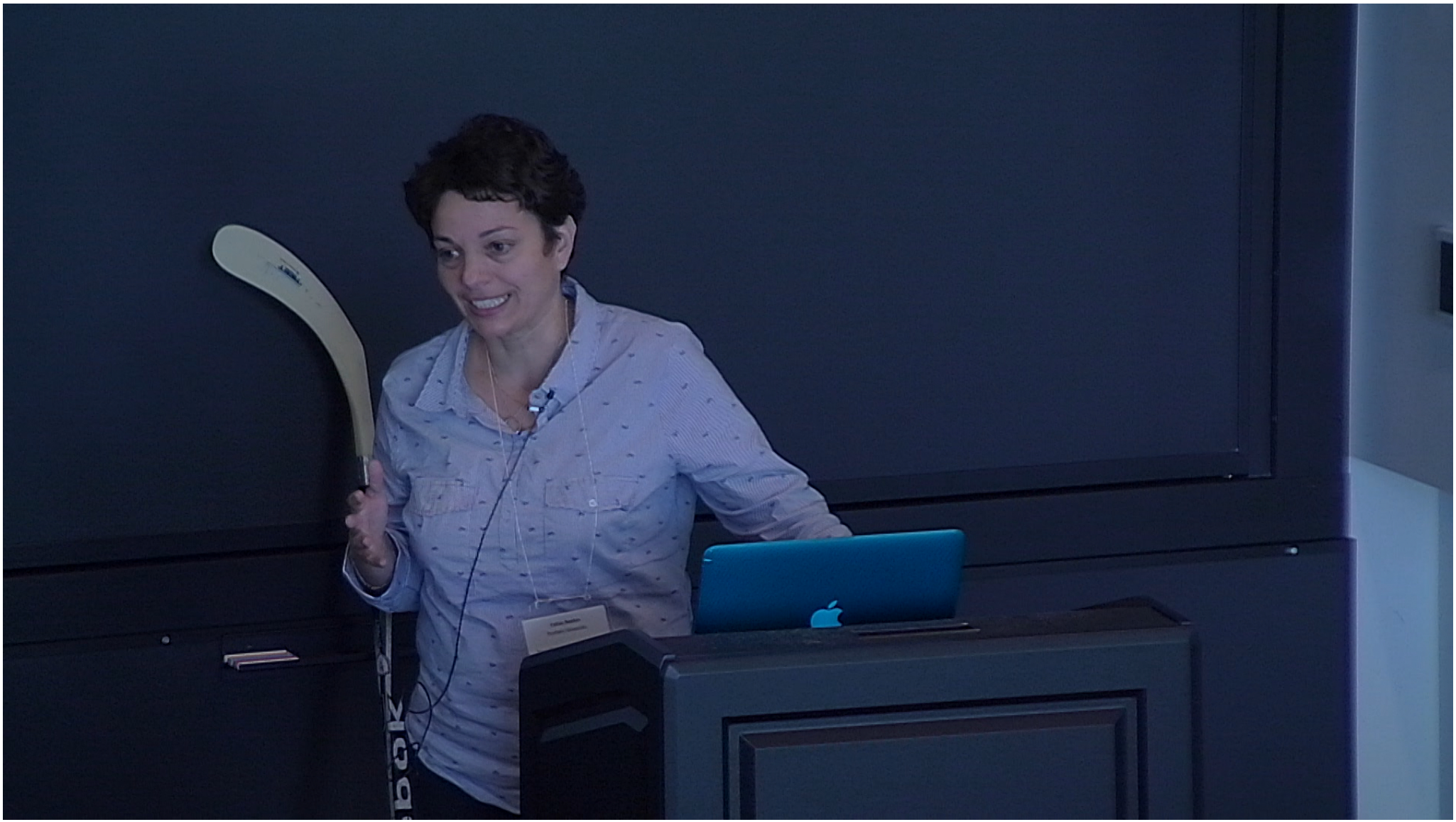
Trying to probe darkness with cosmology

Céline Boehm

IPPP, Durham

LAPTH, Annecy

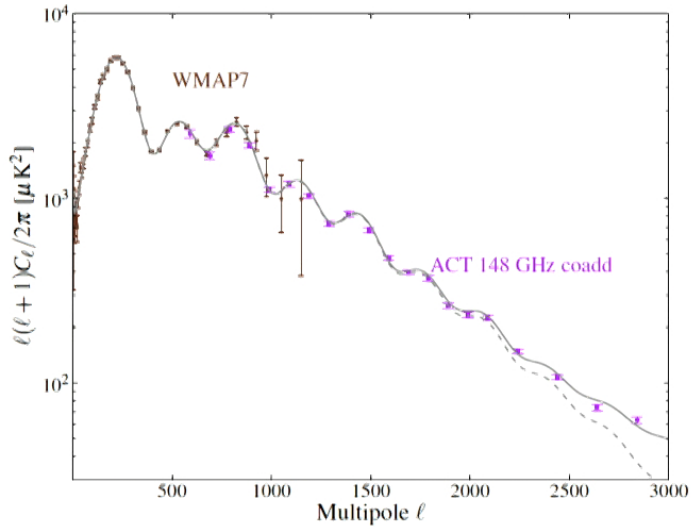
PI, July 2017



Starting with an observation

$$
\begin{aligned}
\dot{\theta}_b &= k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma) \\
\dot{\theta}_\gamma &= k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_b) \ , \\
\dot{\theta}_{DM} &= k^2\psi - \mathcal{H}\theta_{DM} \ ,
\end{aligned}
$$

No DM mass ;
no DM interaction in the DM equation.
Just a modification of gravity...



DM interactions are omitted

and yet DM should have interactions!

does it change the definitions of "cold" DM?

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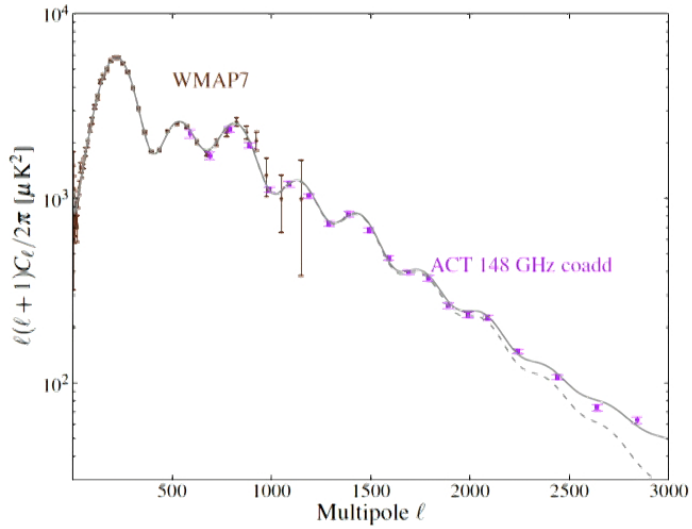

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and yet DM should have interactions!

