Tight Bonds between Sterile Neutrinos and Dark Matter

Jasper Hasenkamp (NYU)

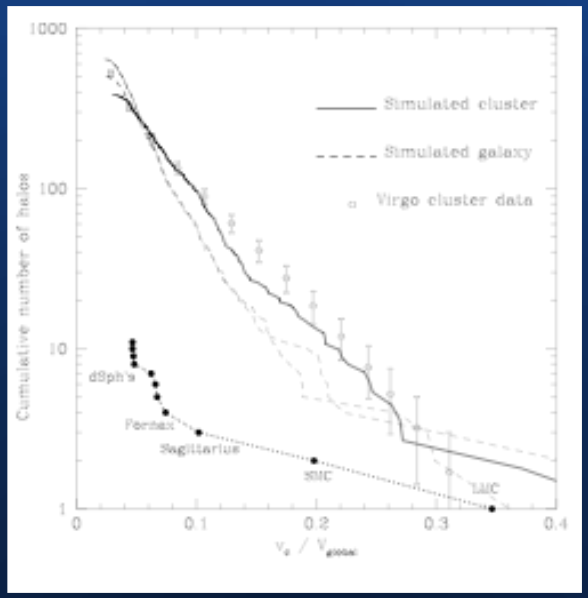
@ DESY Theory Workshop 2014

Based on JH, Bringmann & Kersten, 1312.4947 (JCAP),
Jan Hamann & JH, 1308.3255 (JCAP)
and JH, 1405.6736 (JCAP).

Small-scale Problems

LCDM astonishing success on cosmic scales – not so impressive on galactic scales:

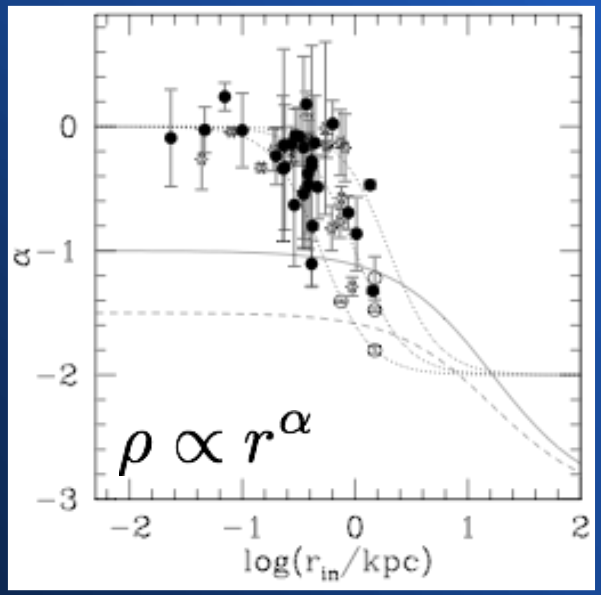
1. Missing satellites?



Moore *et al.*, ApJ '99

many more satellites in simulations than observed

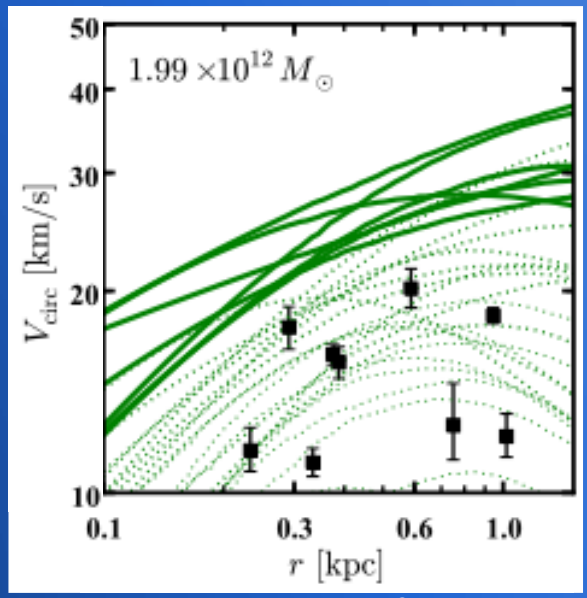
2. Cusps or cores?



