Dark Matter Constraints from Gravitational Coupling

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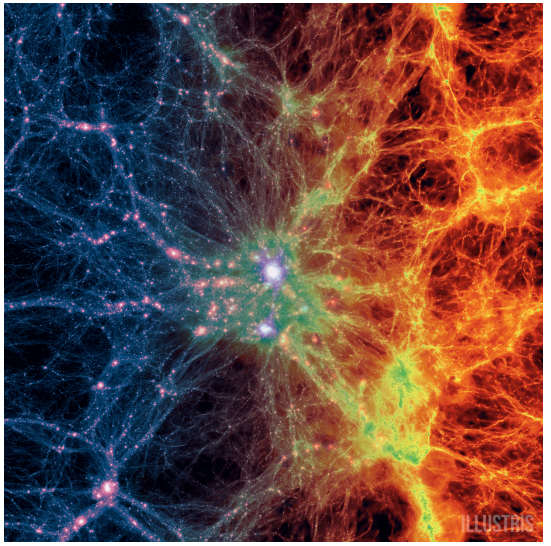
A possible new constraint on dark matter from cosmological structure



Structure constraints:

- How we know there is dark matter
- Not what dark matter **is**, but what it **does**

Classic example: Dwarf Galaxies

Good:

- Dark matter dominated
- Gravitational potential shallow enough to be sensitive but deep enough to have interesting effects

Bad:

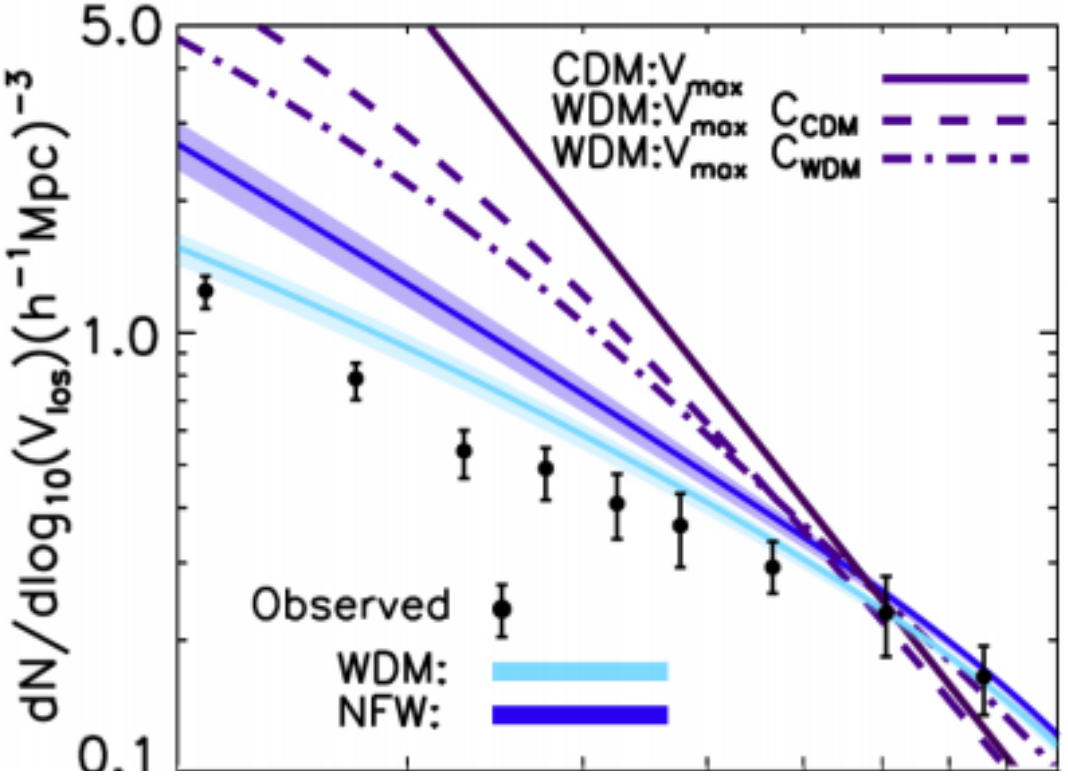
- Sensitive to supernovae, tidal disruption

Eg: Cusp-Core Problem

- Cold dark matter: NFW profile with cusp
- Steeper central halo density than observed

