Absorption towards Pairs of QSOs: QSOs Episodic life times, Galaxy winds and the IGM

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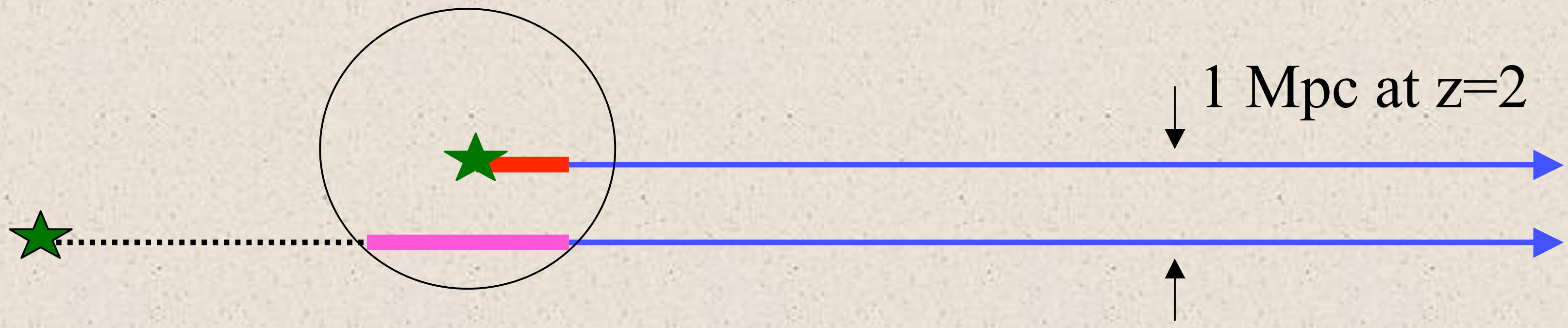
Pairs of QSOs Probe the IGM and Feedback



Absorption far from both QSOs:

- The 3D structure of the HI in the IGM that makes the Lya Forest
- 3D clustering of galaxy halos selected by metals in halos
- Winds from galaxies

Absorption near QSOs explores QSOs environments and "feedback" from QSOs

- See changes along the line of sight to the QSO
- See different effects in the plane of the sky

Talk Contents

Spectra of pairs of QSOs (Tytler et al arXiv 0711.2308)

1. Metal lines absorbers cluster strongly around other absorbers:

    from blue, not red galaxies

    not in fast moving winds

2. We see extra metal systems when a sight line passes by a QSO -

    galaxies clustered near the QSO.

3. Amount of neutral Hydrogen absorption near to QSOs:

    a) no change in front of QSOs: density cancels the QSO UV

    b) 30% more HI behind QSOs:

    QSO episodic lifetime of order 1 Myr (eg 10% duty cycle)

4. Simulations to interpret the IGM

    Simulations do not match data z=2 (Tytler et al. arXiv 0711.2529)

Spectra of 170 Pairings of QSOs

We use 400+ spectra of 310 QSOs from: Keck LRIS 78 – 170 km/s

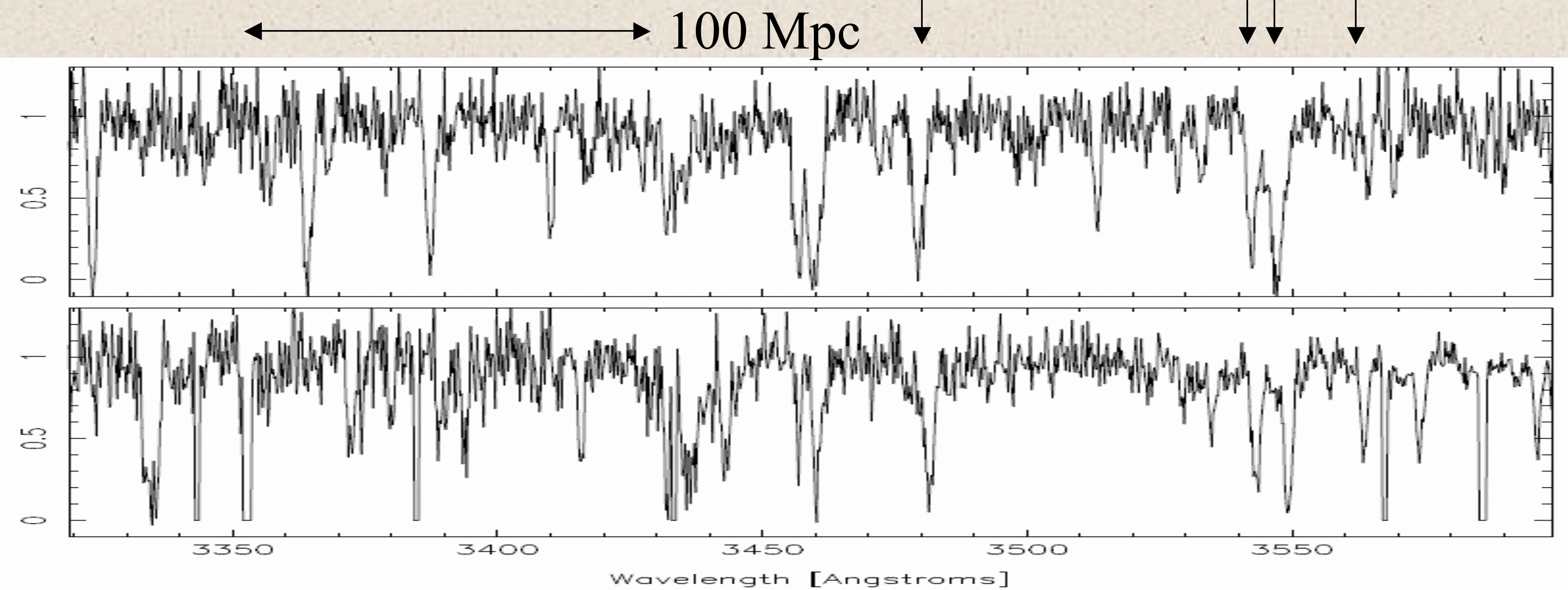
Lick 3-m Kast 250 km/s and SDSS 170 km/s (wider pairs and lower SNR)

LRIS spectra 2 QSOs separation 68 arcsec = 0.58 Mpc

Above: z_{em} = 2.132 r=19.1 most lines are HI from IGM

Below: z_{em} = 1.977 r=19.7 See correlated absorption

100 Mpc



Separations Probed

Redshift z=2

150 arcsec

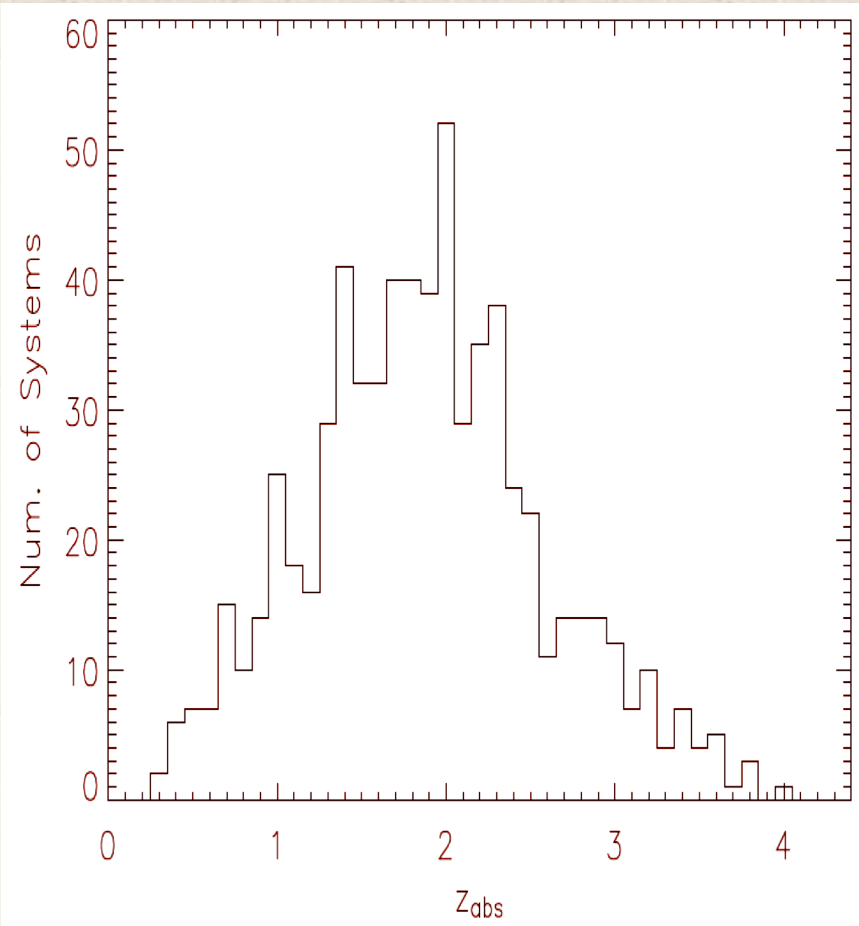
1 Mpc

Absorption in individual halos extends about 100 kpc or one bin in this plot.

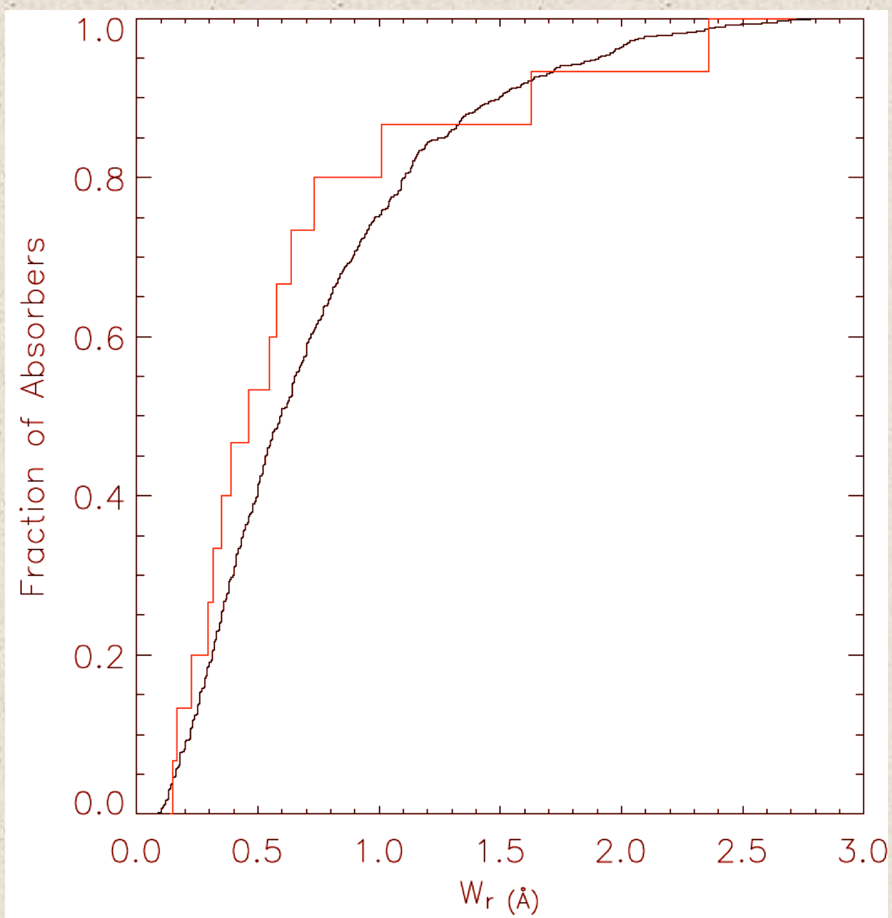
Paired sight lines probe galaxy clustering scales.

691 Metal Line Systems (Non-BAL)

Wide range of absorption redshifts

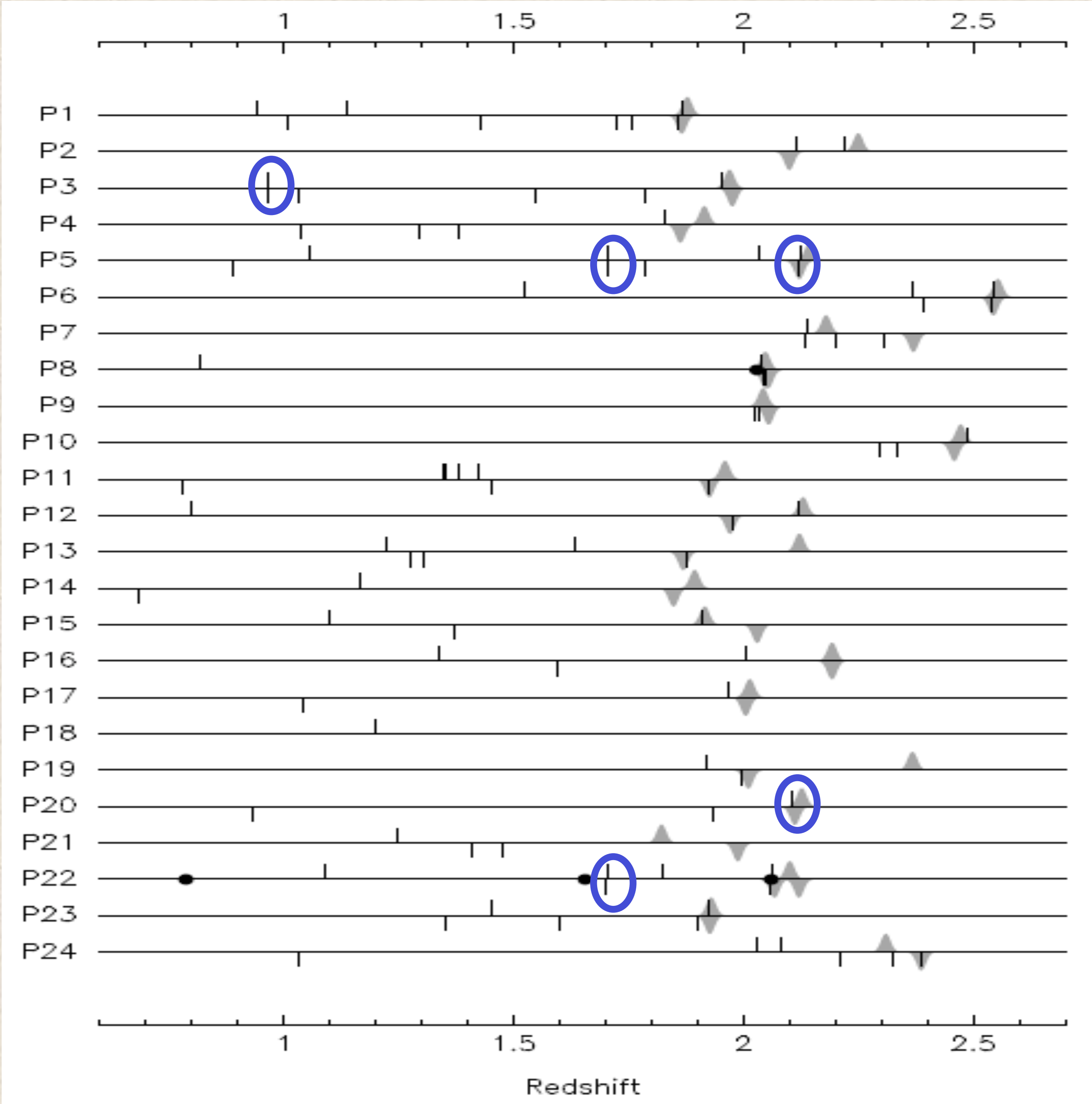


Line strengths show most absorption is in galaxy halos, not IGM



We see Metal Absorbers at same Redshifts

Many absorbers near their QSOs emission redshift (zem)



Absorber-Absorber Clustering

How are absorbers in spectrum of one QSO correlated in 3D with those in the partner QSO spectrum, about 1 Mpc away.