Blok *et al.*, ApJ '01

cuspy inner density profiles in simulations not found in (all) observations

3. Too big to fail?



Boylan-Kolchin, Bullock & Kaplinghat, '11

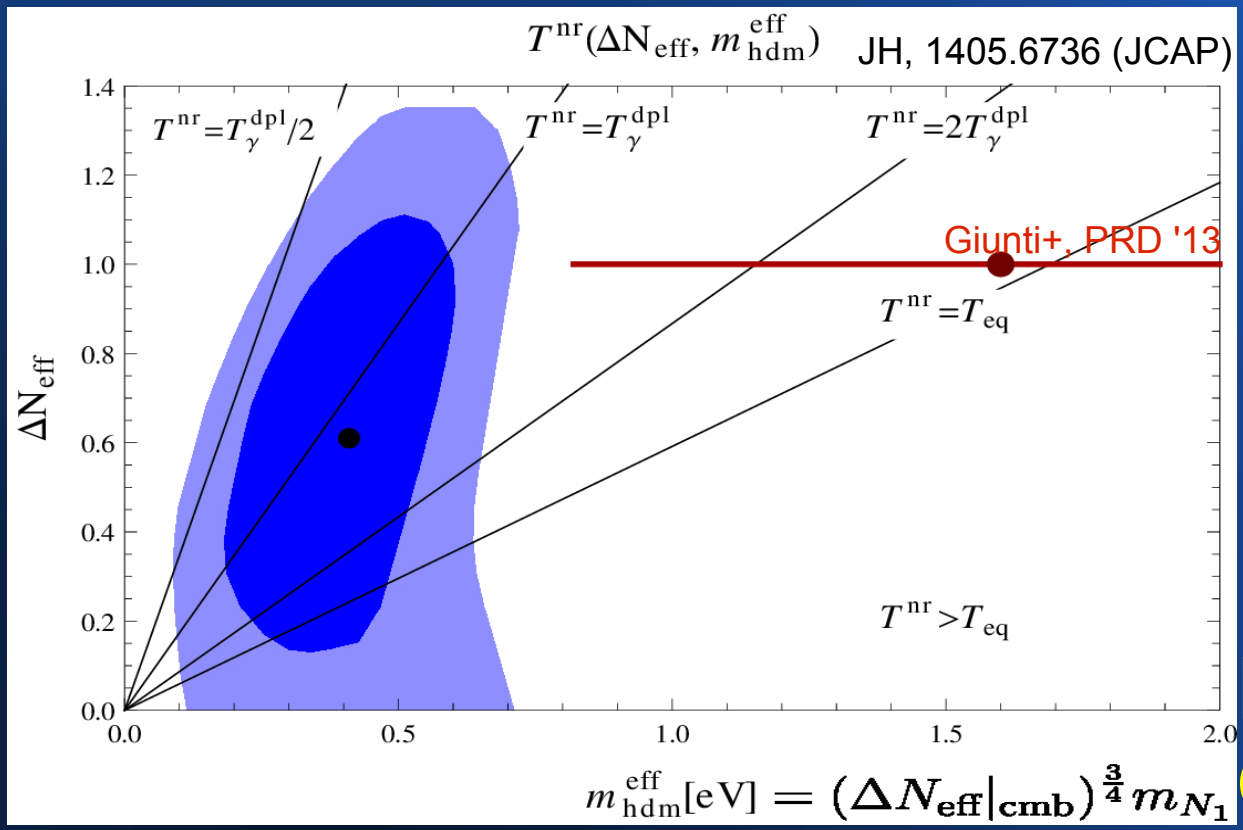
most massive subhalos in simulations too dense to form observed brightest dwarfs

New Life for Sterile Neutrinos ?

between cosmic and galactic scales – galaxy clusters... and more! e.g. Sunyaev's talk

1D posteriors: $\Delta N_{\rm eff} = 0.61 \pm 0.30$ $m_{\rm eff}^{\rm hdm} = (0.41 \pm 0.13)$ eV

