Simulating Quasars at two extremes

Yu Feng CMU

Talk @ Berkeley

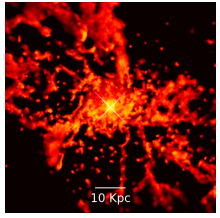
Rupert Croft, Tiziana Di Matteo, Nishikanta Khandai,
Colin Degraf, Steven Wilkins, Terrence Liu, Evan Tucker,
Yohan Dubios, Taysun Kim, Julien Devriend, Hy Trac;
Ross O'Connell, Xiaoying Xu, Mariana Vargas, Shirley Ho,
Julian Bautista, Jean-Marc Legoff

Introduction

Cosmological hydro simulation of quasars and its limitations

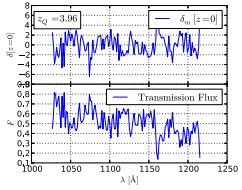
Quasar at small scale

Resimulation of individual halos

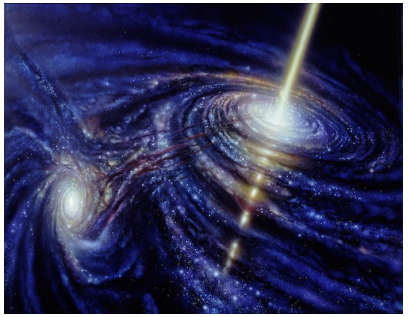


Quasar at large scale

Mocking Quasar and IGM clustering



Quasars



large scale structure;

the IGM; role in reionization;

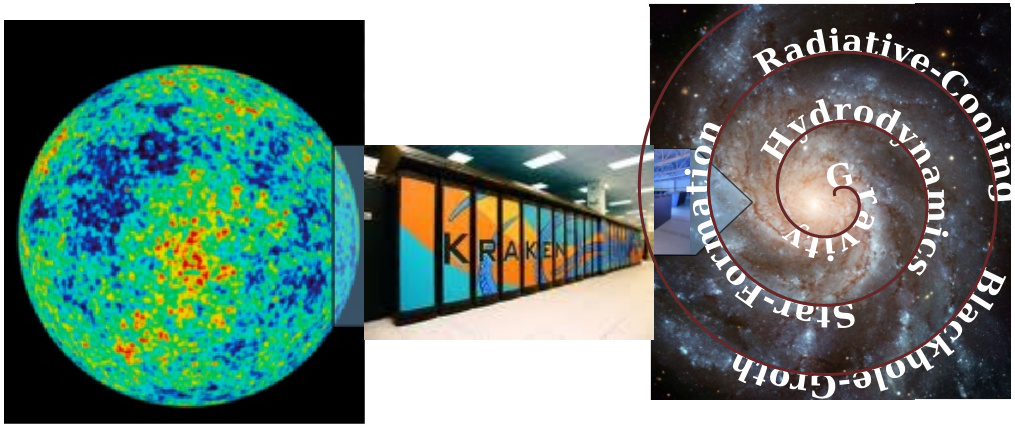
feedback affects estimation of cosmological parameters

galaxy merger and hubble sequence / color diagram?

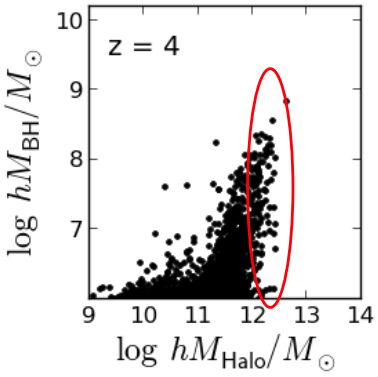
role of feedback in galaxy formation ?

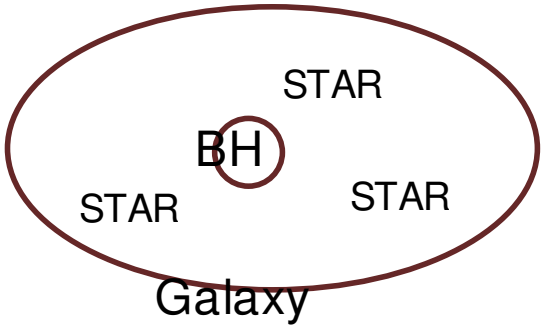
how do galaxy get their gas?

Cosmological Simulation of Quasars



Why and how?