We will see that the absorber-absorber clustering is strong on very small scales, favoring

Absorption in blue, not red galaxies and

Absorption in quiescent gas, not fast moving winds

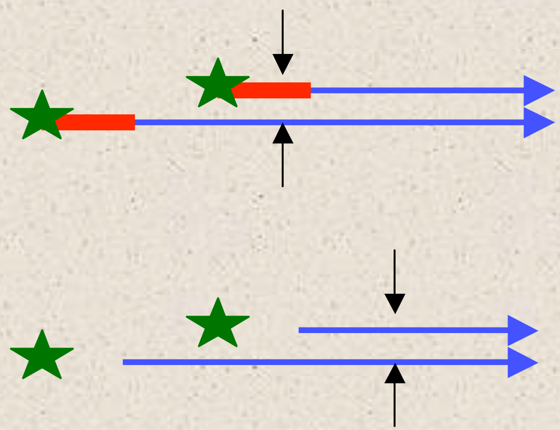
Strong correlation of absorber with absorber

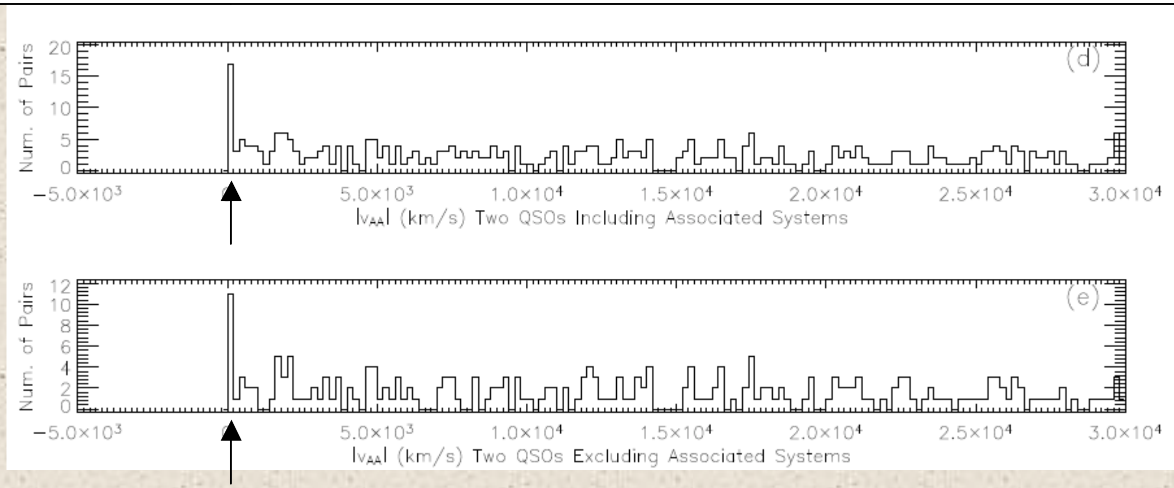
Number of pairs of zabs. Bins delta z = 0.002 = 200 km/s

Excess absorbers in one QSO at z of absorber partner QSO.

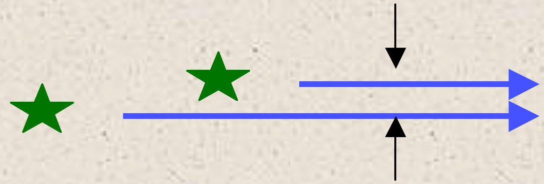
Excess is in one bin: 200 km/s wide

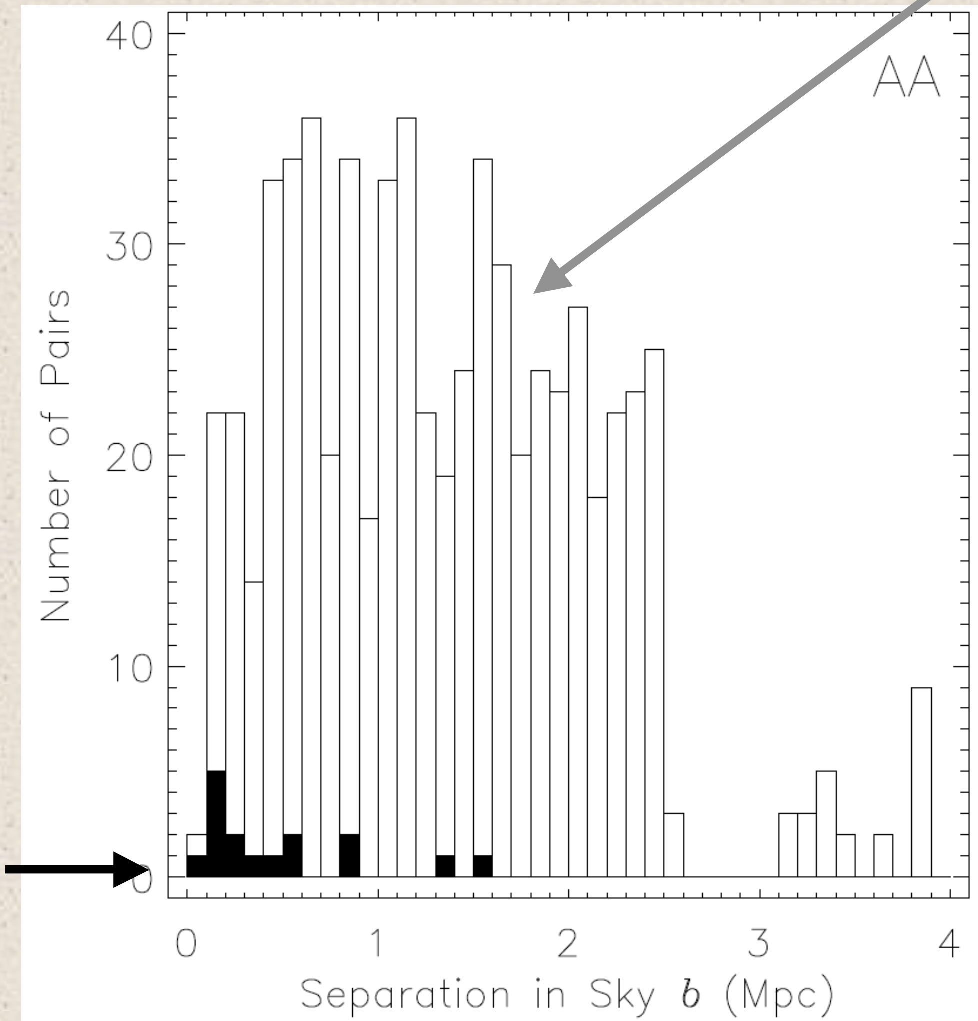
Excess remains when reject all absorbers in red regions near to QSOs.





Absorber-absorber coincidences are at < 0.5 Mpc





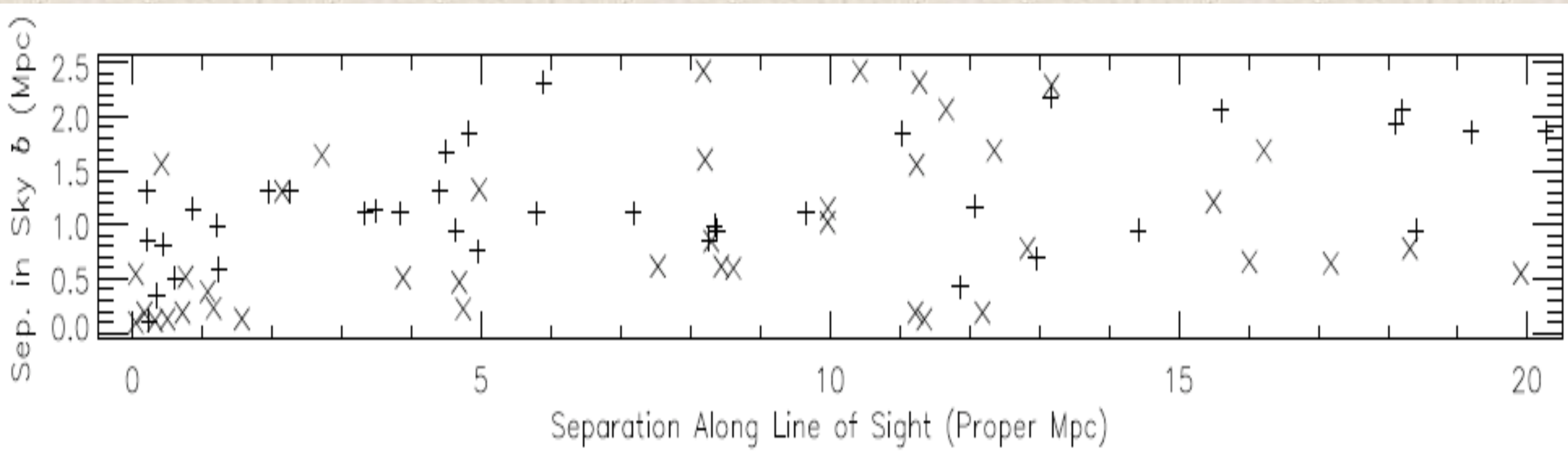
Black: distance to other QSO beam for 16 pairs of z_{abs} systems separated by < 500 km/s

12 of 16 are < 0.5 Mpc

White: Control sample. Distance to other QSO beam for 625 z_{abs} systems

Clearly see 3D clustering of absorbers

Impact parameter in sky



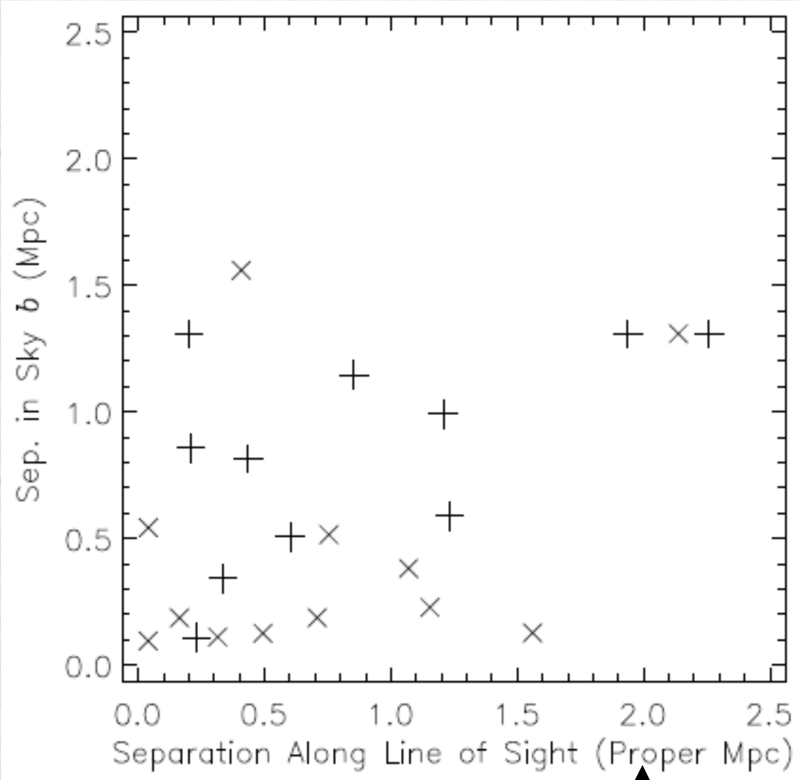
Distance (Mpc) from absorber to absorber. Earth on right.

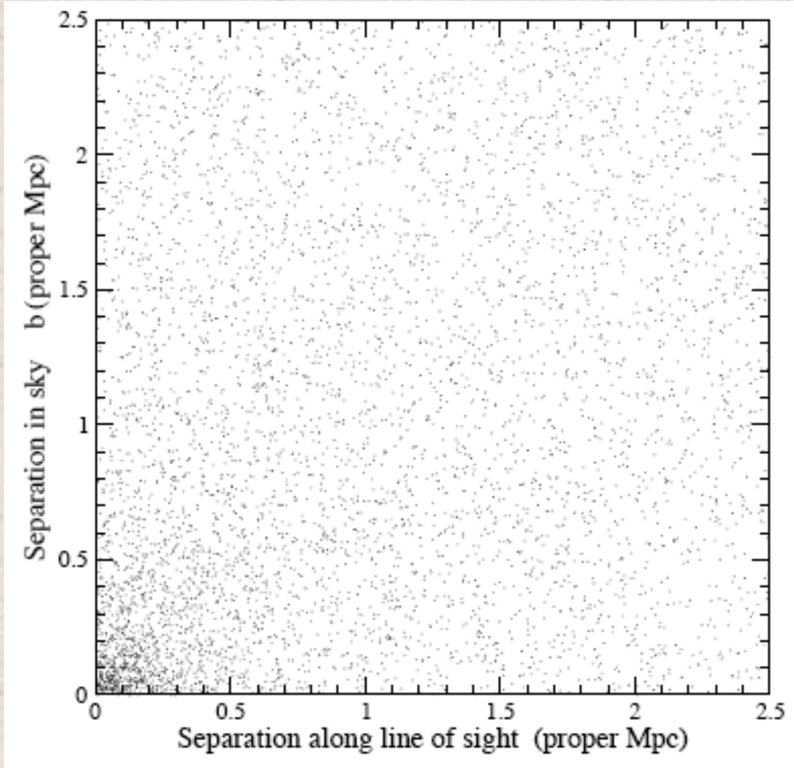
One absorber at origin.

The second, in other QSO spectrum, is the + or x (far from all QSOs)

We already saw the excess near origin in z and in plane of sky.