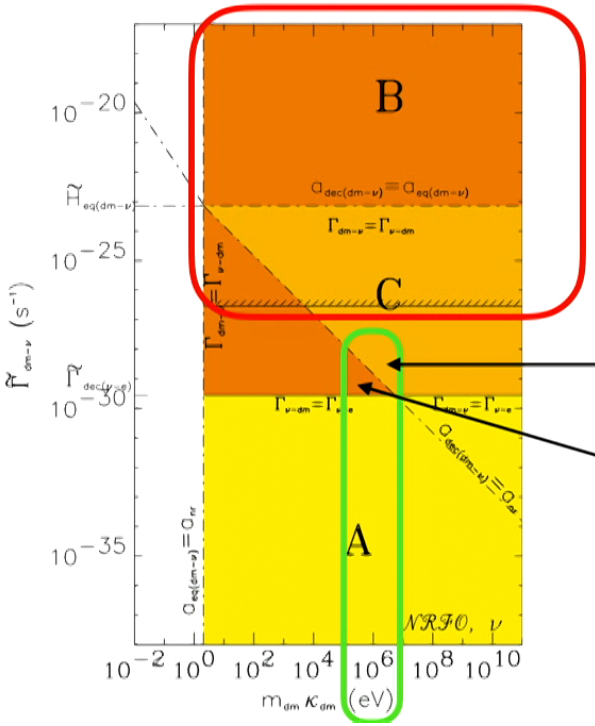
does it change the definitions of "cold" DM?

Constraints on Dark Matter interactions from structure formation: Damping lengths

astro-ph/0012504
astro-ph/0410591

Celine Boehm, Richard Schaeffer

and for any possible initial fluctuations spectrum. We point out the existence of new Dark Matter scenarios and exhibit new damping regimes. For example, an interacting candidate may bear a similar damping than that of collisionless Warm Dark Matter particles. The main difference is due to the Dark Matter coupling to interacting (or even freely-propagating) species. Our approach yields a general classification of Dark Matter candidates which extends the definitions of the usual Cold, Warm and Hot Dark Matter scenarios when interactions, weak or strong, are considered.



DM-neutrino interactions

excluded; too much collisional damping

Region C: new damping (mixed damping)

DM-nu collisional damping: potentially large

nu-e collisional damping: negligible

Dark Matter-neutrino interactions

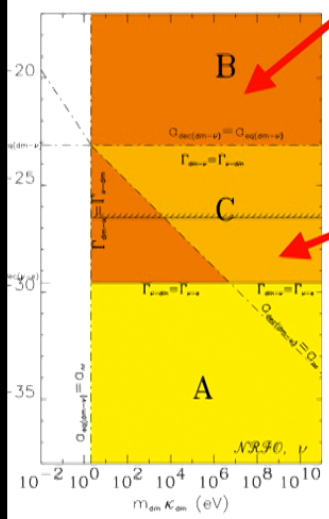
astro-ph/0012504 astro-ph/0410591

Region B

$$l_{\nu d} = 97\ pc\ r_\nu \left(\frac{g'_{*\nu}}{g'_{*dm}}\right)^{\frac{1}{2}} g'^{-1}_{*} \frac{\widetilde{\Gamma}_{dm-\nu}}{2.8\ 10^{-30}\ s^{-1}}$$

$$\widetilde{\Gamma}_{dm-\nu} < 2.9\ 10^{-27}\ s^{-1}\ r_\nu^{-1} \left(\frac{g'_{*dm}}{g'_{*\nu}}\right)^{\frac{1}{2}} g'_{*} \frac{l_{struct}}{100kpc}$$

$$\kappa_{dm}\langle\overline{\sigma v}\rangle_{\nu-dm} < 4.6\ 10^{-30}\ cm^3 s^{-1}\ r_\nu^{-1} \left(\frac{4g'_{*\nu}}{3}\right)^{-1} \left(\frac{g'_{*dm}}{g'_{*\nu}}\right)^{\frac{1}{2}} g'_{*} \frac{l_{struct}}{100kpc}$$



Region C

$$l_{\nu d} \sim 97\ pc\ r_\nu g'^{-1}_{*} \frac{\widetilde{\Gamma}_{dm-\nu}}{2.8\ 10^{-30}\ s^{-1}}$$

$$\widetilde{\Gamma}_{dm-\nu} < 2.9\ 10^{-27}\ s^{-1}\ r_\nu^{-1} g'_{*} \frac{l_{struct}}{100kpc}$$

$a_{dec(dm-\nu)} > a_{nr}$

$$\kappa_{dm}\langle\overline{\sigma v}\rangle_{\nu-dm} < 9.0\ 10^{-28}\ cm^3 s^{-1}\ r_\nu^{-2} \left(\frac{4g'_{*\nu}}{3}\right)^{-1} g'^{\frac{3}{2}}_{*} \frac{m_{dm}\kappa_{dm}}{1MeV} \left(\frac{l_{struct}}{100kpc}\right)^2$$