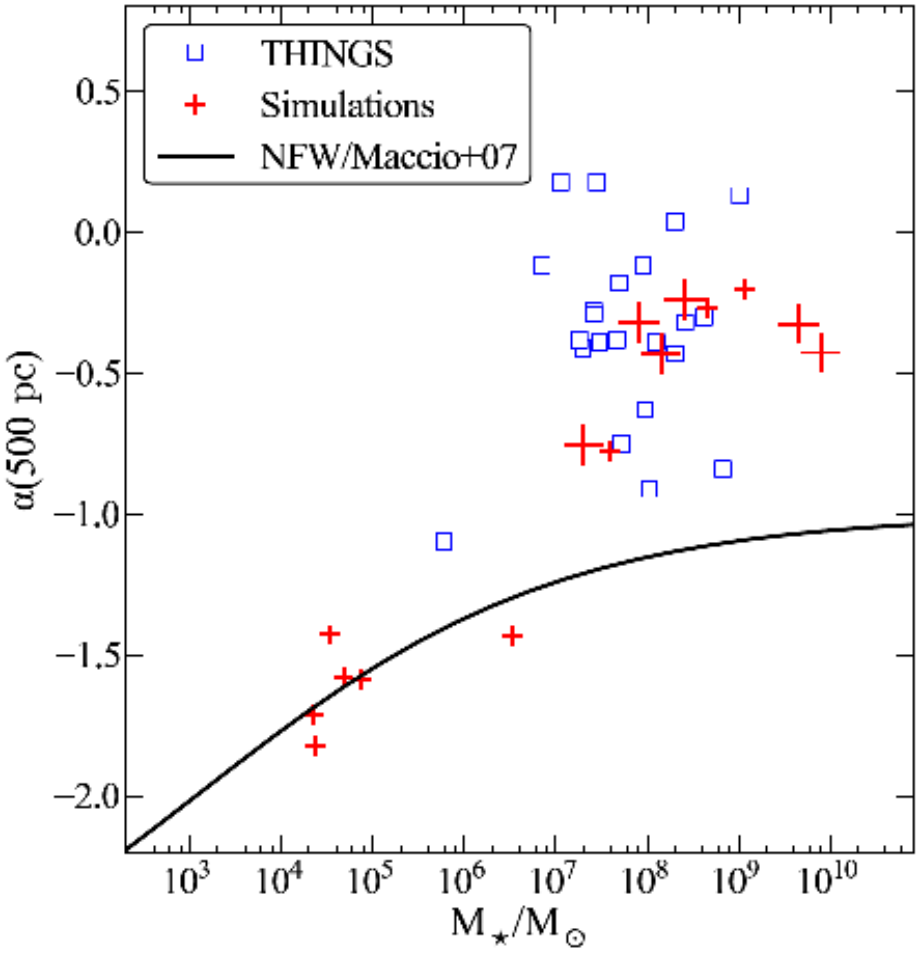
Cusp-Core Solution 1

Warm dark matter softens the halo, matches observations



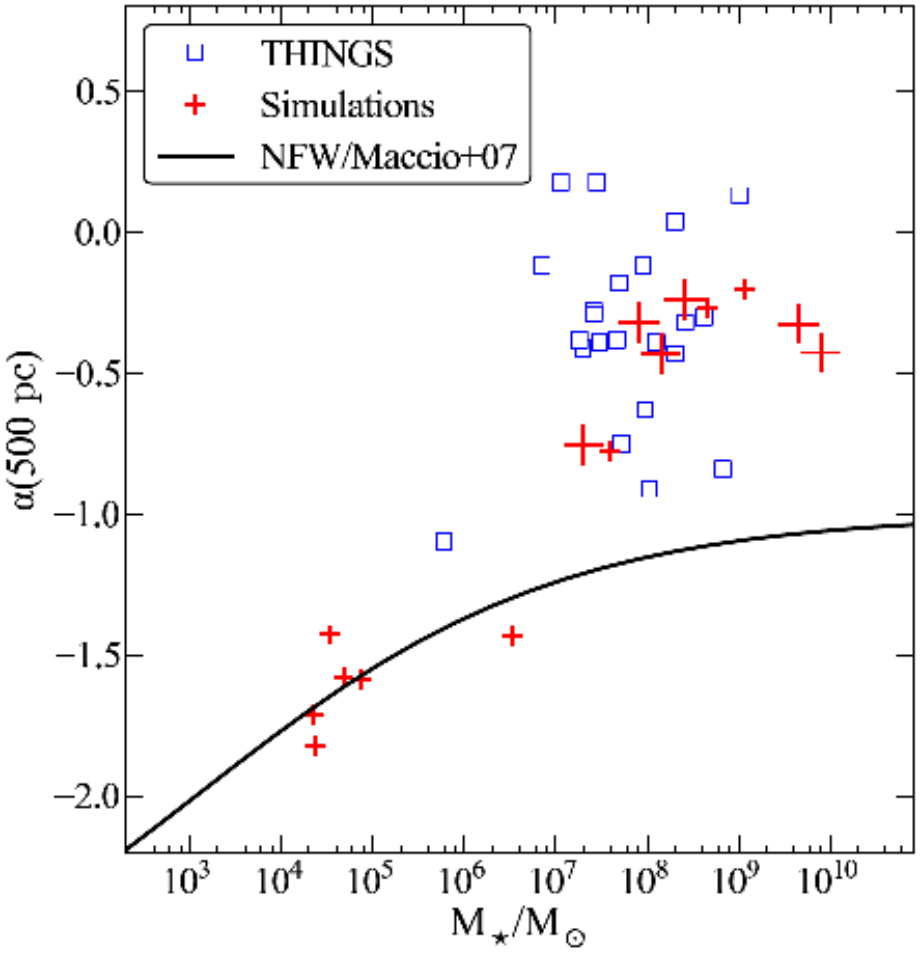
Cusp-Core Solution 2

Simulations including supernovae also match observations (Governato 2012)



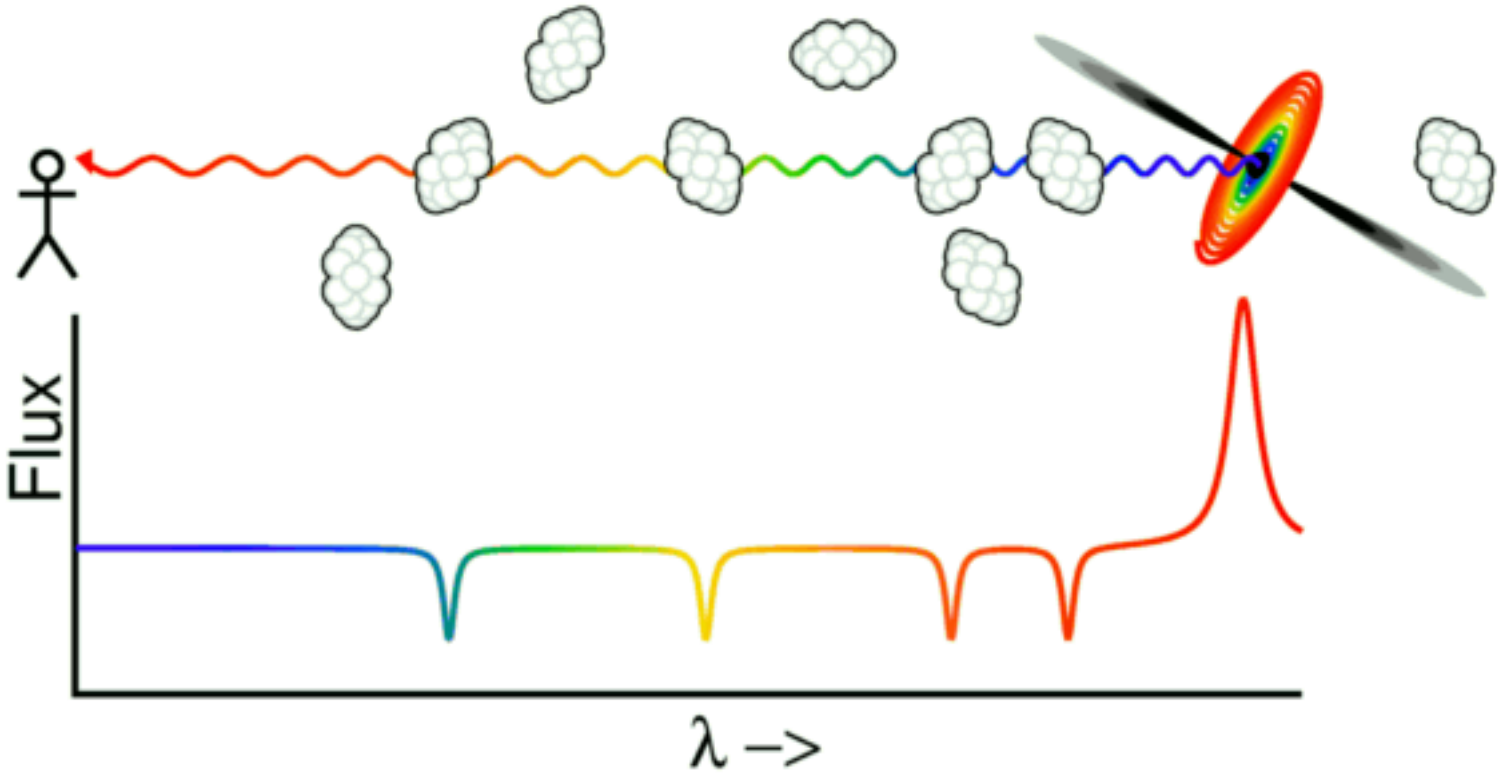
Cusp-Core Conclusion

Dwarf galaxies tell us less about dark matter than we would like



Solution: Hydrogen Absorption

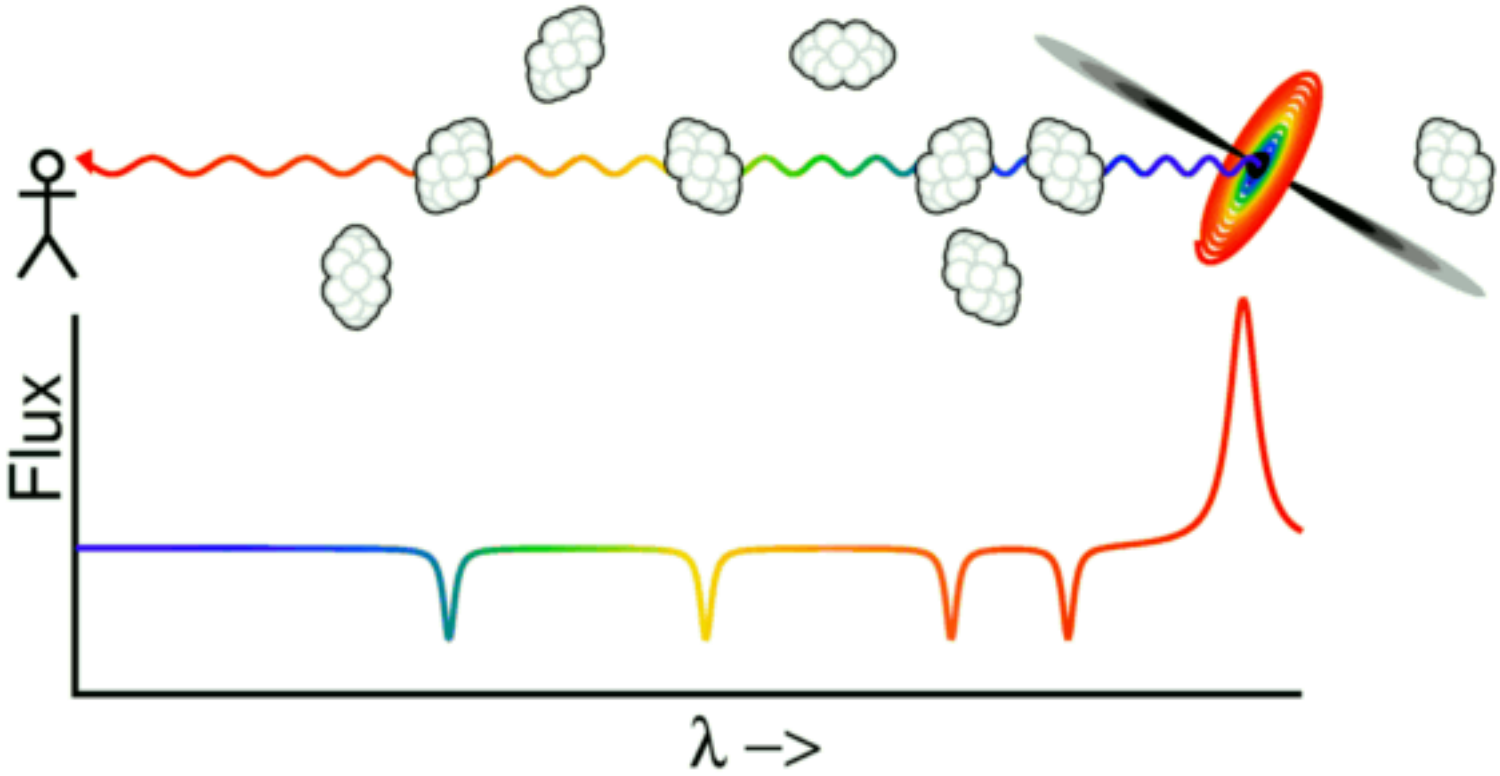
- Gas traces dark matter potential
- Almost totally insensitive to galaxy physics



