THE STATUS OF WARM DARK MATTER

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Dark matter in the galaxy workshop, MITP, May 2016

GRAPPA

GRavitation AstroParticle Physics Amsterdam

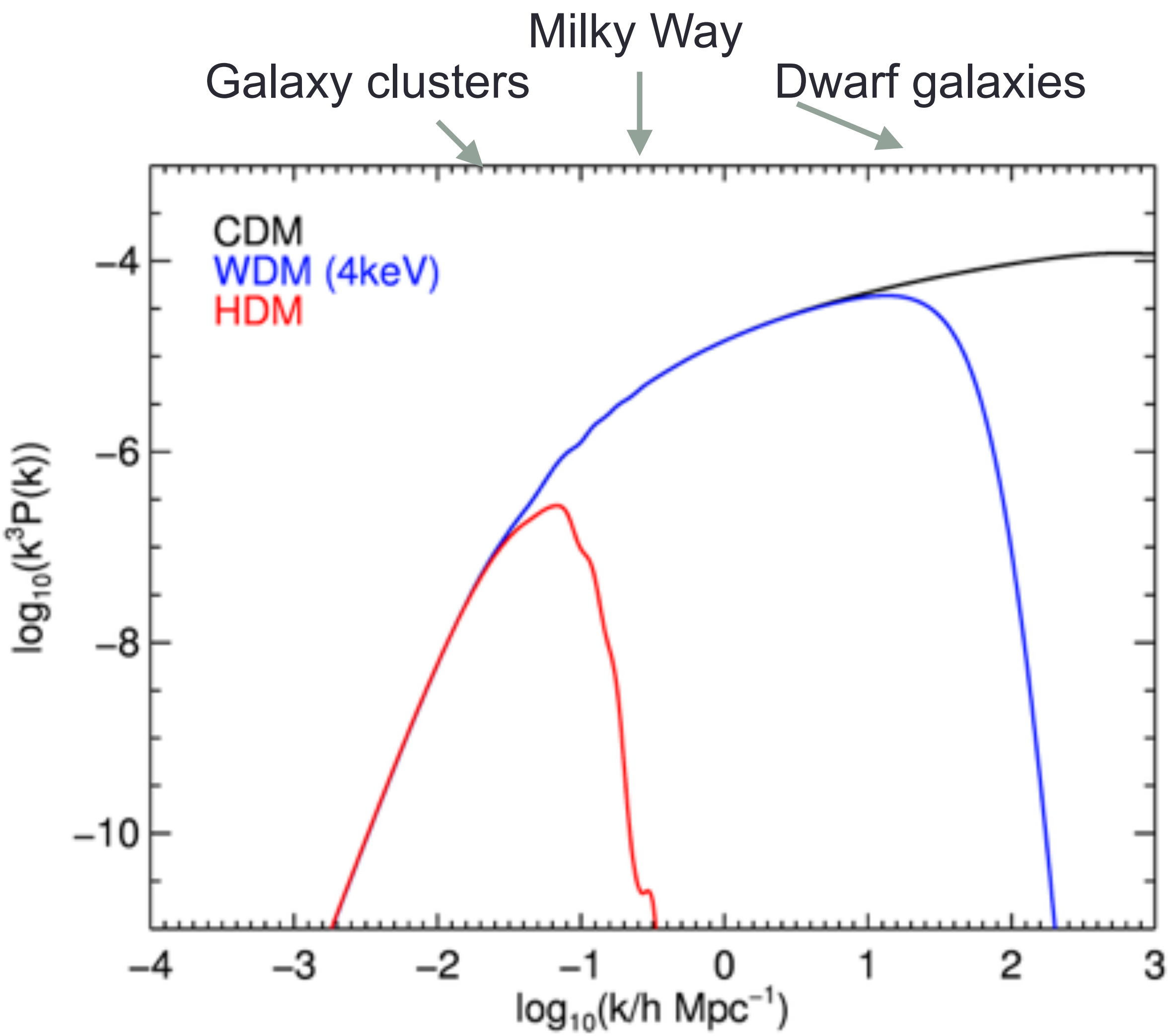
The status of warm dark matter is that it’s…

- Intriguing
- Compatible with current astrophysical bounds
- Incredibly hard to disentangle from astrophysical processes (supernova feedback, intergalactic medium thermal history…)

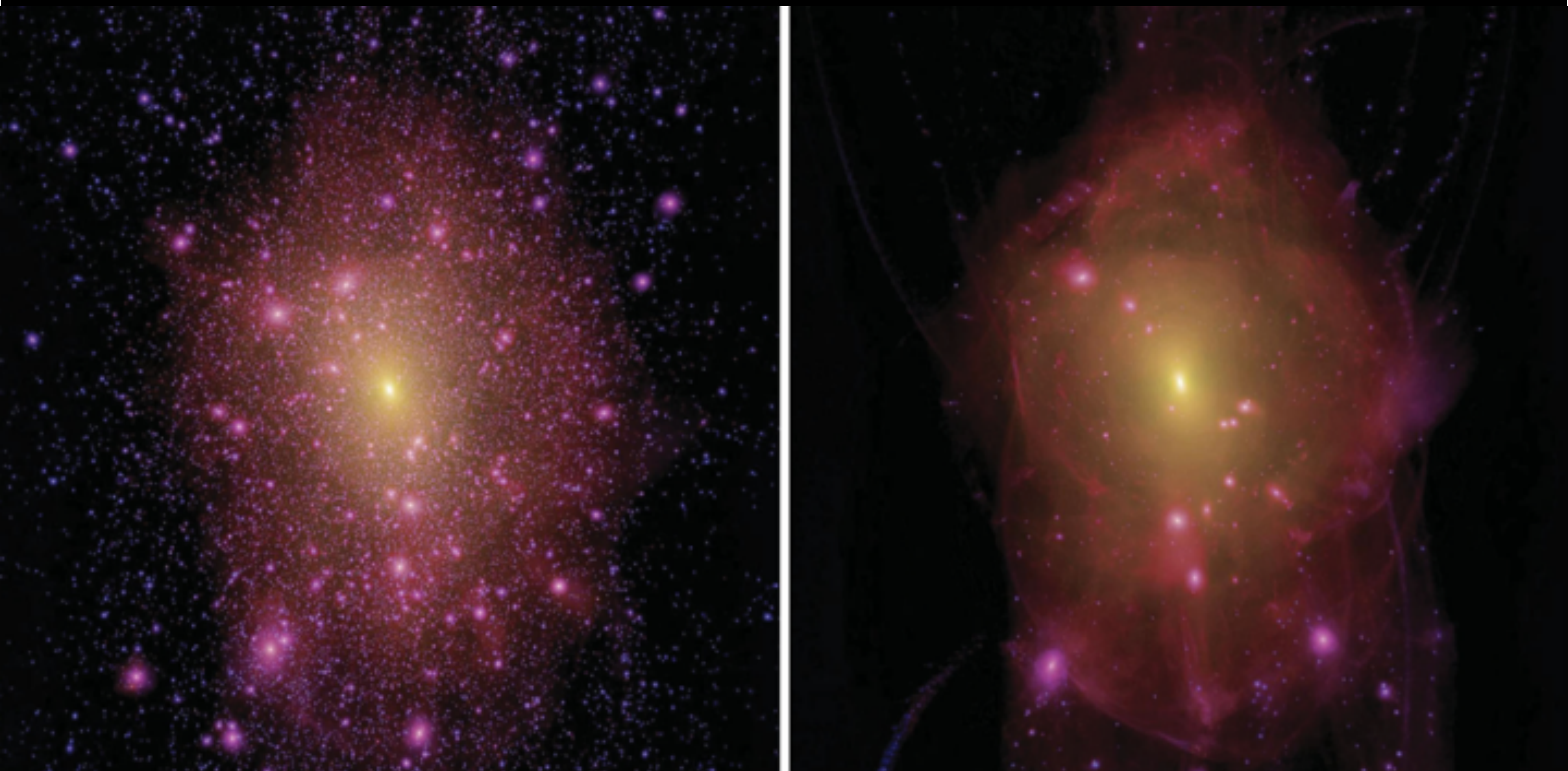
What is warm dark matter (WDM)?