Observed and Expected Absorber clustering





Observed: 400 km/s

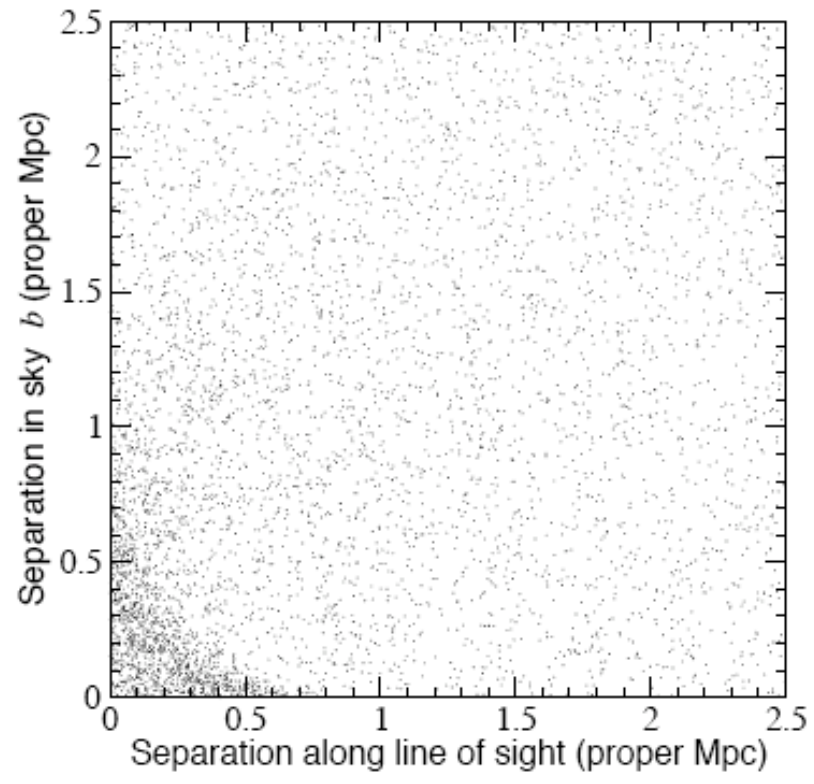
one absorber at origin,
other + or x

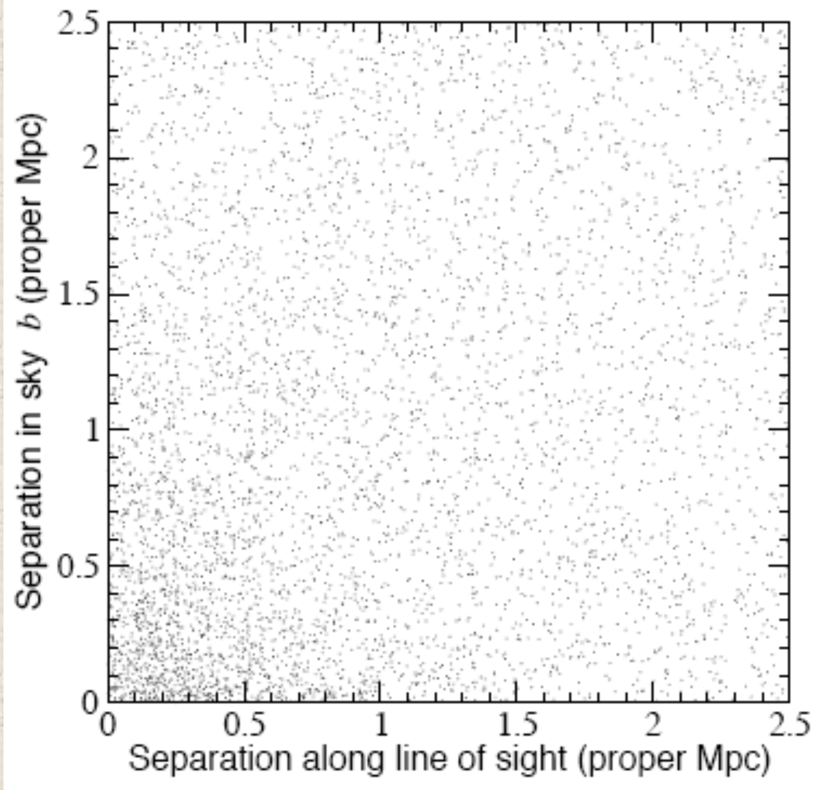
Expected:

Galaxy clustering: $(r/1.24\ \mathrm{Mpc})^{-1.6}$

Redshift errors: 23 km/s each absorber

Include Galaxy motions in Predictions





Expected:

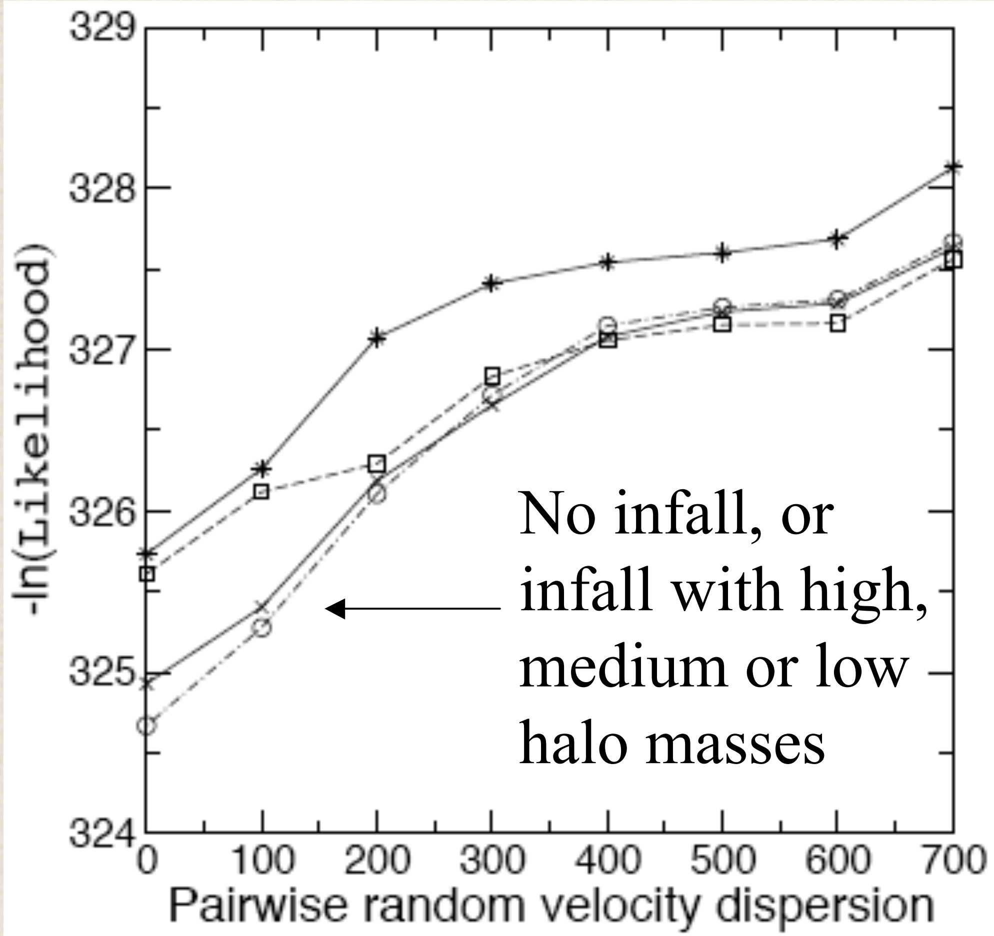
Adding systematic infall to moderate mass halos (Kim & Croft 2007)

Expected:

Adding random pair-wise velocities with sigma=240 km/s for blue galaxies (Coil et al 2007)

Absorbers have small Pair-wise Velocities: in halos of blue not red galaxies

The strong clustering of absorbers on very small velocity scales is incompatible with large pair-wise random velocities of red galaxies: absorbers are in halos of blue galaxies…. or sample too small to see rare clusters.



Coil et al 2007 z=1

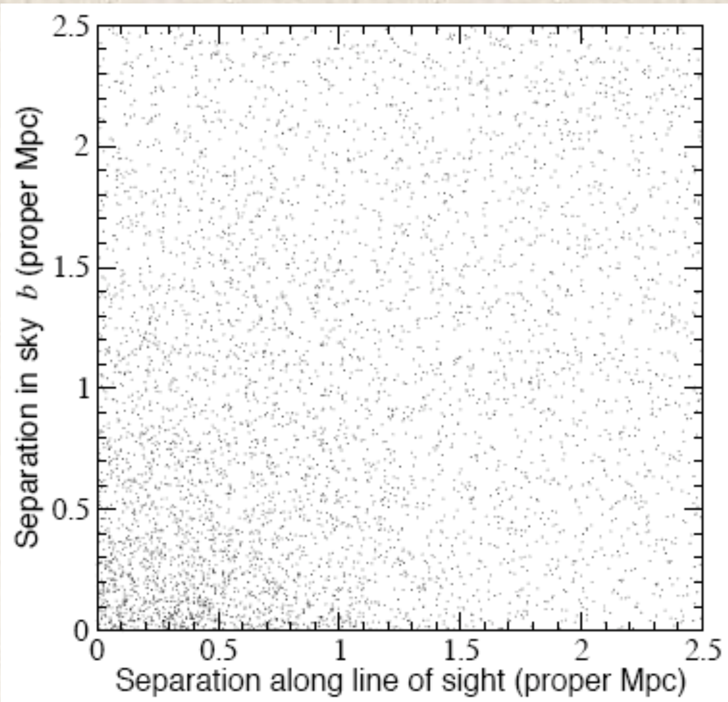
Li et al. 2006

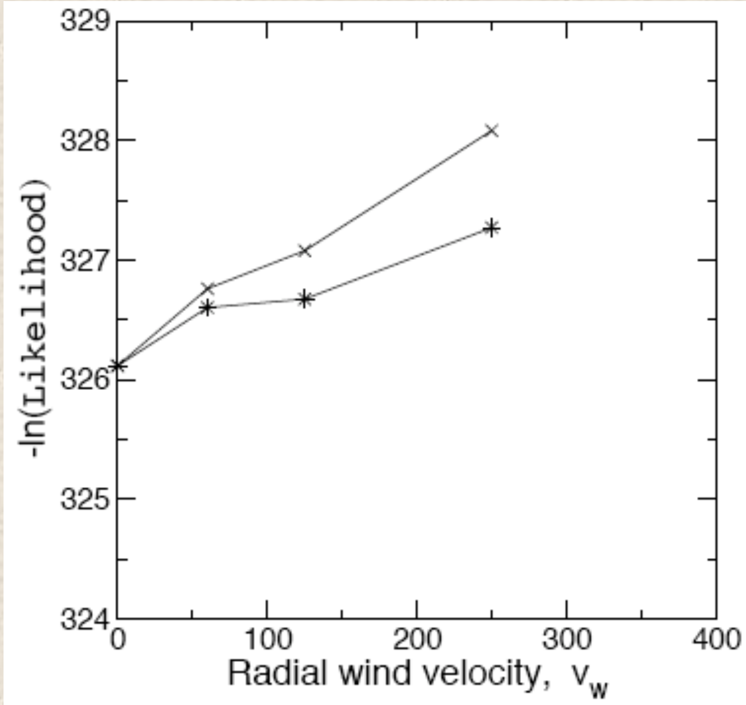
Zehavi et al. 2002 SDSS

Madgwick et al. 2003 2dF

Galaxy data

Typical absorbers not from fast galaxy winds





Expected if absorbers in winds flowing radially out from galaxies at 120 km/s.

Data prefer zero wind velocity. They allow the 250 km/s winds seen by Adelberger et al. 2005 but only in <1/3 of galaxies.

Winds are restricted to LBGs, or they do not extend to >40 kpc with large velocities while making absorption we can see

Meaning of Absorber-absorber Correlation

We discovered in 1994 that there are metals (C, O, Si) in IGM.

We know metal come from winds.. But we do not know when the metals arrived in the IGM.

Steidel, Adelberger et al. find strong winds in Lyman Break Galaxies (LBGs) at z=2-3.

- Outflows of 250 km/s common - large range
- They do not know if these winds reach the IGM

Our spectra have velocity resolution to show most absorbing gas at z=2 is not in fast moving winds (agree with Rauch+01)

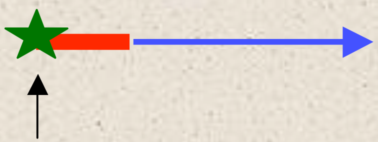
- Typical metal absorbers are not fast winds carrying metals into the IGM at z=2
- More likely metals arrive gradually, over many epochs

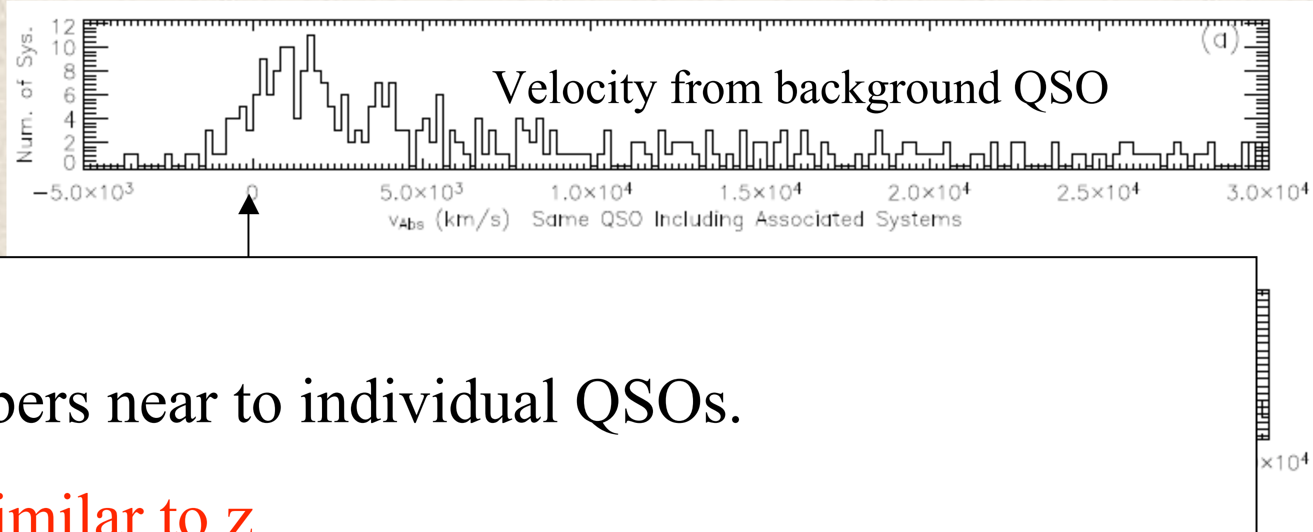
Metal line Absorbers Clustered Around QSOs

We see excess metal line absorbers (galaxy halos) when pass a QSO.

Extra Absorbers near to QSOs

Number of z_{abs} in single sight lines. 310 QSOs. Bins 200 km/s





We see extra absorbers near to individual QSOs.

In red region: z_{abs} similar to z_{em}

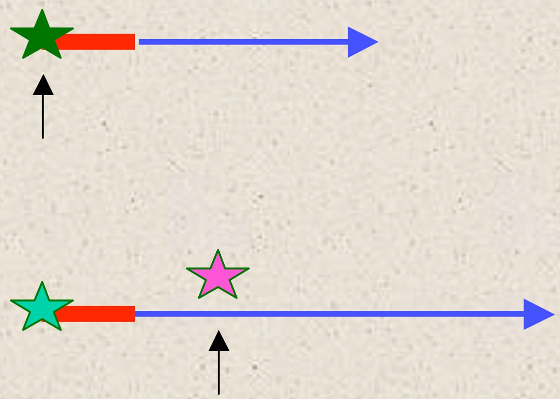
Well known from 1970s.