Ed Wright

Lyman Alpha Forest

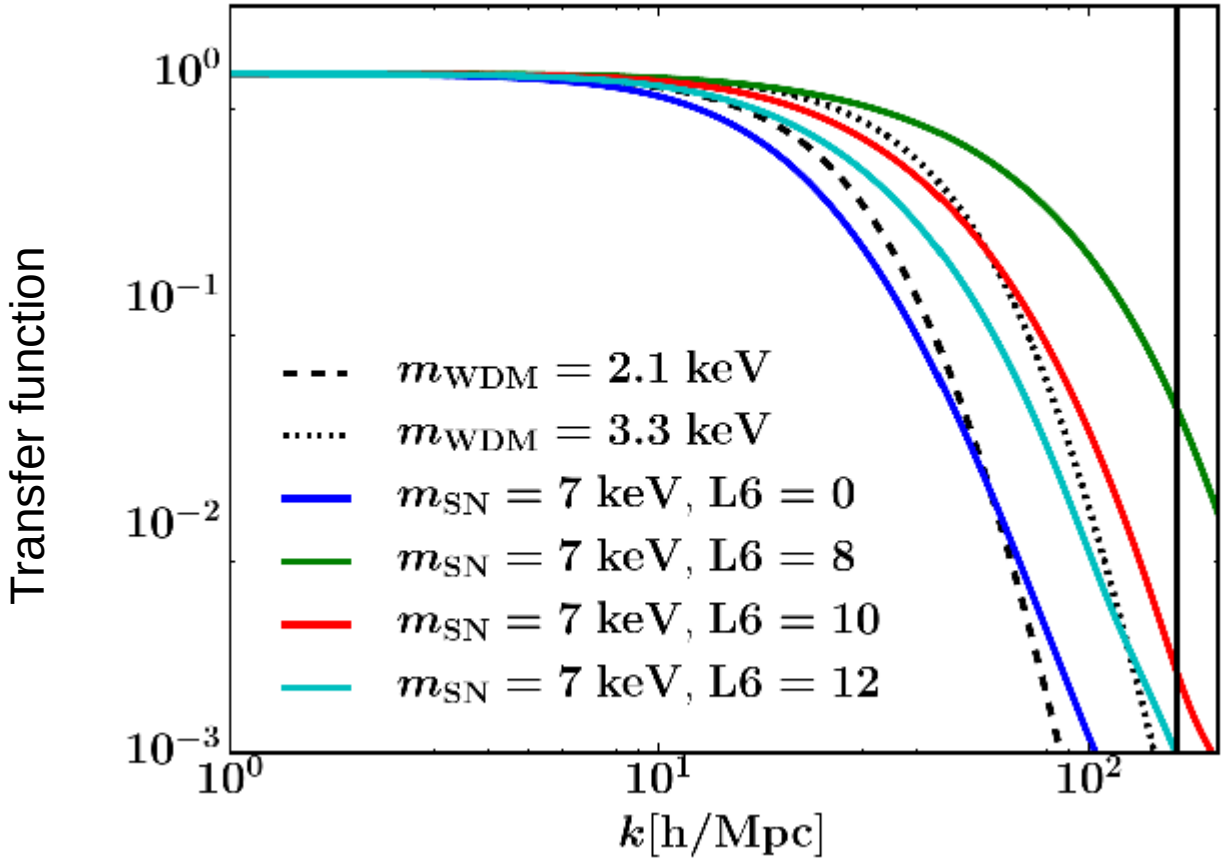
- Correlations between absorption troughs
- Integral of DM clustering at overdensity 10-100



Ed Wright

Lyman Alpha Forest

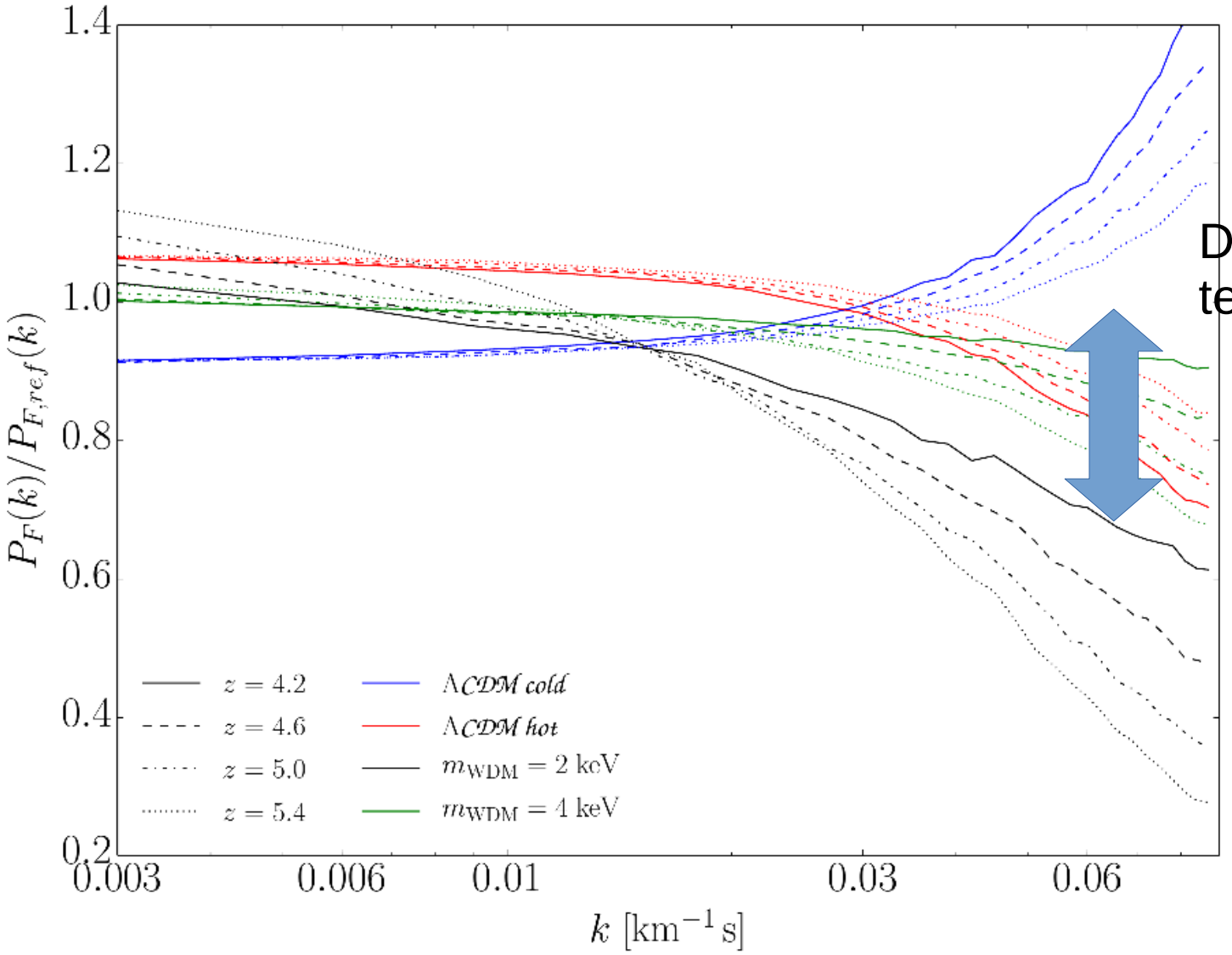
- Thermal DM gives power cutoff
- Detect power cutoff in gas



Garzilli 2015

Lyman Alpha Forest

(Normalization is a nuisance parameter!)