- **WDM** is an **astrophysics-motivated** toy model which **suppresses the number** of **small** dark matter haloes **(<10^{10}M$_{sun}$)**

- It is an approximation to **physically motivated** models such as **keV thermal relics** and **sterile neutrino dark matter.**

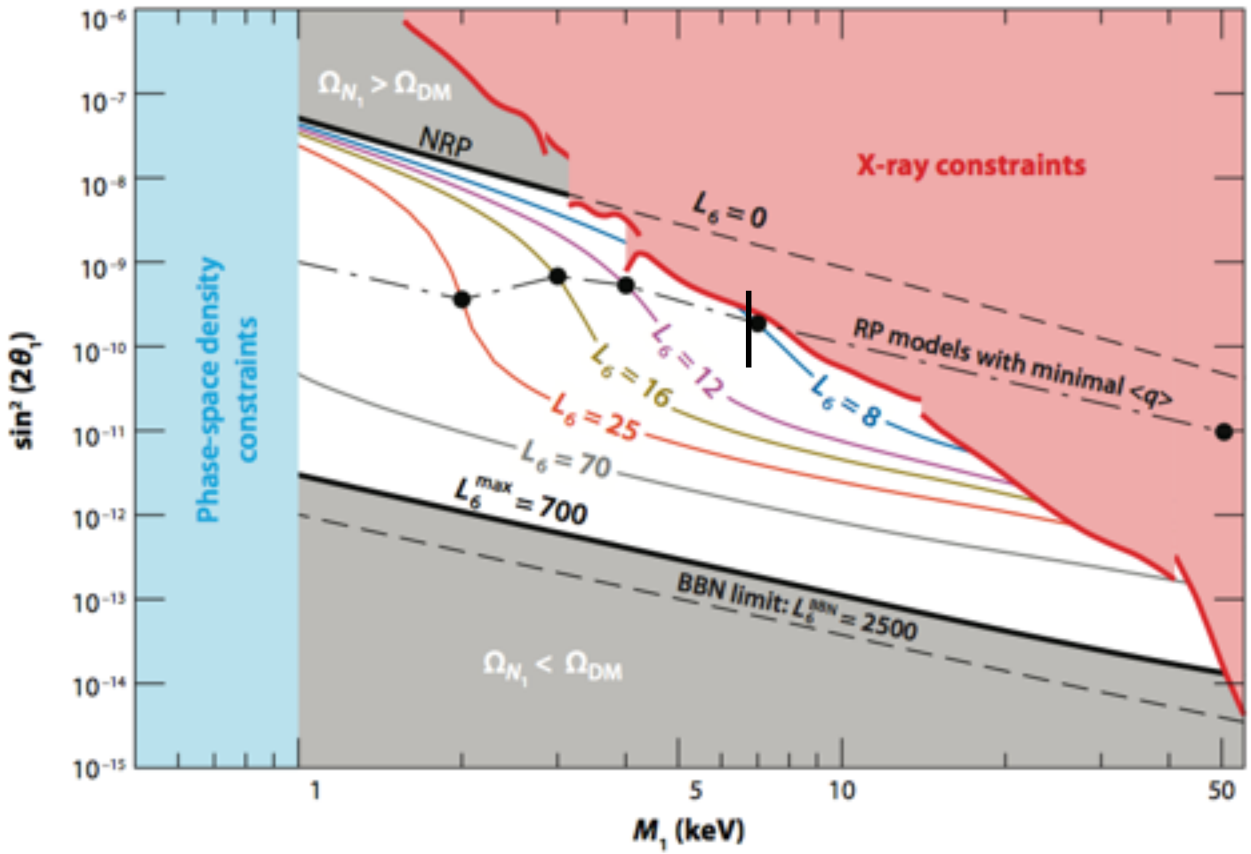


CDM WDM (1.5keV)