$a_{dec(dm-\nu)} < a_{nr}$

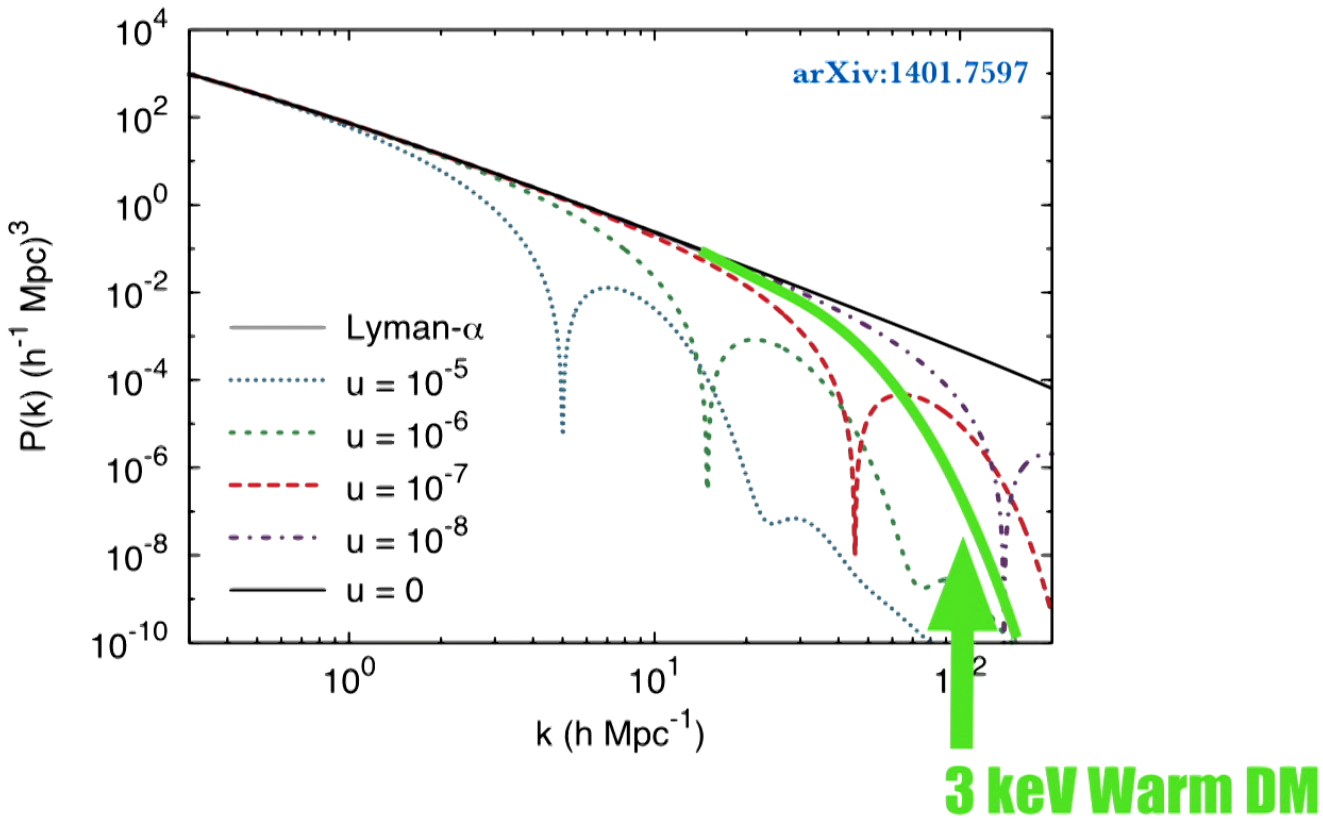
does not exist in this case

MeV DM is like Warm DM

All structures below 100 kpc are erased

Dark Matter-neutrino interactions

MeV DM behaves as Warm DM



Dark Matter-neutrino interactions

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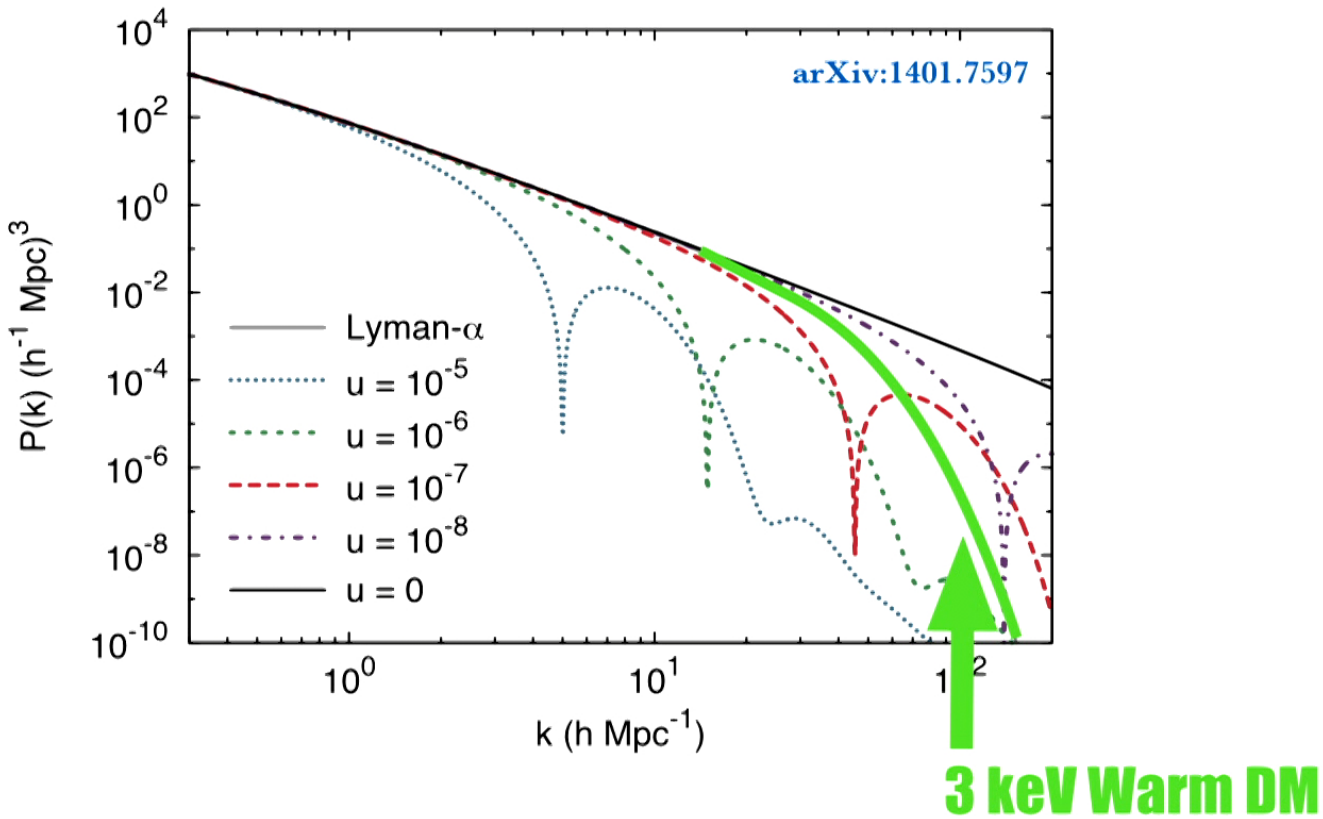
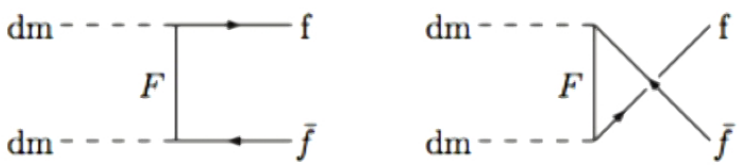