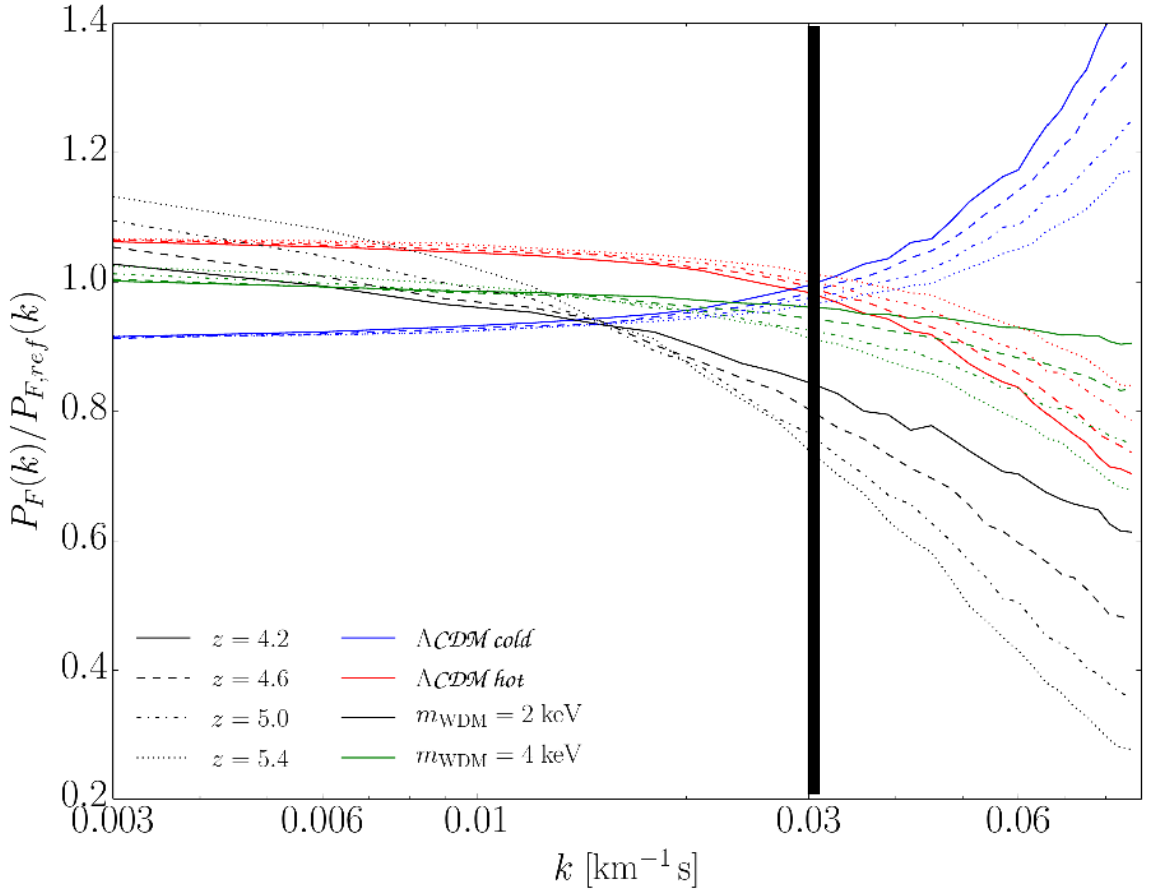


Dark matter temperature

Irsic+2017

Effect of Gas Temperature

- Fundamentally limited by gas temperature
- $T_{gas} > T_{dm}$: gas does not trace dm very well