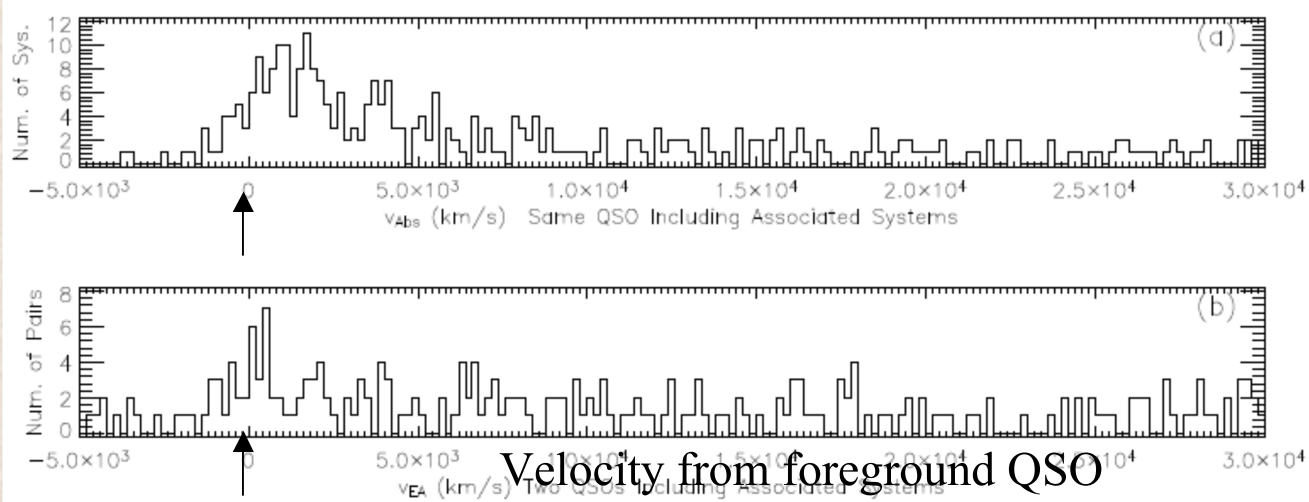
- Mostly because easier to see absorption in emission lines
- Real excess of clustered and ejected absorbers near to QSOs.

Negative velocities from errors in emission redshifts (z_{em})

See New Type of Absorbers when pass a QSO

Number of z_{abs}. 310 QSOs. Bins 200 km/s





Velocity from foreground QSO

Plot velocity difference from z_{em} (QSO1) - z_{abs} (QSO2)

Excess absorbers with velocity difference of 0 - 600 km/s.

Mean v = 213 ± 140 km/s (1.5 sigma from zero, systematic zem error?)

More concentrated near z_{em} than are QSO2 own absorbers.

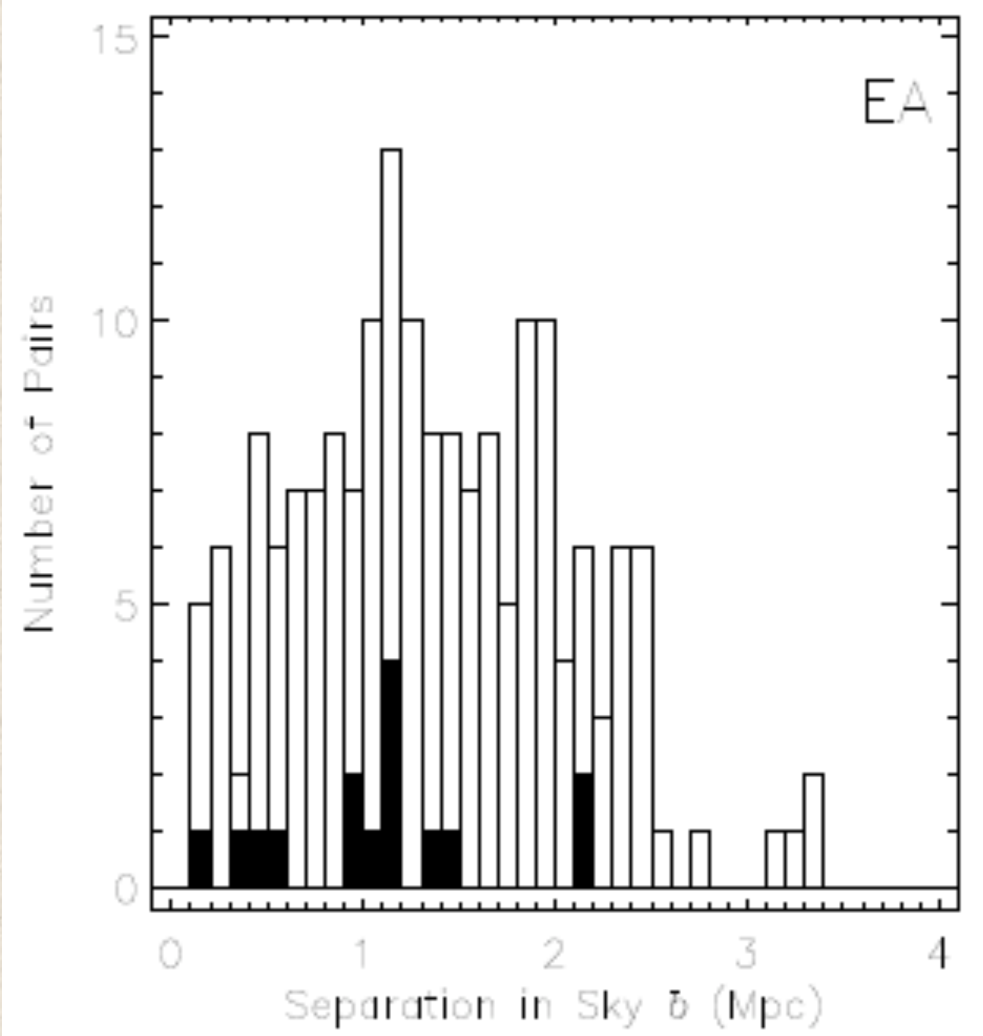
From group of galaxies around QSO

Mostly not seen when look directly at a QSO: destroyed by UV?

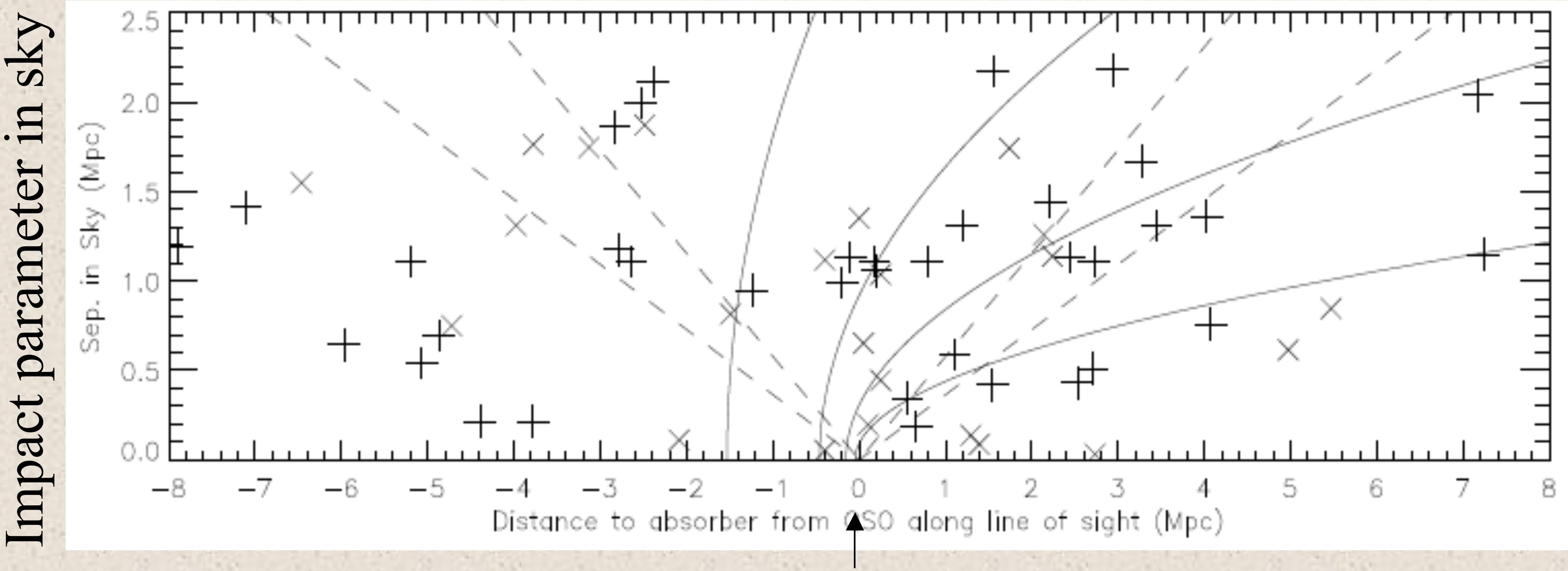
Transverse Associated absorbers also Detected in Distribution in Plane of sky

Absorption is more common when pass close to a QSO in the sky:

2% chance of the black distribution (absorption seen) coming by chance from the white one (all sight lines passing QSOs)



In 3D absorbers are almost uniform around QSOs



Distance (Mpc) from QSO to absorber (+ or x Hennawi et al 06)

64 absorbers seen when pass 313 QSOs (at origin).

Dashed lines are 20 and 40 degrees from ray to Earth on right.

Parabolas are illuminated if QSO on for 0.3, 1, 3 or 10Myr

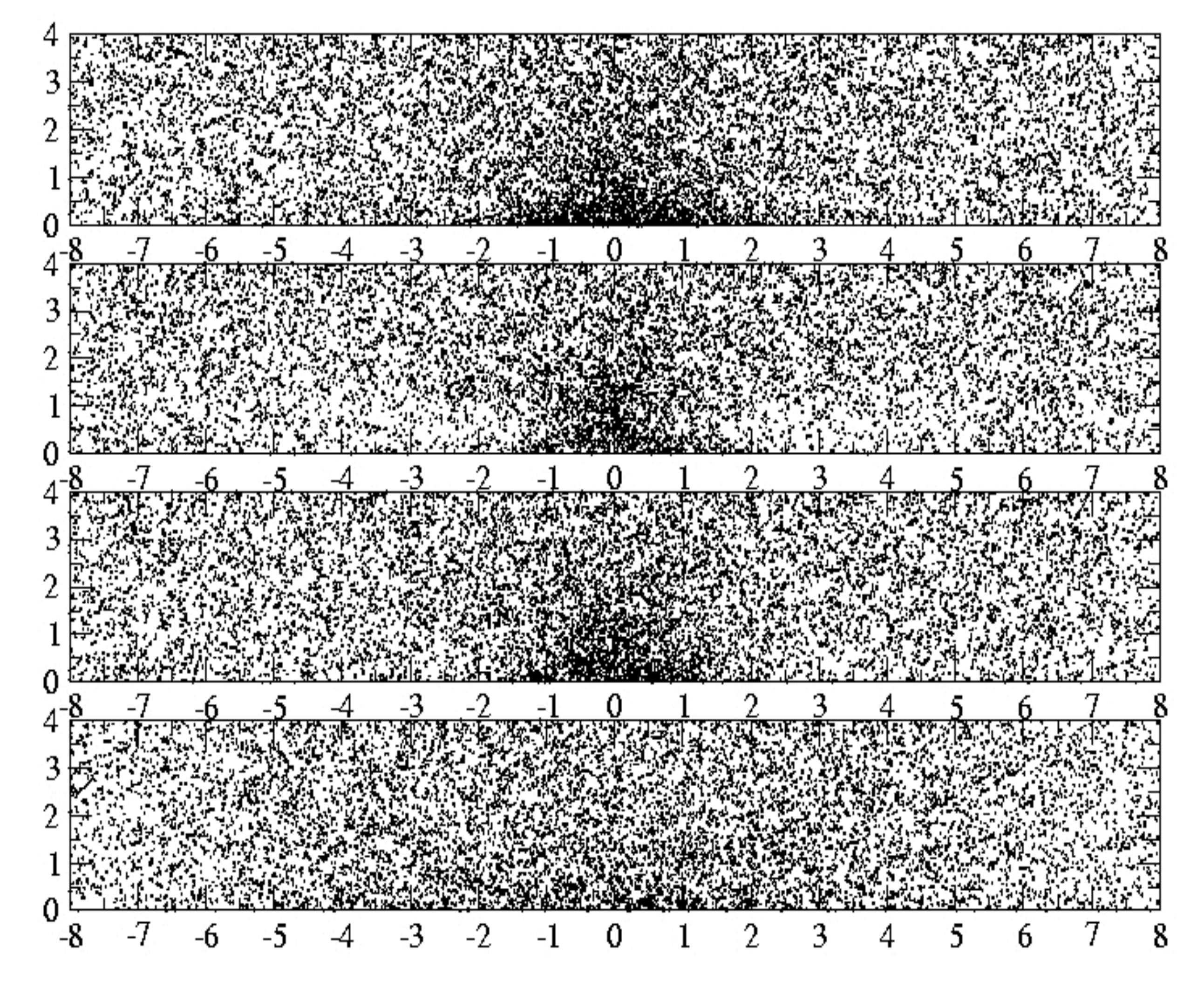
It will be very hard to see beamed UV

Clustering, infall, 400 km/s random pair-wise velocities

As above and removing points in a cone with half apex angle 20 degrees, pointing to us

Now cone axis is tipped with probability proportional to angle

Adding errors from emission redshifts:
35% 2Mpc (400 km/s),
35% 4Mpc,
30% 8Mpc



Transverse Proximity Effect

We discussed metal lines seen when we pass by a QSO.

Now let's look at the absorption in neutral Hydrogen.