Can (Thermal) DM be lighter than a few GeVs?

astro-ph/0208458 hep-ph/0305261 "WIMPless miracle"

Inspired from SUSY but more general



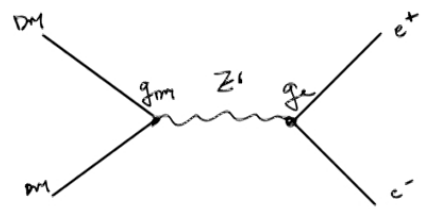
$$\sigma v \propto \frac{1}{m_F^4} \left((C_l^2 + C_r^2)\ m_f + 2 C_l\ C_r\ m_F \right)^2$$

$$\sigma v \propto \frac{1}{m_F^2}$$

mirror fermions

light DM is ok

Simplified model approach



$$\sigma v \propto v^2\ \frac{m_{\rm DM}^2}{m_{Z'}^4}\ g_{\rm DM}^2\, g_e^2$$

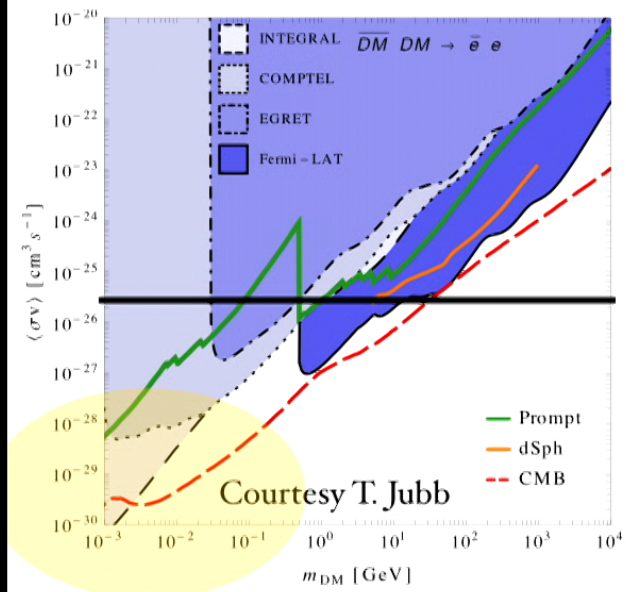
$$m_{\rm DM} \simeq m_{Z'}$$

dark photons/dark Z'

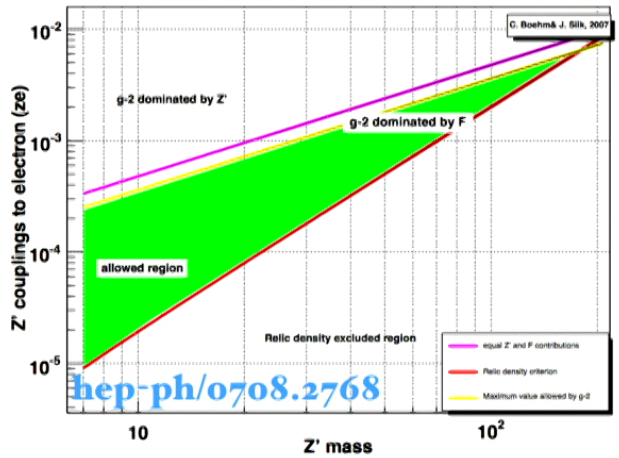
light DM is ok if light mediator

A few constraints

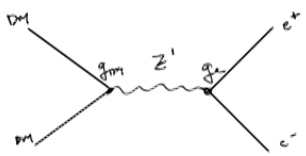
Gamma-rays Milky Way



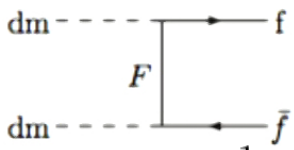
g-2 of electrons



better limits now for Z' !



$\sigma v \propto v^2$ **OK**



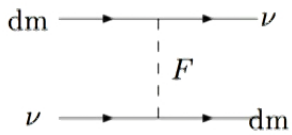
$\sigma v \propto \frac{1}{m_F^2}$

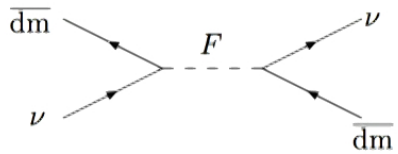
OK if suppressed unless f = nu

annihilations into neutrinos

Do these interactions help with the damping?

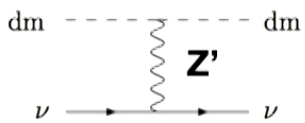
hep-ph/0305261





$$\sigma \propto T^2$$

unless... $m_{\rm DM} \simeq m_F$



nu-e experiments

ered for explaining the $g-2$). We can fit the mean value of CHARM II findings by imposing $u_l^\nu \sim u_l^e \sim [0.3, 0.6]\ \sqrt{1.5}\ 10^{-6}(m_{Z'}/\text{MeV})$ (no significant deviation from the Standard Model prediction should be detected if $u_l^\nu = u_l^e < 0.1\ \sqrt{1.5}\ 10^{-6}(m_{Z'}/\text{MeV})$).

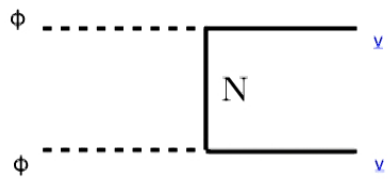
in both cases, it is hard to make the elastic scattering cross section large...

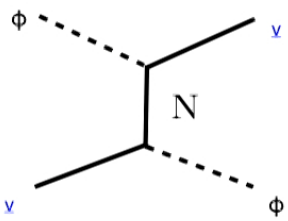
DM-neutrino interactions

Effective theory
(N singlet of SU(2) for example)

hep-ph/0612228

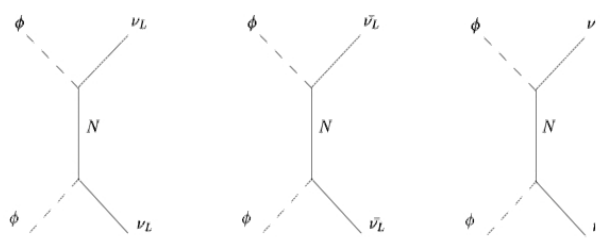
see realisation in arxiv:1512.08796

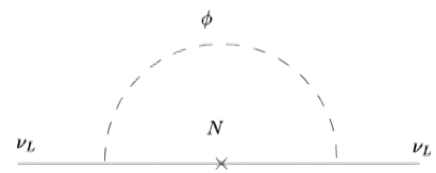




If thermal DM for example

$$\sigma_{\mathrm{DM}-\nu} \simeq 1.2\ 10^{-36} \left(\frac{m_N}{MeV}\right)^2 \left(\frac{\langle\sigma v\rangle}{3\ 10^{-26}\ \mathrm{cm}^3/\mathrm{s}}\right) \left(\frac{m_{\mathrm{DM}}}{MeV}\right)^{-2}\ \mathrm{cm}^2$$