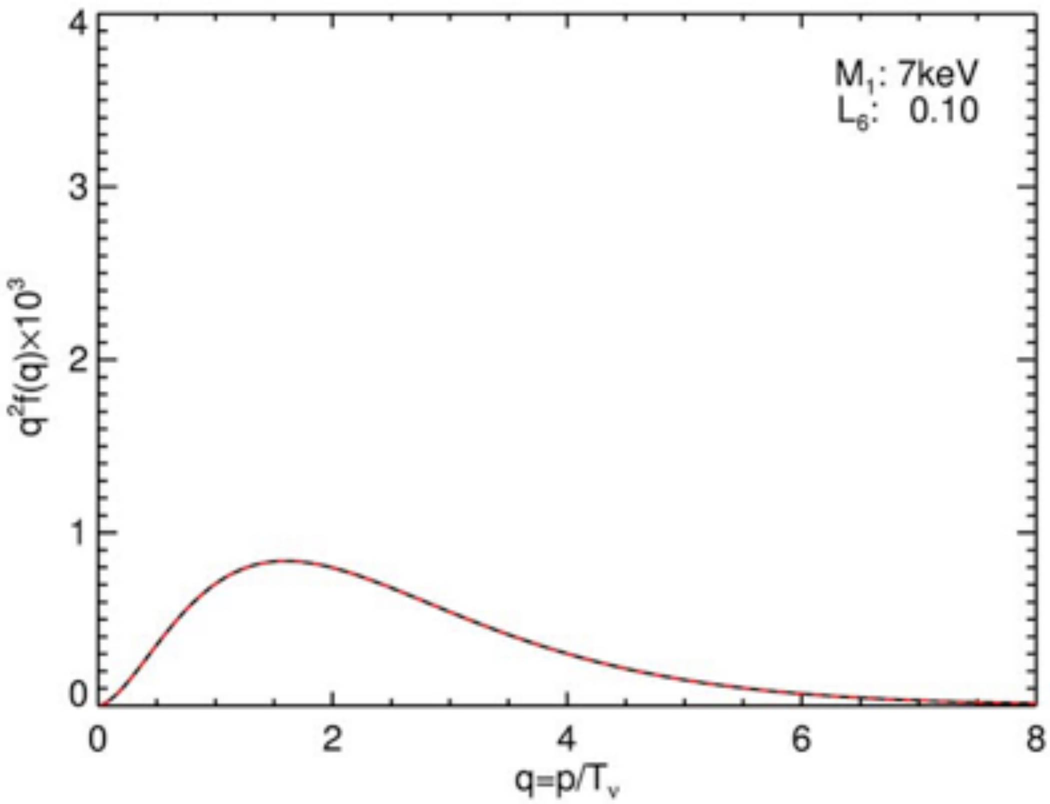
FRANCESC SLIDES

Why study sterile neutrinos (not just for dark matter):



Boyarsky, Ruchayskiy & Shaposhnikov 2009

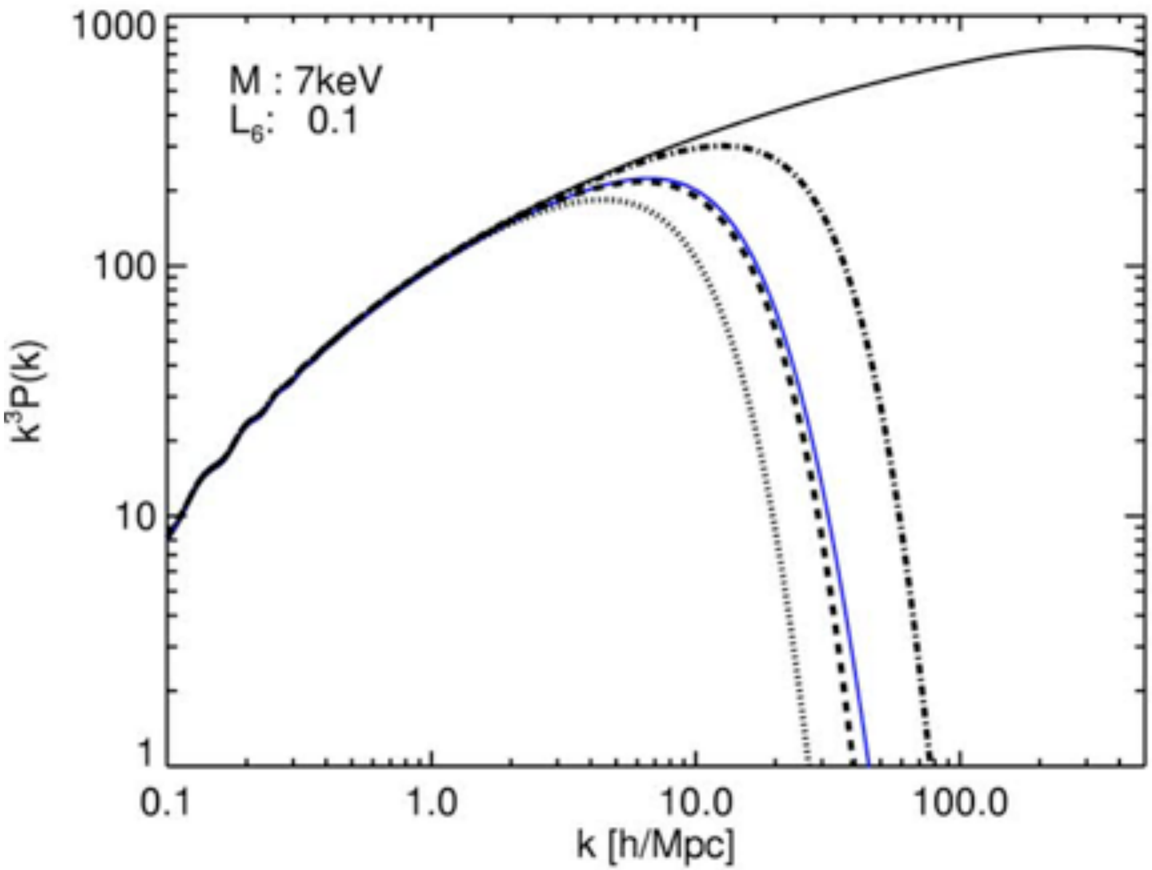
Theory – resonant production



Lovell et al. 2015

- Lepton asymmetry boosts production below some momentum scale.
- Pure non-resonant power spectrum is modified for small lepton asymmetries.
- Optimally cold spectrum for some value of L_6 (typically 8-25 depending on sterile neutrino mass)
- For higher lepton asymmetries all momenta are enhanced: same spectrum as non-resonant production!

Theory -> Cosmology & Galaxy Formation



- Change in L_6 reflected in high redshift matter power spectra.
- Behaves similarly to WDM thermal relic, shallower cutoff close to maximum L_6 point.
- Consequences for halo abundance, structure, formation time…
- **Good cutoff agreement between L_6=8 and Viel et al. 2σ Lyman-α constraint.**
- Will mostly use thermal relic spectra except where stated otherwise.

Lovell et al. 2015

Astrophysics goals:

1. Constrain (measure?) WDM parameters
2. Compare to CDM: which gives a better fit?

When and where to look for WDM (post CMB)?