10 Kpc .vs. 0.000001pc

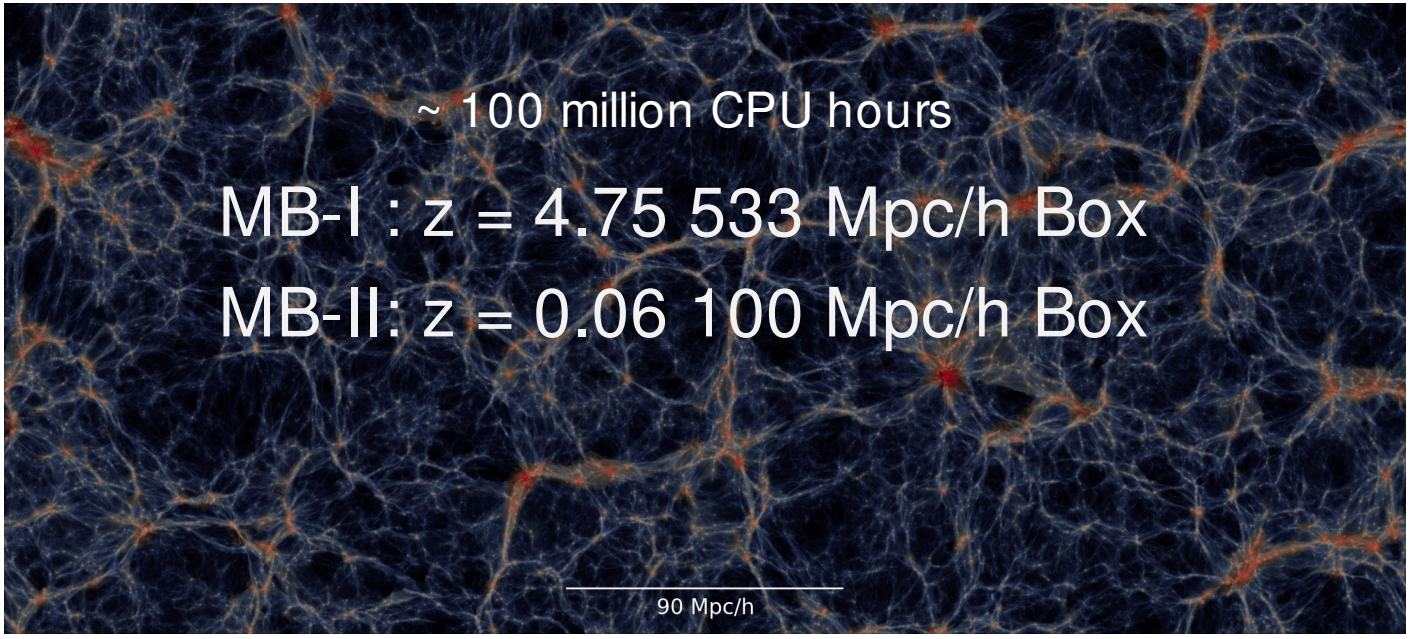
Similar Halos can grow different BHs

Resolve SMBH hosting halos

Subgrid modeling of BH and Star formation

Large sample volume to include extreme objects

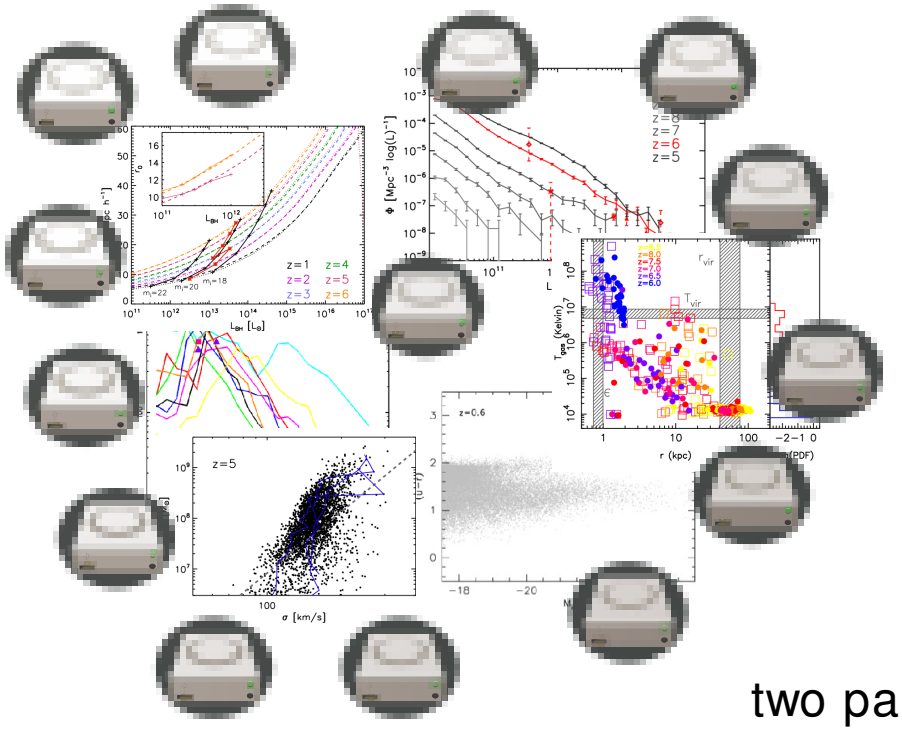
Result: two giant hydro simulations with SMBH