With MeV DM ($m_N = m_{DM}$) one obtains

$$m_{\nu_L} \simeq \sqrt{\frac{\langle\sigma v_r\rangle}{128\,\pi^3}}\, m_N^2 (1 + m_\phi^2/m_N^2)\, \ln\left(\frac{\Lambda^2}{m_N^2}\right)$$

$$0.01\ \mathrm{eV} < m_\nu < 1\ \mathrm{eV}$$

DM-neutrino interactions ("expert" version)

arXiv:astro-ph/0112522

$$\dot{\theta}_b = k^2\psi - \mathcal{H}\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}(\theta_b - \theta_\gamma)$$
$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) - \dot{\kappa}(\theta_\gamma - \theta_b)\,,$$
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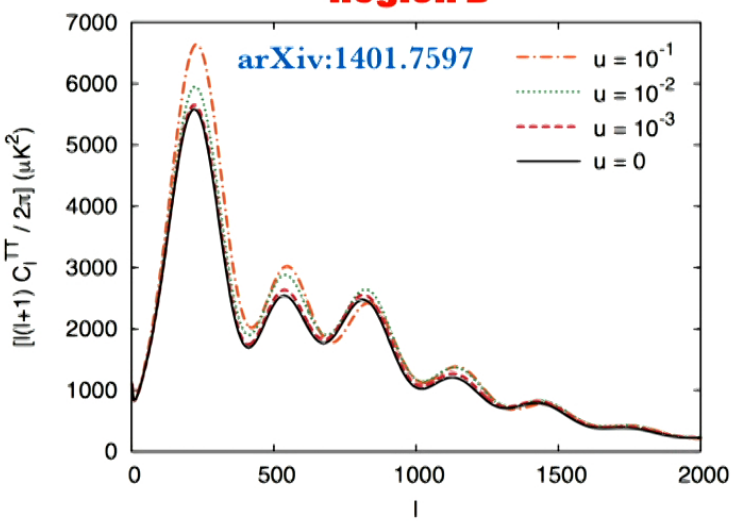
$$\dot{\theta}_{DM} = k^2\psi - \mathcal{H}\theta_{DM} - S^{-1}\dot{\mu}(\theta_{DM} - \theta_\gamma)\,.$$

arXiv:astro-ph/0606190,
arXiv:0911.4411,
arXiv:1209.5752, ...

$$\dot{\theta}_\nu = k^2\psi + k^2\left(\frac{1}{4}\delta_\nu - \sigma_\nu\right) - \dot{\mu}(\theta_\nu - \theta_{DM})\,,$$
$$\dot{\theta}_{DM} = k^2\psi - \mathcal{H}\theta_{DM} - S^{-1}\dot{\mu}(\theta_{DM} - \theta_\nu)\,,$$

Region B



Region c of mixed damping still to be probed

Impact on cosmological parameters

DM-nu interactions arXiv:1401.7597

CMB alone

	$100\,\Omega_b h^2$	$\Omega_{DM} h^2$	$100\,h$	$10^{+9}\,A_s$	n_s	z_{reio}	N_{eff}	$10^{+2}\,u$	$10^{+13}\,u_0$
No interaction	$2.205^{+0.028}_{-0.028}$	$0.1199^{+0.0027}_{-0.0027}$	$67.3^{+1.2}_{-1.2}$	$2.196^{+0.051}_{-0.060}$	$0.9603^{+0.0073}_{-0.0073}$	$11.1^{+1.1}_{-1.1}$	(3.046)	–	–
	$2.238^{+0.041}_{-0.041}$	$0.1256^{+0.0055}_{-0.0055}$	$70.7^{+3.2}_{-3.2}$	$2.251^{+0.069}_{-0.085}$	$0.977^{+0.016}_{-0.016}$	$11.6^{+1.3}_{-1.3}$	$3.51^{+0.39}_{-0.39}$	–	–
$\sigma_{DM-\nu}$ constant	$2.225^{+0.029}_{-0.033}$	$0.1211^{+0.0027}_{-0.0030}$	$69.5^{+1.2}_{-1.2}$	$2.020^{+0.063}_{-0.065}$	$0.9330^{+0.0104}_{-0.0095}$	$10.8^{+1.1}_{-1.1}$	(3.046)	< 3.99	–
	$2.276^{+0.043}_{-0.048}$	$0.1299^{+0.0059}_{-0.0061}$	$75.0^{+3.4}_{-3.7}$	$2.086^{+0.068}_{-0.089}$	$0.956^{+0.017}_{-0.016}$	$11.6^{+1.2}_{-1.3}$	$3.75^{+0.40}_{-0.43}$	< 3.27	–
$\sigma_{DM-\nu} \propto T^2$	$2.197^{+0.028}_{-0.028}$	$0.1197^{+0.0027}_{-0.0027}$	$67.8^{+1.2}_{-1.2}$	$2.167^{+0.052}_{-0.059}$	$0.9527^{+0.0086}_{-0.0085}$	$10.8^{+1.1}_{-1.1}$	(3.046)	–	< 0.54
	$2.262^{+0.042}_{-0.046}$	$0.1326^{+0.0065}_{-0.0072}$	$75.3^{+3.6}_{-4.0}$	$2.257^{+0.072}_{-0.084}$	$0.981^{+0.017}_{-0.017}$	$11.9^{+1.3}_{-1.4}$	$4.07^{+0.46}_{-0.52}$	–	< 2.56