JH & Hamann, JCAP '13
see also Wayne Hu et al. and Battaye & Moss, both PRL'14



Signal data-dependent:

- galaxy cluster – mass
- H0 – dark radiation
- WL – both
- CMB sensitivity (very) limited: physically(!) not statistically – new era of precision on HDM

Precision era: Qualitatively new HDM

What could/should it be? Can we ever tell? → JH, JCAP'14

U(1)x Model

$$G = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_X$$

particle	V	χ	ν_{R_1}	ν_{R_2}	Θ	ξ
charge	0	1	X	-X	2 X	X

- Symmetry broken by VEV

$$246\ \text{GeV} \simeq v_{\text{ew}} \gg v_\Theta \sim \ \text{MeV} \gg v_\xi$$

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_R + \mathcal{L}_x + \mathcal{L}_{\text{kin. mix.}} + \mathcal{L}_{\text{Higgs}}$$

$$\mathcal{L}_R \supset -\frac{1}{2}\overline{\nu_{R_1}^c} M_1 \nu_{R_1} - \frac{1}{2}\overline{\nu_{R_2}^c} M_2 \nu_{R_2} - \overline{\nu_{R_1}^c} M_{RR} \nu_{R_2} - \overline{\nu_L} M_{LR} \nu_{R_1} + \text{h.c.}$$

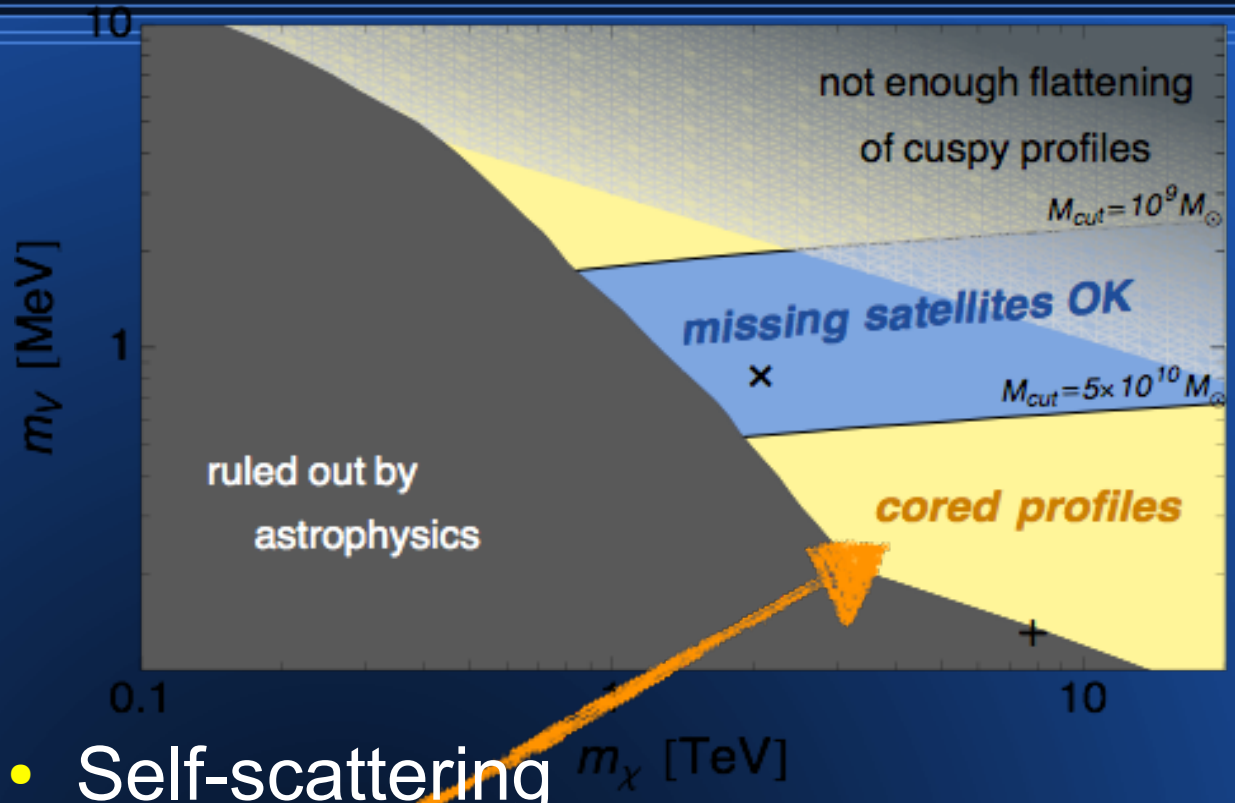
$$(\nu_e, \nu_\mu, \nu_\tau, \nu_{R_1}^c, \nu_{R_2}^c) \Rightarrow (\nu_1, \nu_2, \nu_3, N_1, N_2)$$