We expect 10-100x less HI because higher UV flux near to QSO

We expect factor of few higher density near to QSOs…

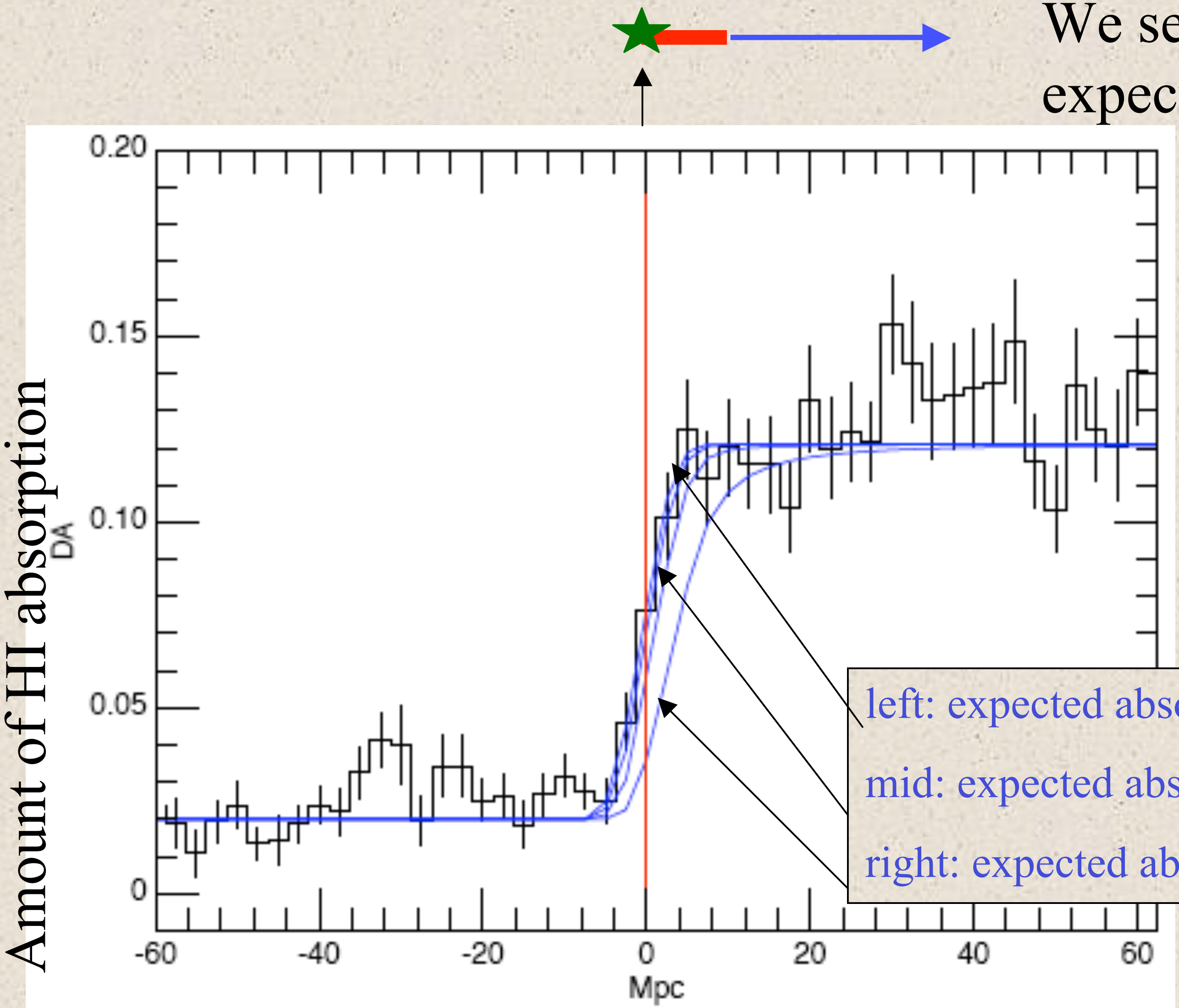
This gives faster recombination: more HI

Some cancellation of the UV flux

(Loeb & Eisenstein 1995; Faucher-Giguere + 08)

Line of Sight Proximity Effect

We see more HI than expect in line of sight.



Amount of HI absorption

left: expected absorption for 0.01 L(QSO)

mid: expected absorption for 0.1 L(QSO)

right: expected absorption for L(QSO)

Mpc from the nearer QSO

Why is there more Neutral Hydrogen near QSOs than expected?

The enhanced ionization from QSO flux is cancelled by denser gas near QSO

A larger effect for our lower luminosity QSOs because excess QSO flux limited to region where density is enhanced

At 4 Mpc from $z > 4$ QSOs Guimares+07 find 5x gas density, implying 25x more HI, but others think this is excessive

Extra absorption from H in metal systems near the QSOs

Low luminosity sources show more intrinsic absorption in X rays

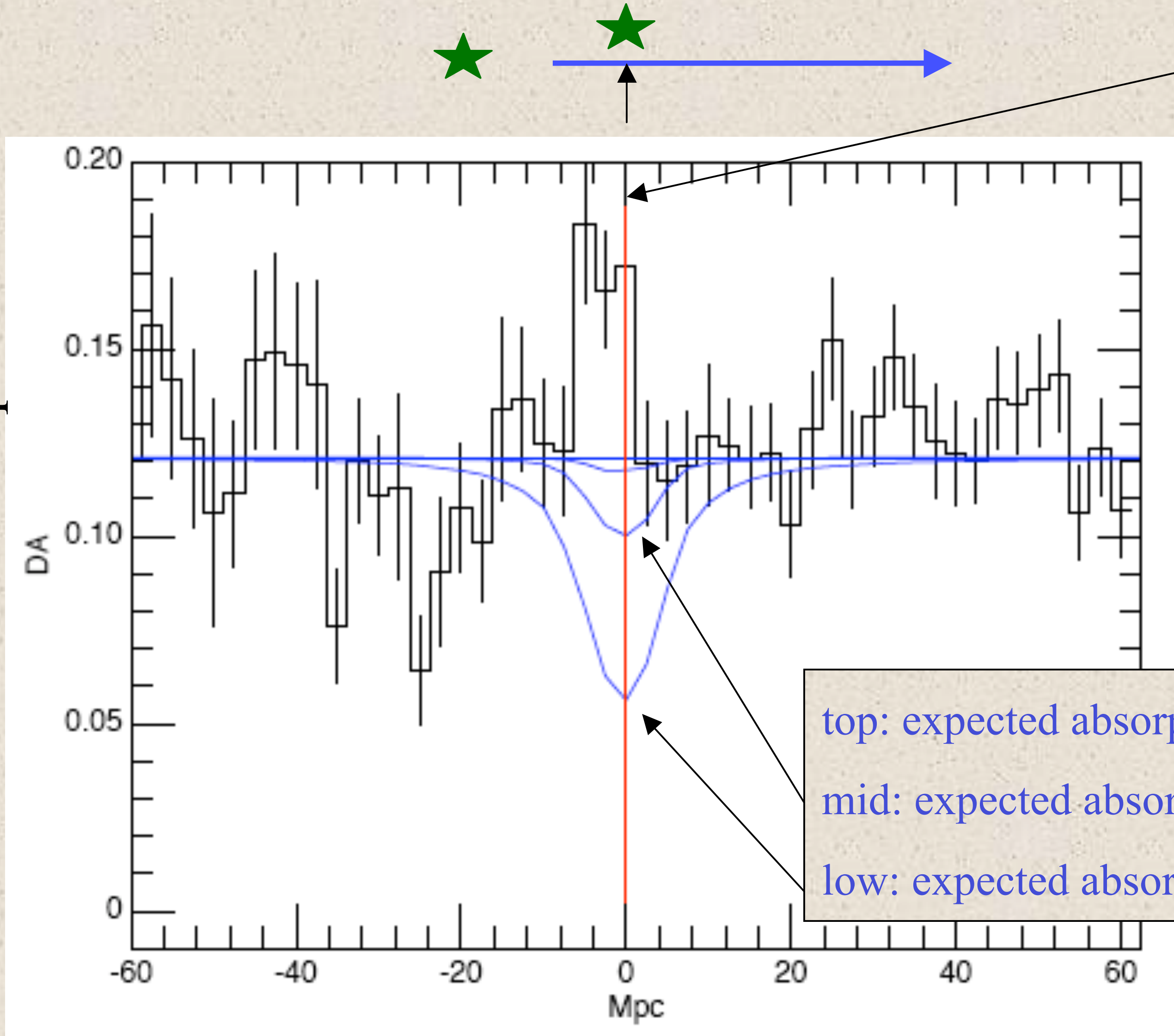
Alternatives

a) QSO UV bright episode lasting < 10,000 yrs – gas not fully ionized

b) We use UVB from mean opacity. High Lum QSOs give 2x higher UVB

c) Remaining systematic errors on QSOs prob 300 km/s – not important

Neutral Hydrogen Near QSOs: Transverse Proximity Effect



Amount of HI absorption

Mpc from the nearer QSO

1.4x more HI behind QSOs, peak -500 km/s.

Opposite of the transverse proximity effect (blue)

top: expected absorption for 0.01 L(QSO)

mid: expected absorption for 0.1 L(QSO)

low: expected absorption for L(QSO)

Why is there no Transverse Proximity Effect?

Our results confirm small sample result of Croft

Less UV in plan of sky and behind QSOs than coming towards us

QSO UV emission is beamed, confined to the line of sight (more QSOs per cubic Mpc, changed re-ionization)

- Implies most QSOs not pointing at us
- But why more HI behind than in front of QSOs?

QSOs typically 10 x less luminous in UV 1 Myr ago

- Short episodes of high UV. << 10^8 yr for growth of the BH
- Caused by (fragmentation) instabilities in accretion disks, or lack of fuel.

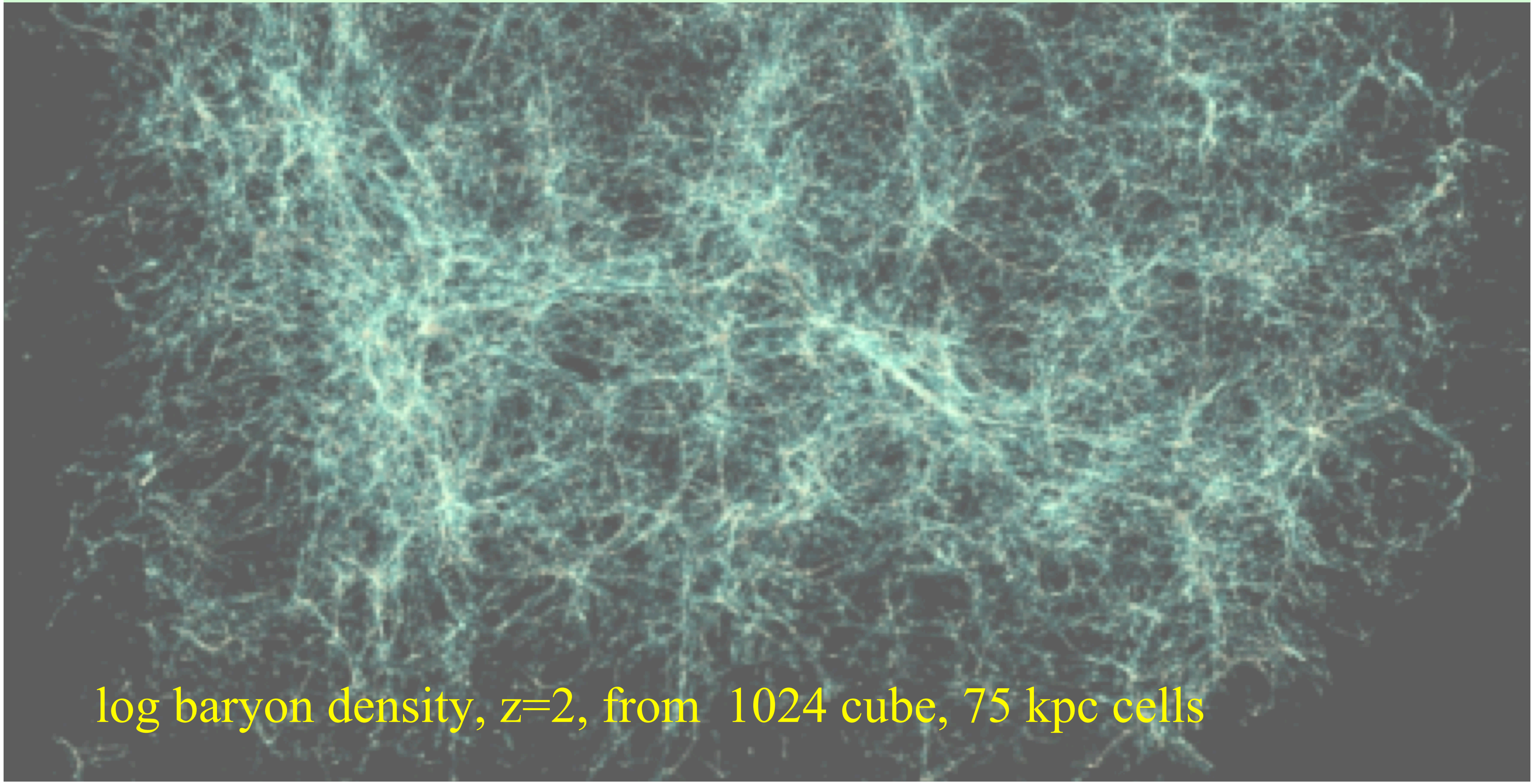
60 large ENZO Hydrodynamic Simulations

Cell size: 18, 37, 75, 150 kpc (comoving, h=0.71)

Box size: 9, 19, 38, 77 Mpc (comoving)

Various cosmological and astrophysical parameters

Available on web: Jena et al. MN 2005 or email



H absorption is sensitive to many Parameters

cosmological parameters: H_o Ω_Λ Ω_m Ω_b Power spectrum

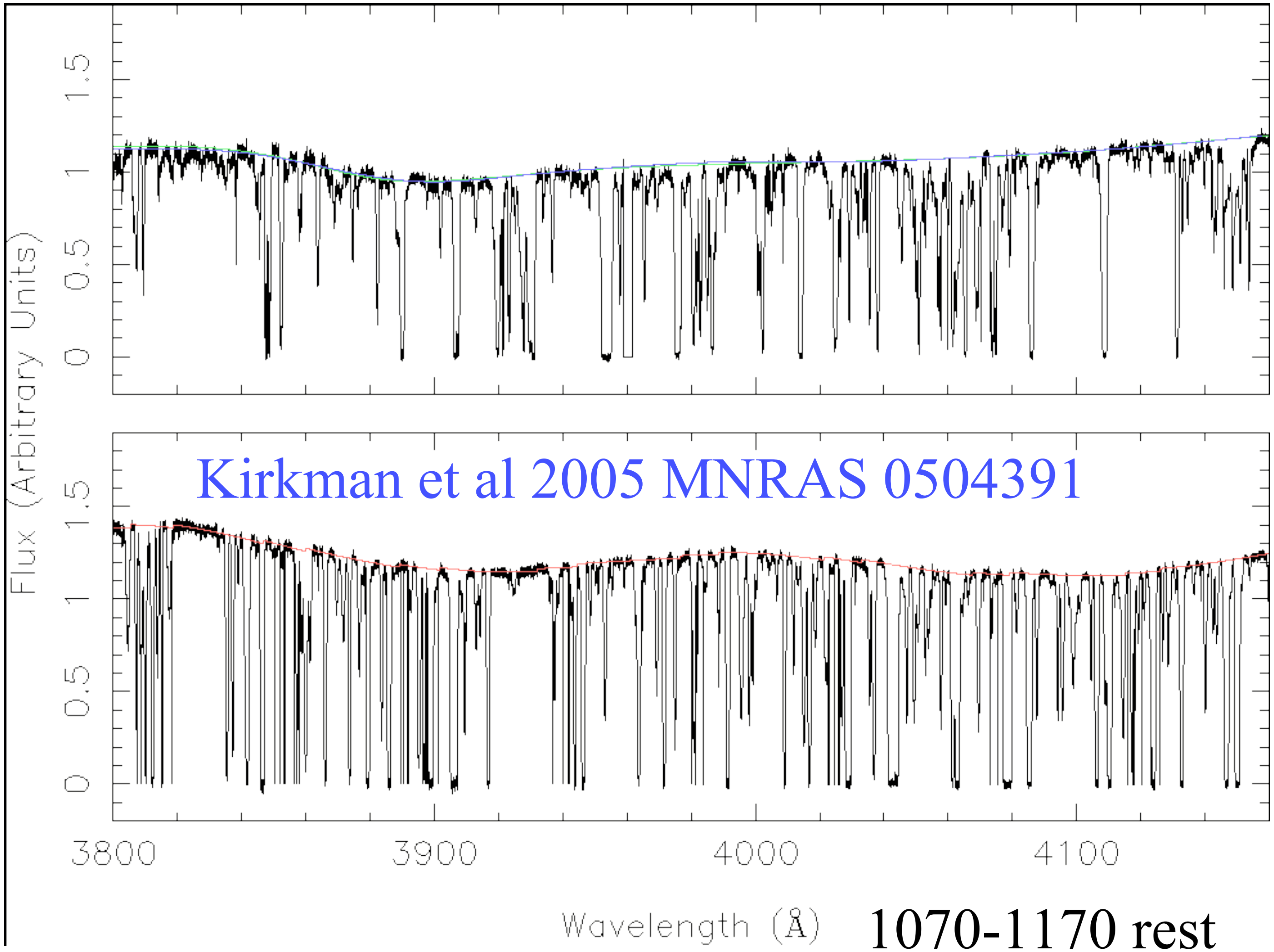
astrophysical parameters: UVB photoionization
heating (UVB spectrum)

We need to adjust all of these to fit the Lya Forest.

