Measuring the small scale power spectrum with Lyα forest data

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Measuring the matter power spectrum

\[ P(k) = k^n T^2(k) \]

observed

linear physics

quantum fluctuations in the early universe

SDSS galaxy clustering

Lyα forest

Gravitational lensing

Cluster abundance

Cosmic microwave background

amplitude

Density fluctuations

Scale (millions of lightyears)

length scale

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Tegmark
Neutral hydrogen is an excellent tracer of the matter distribution

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\[ \tau_{\text{HI}} = A \left( \frac{\rho}{\bar{\rho}} \right)^{\alpha} \quad 1.6 \leq \alpha \leq 2.4 \]
High resolution – High S/N

Low resolution – Low S/N

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- 3035 SDSS spectra
- low S/N (~5-15)
- low resolution (~100 km/s)

Pros:
- small statistical errors
- split in many redshift bins over a wide redshift range

Cons:
- rather large corrections for noise and resolution
Measuring present-day amplitude and primordial slope of matter power spectrum: $\sigma_8$, $n_s$
Viel, Haehnelt & Lewis 2006

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$\sigma_8 = 0.8 \pm 0.04$ and $n=0.96 \pm 0.01$
Constraints on warm dark matter and neutrino masses
Warm Dark Matter

Neutrinos

Length scale

Length scale

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The mass of dark matter particles

- **Cold dark matter**
  - $\Lambda\text{CDM}$
  - 30 comoving Mpc/h $z=3$

- **Warm dark matter**
  - WDM 0.5 keV

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$M_{\text{wdm}} > 2.4$ keV

$M_{\text{wdm}} > 4$ keV

$M_{\text{wdm}} = 8$ keV

55 Keck spectra
DM is pretty cold

There is little room left for effects on the DM halo mass function (or DM halo profiles).

The parameter space for sterile neutrinos appears pretty much closed.
Caveat: Ly-alpha and WMAP not fully consistent
Beyond the flux power spectrum
An improved measurement of the flux distribution of the Ly$\alpha$ forest in QSO absorption spectra: the effect of continuum fitting, metal contamination and noise properties

T.-S. Kim,$^{1,2}$† J. S. Bolton,$^{2,3}$ M. Viel,$^{2,4}$ M. G. Haehnelt$^2$ and R. F. Carswell$^2$

20 UVES/VLT spectra with S/N $>$70 per pixel
Possible evidence for an inverted temperature–density relation in the intergalactic medium from the flux distribution of the Lyα forest

J. S. Bolton, M. Viel, T.-S. Kim, M. G. Haehnelt and R. F. Carswell

The shape of the flux PDF depends mainly on the slope of the temperature-density relation and the effective optical depth.

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An inverted temperature density relation?

\[ T \propto \rho^{\gamma - 1} \]

\[ \tau \propto \frac{\alpha \rho^2}{\Gamma_{\text{phot}}} \propto \frac{T^{-0.7} \rho^2}{\Gamma_{\text{phot}}} \propto \rho^\alpha \]

1 \leq \gamma \leq 1.6

1.56 \leq \alpha \leq 2

Bolton et al. 2008
Underdense regions appear to hotter than generally assumed!
Radiative transfer effects during helium reionization?
Other heating processes?

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The amplitude of the matter power spectrum inferred from Ly-alpha forest data decreases with decreasing $\gamma$.

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Neutrinos

This should weaken upper limits on neutrino masses from Ly$\alpha$ forest data.

Length scale

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Summary

- consistent results from high and low-resolution Lya forest data and independent analysis by two groups
- Lya forest data favours somewhat larger fluctuation amplitude than WMAP 3 data
- tight lower limits on WDM ($m_w > 4\text{KeV}$)
- new accurate measurement of flux PDF suggests that thermal state of the IGM more complex than previously assumed (inverted temperature-density relation)
- fluctuation amplitude inferred Lya forest data about 5-10% ($1\sigma$) lower
- published upper limits on sum of neutrino masses most likely significantly weakened

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