Tight Bonds between Sterile Neutrinos and Dark Matter

Jasper Hasenkamp (NYU)

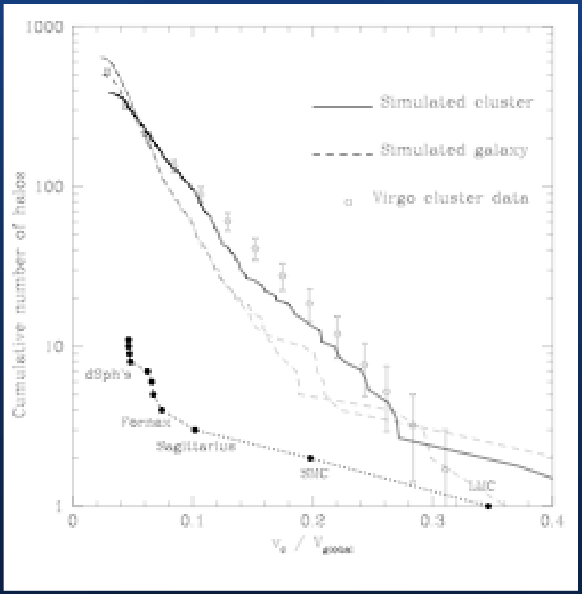
at COSMO 2014 in Chicago

Based on JH, Torsten Bringmann & Jörn Kersten, 1312.4947 (JCAP)

Small-scale Problems

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

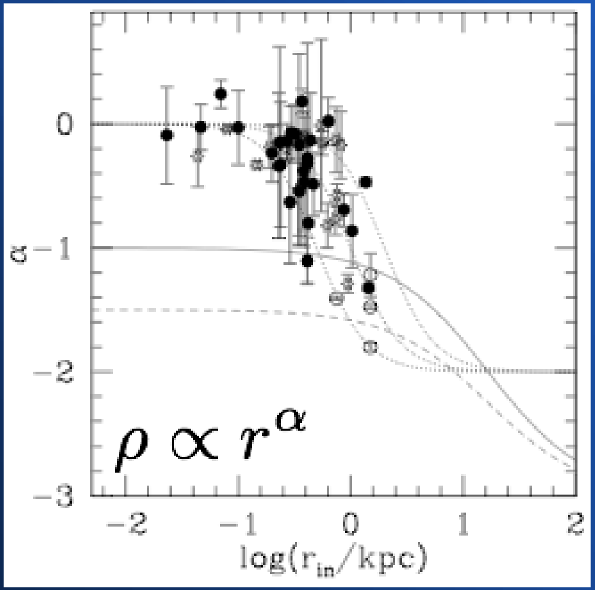
1. Missing satellites?



Moore *et al.*, ApJ '99

many more satellites in simulations than observed

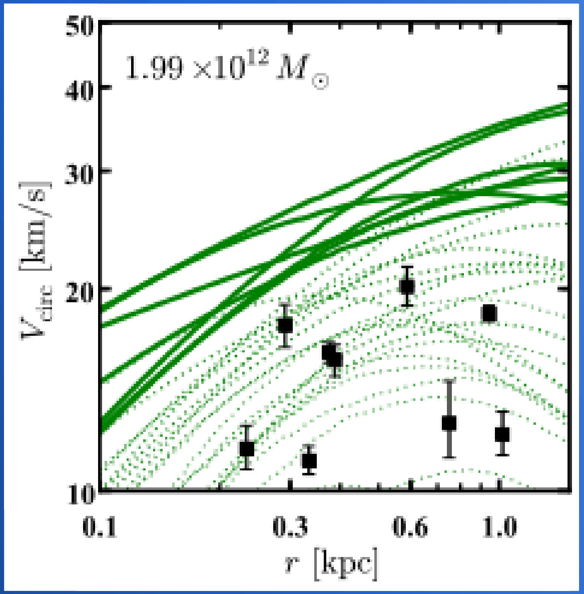
2. Cusps or cores?