Relative to CDM:

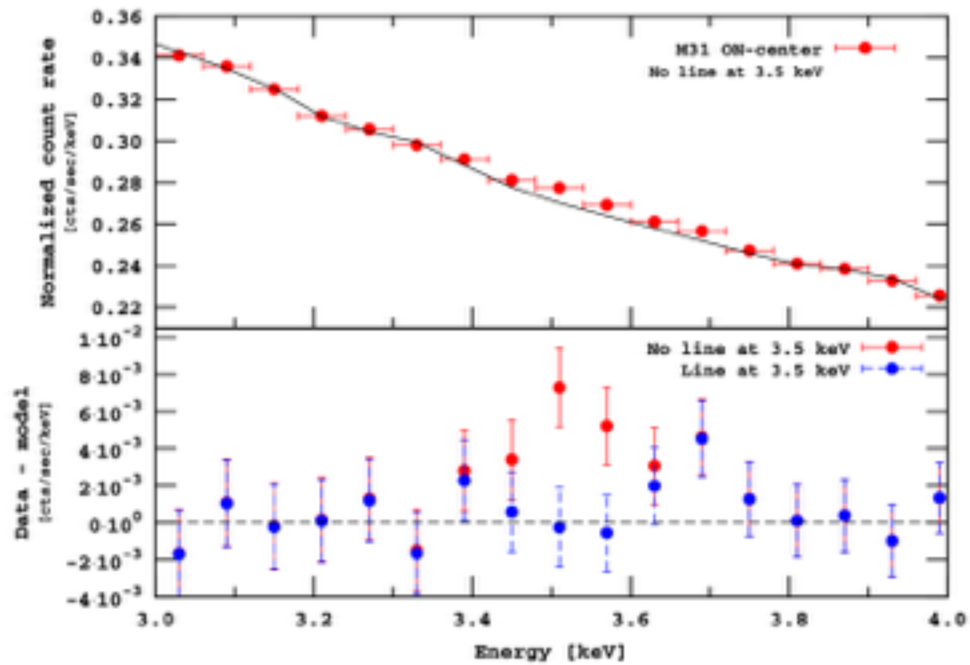
- Fewer small haloes
- Form at later times
- Structures are less dense
- Decay into X-rays

Uncertainties:

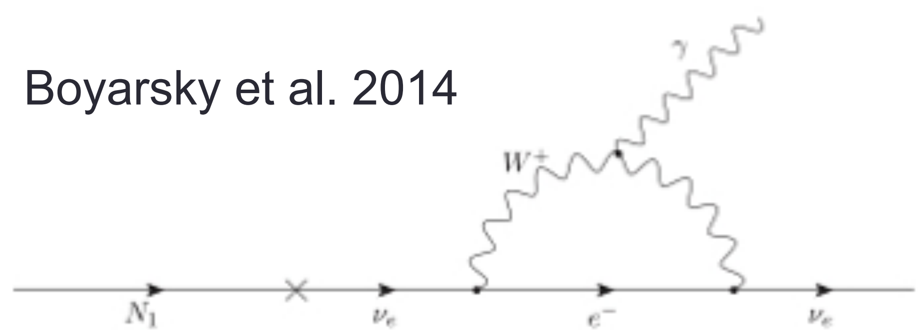
- Mass of the Milky Way halo, $[0.5,2.0]\times10^{12}M_{sun}$
- Strength of baryon feedback
- Systematic error in particle physics calculations

When and where to look for WDM - X-ray decay

- Line detected in galaxy clusters, M31 galaxy, Milky Way centre at 3.55keV
- Consistent with 2-body decay: N=>v+photon
- Presence disputed in some targets, may have astrophysical origin in others