If we know all but one, can find that one,
if priors well known
potentially small error, competitive with best

Mean Flux: We use HIRES at z =2.2 – 3.5

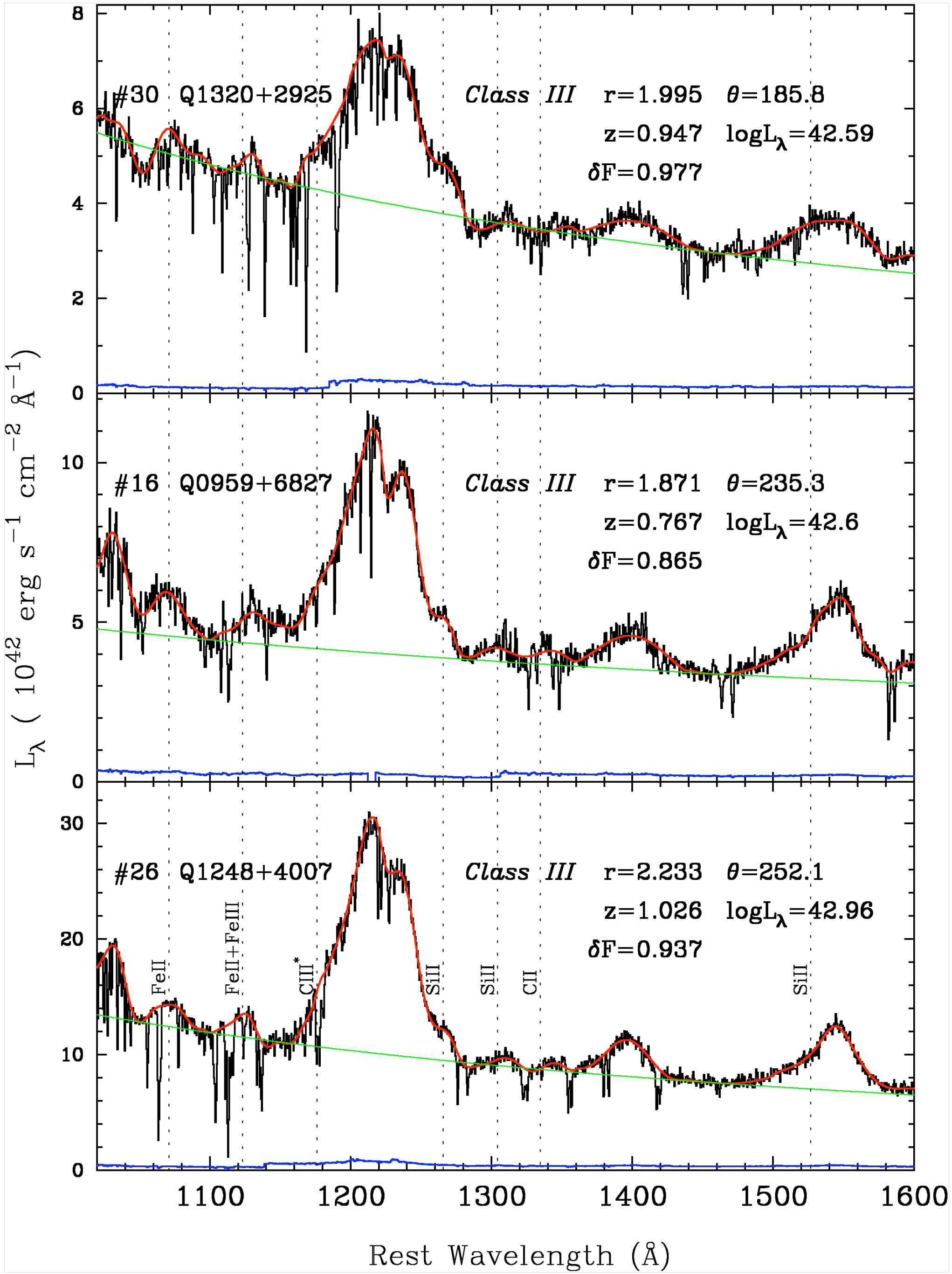
Sigma of continuum fit error per 121Ang is 1.2%.
Mean error for 275 such segments is +0.29%



1070-1170 rest

HIRES flux calibrated with 2 fits

Artificial: realistic emission lines and errors



Emission Lines Strong in 1/4 QSOs

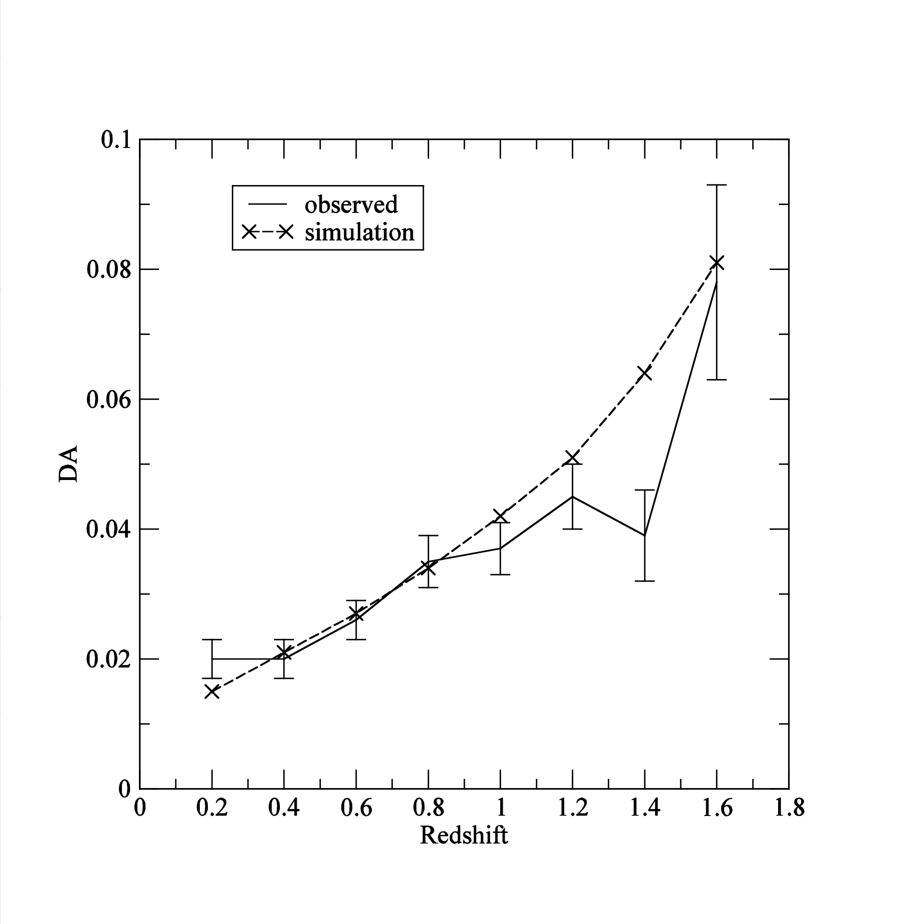
In low S/N they are hard to see.

You might place continuum too low and systematically underestimate the amount of absorption

Suzuki ApJ 618, 592
astro-ph/0503248

Simulations Match data at 0.1 < z < 1.6

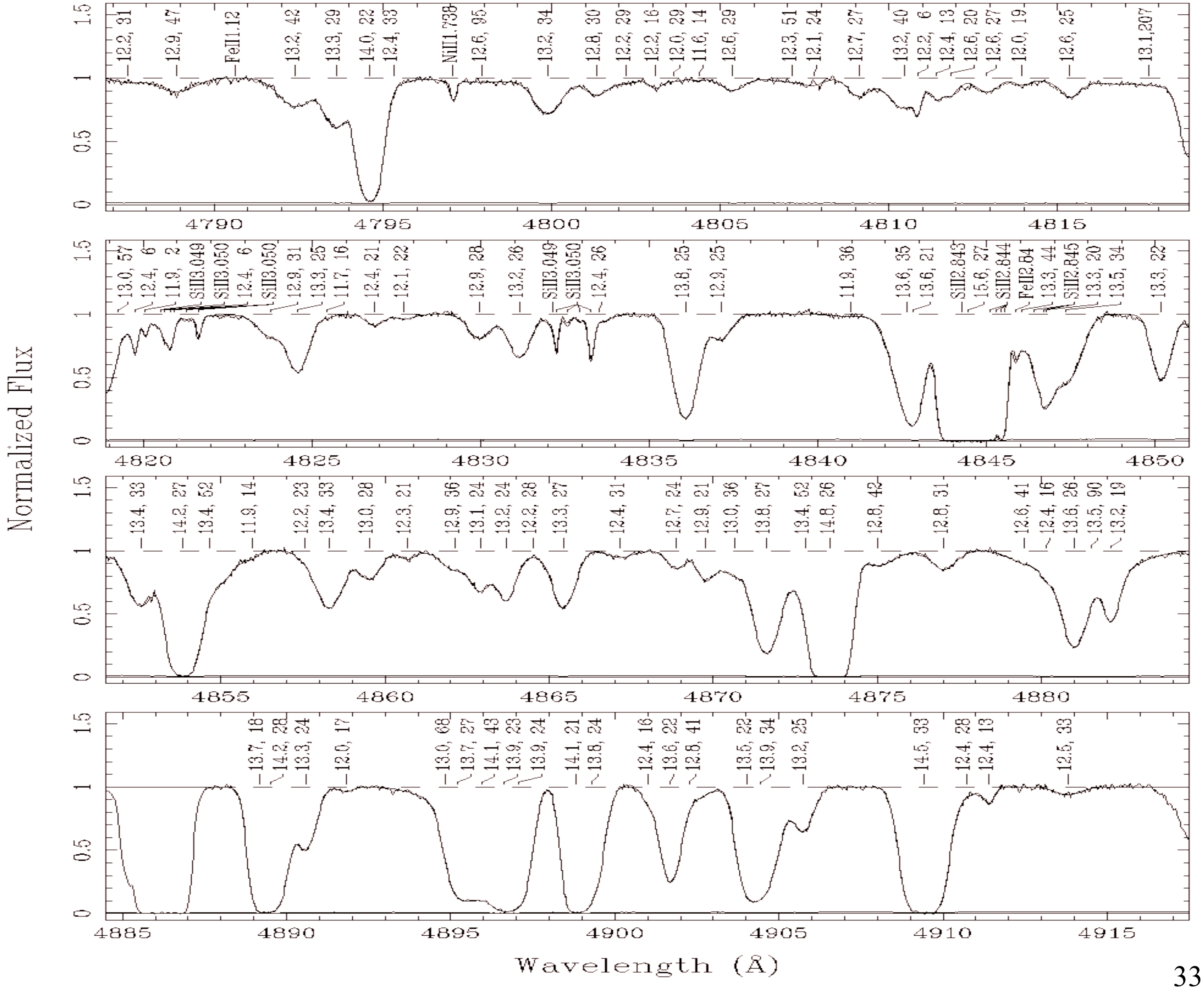
Paschos + 0802.3730 76 Mpc box with 1024^3 75 kpc cells.