Cuboid Remap by J. Carlson, M. White 2010

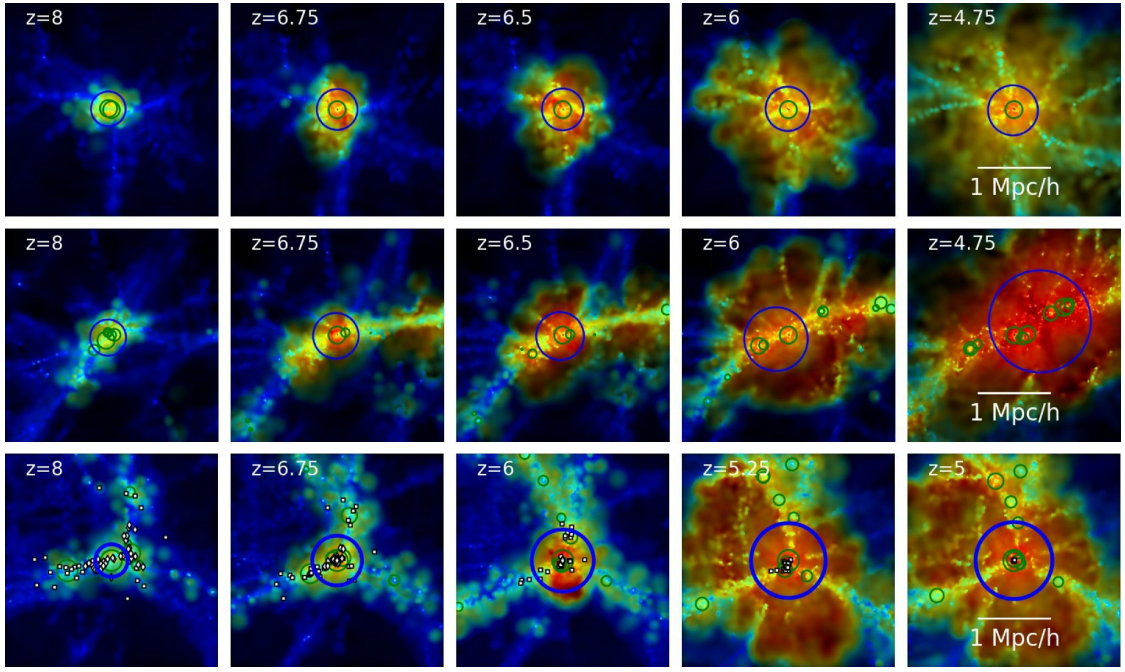
Show gigapan

Science rising from hundreds of tera-bytes of data



two particular things

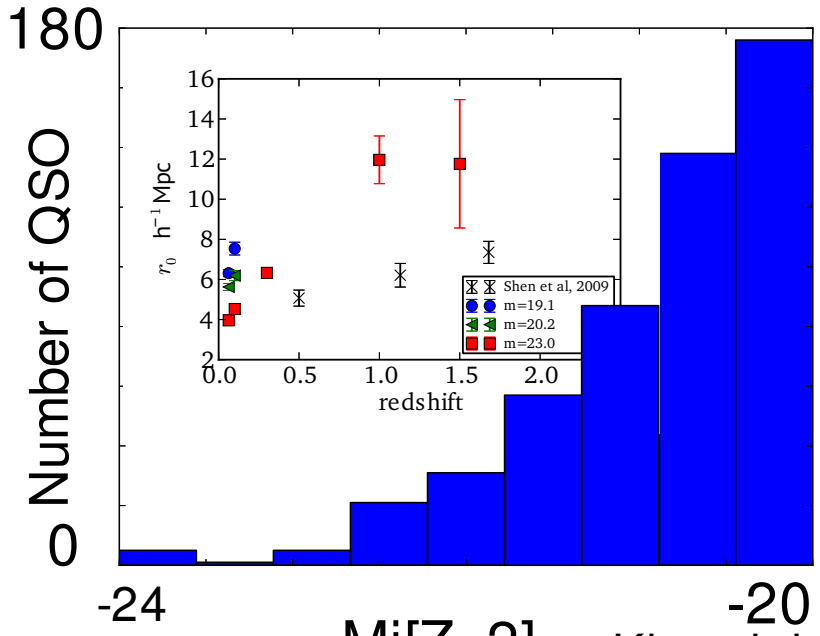
How do gas arrive at Quasars?



Di Matteo et al 2011

Clustering & Large scale structure?

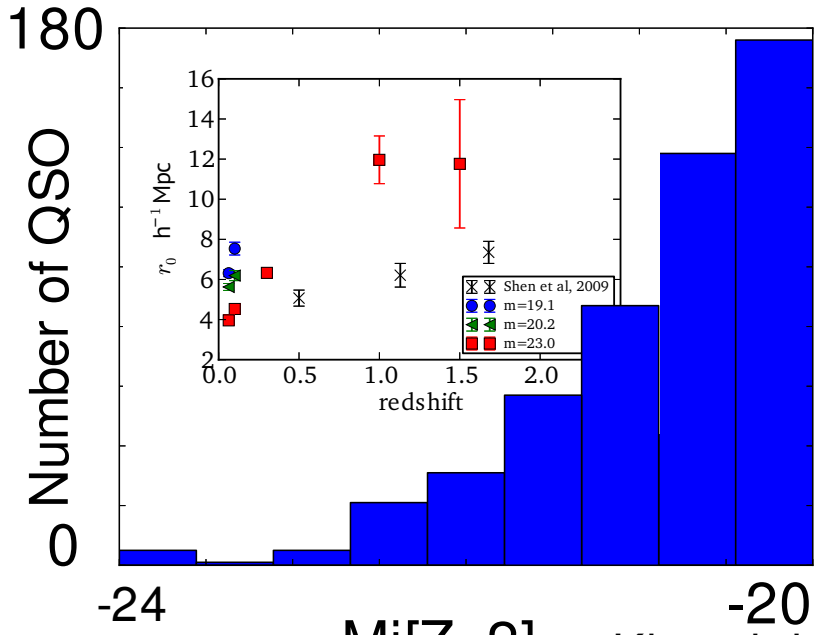
extrapolate with HOD?



Khandai et al in prep

Clustering & Large scale structure?

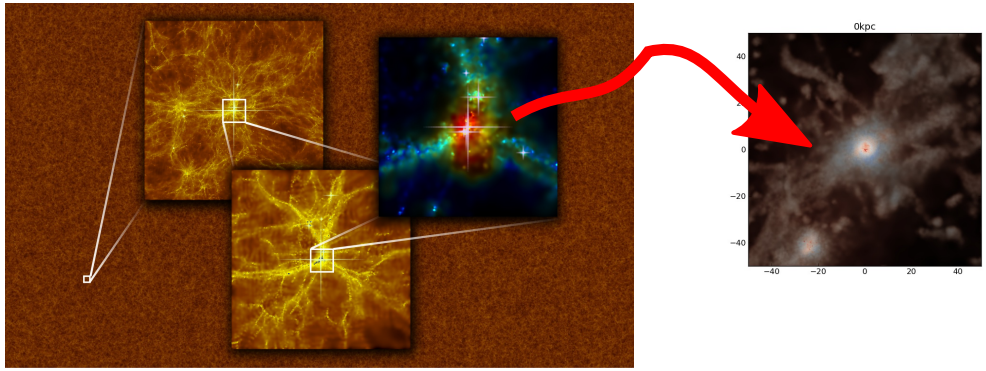
extrapolate with HOD?