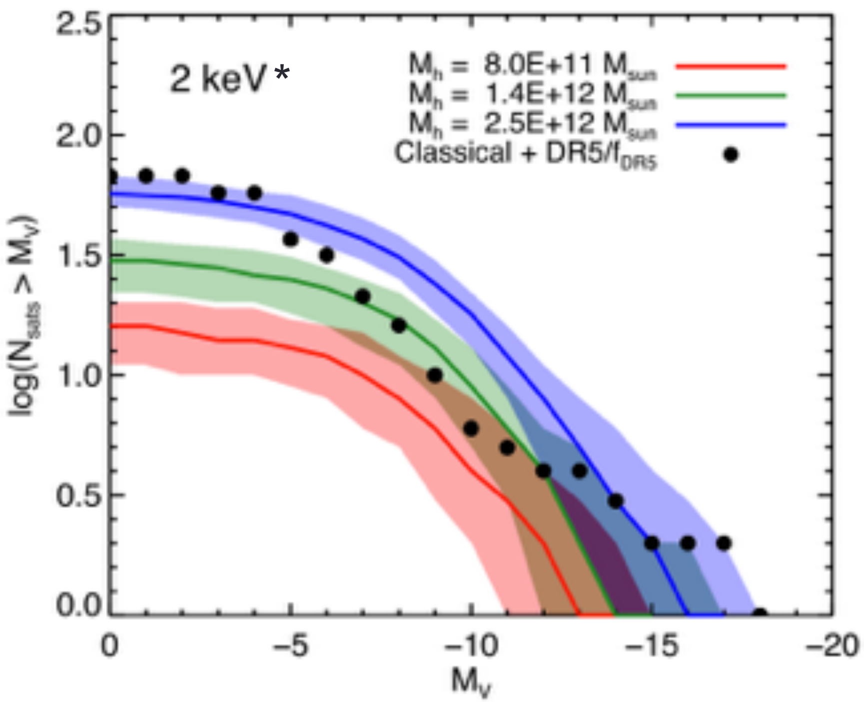
Boyarsky et al. 2014

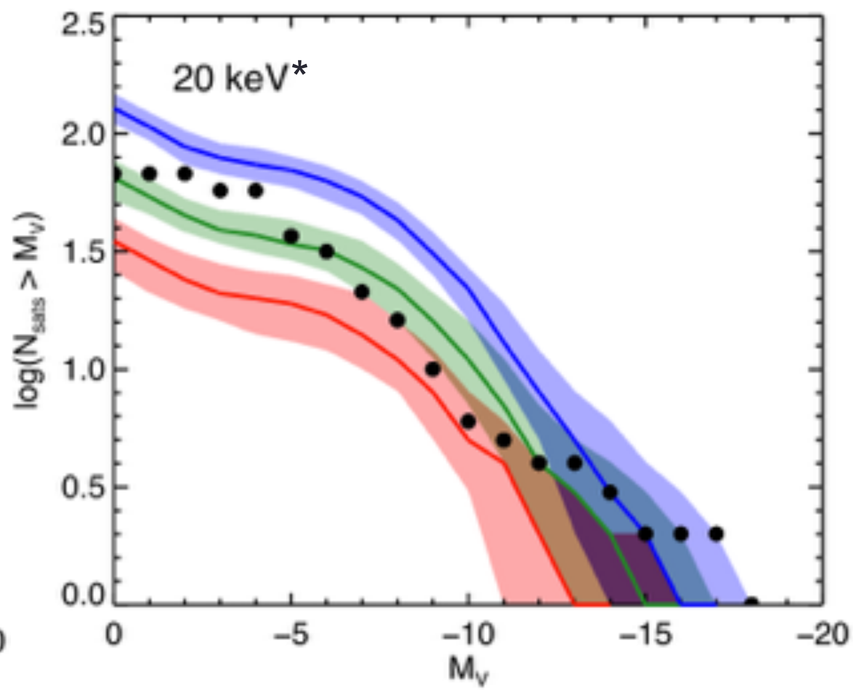


When and where to look for WDM- Milky Way satellite counts

Cumulative satellite abundance

*thermal relic masses

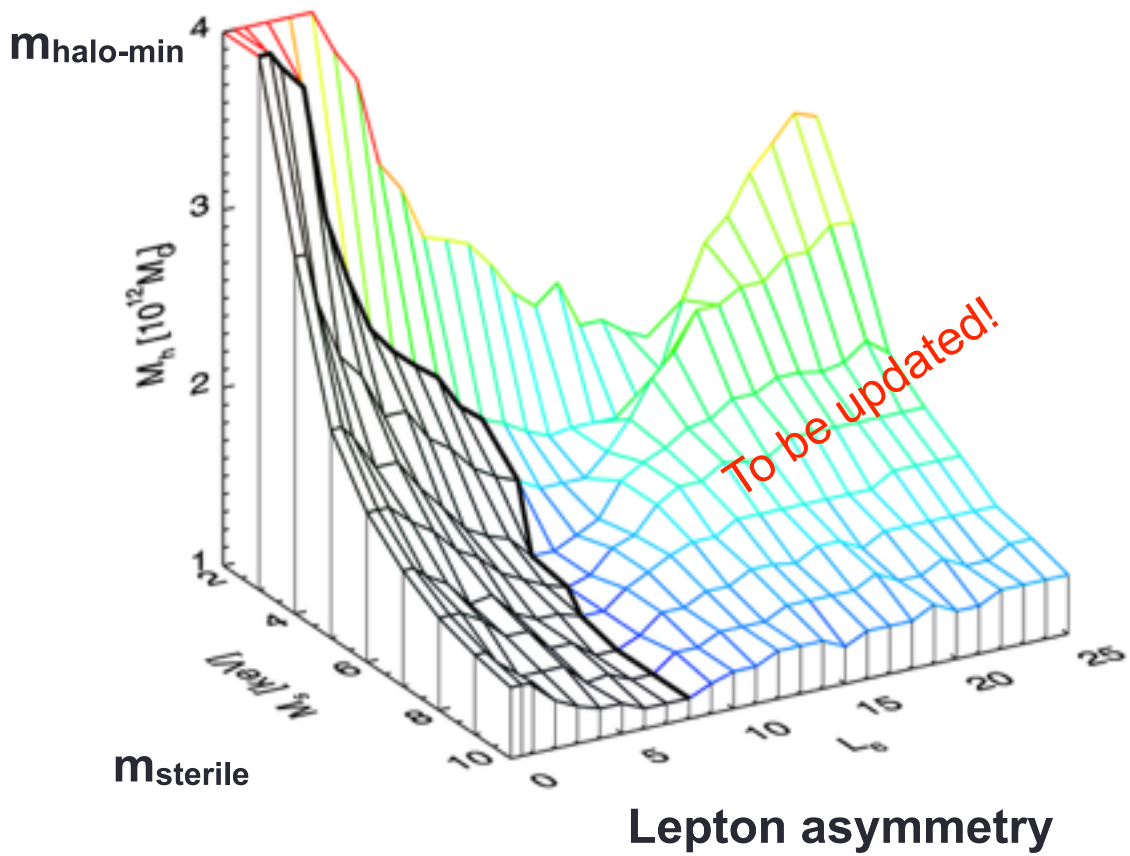




Satellite luminosity

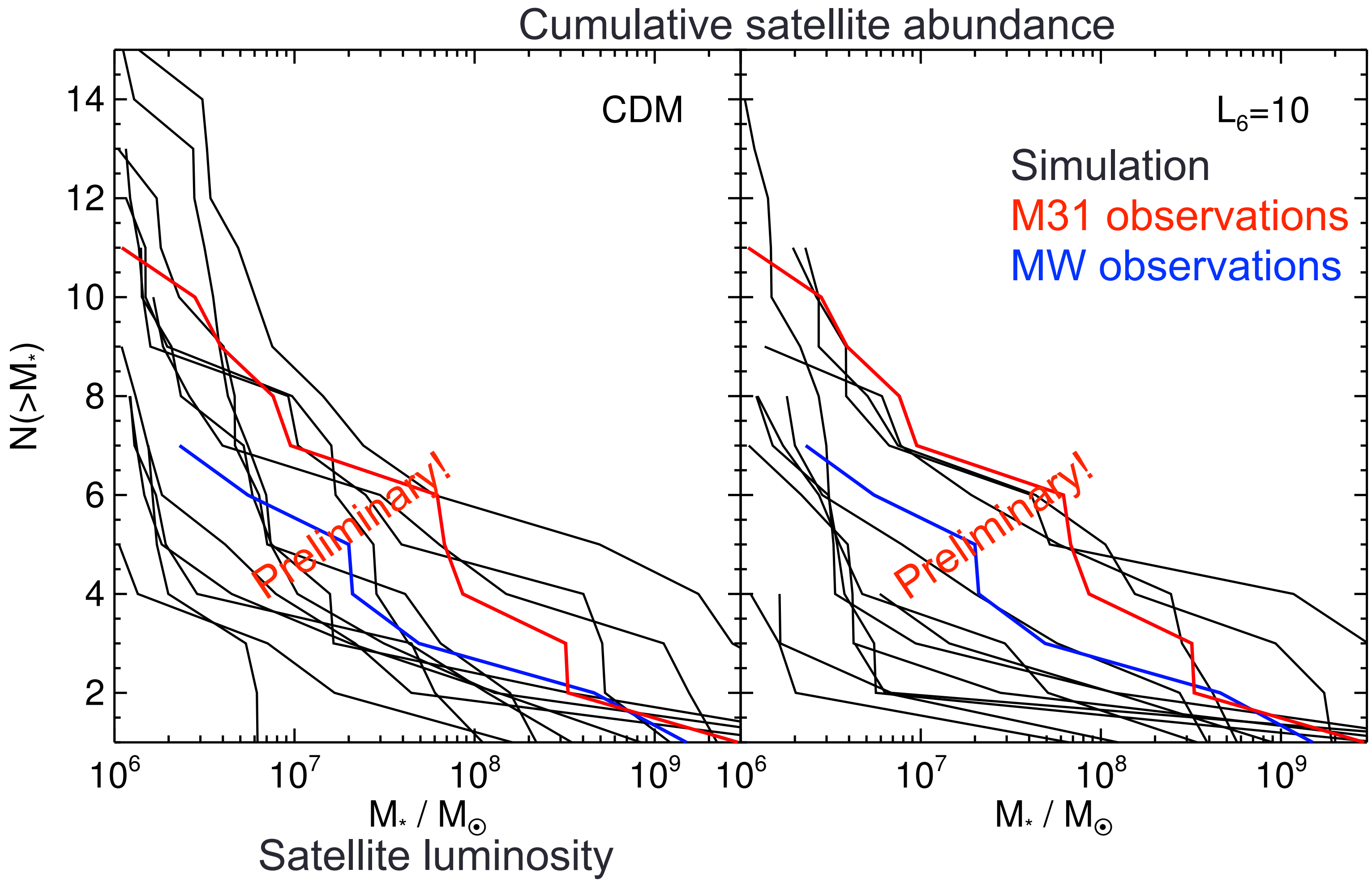
Kennedy et al. 2014

When and where to look for WDM- Milky Way satellite counts