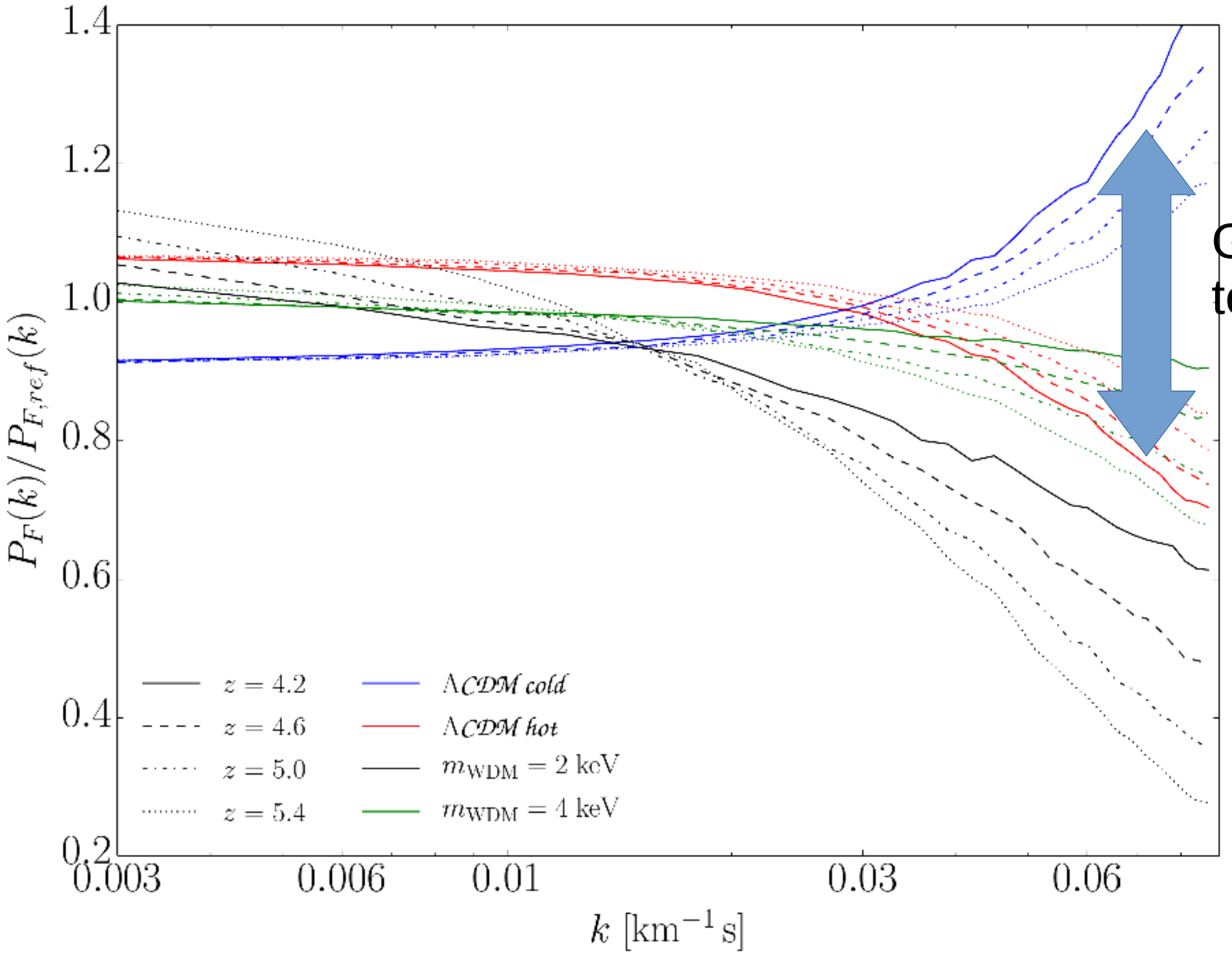


Thermal cutoff scale: ~ 30 km/s

Irsic+2017

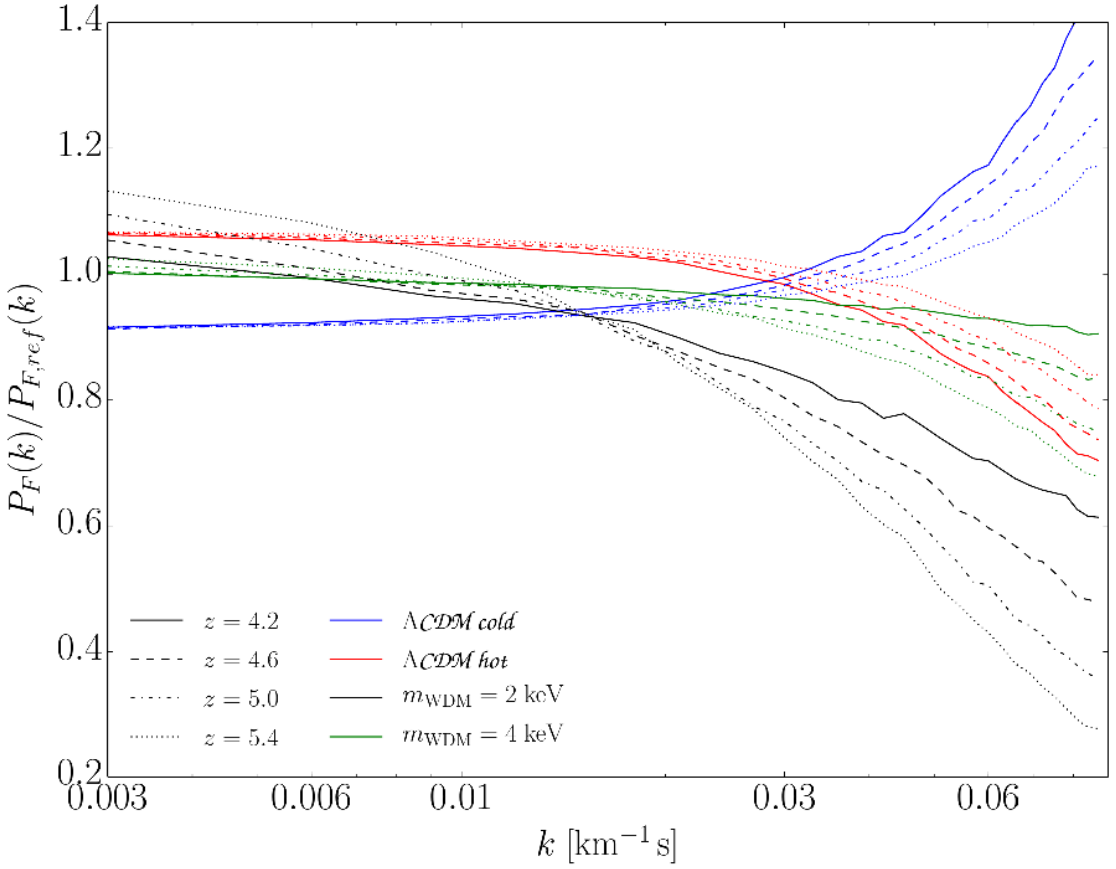
Effect of Gas Temperature

(Normalization is a nuisance parameter!)



Lyman Alpha Forest

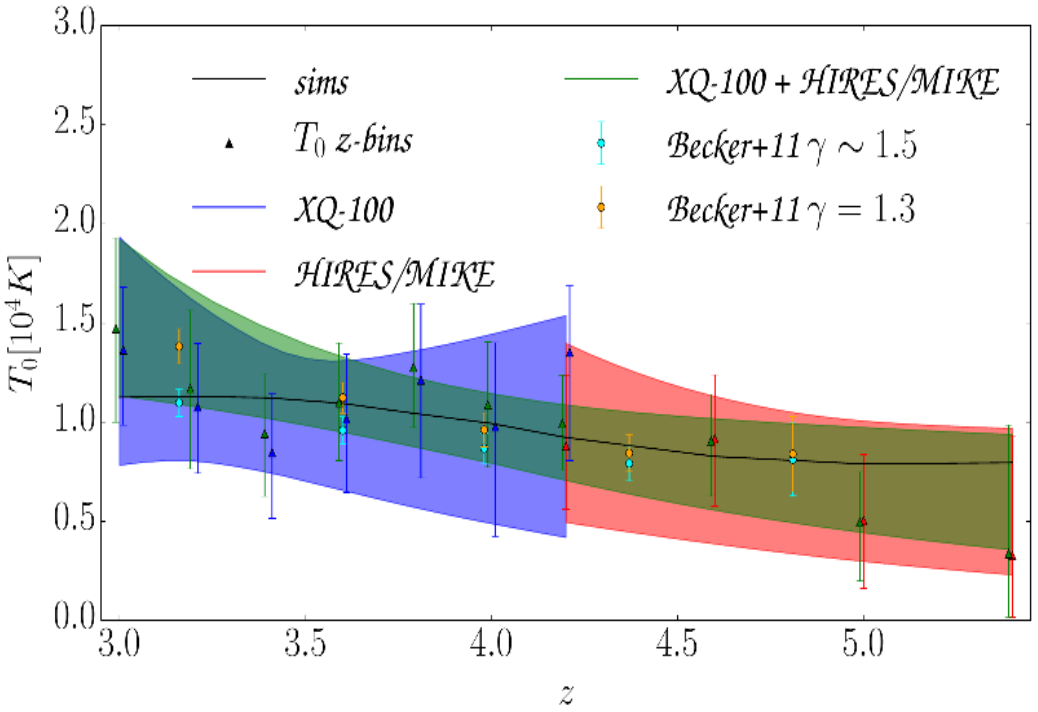
- Thermal dark matter relic of > 3.5 keV at 95% (Dodelson-Widrow sterile neutrino is ~41 keV)



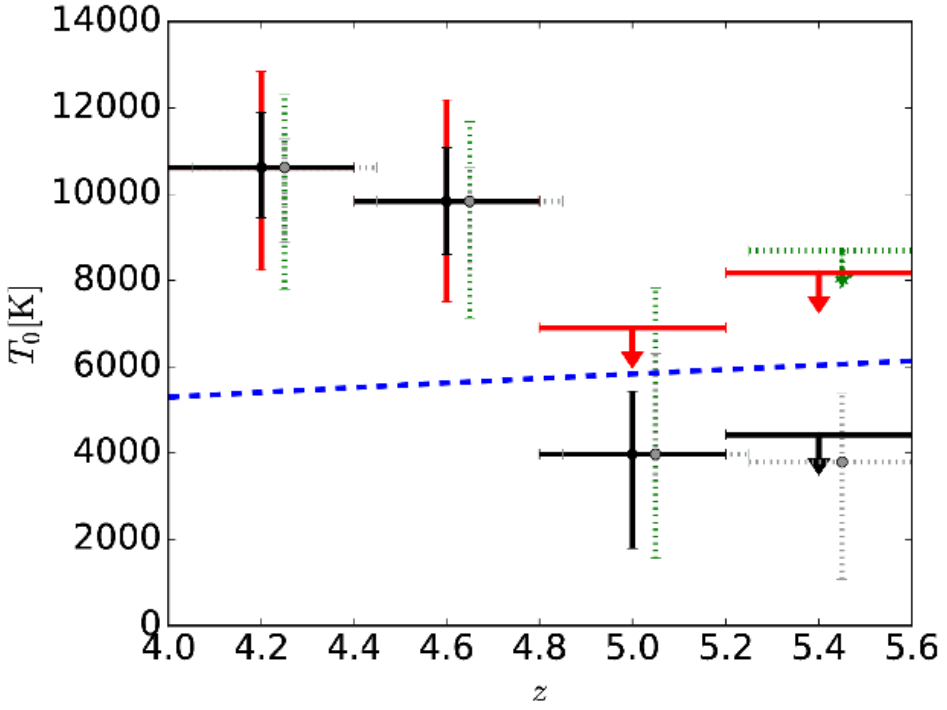
Irsic+2017

Some Alternative Limits

- Weaker limits from Garzilli+2015: weaker assumptions about reasonable T(z)