Khandai et al in prep

Go Smaller: What happened near that Quasar?

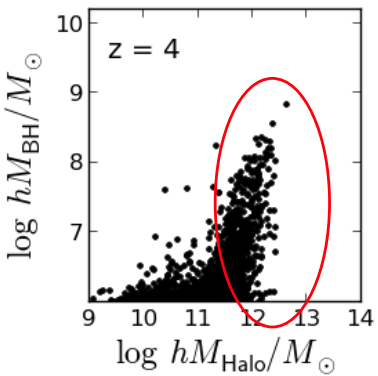
Resimulate from Cosmological sim at higher resolution



Select rare peaks and re-simulate

Highest resolution, detailed studies

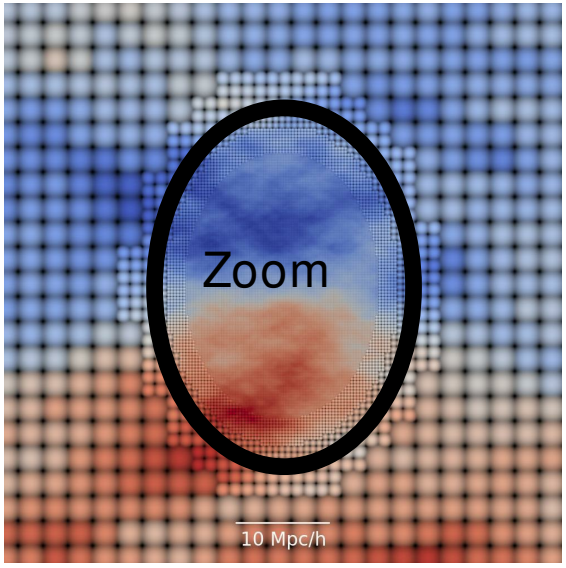
of host and quasar, detailed modeling



Li et al., Sijacki et al., Alvarez et al.,
Cattaneo et al., Bellovary et al. Teyssier et al,.
Dubois et al., Devriendt , et al.

This time, we know apriori these halos

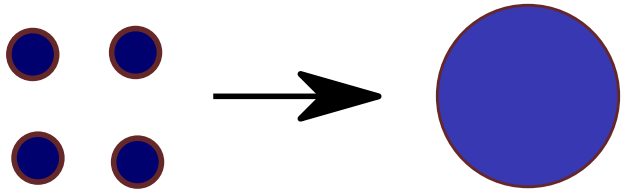
host extreme blackholes.



Initial Condition

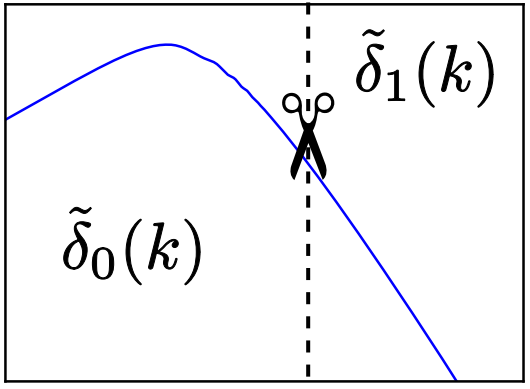
Multi-level Mesh method

Outside: Combine Particles



Keep center of mass!

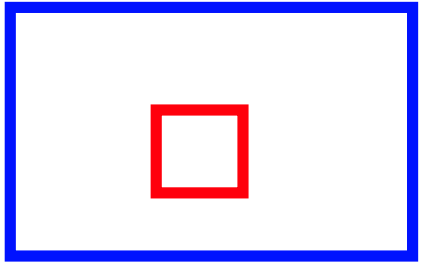
Inside: a broken power spectrum.



$$\delta(x) = F\left[\tilde{\delta}_0(k)\right] + F\left[\tilde{\delta}_1(k)\right]$$

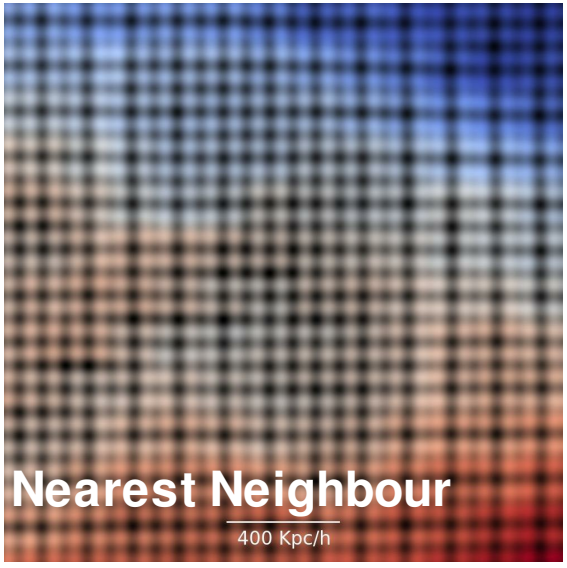
$\tilde{\delta}_0(k)$ from original simulation

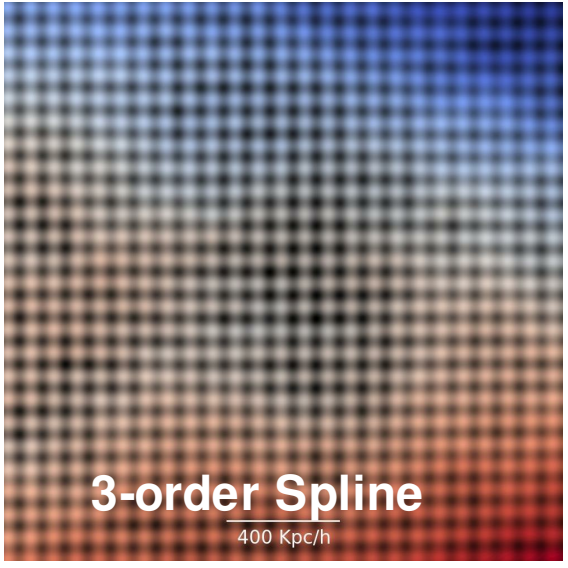
$\tilde{\delta}_1(k)$ from smaller scalepower

