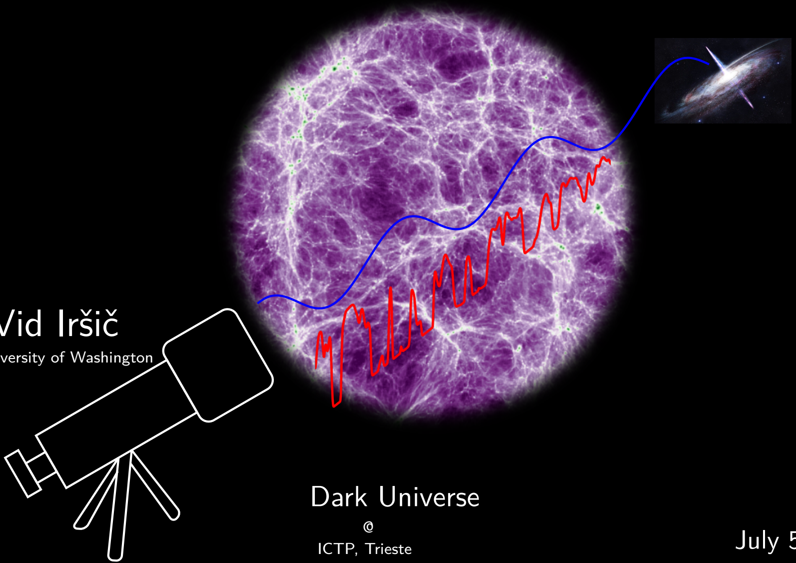
Dark Matter from Lyman-α forest



Vid Iršič

@ University of Washington

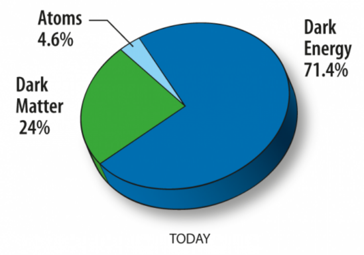
Dark Universe

@

ICTP, Trieste

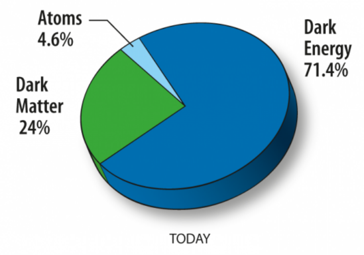
July 5, 2018

Cold Dark Matter problems (?)



Cold Dark Matter (CDM):
heavy, non-interactive particle(s) → WIMPs

Cold Dark Matter problems (?)



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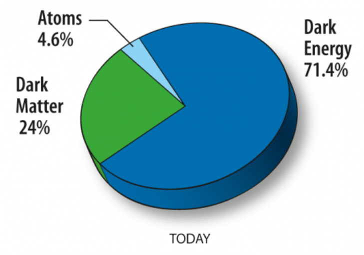
CDM problems of small-scale physics:

- Missing satellites
- Core/Cusp problem
- ...

Cold Dark Matter problems (?)



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→ Alternative DM models (Warm DM, Fuzzy DM, Self-interacting DM, ...)

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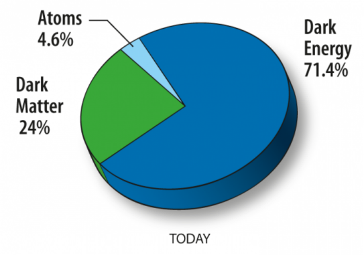