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

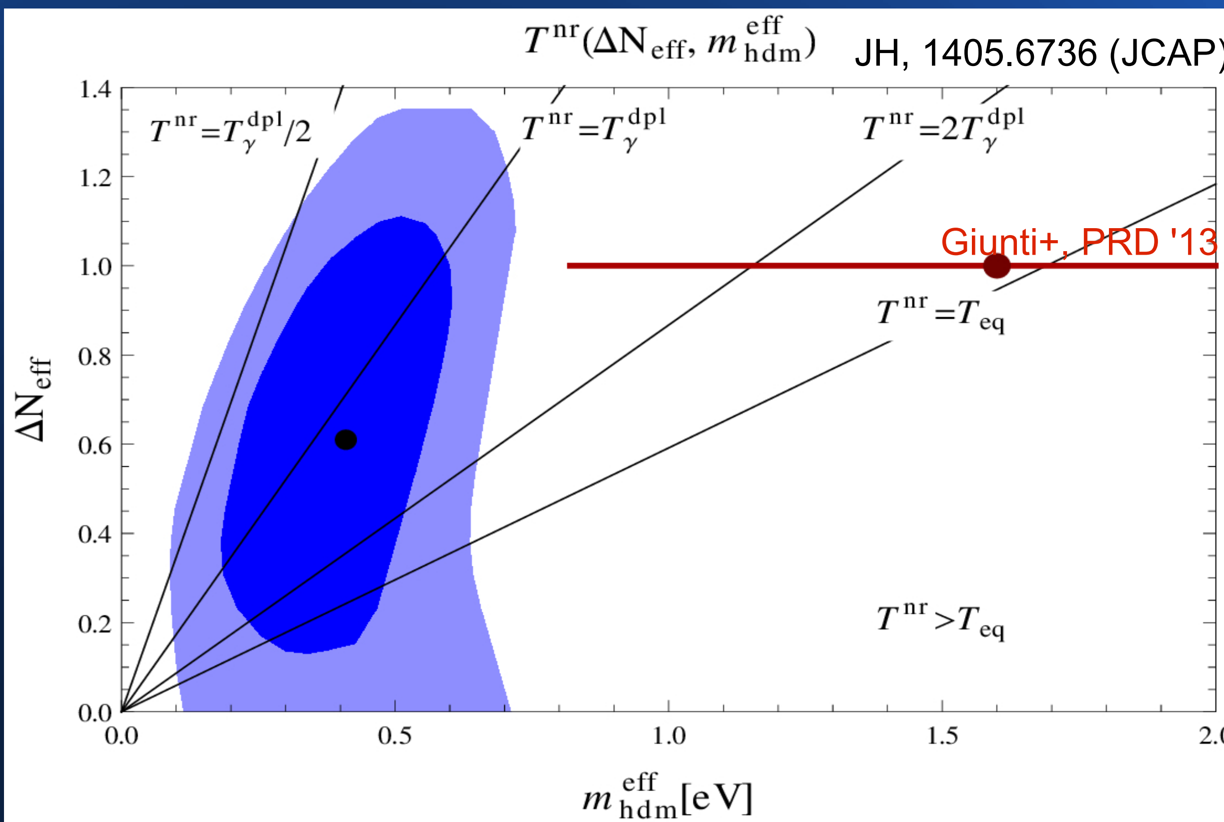
most massive subhalos in simulations too dense to form observed brightest dwarfs

New Life for Sterile Neutrinos

between cosmic and galactic scales – galaxy clusters and high vs. low redshift:

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



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,1405.6736

U(1)x Model

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

- Symmetry broken by VEV

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

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

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

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

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

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

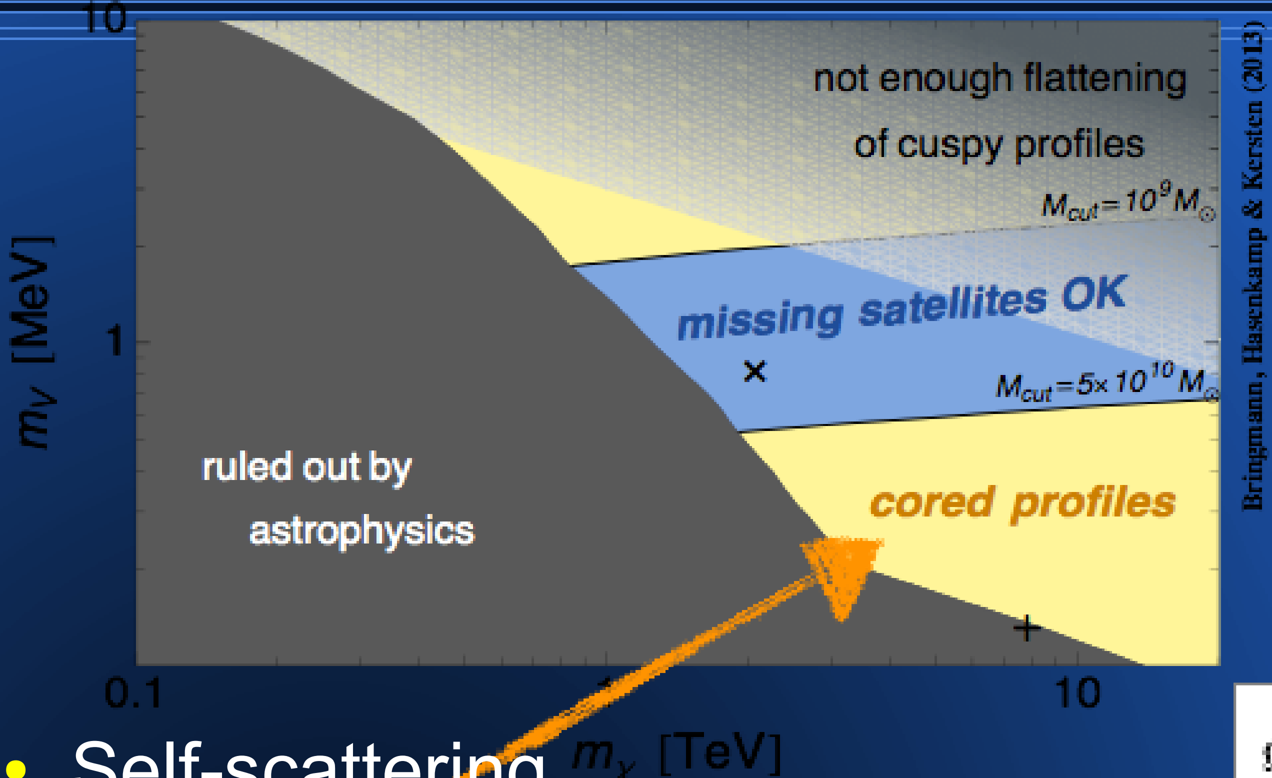
- tight constraints

$$\mathcal{L}_{\text{kin. mix.}} = -\frac{\epsilon}{2}F^x_{\mu\nu}F^{\mu\nu}$$