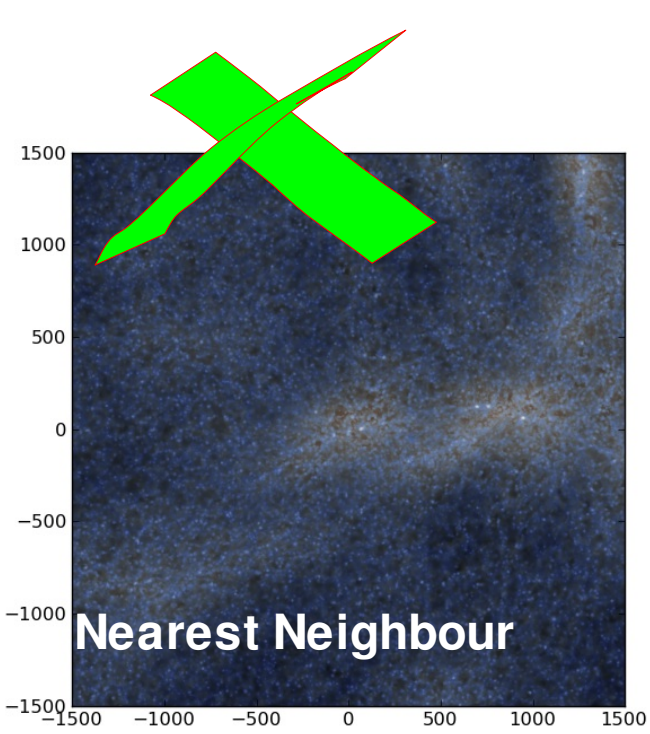


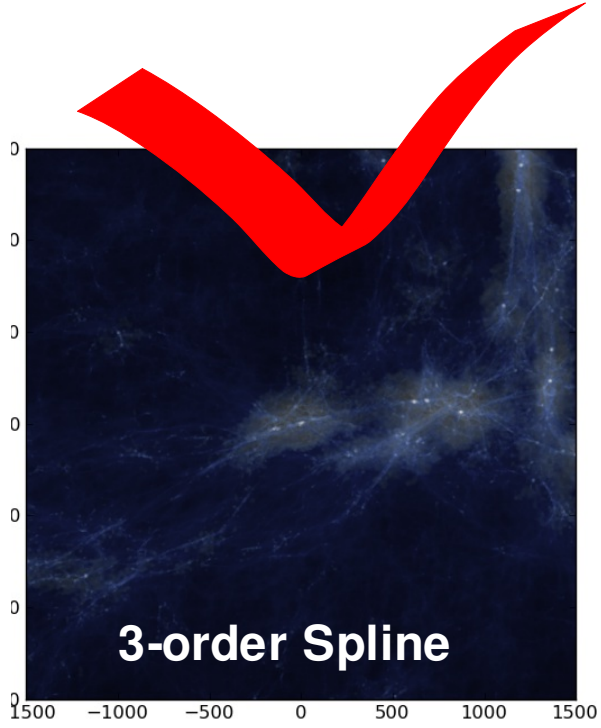
Small things have big consequences

Interpolation matters






1500
1000
500
0
−500
−1000
−1500
−1500
−1000
−500
0
500
1000
1500
Nearest Neighbour