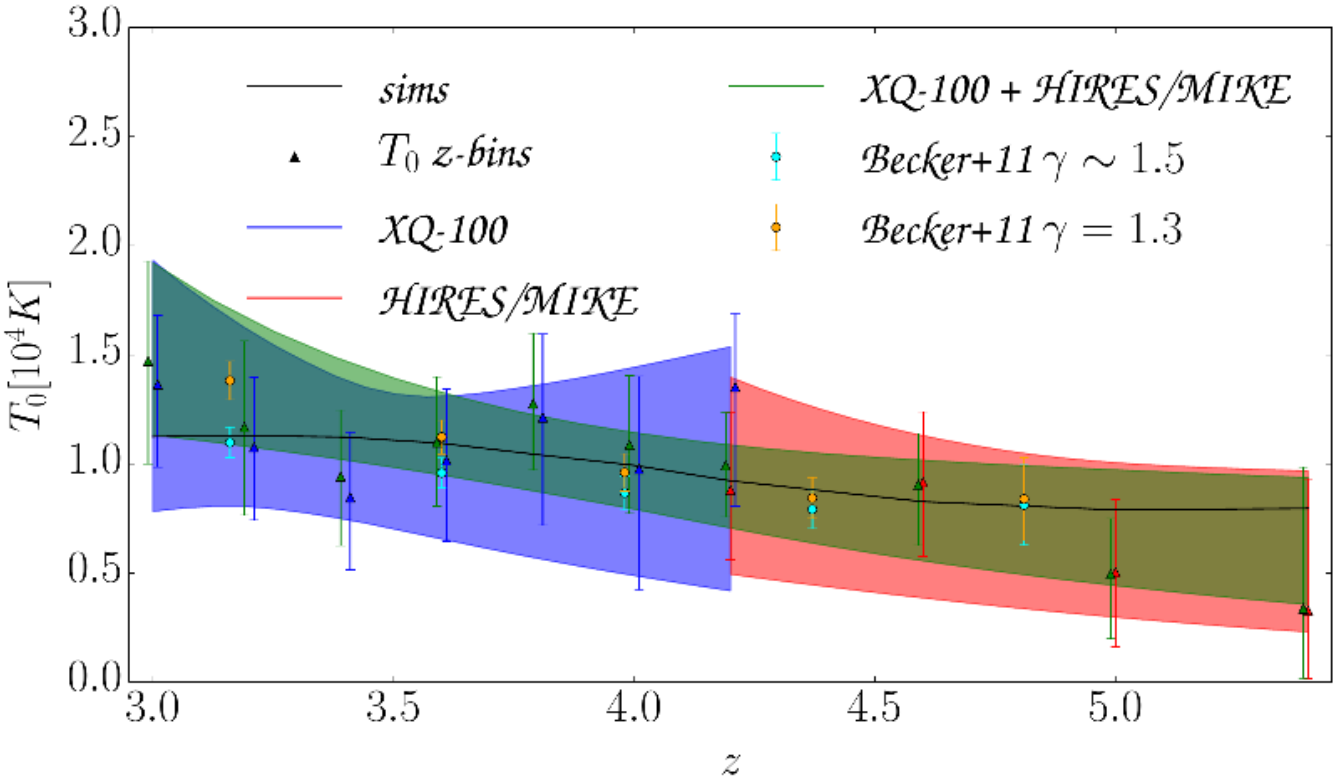
Irsic+2017



Garzilli+2015

Lyman Alpha Forest

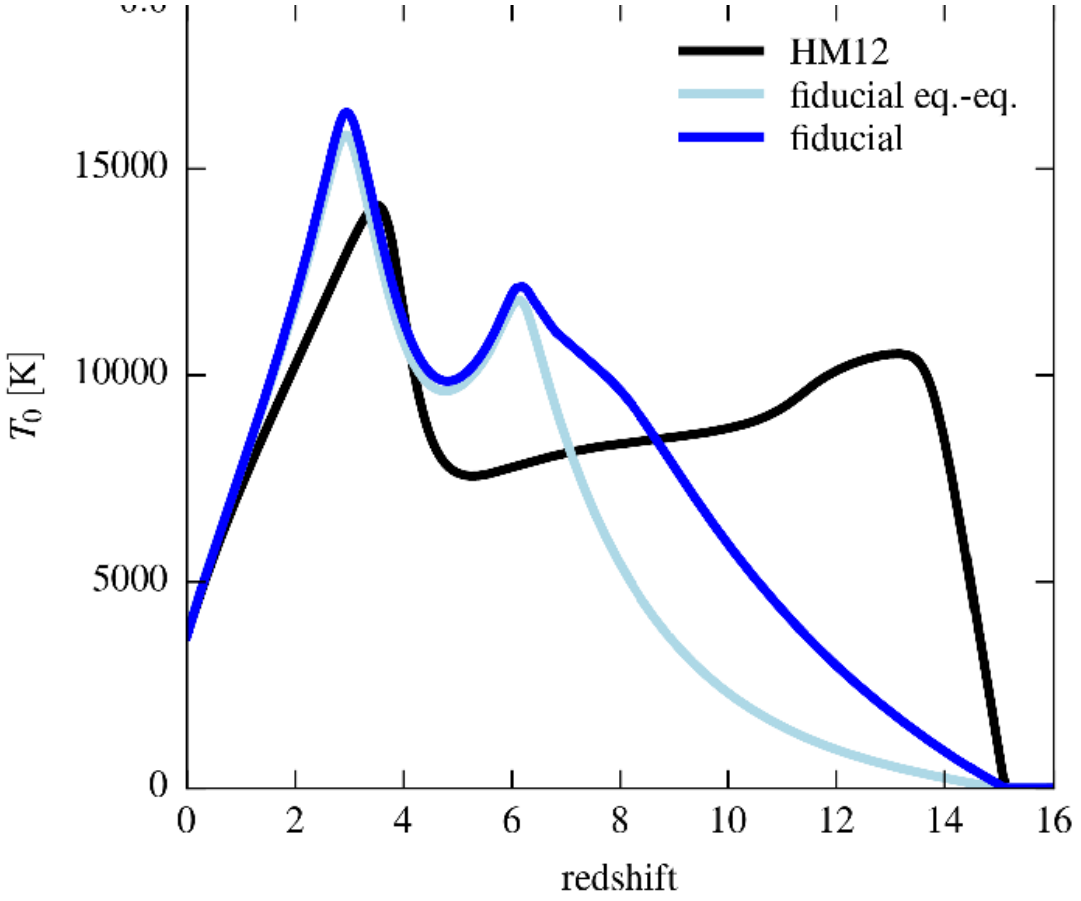
- Different weaker limits from Garzilli+2018, because they use only data at z > 4.5



Irsic+2017

Can we do better?

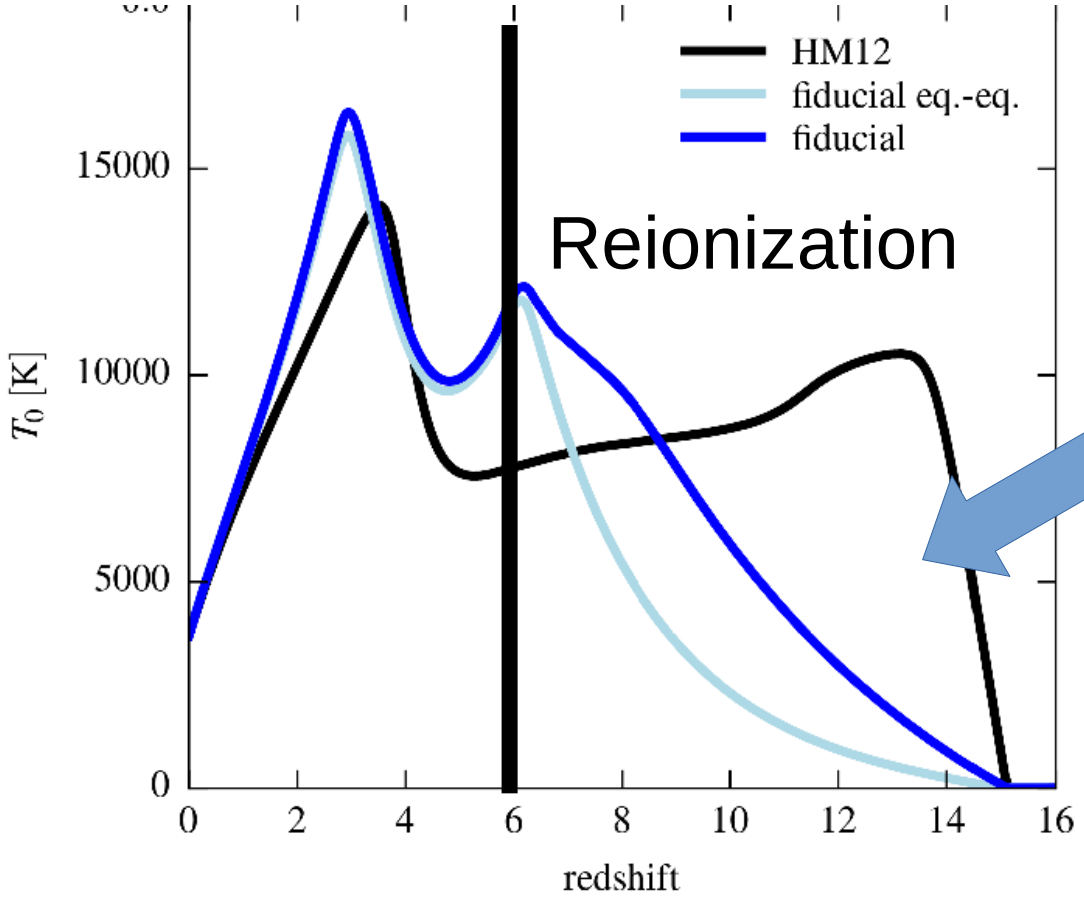
- Want gas insensitive to supernova physics
- With lower gas temperature