Planck

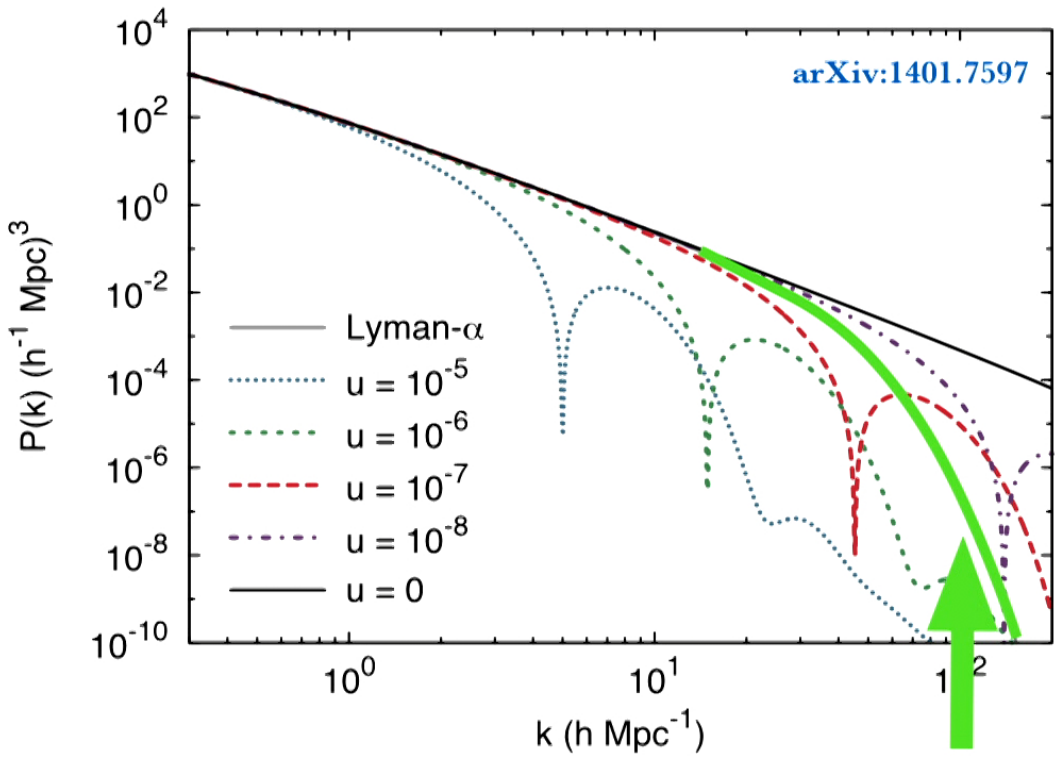
H0 changes because of the additional source of damping!

Could this be the reason why independent measurements of Ho are inconsistent with CMB measurements?

Technically still LCDM!