1500
−1000
−500
0
500
1000
1500
3-order Spline

BH growth converged?
Thermal feedback

regulates the growth

A transition near z = 7

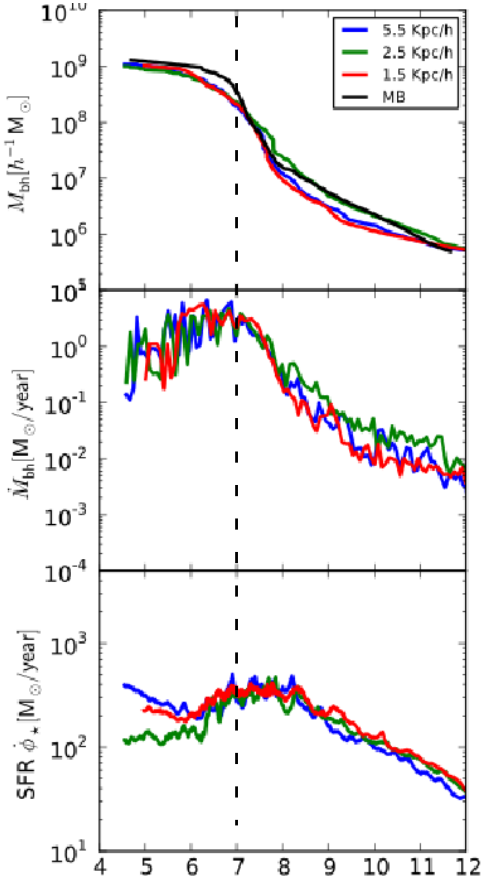
Bondi-scaling Growth

$$\frac{dM}{dt} \propto \frac{\rho M^2}{c_s^3}$$

w/ eddington limit

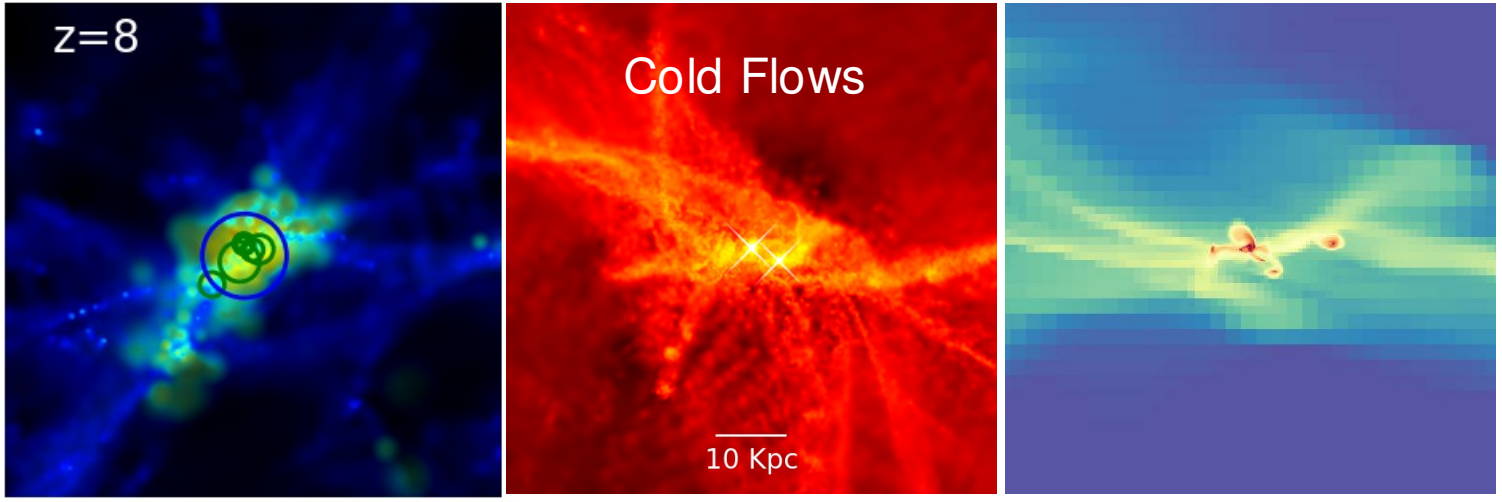
Something happened to **cold gas**

(Play movie)



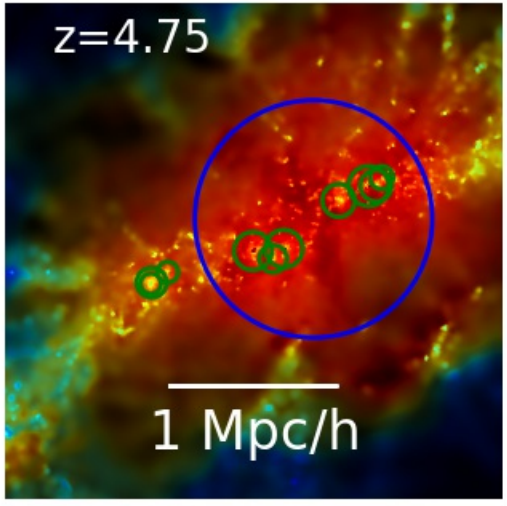
At high Z, cold gas in filaments directly arrives to the proximity of blackholes

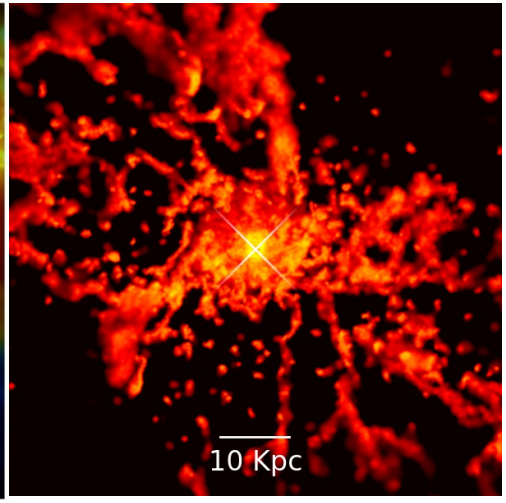
Young BHs are too weak to repel surrounding gas



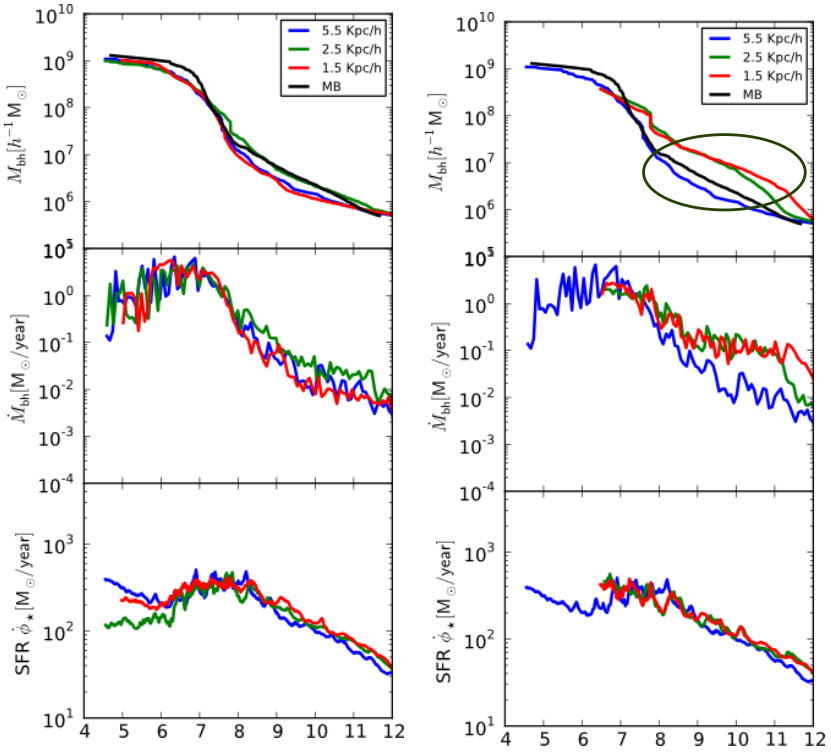
Halo virialize; and filaments break

Mature BHs keep cold gas away





Modifying BH model



1 kpc/h bubble

e.g, heating within I-front

Stronger early growth

Brighter Quasars

Radiative Transfer?