Puchwein 2018

Can we do better?

- Want gas insensitive to stellar physics
- With lower gas temperature

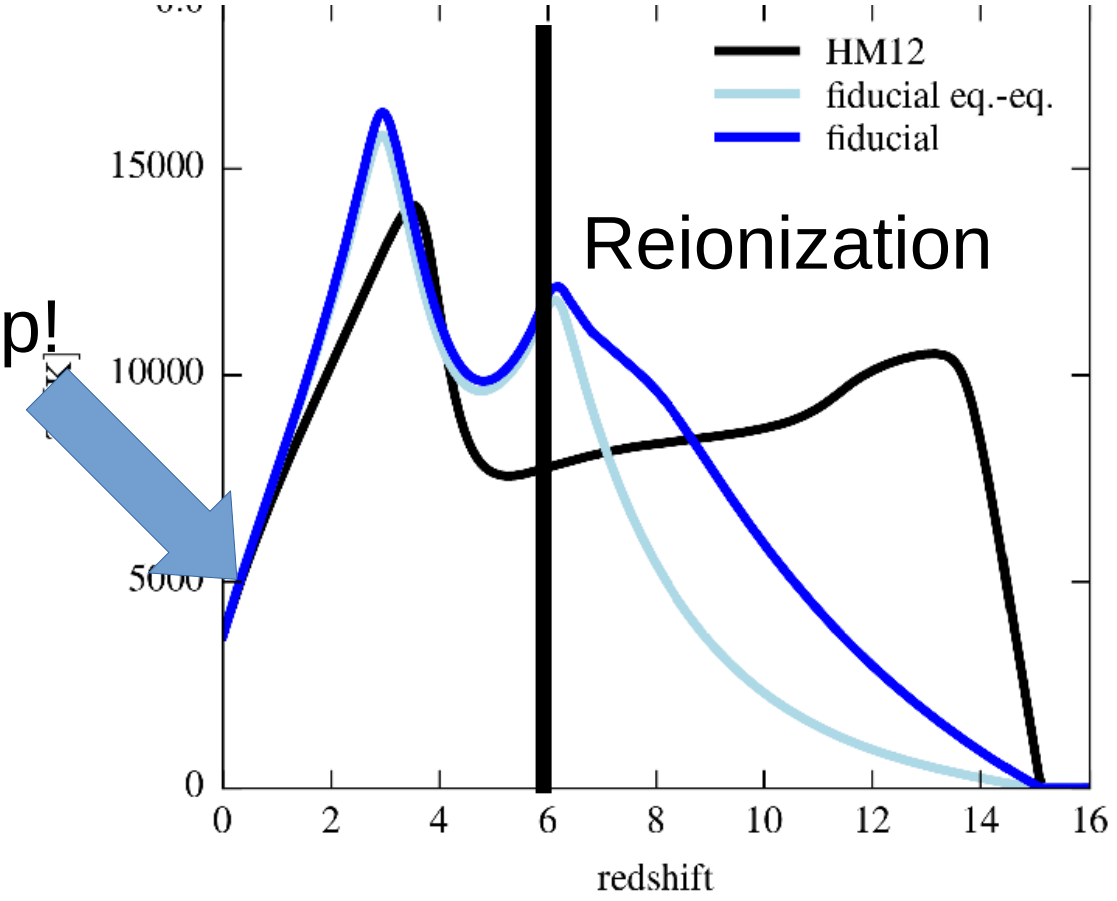


Low temp but saturated absorption

Puchwein 2018

Better WDM probe?

- Need to be in space
- T ~ 5000 K < 15000 K



Low temp!

Puchwein 2018

Dark Halos

- If $T_{vir} < T_{igm}$, gas free-streams from halo
- Forms dark halos without gas or stars (Efstathiou 1992, many others)
- Affects field halos $M < 10^9$ Msun

Absorption from Dark Halos

- But the IGM is cooling so halos do not stay pressure supported
- Form stars after free-fall time of ~1 Gyr.
- M ~ 5×10^8 - 10^9 Msun are collapsing at z ~ 0

Better WDM probe?

- **While collapsing,** these halos are great dark matter probes!
- No stars: completely dark
- Small halos, very dark matter dominated
- May be visible in absorption!

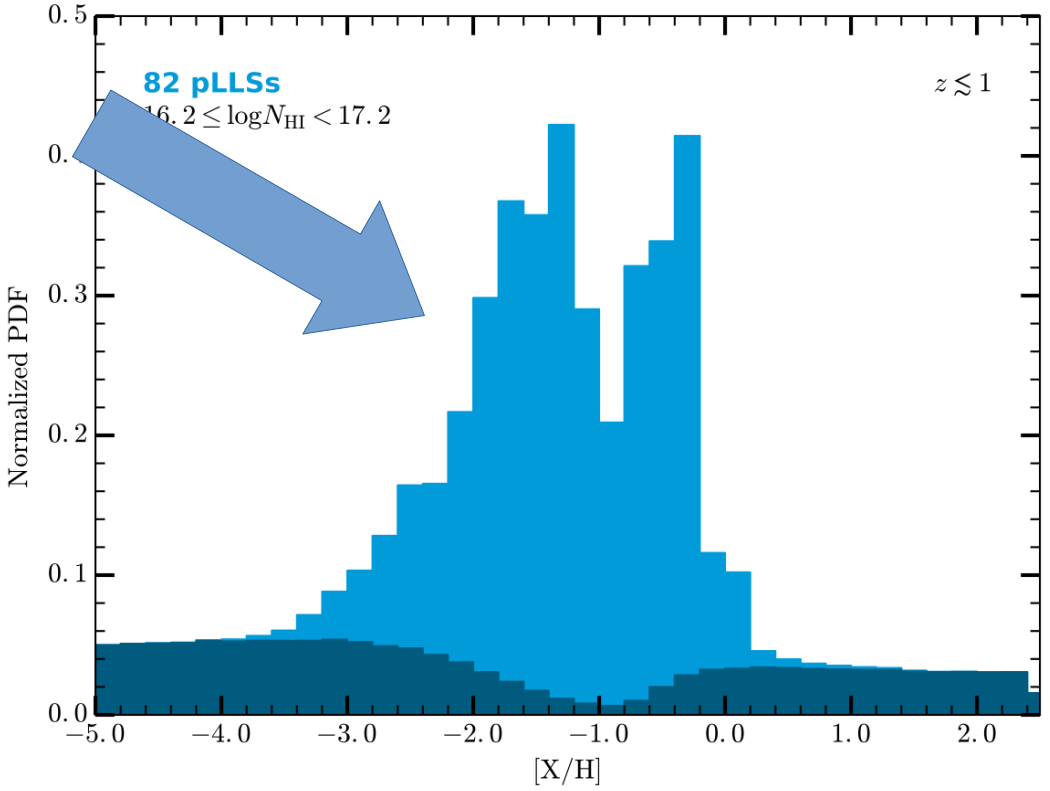
What do they look like?