$$\mathcal{L}_x = \bar{\chi}(i\partial\!\!\!/ - m_\chi)\chi - \frac{1}{4}F^x_{\mu\nu}F^{x\mu\nu} - \frac{1}{2}m_V^2 V_\mu V^\mu - g_X V_\mu \left(X_{\nu_R}\overline{\nu_{R_1}}\gamma^\mu \nu_{R_1} - X_{\nu_R}\overline{\nu_{R_2}}\gamma^\mu \nu_{R_2} + \bar{\chi}\gamma^\mu\chi\right)$$

- Thermalisation via Higgs portal

$$\mathcal{L}_{\text{Higgs}} \supset \kappa|\phi|^2|\Theta|^2 \supset \frac{\kappa}{4} v_\phi \phi \Theta^2 \simeq \frac{\kappa}{4} v_\phi h h_x^2$$

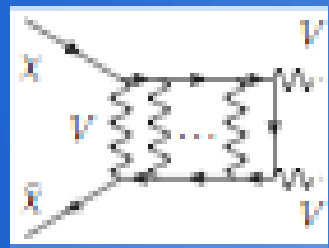
Self-Interacting Dark Matters



- Kinetic decoupling
  Bringmann, PRL '12

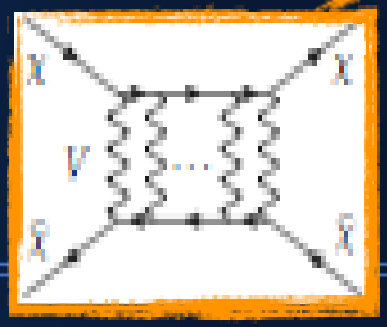
  - temperatures
  - charges

- Freeze-out



$$\Omega_{\rm calm} h^2 = 2\,\Omega_\chi h^2 \sim 0.11 \left(\frac{0.67}{g_\chi}\right)^4 \left(\frac{m_\chi}{\rm TeV}\right)^2$$