Summary

Resimulation from cosmological SPH simulation

Cold flow vs No-cold flow

The low redshift accretion of SMBH appears stochastic

Stromgren sphere / I-front afffects BH growth at high-z

Thermal feedback eventually build up and take over any subtle physics for 10^{10} Blackholes

Future: Radiative Transfer? Alternative SPH scheme?

Go Bigger: Mocking Clustering of Quasars and IGM

- IGM: Forest

  Understanding LyaF-Quasar cross-correlation

  Systematics of non-random sightlines on LyaF auto-correlation

  How independent are LyaF auto-correlation and LyaF-Quasar cross-correlation?

- Quasar

  UV background fluctuations due to Quasars

  Mocks with Quasar Light Echos

SMBH Simulations are small and expensive

We need 10 Gpc/h Box, hundreds of realizaitons

Full hydro is great, but unnesseary for now

Linear theory + bias

LyaF forest; Fluctuating Gunn Peterson

Revisit the broken power spectrum

$$\delta(x) = F\left[\tilde{\delta}_C(k)\right] + F\left[\tilde{\delta}_F(k)\right] + F\left[\tilde{\delta}_\alpha(k)\right]$$

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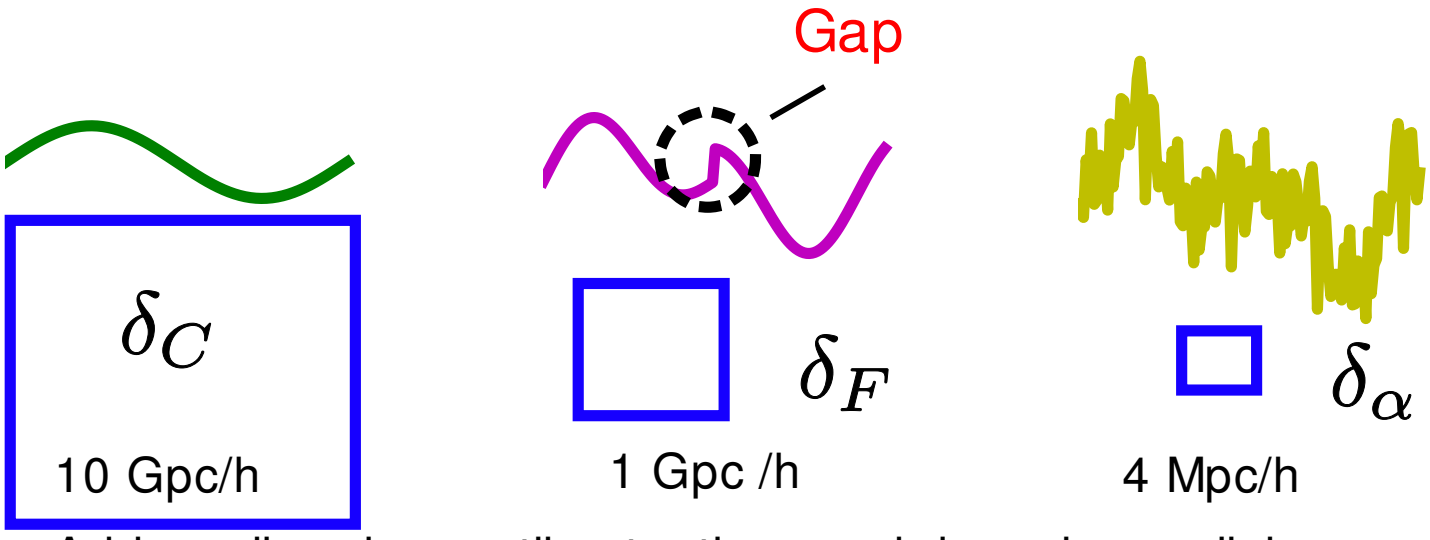


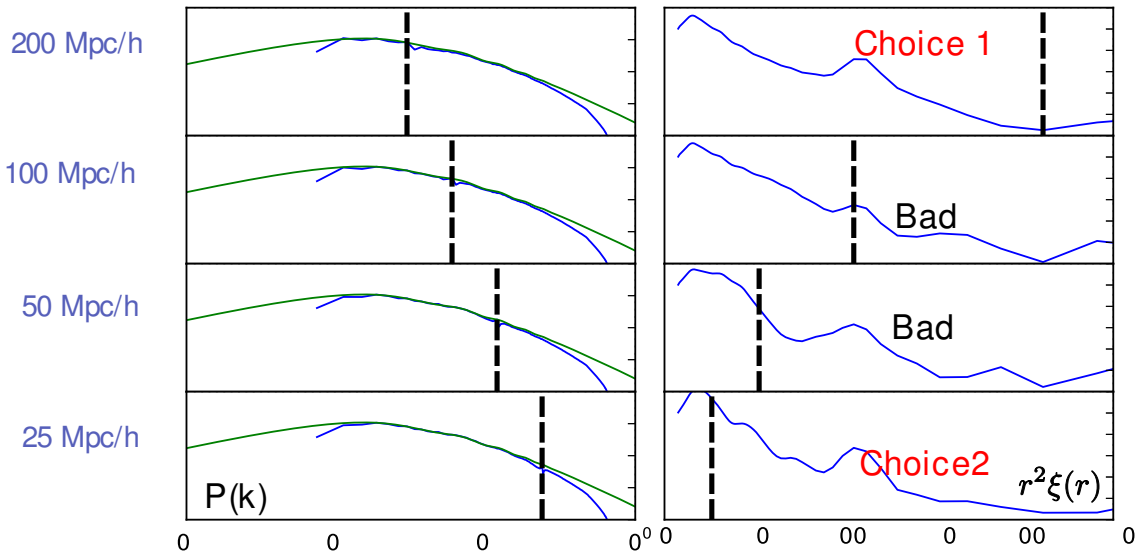
Add small scale one tile at a time, and do so in parallel