Lovell et al. 2015

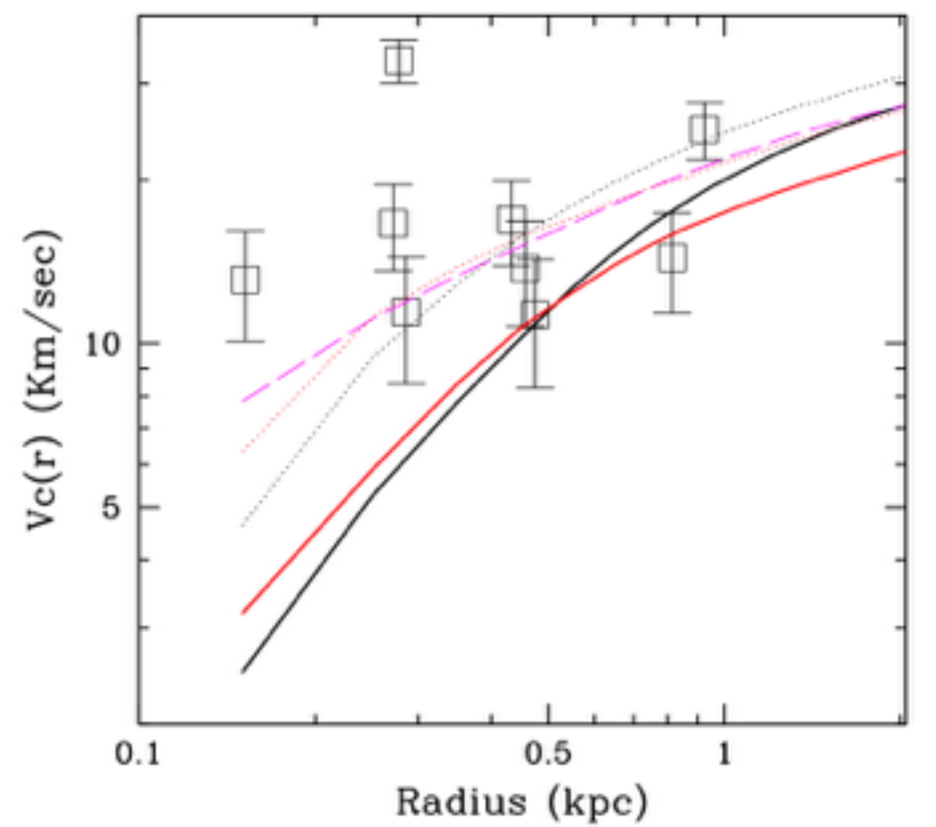
When and where to look for WDM - Milky Way satellite counts



Lovell et al. (in prep.)

When and where to look for WDM - Milky Way dwarf galaxy densities

- WDM lowers dwarf central density relative to CDM at radii ~1kpc.
- Effect comparable to lowering of central densities due to feedback.
- Also affected by halo-to-halo scatter.