- Number density ~ 1 / Mpc^3
- HI column density of ~ 10^{17} cm^{-2}
- Only at z < 1.5 when the IGM is cooling
- Metal-poor

What do they look like?

- Observed: metal-poor HI ~ 3×10^{16} cm^{-2}
- Number density ~ 0.8 / Mpc^3 at z = 0.1 - 1

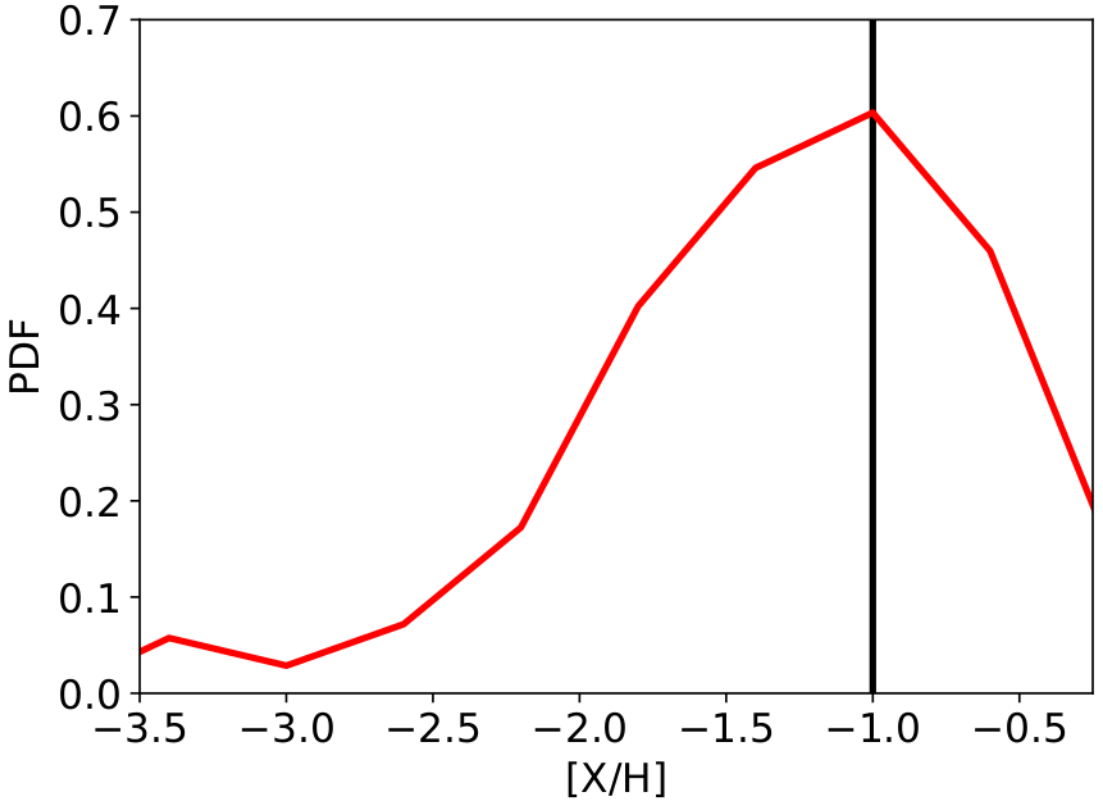
These!



Lehner, 11,18

What do they look like?

- Not in (galaxy formation) simulations because not resolved!



Better WDM probe

- Simple Poisson estimates suggests ~20% constraints on number density from existing data
- May constrain 5 keV thermal WDM at 2-sigma (assuming no degeneracies, Fisher forecast)!
- Only 82 objects! We can get more!

Summary

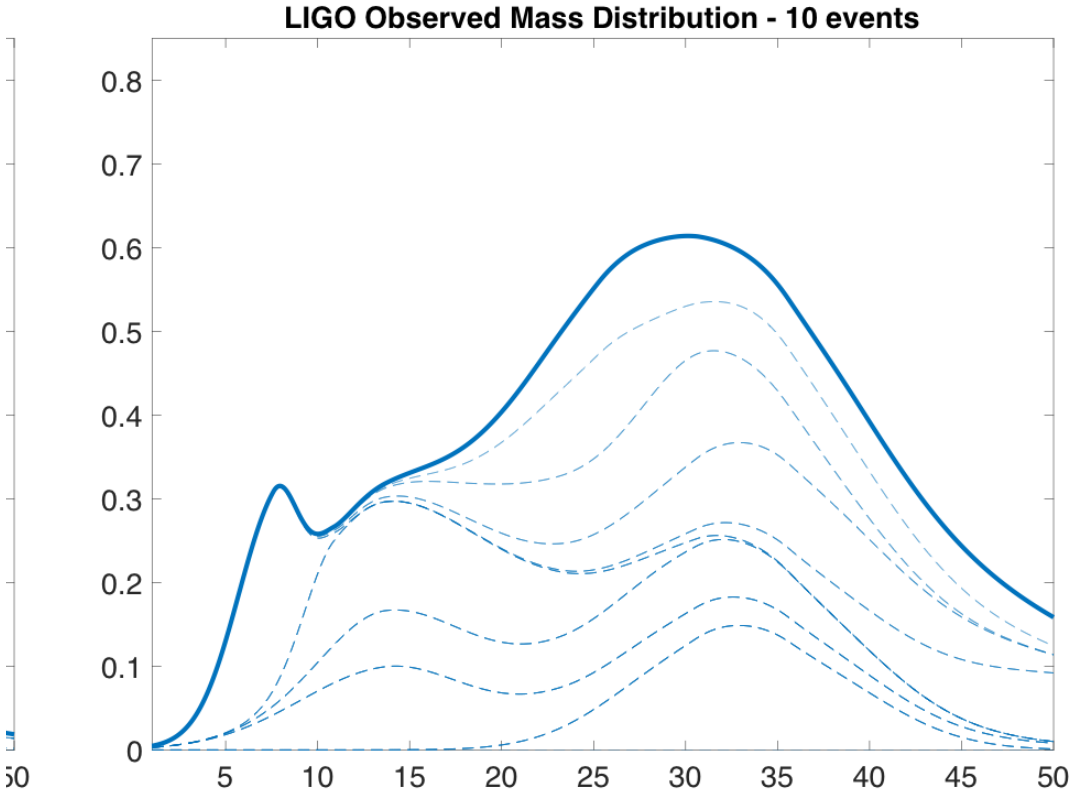
- Neutral hydrogen at $z > 5.5$ is current best limits on dark matter: thermal relic with $m > 5.3$ keV

- Metal-poor gas reservoirs at $z < 1$ can count dark halos and may potentially constrain thermal relic dark matter even better

Aside: Did LIGO Detect Primordial Black Holes? An Update

LIGO Mergers Still Plausibly Primordial

Mass function:



+ Some evidence for misaligned spins

30 Msun Black Holes cannot be all DM

- Non-detection of lensed supernovae (Zumalacarregui & Seljak): “No LIGO Macho”

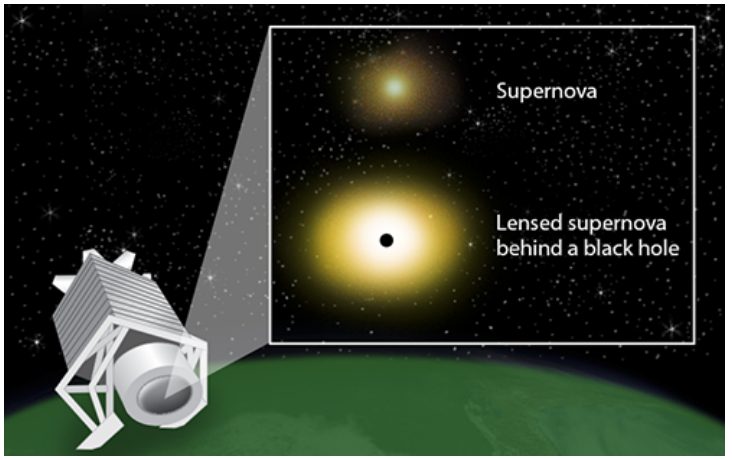


Image: APS magazine ‘Physics’

- ~30 Msolar PBH < 30 % of dark matter at 2-sigma