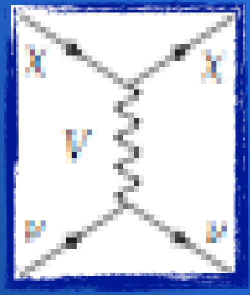
- Thermalisation via Higgs portal

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

Self-Interacting Dark Matters

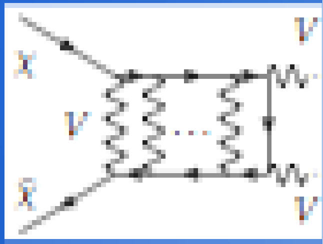


- Kinetic decoupling
  Bringmann, PRL '12



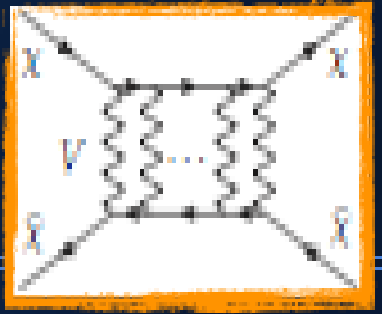
  - temperatures
  - charges

- Freeze-out



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

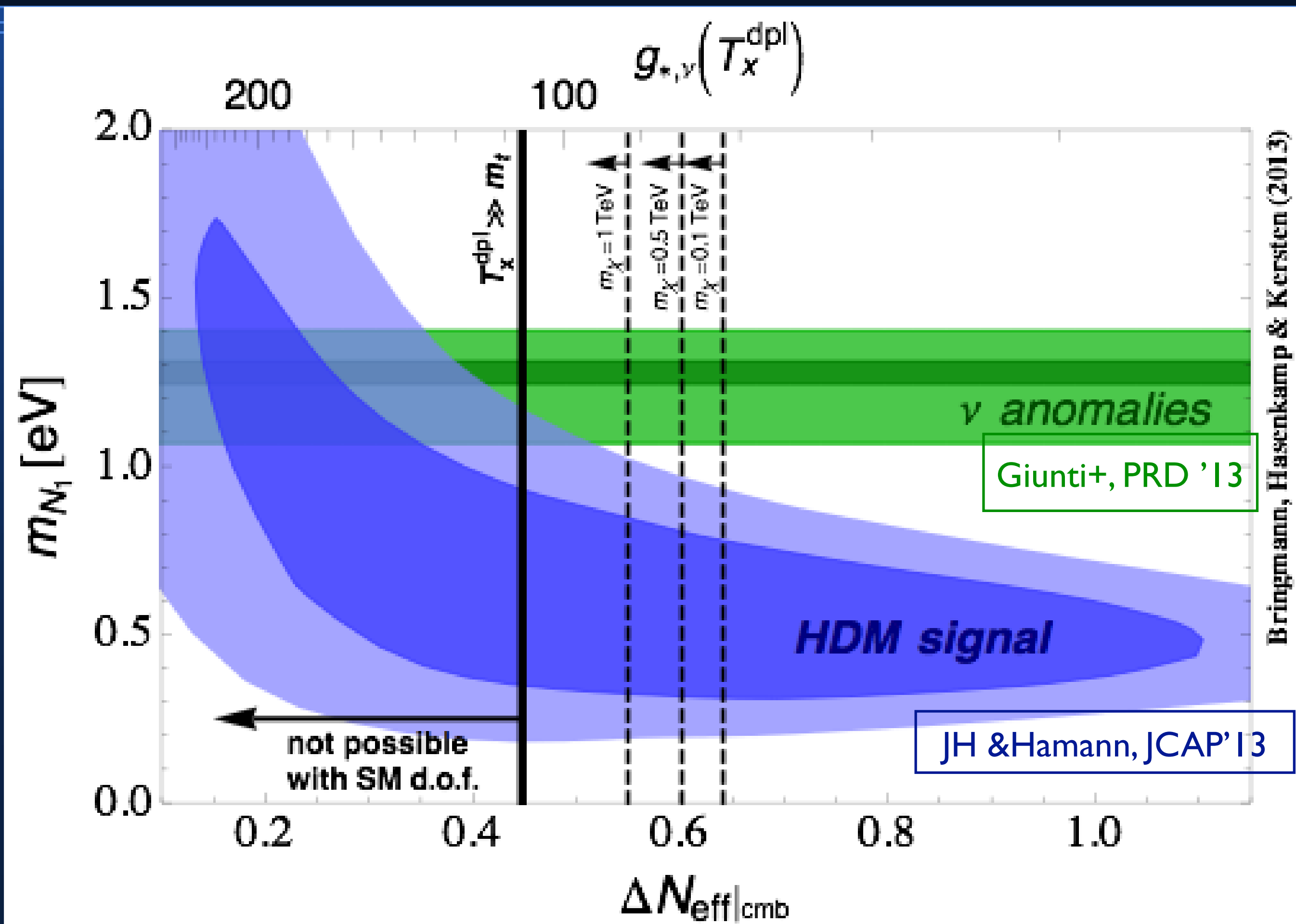
- Self-scattering



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

ALL small-scale problems
SIMULTANEOUSLY

the Hot Dark Matter Admixture



Sterile neutrinos form deserved HDM naturally

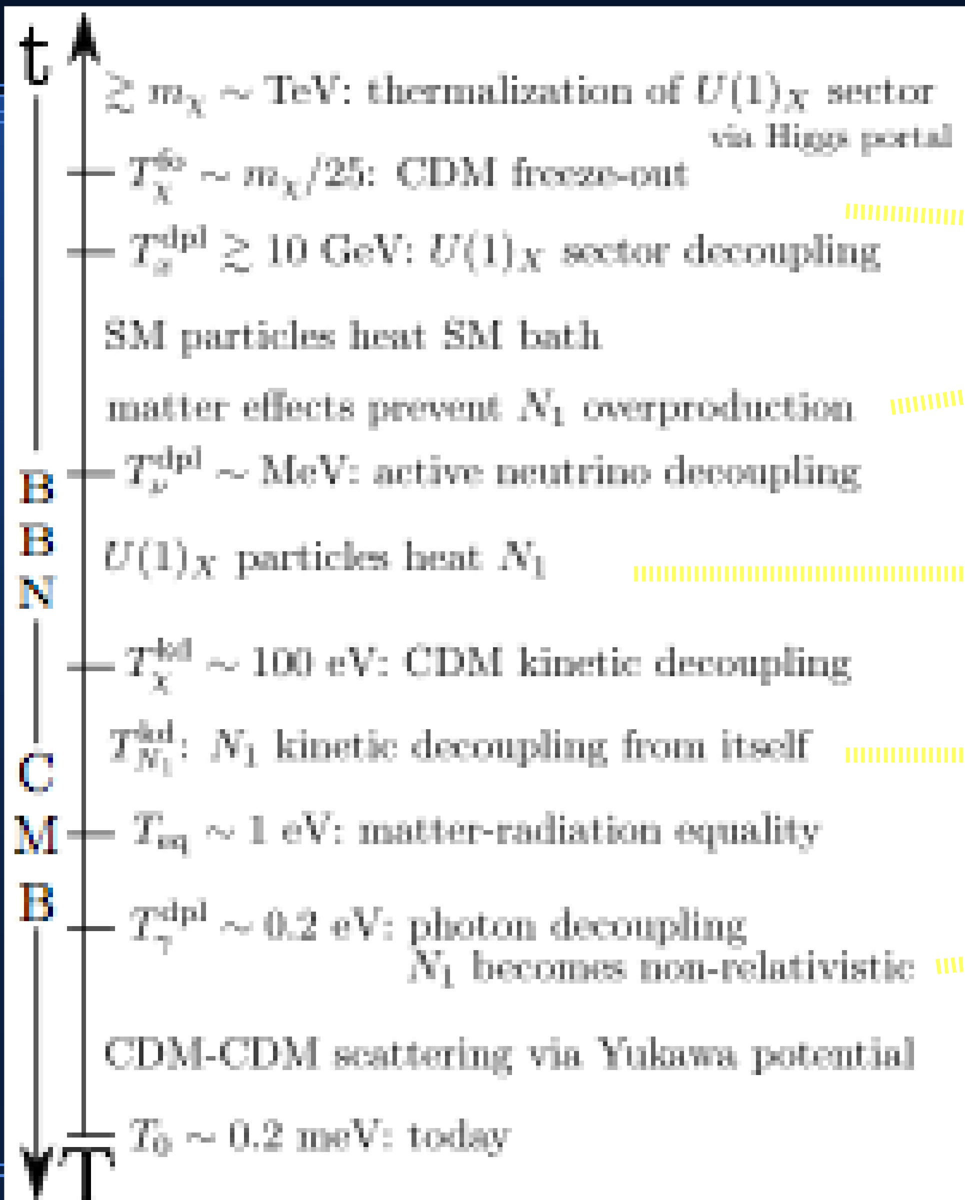
AND

may explain the observed neutrino anomalies

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

$$m^{\rm eff}_{\rm hdm} \equiv \left[T_{N_1}/T_\nu^{\Lambda\rm CDM}\right]^3 m_{N_1} = (\Delta N_{\rm eff}|_{\rm cmb})^{\frac{3}{4}} m_{N_1}$$

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
- increase in radiation density AFTER BBN – promising
- early enough – eventhough fix
- reminder: qualitatively new HDM

sterile neutrino unstable – no impact?

Conclusion & Outlook

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

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 ;-)

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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 :)