	HST spectra	simulation
f(N) index z=0.5-1.0	1.57 ± 0.05	1.62
f(N) index z=1.0-1.5	1.58 ± 0.04	1.63
Median b z=0.5-1.0	29 km/s	28.3
Median b z=1.0-1.5	28	28.5

But, HST high resolution spectra incapable of seeing the differences detected at z=2

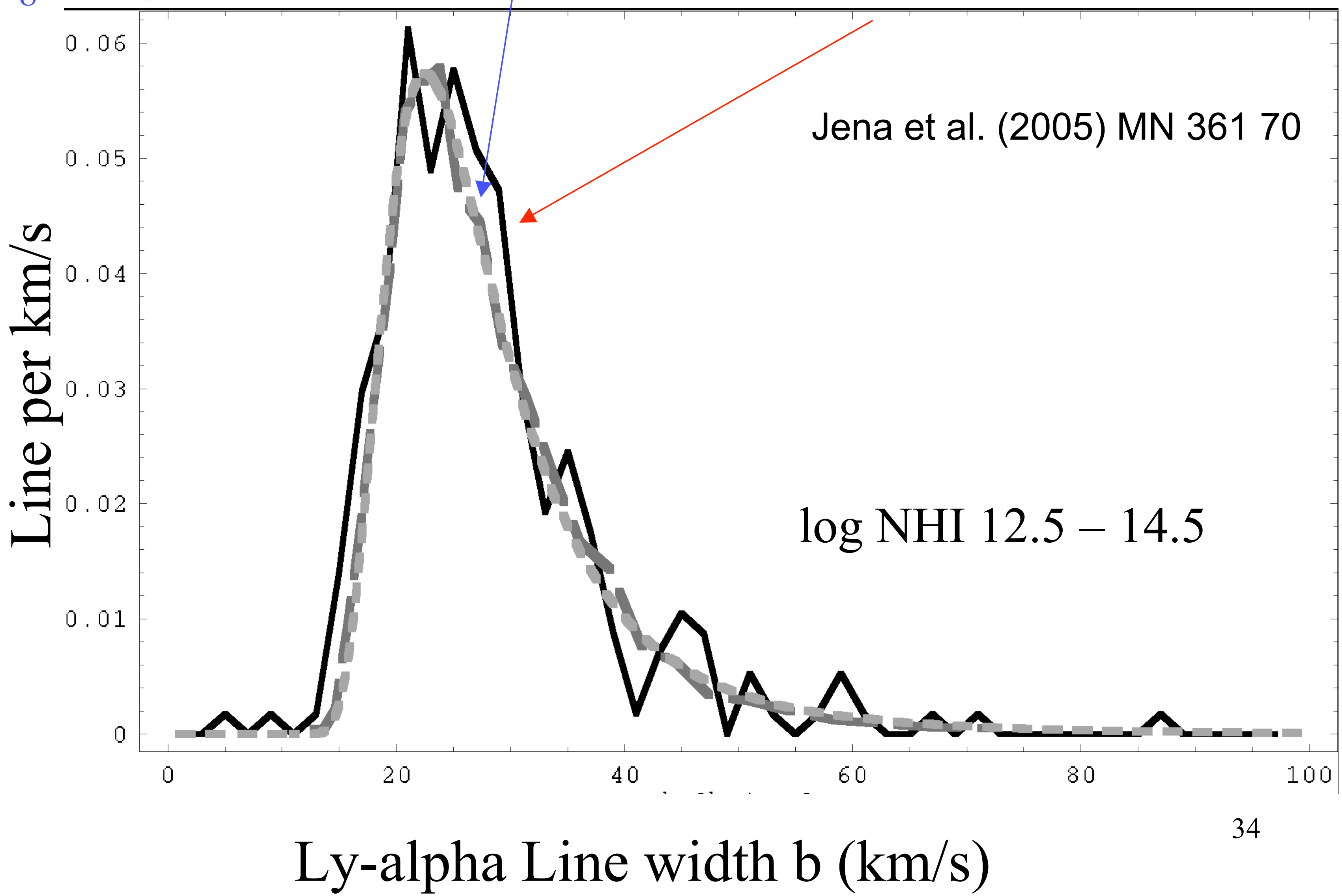
Line width is measured with b parameter



Mean line Width constrains IGM Temperature

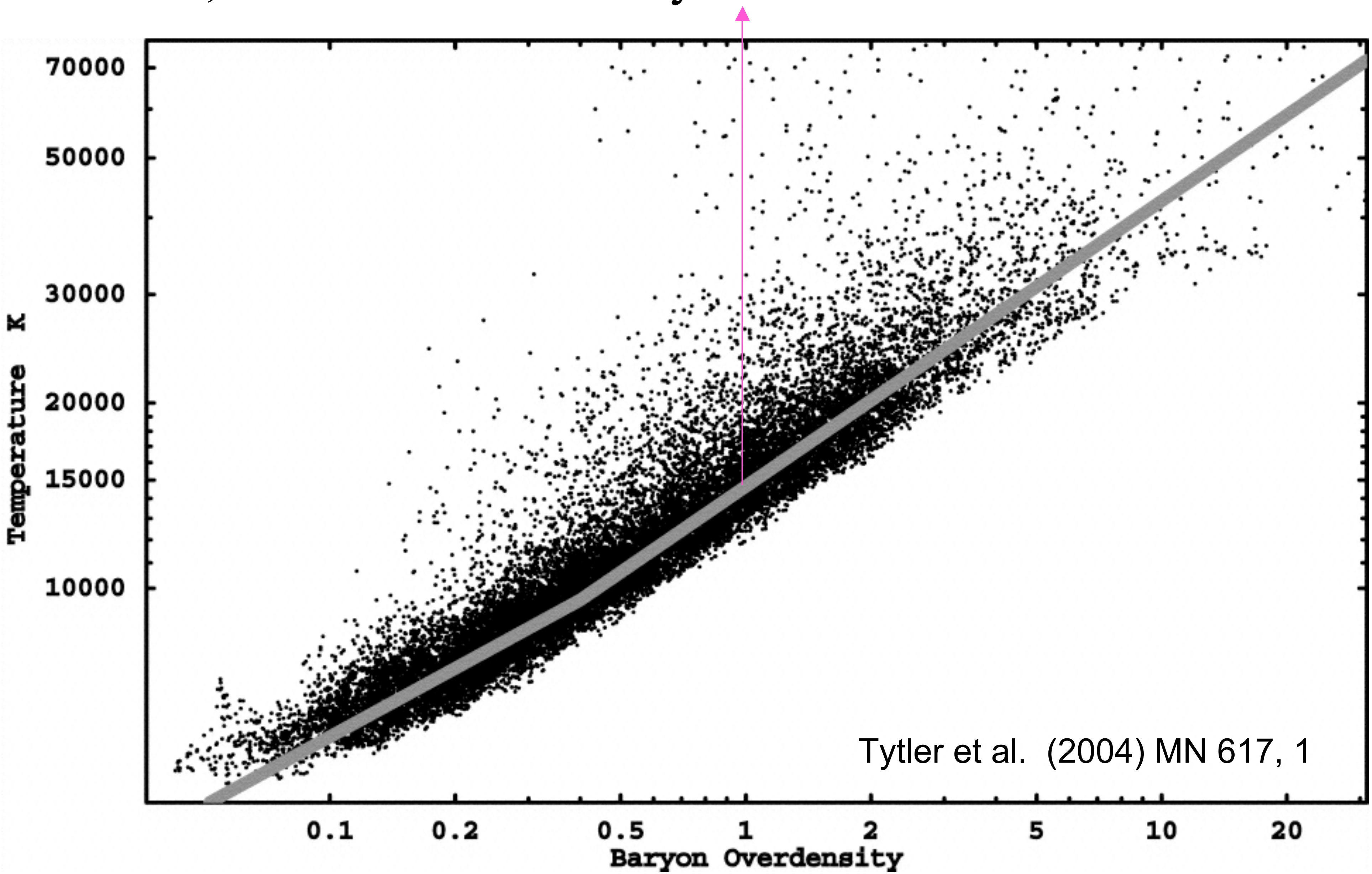
Simulation with T=14,300 K at mean density at z=2

σ_8=0.9, n=1 fits Kim et al 286 lines



Temperature-Density

14,300 K at mean density at z=2



Simulations do NOT match the Lya forest data

Tytler et al. arXiv 0711.2529

Data from SDSS (x) and HIRES/UVES (+) have

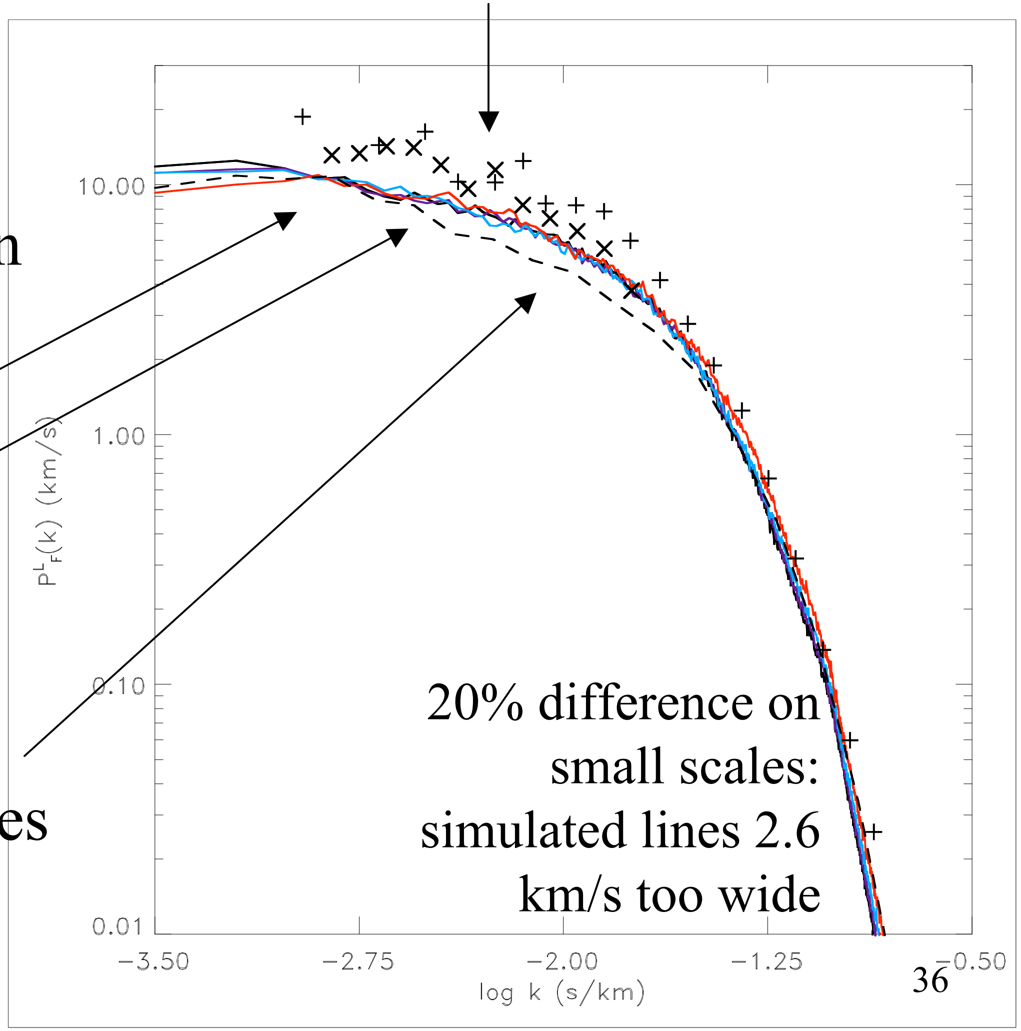
50% more power than simulations on large scales

Power spectrum of the flux in the Lya forest changes little with box size from

76 Mpc (black) to

19 Mpc (red)

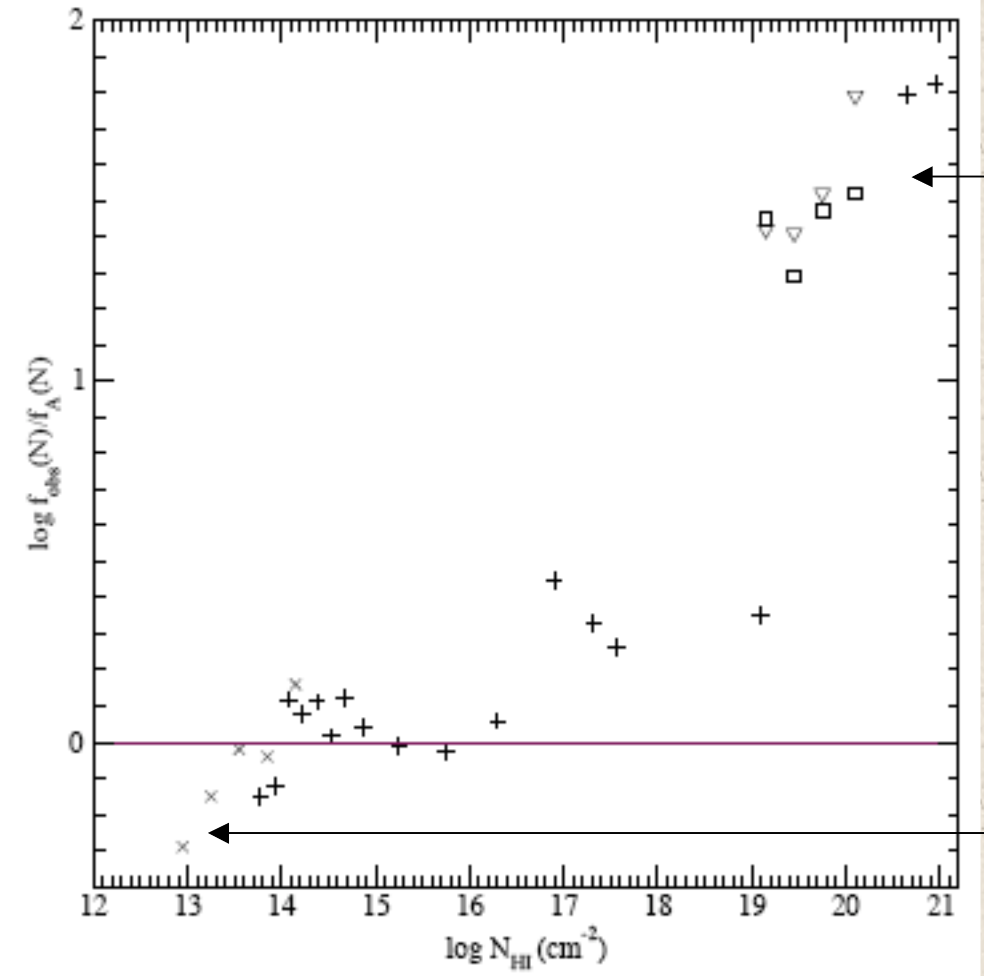
Reducing cell size from 75 kpc cells at 18 kpc cells makes worse (dashed).