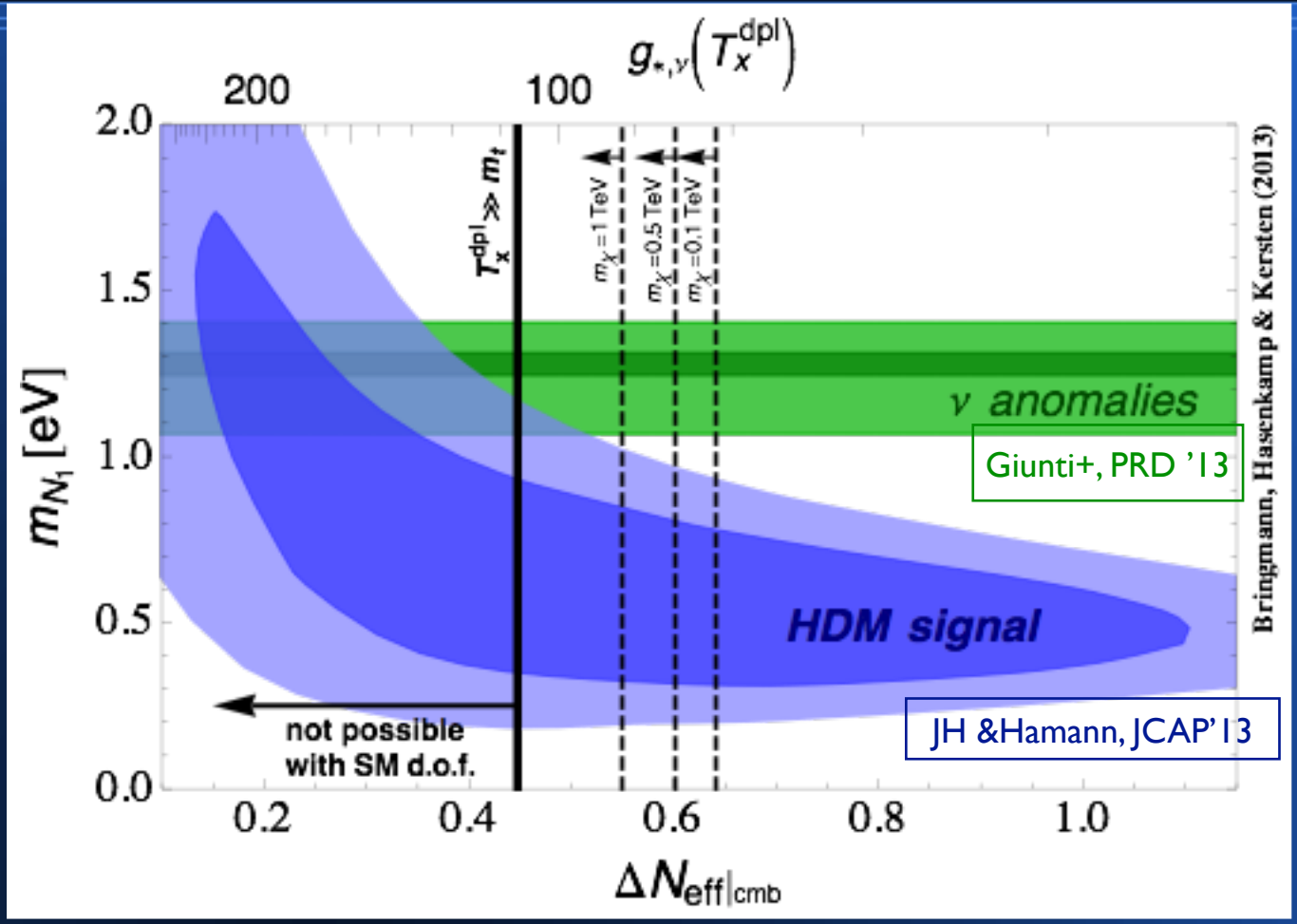
- Self-scattering



- Yukawa-interacting CDM
  Loeb & Weiner, PRL '11

ALL small-scale problems
SIMULTANEOUSLY

Hot Dark Matter Admixture



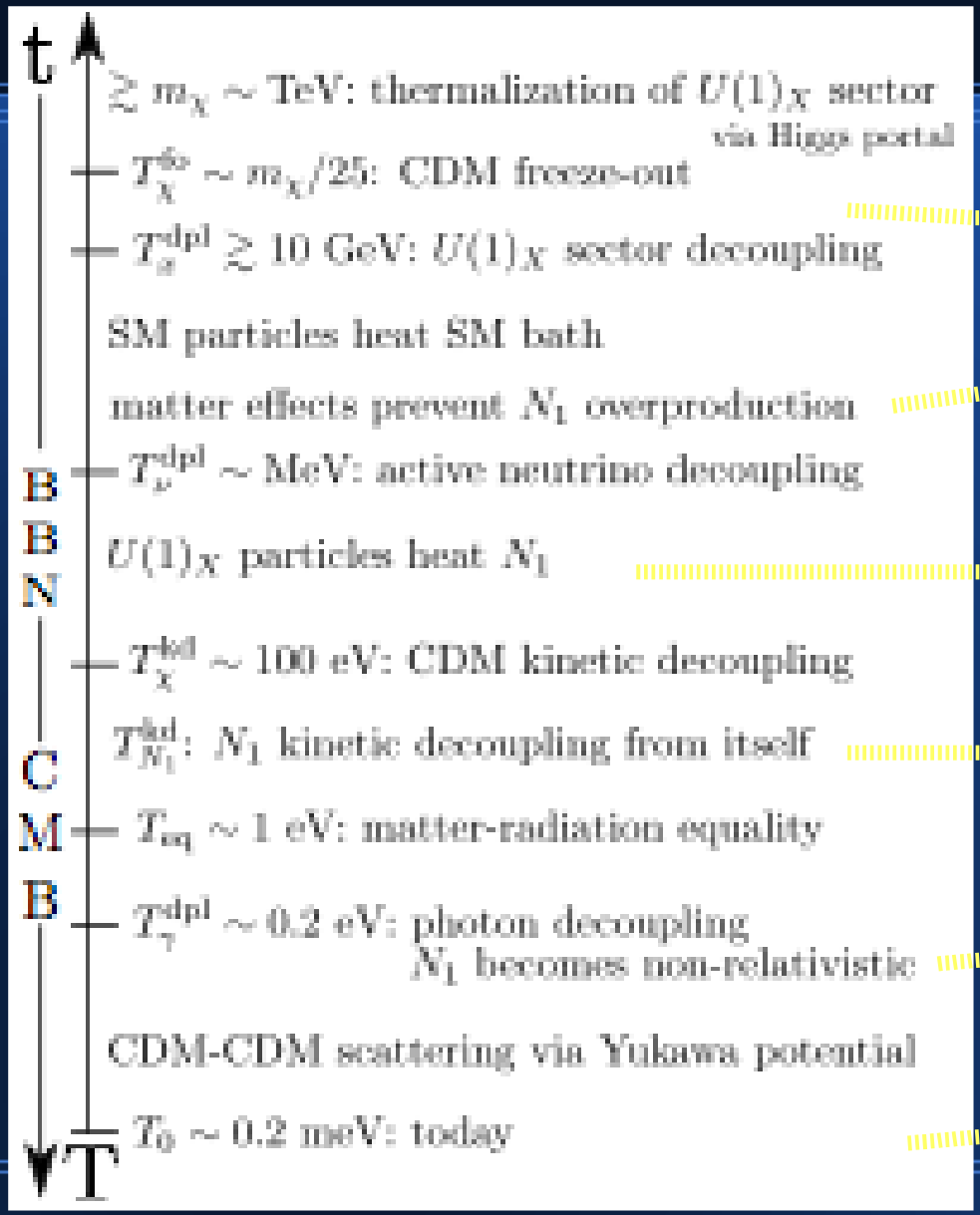
$$\Delta N_{\rm eff}|_{\rm cmb} = \Delta N_{\rm eff}|^{\rm max}_{\rm bbn} \simeq \left[58.4/g_{*,\nu}(T_x^{\rm dpl})\right]^{\frac{4}{3}}$$

Sterile neutrinos form deserved HDM naturally

AND

may explain the observed neutrino anomalies

Cosmology overview



more features:

- simplest case – no necessity
- neutrino mixing angles FREE to fit anomaly data
  Dasgupta & Kopp PRL '14
  Hannestad, Hansen & Tram PRL '14
  see also Ninetta Saviano's talk!
- increase in radiation density AFTER BBN – promising
- early enough – eventhough fix
- reminder: qualitatively new HDM
- unstable sterile neutrino

Conclusion & Outlook

All small-scale and an intermediate-scale structure formation problem solved by solution to neutrino anomalies!

Bottom up approach – cover minimal(!?) phenomenology → UV completion missing!

- $(\nu_e, \nu_\mu, \nu_\tau, \nu^c_{R_1}, \nu^c_{R_2}) \Rightarrow (\nu_1, \nu_2, \nu_3, N_1, N_2)$ → CMB, supernovae,...
- better dark sector? → dark sector-SM connections!? → different phenomenology
- … → better ideas wanted ;-)

Conclusion & Outlook

All small-scale and an intermediate-scale structure formation problem solved by solution to neutrino anomalies!

Thank you for your attention!

Questions/Comments are welcome