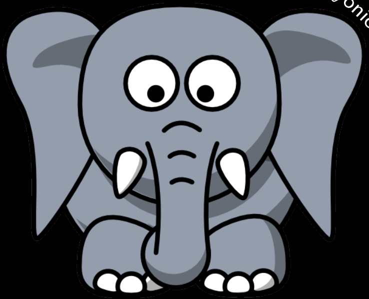

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- Missing satellites
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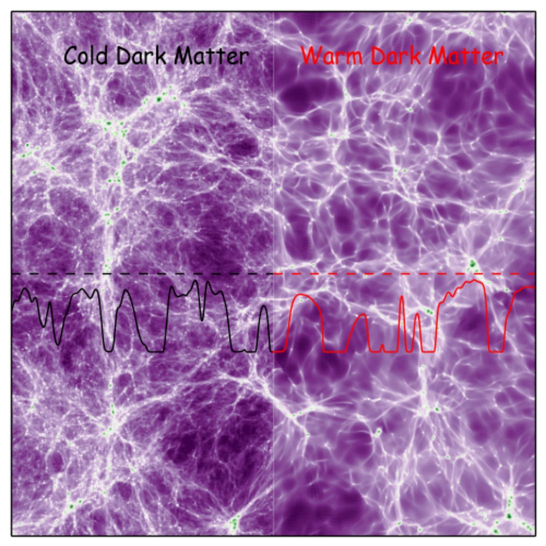
$\rightarrow$ Alternative DM models (Warm DM, Fuzzy DM, Self-interacting DM, ...)

Non-CDM erases small scale structure



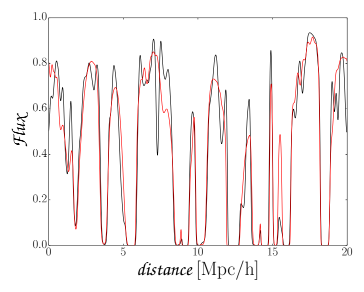
Warm Dark Matter (WDM):

Free-streaming of DM particles

(From the time they decouple until they become non-relativistic)

$\Longrightarrow$ erases small scale structure

Typical $\lambda_{\rm FS} \sim {\rm Mpc/h}$



Flux power spectrum - wide redshift range

XQ-100 Legacy Survey:

100 VLT/XSHOOTER spectra of QSOs
(Lopez et al. 2016)

7 redshift bins: $z = 3.0 - 4.2$

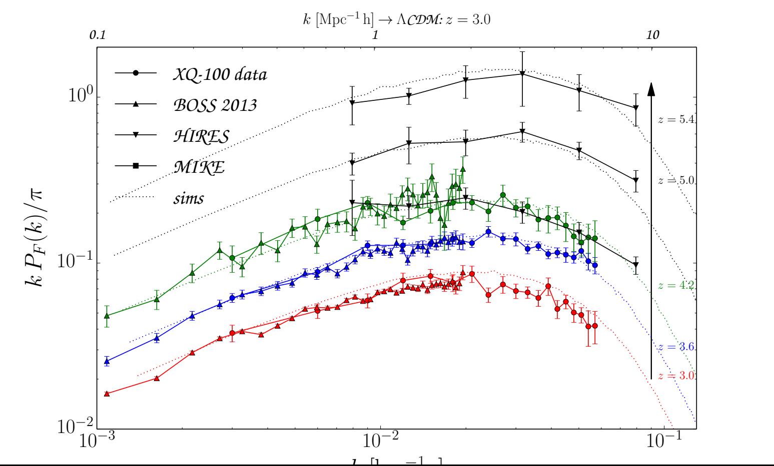
19 k-bins: $k = 0.003 - 0.06$ s/km

HIRES/MIKE:

14 HIRES + 11 MIKE spectra of QSOs
(Becker et al. 2011, Viel et al. 2013)

4(3) redshift bins: $z = 4.2 - 5.4$

6 k-bins: $k = 0.008 - 0.08$ s/km



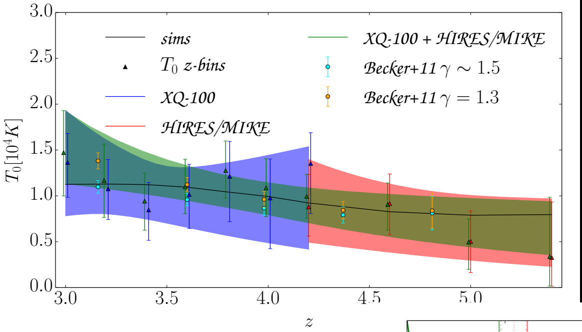
Cosmological parameter inference - WDM

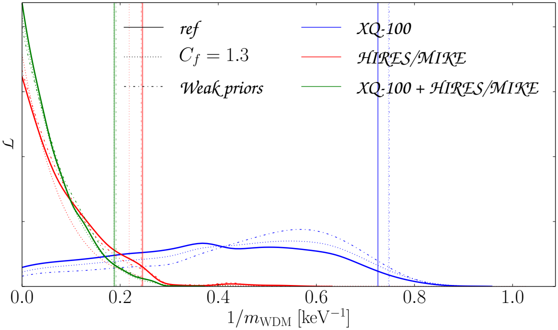
- Parameters (p): $\bar{F}(z)$, T_0 (T^A, T^S), γ (γ^A, γ^S), σ_8, $n_{\rm eff}$, $z_{\rm rei}$, $f_{\rm UV}$ + $m_{\rm WDM}$
- A grid of simulations (3x, 3x3 + 3x4, 3x3, 3, 3, 3x4, 3, 4x3 + 4x3)
- Interpolation scheme among the grid points
- run (4) MCMC chains for each model we desire to test (e.g. different data-set, different priors, adding systematic errors, etc.) $\rightarrow$ maximizing the likelihood $\mathcal{L}(p|d)$

Parameter	XQ-100	HIRES/MIKE	Combined
$m_{\rm WDM}$ [keV]	> 1.4	> 4.1	> 5.3
σ_8	$[0.75, 0.92]$	$[0.75, 1.32]$	$[0.83, 0.95]$
$n_{\rm eff}$	$[-2.42, -2.25]$	$[-2.53, -2.11]$	$[-2.43, -2.32]$
$T^A(z_{\rm p})$ [10^4 K]	$[0.73, 1.27]$	$[0.46, 1.12]$	$[0.74, 1.06]$
$T^S(z_{\rm p})$	$[-4.39, 1.89]$	$[-4.78, -1.80]$	$[-3.22, -0.82]$
$\gamma^A(z_{\rm p})$	$[1.12, 1.45]$	$[1.08, 1.52]$	$[1.23, 1.69]$
$\gamma^S(z_{\rm p})$	$[-1.89, 0.17]$	$[-1.18, 1.77]$	$[-0.07, 1.81]$
$z_{\rm rei}$	$[6.5, 15.66]$	$[6.26, 14.88]$	$[6.25, 13.43]$
$f_{\rm UV}$	$[0.06, 0.96]$	$[0.05, 0.96]$	$[0.05, 0.94]$
$\chi^2/d.o.f.$	$134/124$	$33/40$	$185/173$

Marginalized constraints at 95 %, obtained from the MCMC analysis. The pivot redshifts for different data sets are: $z_p = 3.6$ for XQ-100, $z_p = 4.5$ for HIRES/MIKE and $z_p = 4.2$ for XQ-100 + HIRES/MIKE.

WDM mass constraints





$T_0(z), \gamma(z)$ are power-laws

$\rightarrow m_{\rm WDM} > 5.3$ keV @ 2σ

$T_0(z)$ free + $\dfrac{\partial T_0}{\partial z}$ bounded

$\rightarrow m_{\rm WDM} > 3.5$ keV @ 2σ

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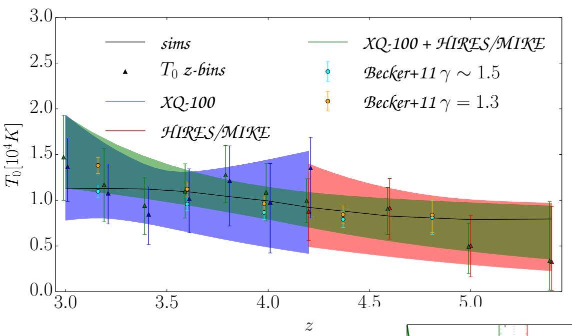