20% difference on small scales: simulated lines 2.6 km/s too wide

Simulations Lack High Column Density lines

Observed/simulated number absorbers



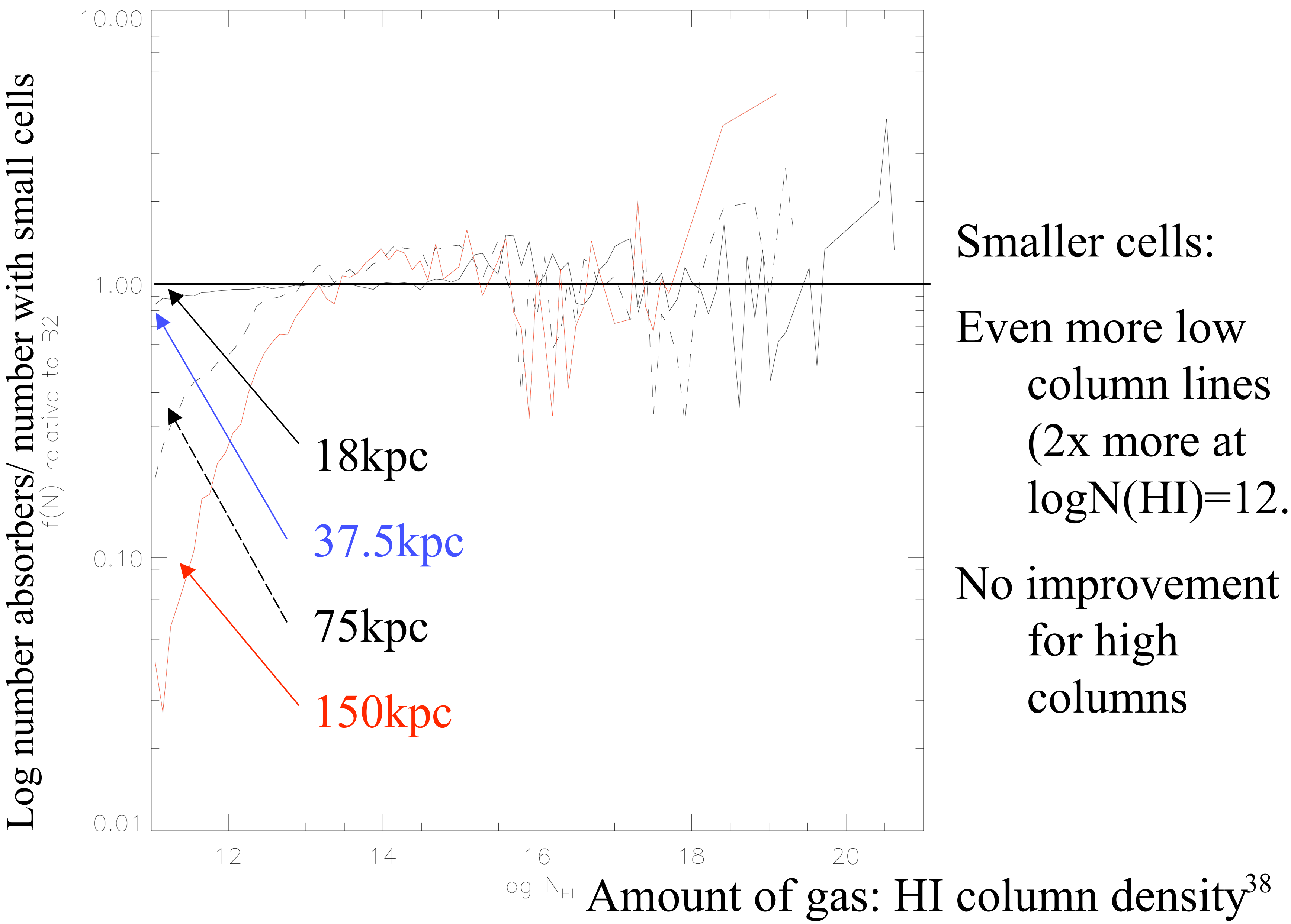
Simulations have 30x too few lines

Simulations have too many low column lines - worse with smaller cells

Amount of gas: HI column density

Tytler et al. arXiv 0711.2529

Smaller Cells make column density distribution worse



Smaller cells:

Even more low column lines (2x more at logN(HI)=12.5)

No improvement for high columns

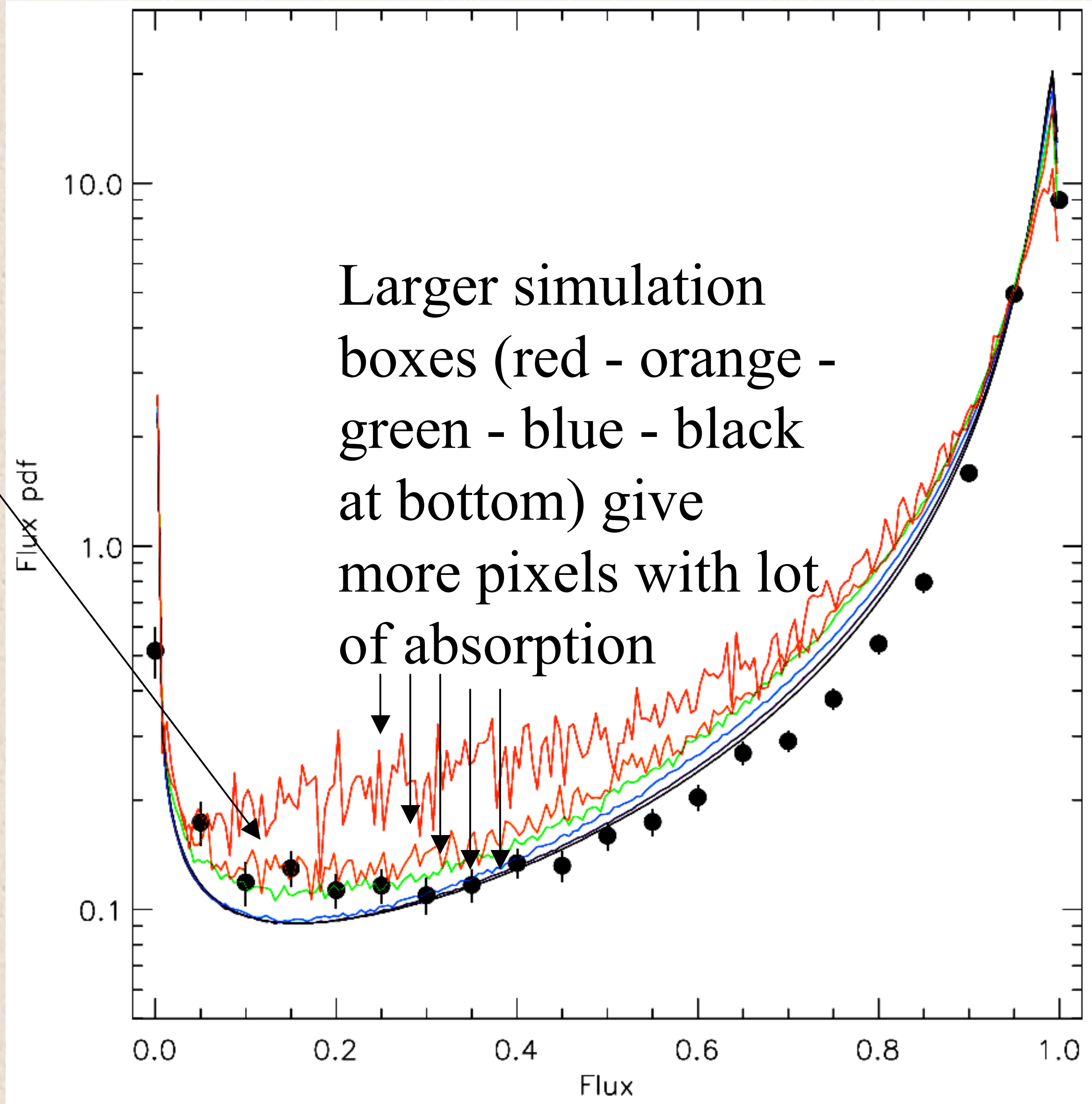
Simulations have too few pixels with lot of absorption

Tytler et al. arXiv 0711.2529

Data from Kim et al. 2007 show more pixels with a lot of absorption.

We confirm Bolton+08

Expected because simulations lack absorption with high column densities.



Data, Simulation, Astrophysics or Cosmology?

We might make simulations agree with data if we:

1. Change the simulation. Kohler & Gnedin 07 find 3 kpc cells (25x smaller), with radiative transfer give correct number of high column lines (LLS)

   Might also make Lya lines that match data.

2. Change the astrophysics.

   We use UV from QSOs + galaxies… is this correct?

   IGM might be heated by X-rays or Cosmic Rays

3. Change the cosmological parameters.

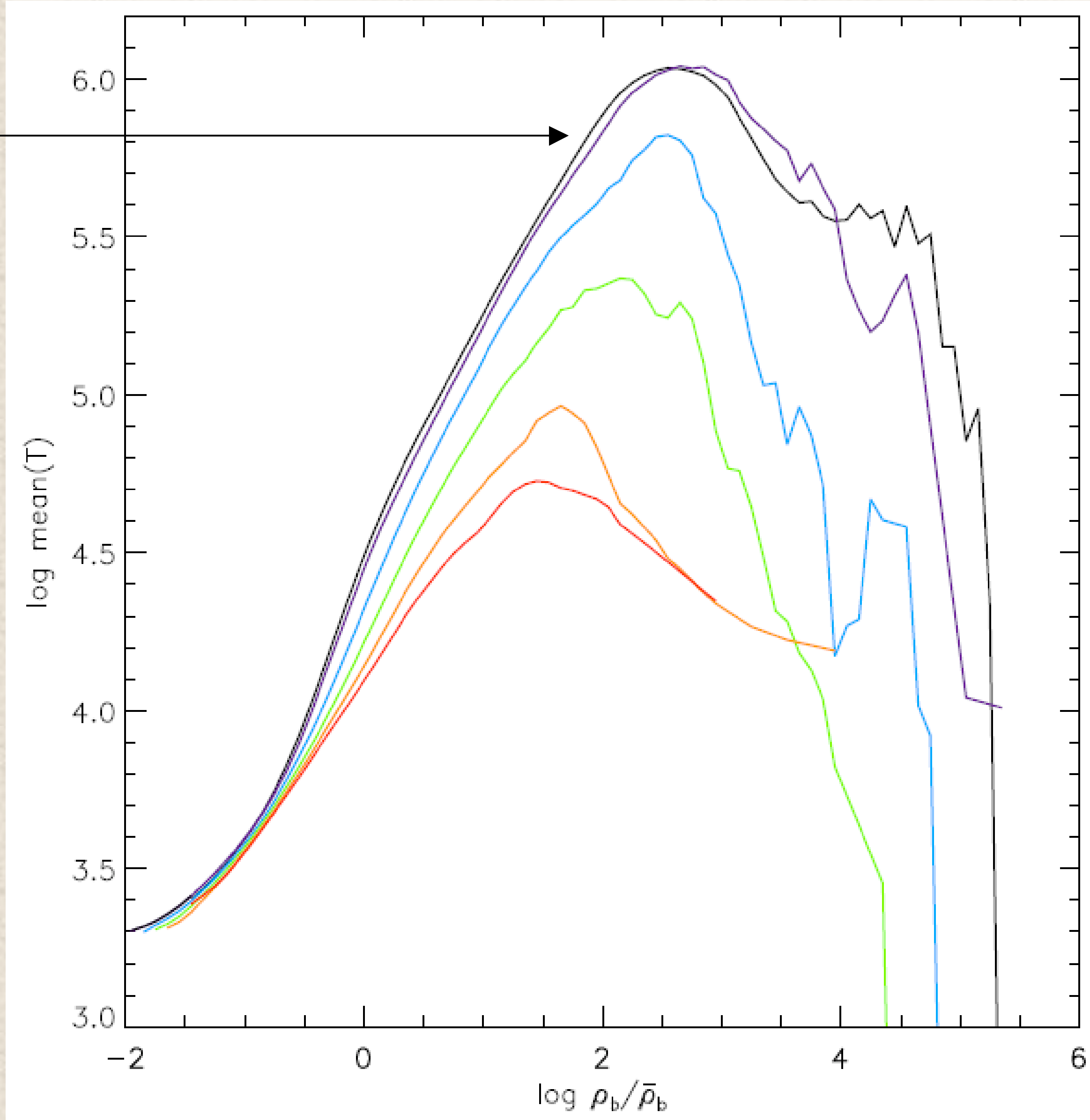
   WMAP5 likes $\sigma_8 = 0.80 \pm 0.04$

   We used $\sigma_8 = 0.90$

   We prefer $\sigma_8 > 0.9$ challenging normal inflation

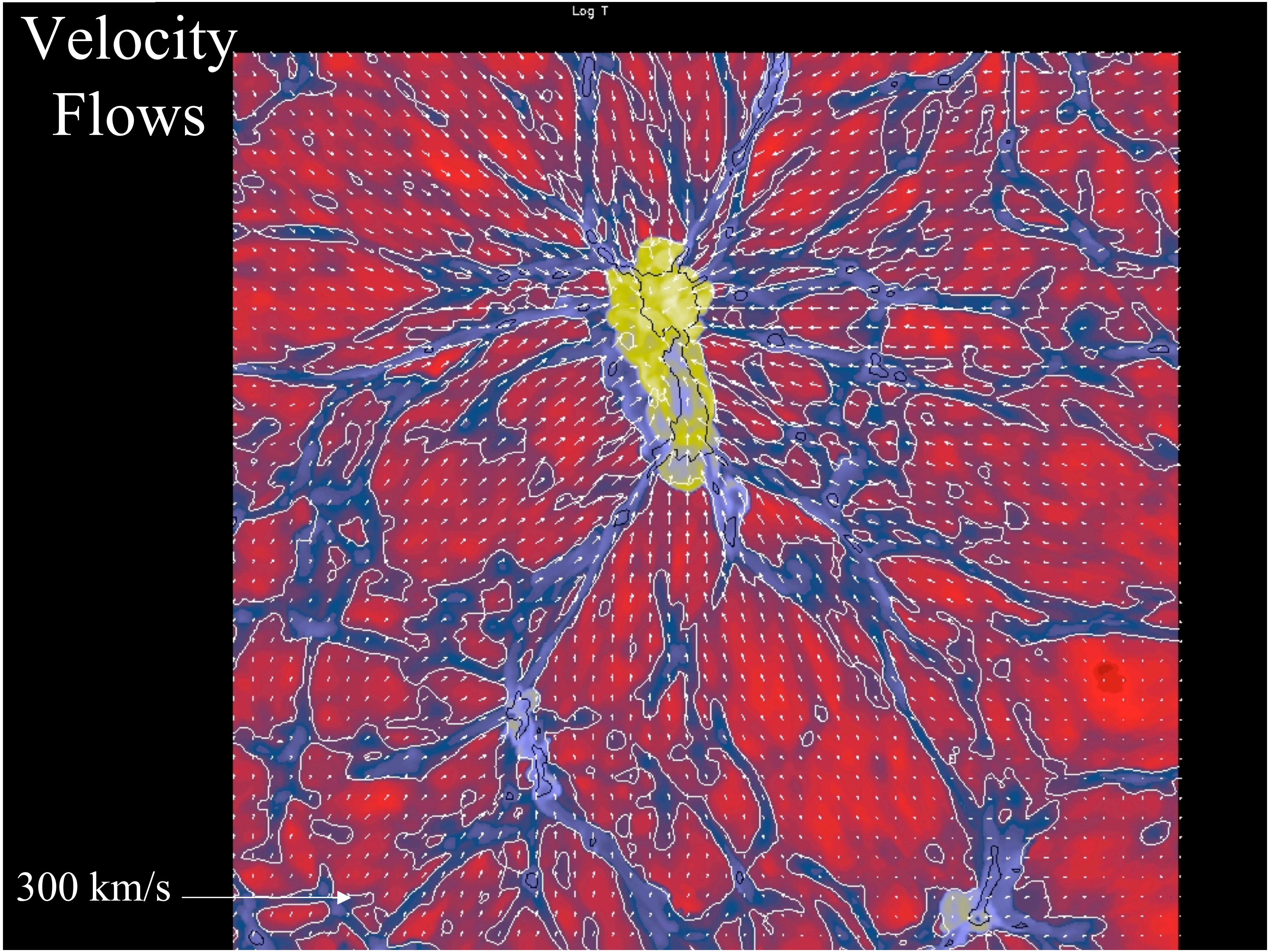
Large Scale Power makes IGM Hotter

Larger boxes are hotter at all densities



Tytler et al. arXiv 0711.2529

Velocity Flows



Ly-alpha Forest

Line=density

30 Mpc

1 cell =

75 kpc

Color=T

Ly-a lines form near warm/ hot gas