Squares=observations

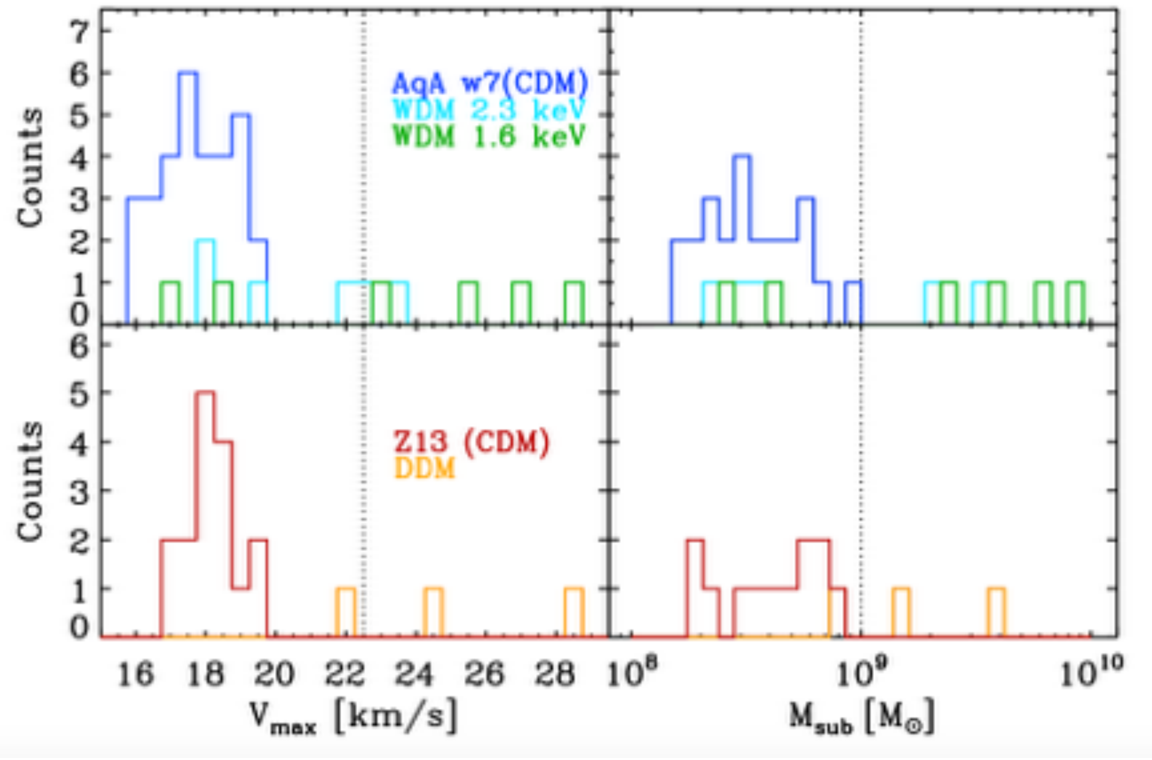
Solid lines=hydro runs

Dotted lines = DMO runs

Governato et al. 2015

When and where to look for WDM - Milky Way satellite densities

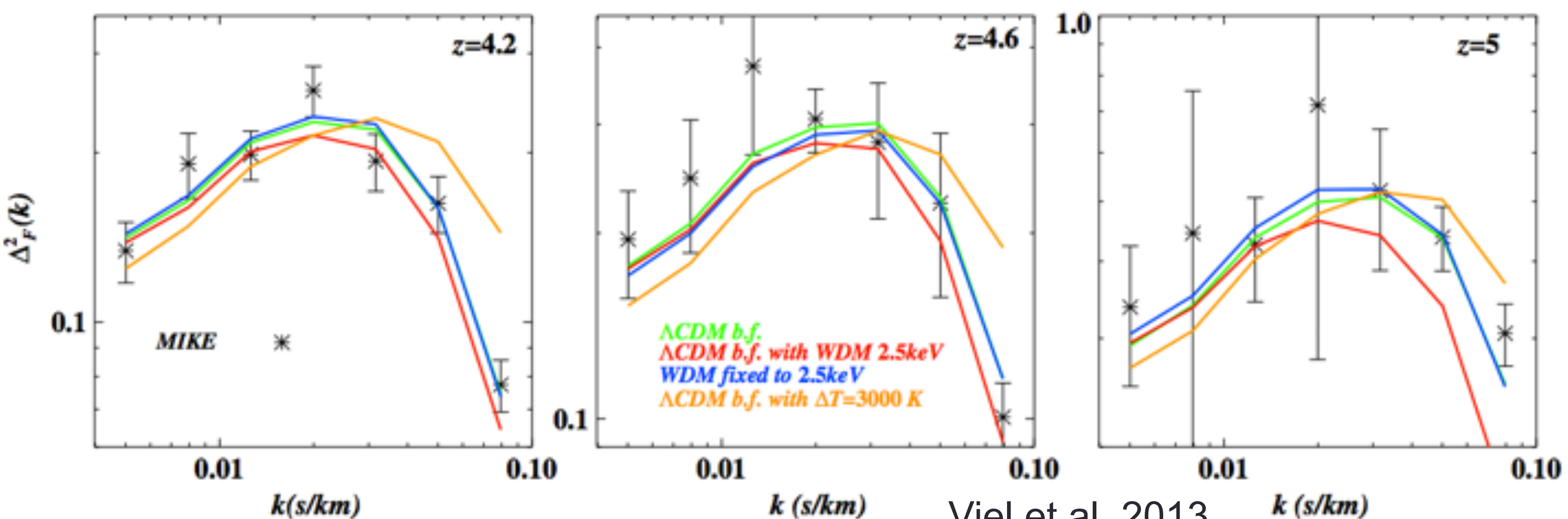
- Fit observed photometry and kinematics of Fornax stars to dark matter-only simulations of satellite galaxies, CDM and two WDM thermal relic models.
- Best WDM fits occur for V_{max}> 22km/s. Higher value than for CDM, due to lower concentrations.



Wang et al. 2016

When and where to look for WDM - Lyman-alpha forest

- Quasar spectra partially absorbed by hydrogen clouds. Linked to small scale structure.
- Viel et al 2013 3σ limit of 2.5keV. May be relaxed if the gas temperature at z=5 is lower.



Viel et al. 2013

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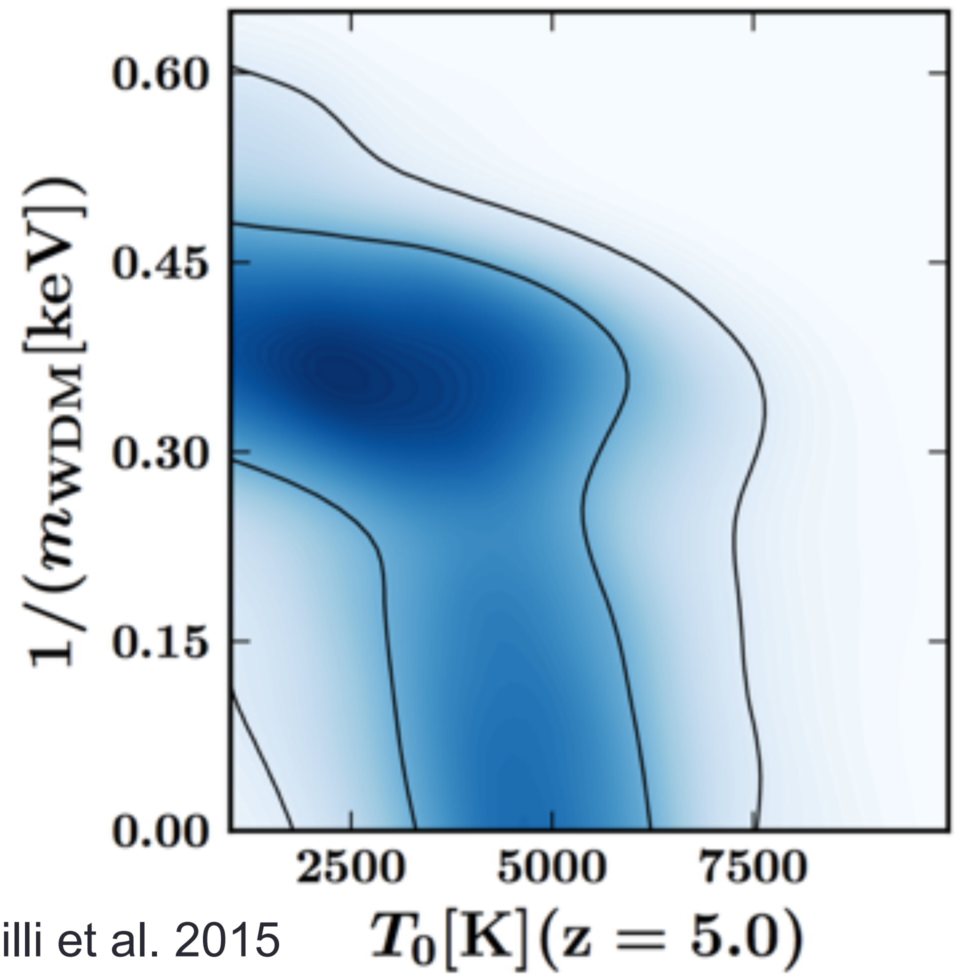
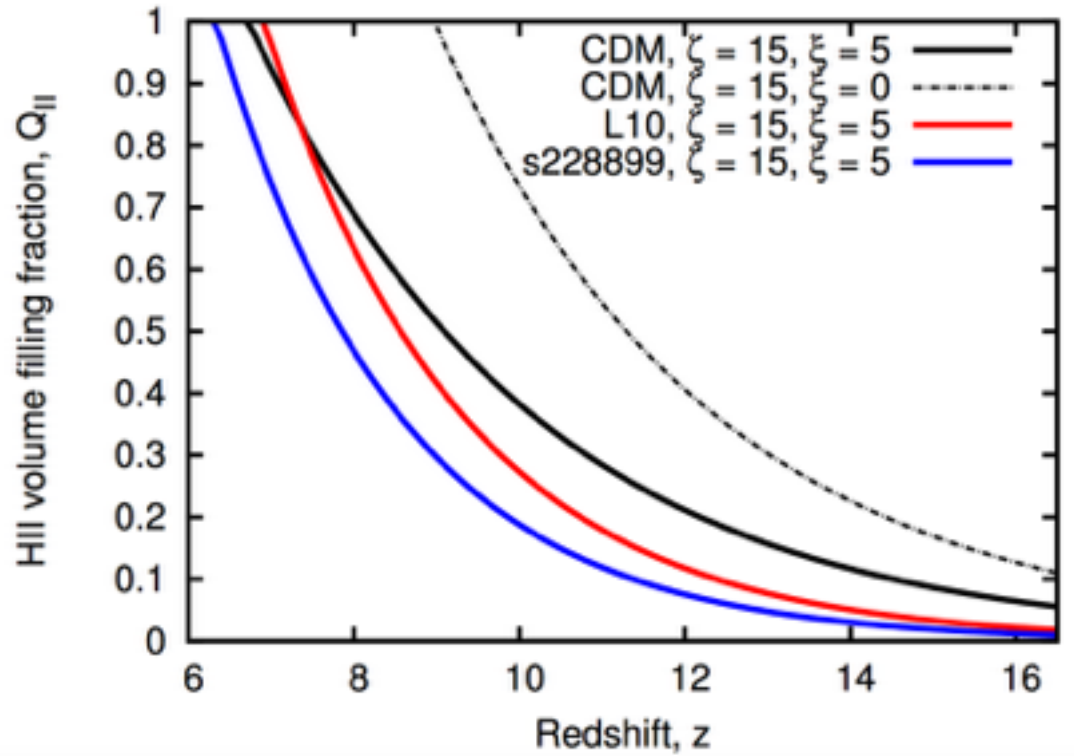