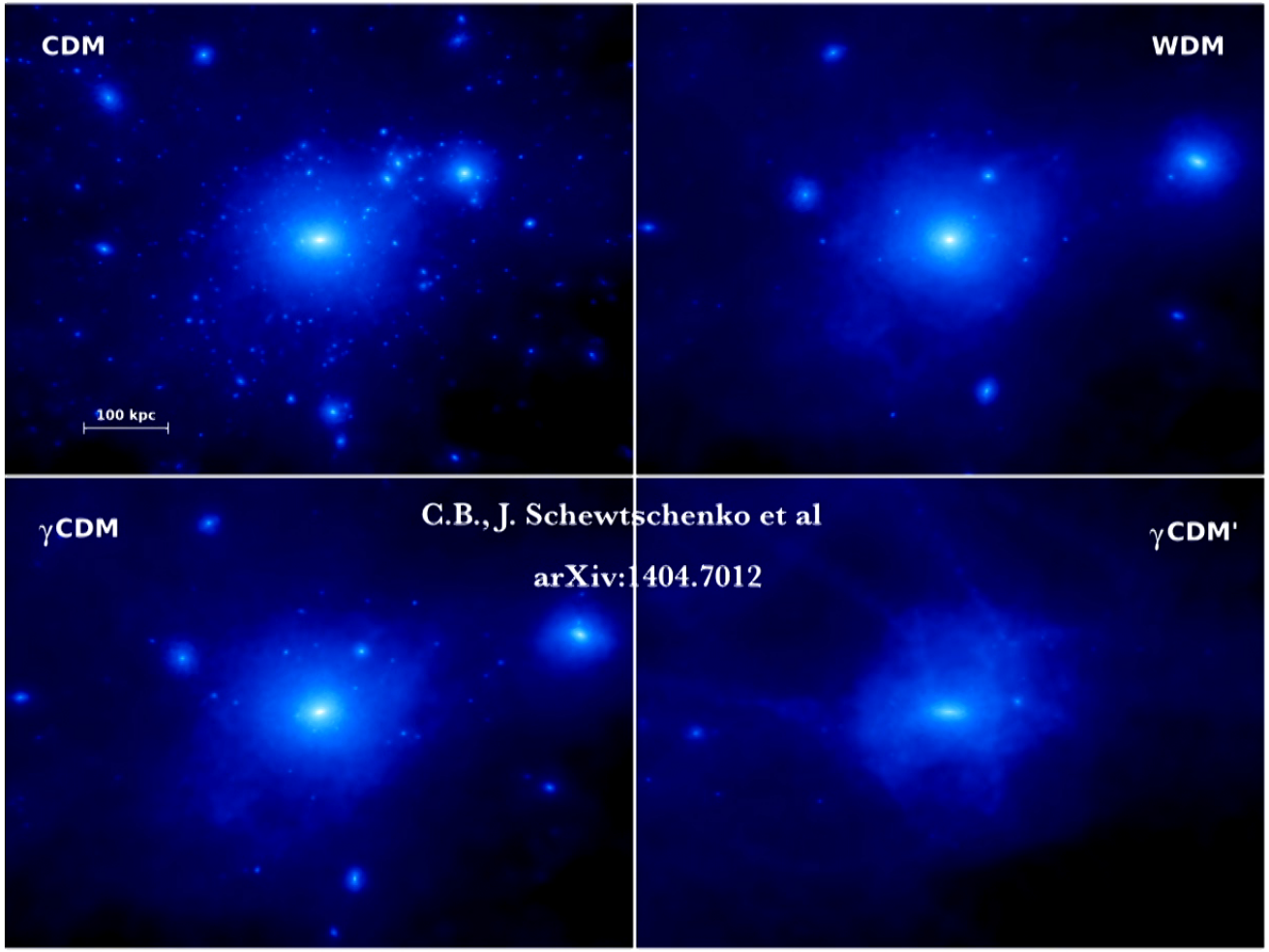
Dark Matter-neutrino interactions

MeV DM behaves as Warm DM



Region B

3 keV Warm DM

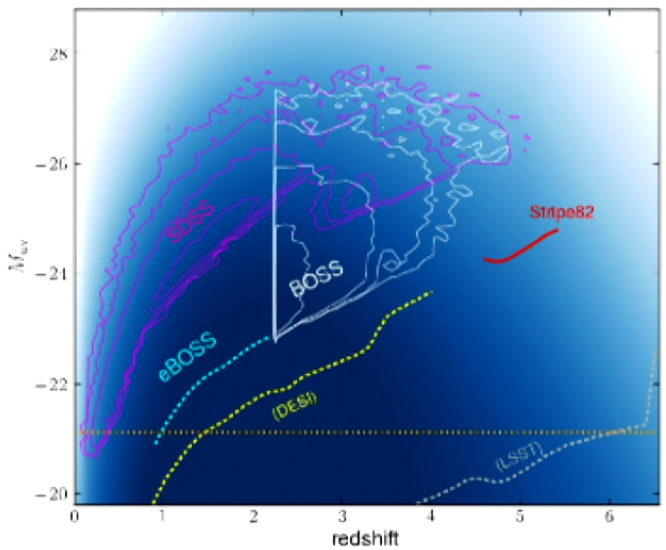


C.B., J. Schewtschenko et al

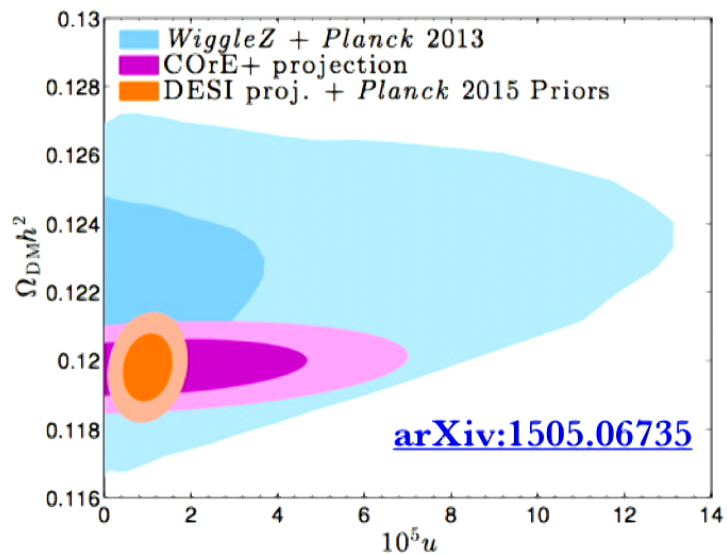
arXiv:1404.7012

$$\sigma_{\mathrm{DM}-\gamma} \lesssim 10^{-33} \left(\frac{m_{\mathrm{DM}}}{\mathrm{GeV}}\right) \mathrm{cm}^2$$

Detection prospects

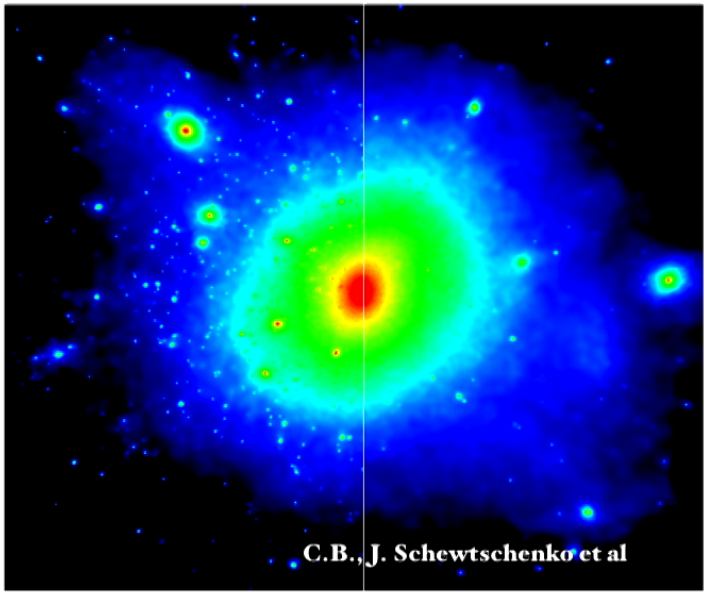


Courtesy JP Kneib

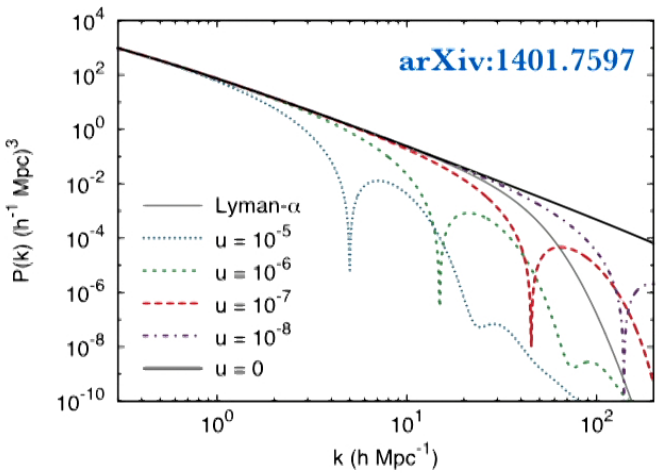


With DESI we gain a factor 10 for the DM-photon interactions

DESI and LSST will set strong bounds (stronger than CMB)



Smaller sigma_8



arXiv:1512.06774 arXiv:1412.4905

Higher H0 so looks like a way to reconcile CMB and strong lensing

Structure formation severely constrains such primordial DM interactions!

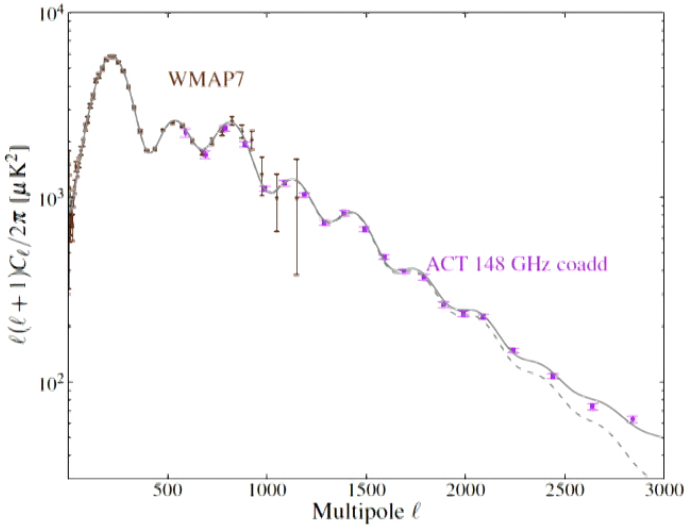
	$100\,\Omega_b h^2$	$\Omega_{DM} h^2$	$100\,h$	$10^{+9} A_s$	n_s	z_{reio}	N_{eff}
Lyman-α limit	$2.246^{+0.039}_{-0.042}$	$0.1253^{+0.0053}_{-0.0056}$	$71.5^{+3.0}_{-3.3}$	$2.254^{+0.069}_{-0.082}$	$0.979^{+0.016}_{-0.016}$	$11.7^{+1.2}_{-1.3}$	$3.52^{+0.36}_{-0.40}$

Looks good doesn't it?