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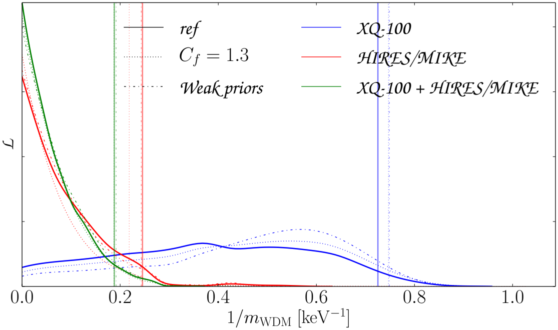

What next?

With conservative thermal history:

$m_{\rm WDM} > 2.1$ keV (2σ) (HIRES/MIKE) $\rightarrow m_{\rm WDM} > 3.5$ keV (2σ) (HIRES/MIKE + XQ-100)

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$\downarrow$

New high-z QSOs in the future:

DESI (14,000 sq. deg.) ~ 25 QSO spectra at $z > 4.0$ (and $m < 18.5$)

SkyMapper (17,200 sq. deg.) ~ 30 QSO spectra at $z > 4.0$ (and $m < 18.5$)

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How much do we gain?

Simple forecast

With conservative thermal history:

$m_{\rm WDM} > 2.1$ keV (2σ) (HIRES/MIKE) $\rightarrow$ $m_{\rm WDM} > 3.5$ keV (2σ) (HIRES/MIKE + XQ-100)

$\downarrow$

25 QSOs: $m_{\rm WDM} > 2.3$ keV

$\downarrow$

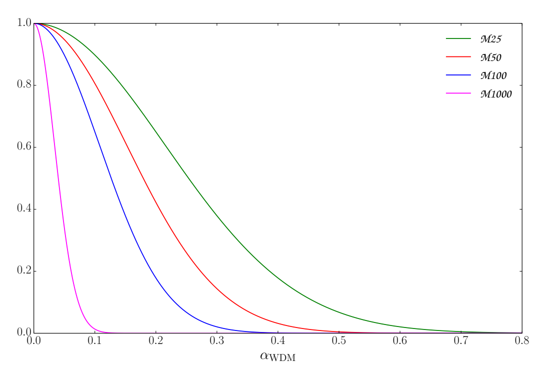
50 QSOs: $m_{\rm WDM} > 3.3$ keV

$\downarrow$

100 QSOs: $m_{\rm WDM} > 4.6$ keV

$\downarrow$

1000 QSOs: $m_{\rm WDM} > 14.7$ keV



Conclusions

Cosmological & Astrophysical Constraints on WDM:

- Combined data: XQ-100 + HIRES/MIKE (high resolution, high redshift)
- Large redshift range and probing small scales
- Constraints on WDM from combined data: $m_{\rm WDM} > 5.3$ keV at 2σ.
- Constraints on WDM from combined data: $m_{\rm WDM} > 3.5$ keV at 2σ (conservative thermal history)
- The paper: Iršič+17 PRD 06 02 astro-ph/1702.01764

Simple forecasts for the future:

- Larger redshift range $\rightarrow$ 60% better constraints: 2.1 keV $\rightarrow 3.5$ keV (2σ)
- Better thermal priors $\rightarrow$ 50% better constraints: 3.5 keV $\rightarrow 5.3$ keV (2σ)
- DESI/SkyMapper/LSST will give ~ 100 high-z QSOs observable with Keck HIRES/VLT UVES
- +ELTs will give ~ 1000 high-z QSOs
- Forecast for WDM from 100(1000) high-z QSOs: 2.1 keV $\rightarrow 4.6(14.7)$ keV (2σ)
- The paper: Iršič+18 in prep Coming soon!