Garzilli et al. 2015

When and where to look for WDM - Reionisation

- Later collapse of haloes delays star formation.
- Therefore fewer ionising photons in the early Universe -> reionisation delayed.
- Minihaloes ($10^5 M_{sun}$) absent in WDM, may enable faster reionisation.



Rudakovskiy & Iakubovskiy 2016

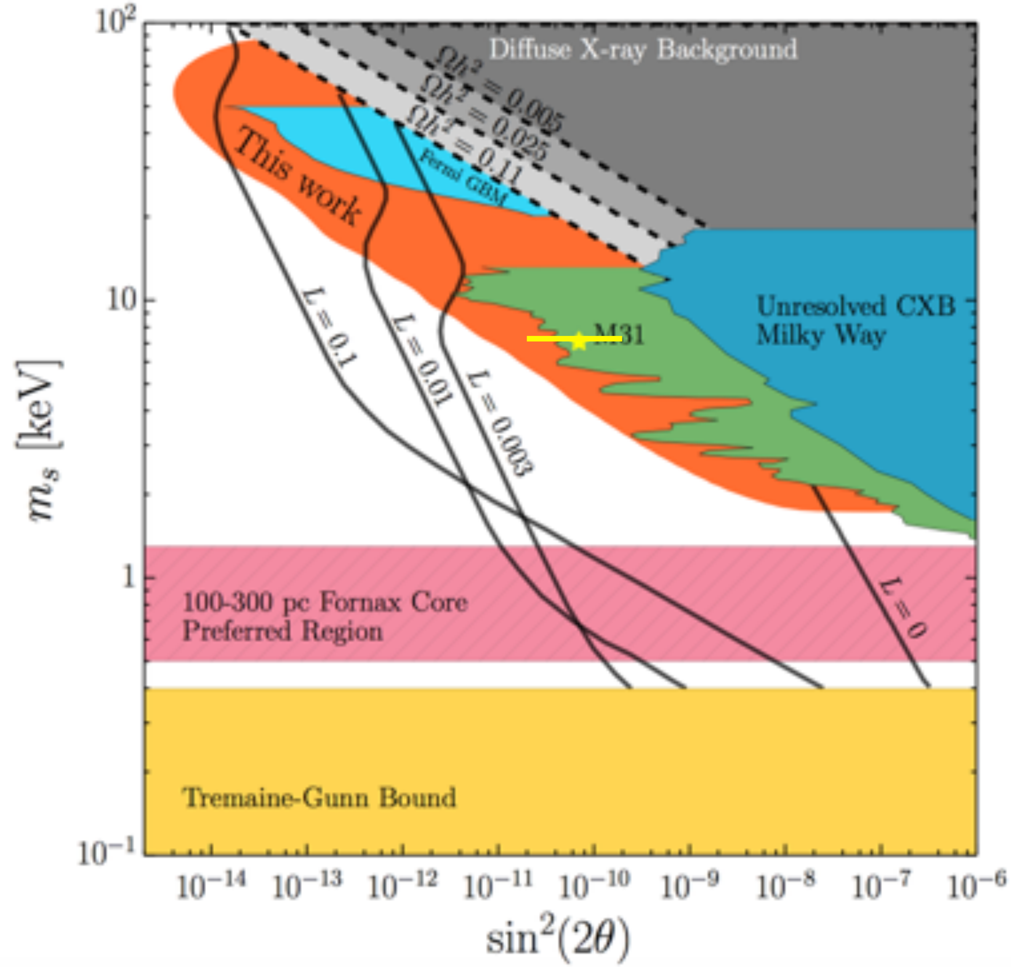
When and where to look for WDM - Gravitational lensing

- Small dark matter subhaloes ($<10^8 M_{sun}$) can interfere with lensing Einstein rings.
- Detection of many small haloes can set constraints on WDM parameters.
- Relatively insensitive to baryon model.
- But is sensitive to halo profile.

10kpc

When and where to look for WDM - Supernova energetics

- Sterile neutrinos may be produced in supernova, carry away energy.
- Initial constraints from SN1987A produce competitive limits, possibly rule out sterile neutrinos as 3.55keV line candidate.



Arguelles, Brdar & Kopp 2016

Summary

- Sterile neutrino dark matter is an intriguing alternative to WIMPs
- keV dark matter particles are predicted in well-motivated particle physics scenarios that address some of the shortcomings of the Standard Model, such as neutrino oscillations and baryogenesis. The rich phenomenology in the dark sector can be tested at ongoing and future experiments.
- Candidate signal detected as 3.5keV line.
- Production mechanism leads to suppression of dwarf galaxy properties, small gas clouds, even supernova properties.