	$100\,\Omega_b h^2$	$\Omega_{DM} h^2$	$100\,h$	$10^{+9}\,A_s$	n_s	z_{reio}	N_{eff}
Lyman-α limit	$2.246^{+0.039}_{-0.042}$	$0.1253^{+0.0053}_{-0.0056}$	$71.5^{+3.0}_{-3.3}$	$2.254^{+0.069}_{-0.082}$	$0.979^{+0.016}_{-0.016}$	$11.7^{+1.2}_{-1.3}$	$3.52^{+0.36}_{-0.40}$

uhmm... can't reproduce high value of Ho anymore because the CMB data improved!

- sigma_8 still but Lyman alpha
- suppression of power
- but same Ho as Planck

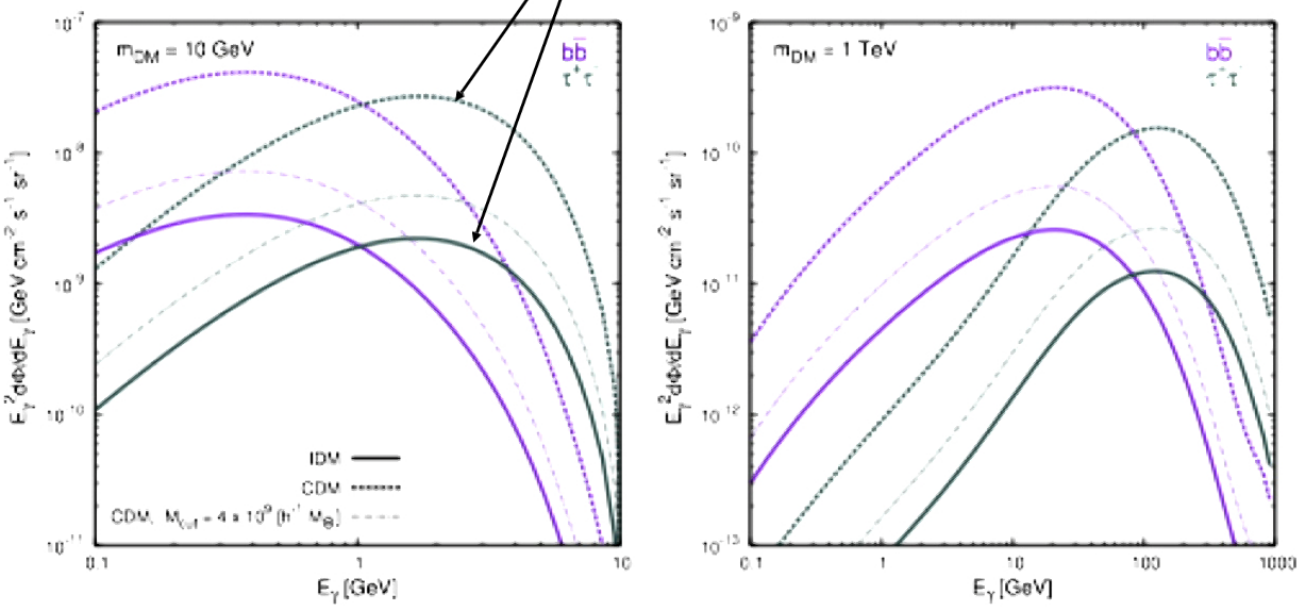


DM indirect detection searches

Extragalactic gamma-ray signal: damping + annihilations

wo/with damping

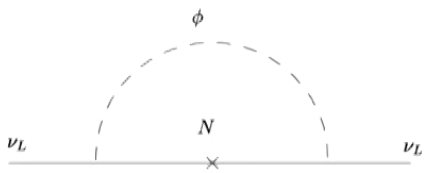
arXiv:1602.07282



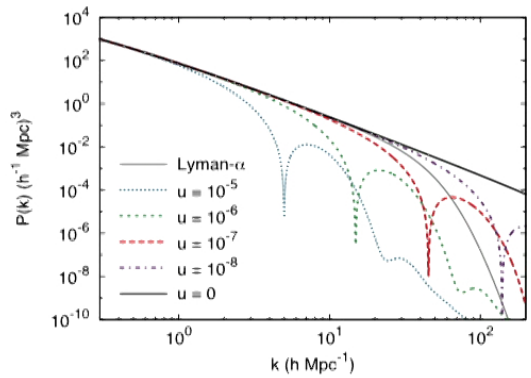
Same signal as in LCDM but suppressed
so one could mistaken the damping effect with a smaller annihilation cross section

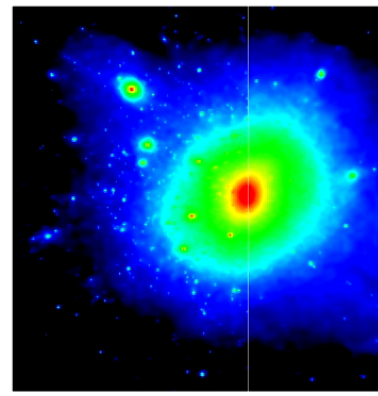
Conclusions

Interest in DM-nu because



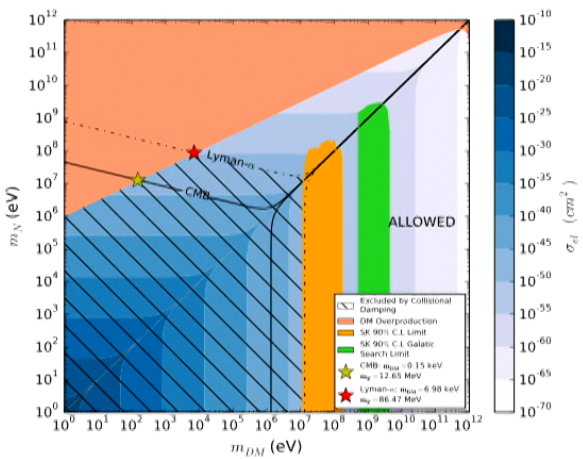
neutrino masses





lower sigma-8 suppression of sat

got excited by Ho but ...



At least can be used to constrain some models