Setting the split

Trade-off

Tests on 256 mesh over 1.6 Gpc/h Box with FFT

$$\frac{2\pi}{L_f} \leq k_B \leq \frac{N_C}{2}\frac{2\pi}{L} \qquad L_B = \frac{2\pi}{k_B}$$



Painting Quasars

Mo & White (1996)

$$\delta_q(x) = b(z)\delta_m(x)$$

Bias

Smoothed to 10 Mpc/h

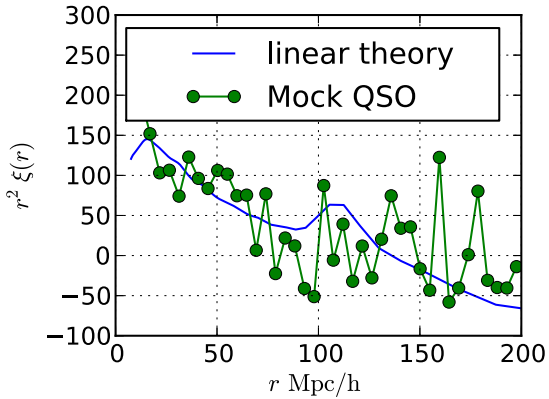
$$n_q(x) = \bar{n}_q(z)\left(1 + b(z)\delta_m(x)\right)$$

Uniformly painted within a cell

mean density

Assume Linear Bias

Uncorrelated within 10 Mpc/h



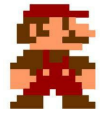
QSO correlation Function

Making Spectra

1 Draw sightlines in each small scale tile

Bresenham's Line Algorithm

Liang Barsky Line Cliping Algorithm



2 Lognormal + FGPA

$$F = \exp(-\tau)$$

$$\tau = a(z)\exp\left(\beta D(z)\delta_m(x)\right)$$

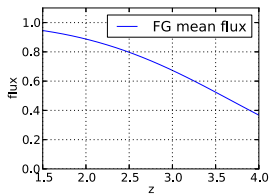
3 Redshift distortion

$$\Delta R = F_\Omega(z)D(z)\varphi(x)\cdot\hat{r}$$

Initial displacement at 3 Mpc/h scale

3 Match mean transmission flux

$$\bar{F}(z)[a(z)] = F_{obs}(z)$$



4 Rebin pixels to ~ 3 Mpc/h

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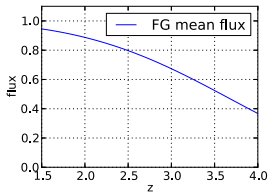

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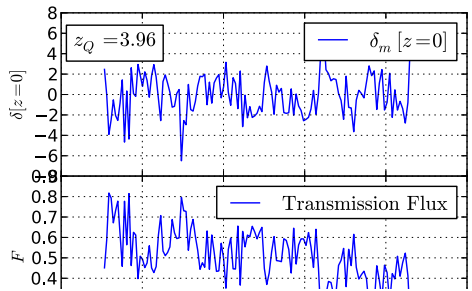

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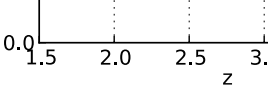
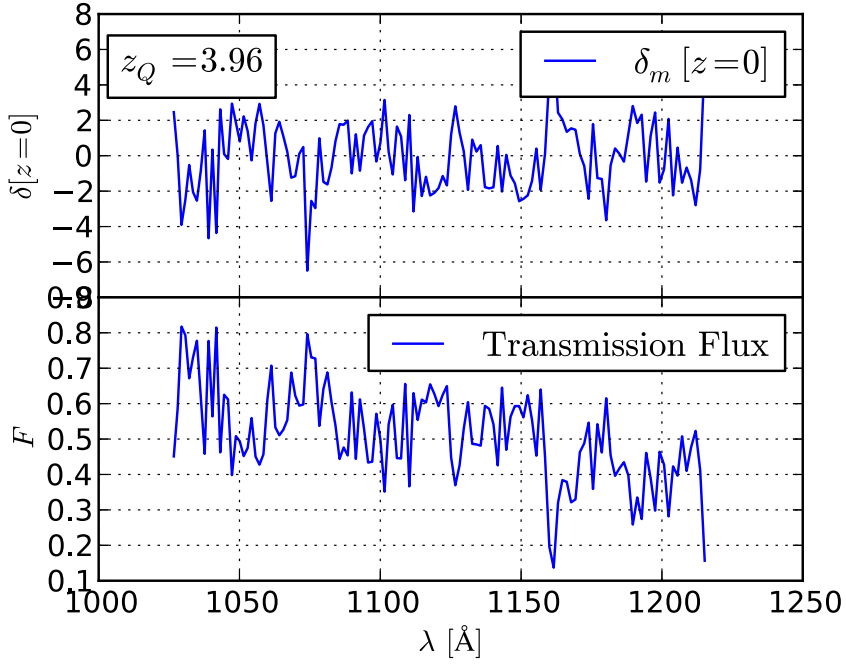
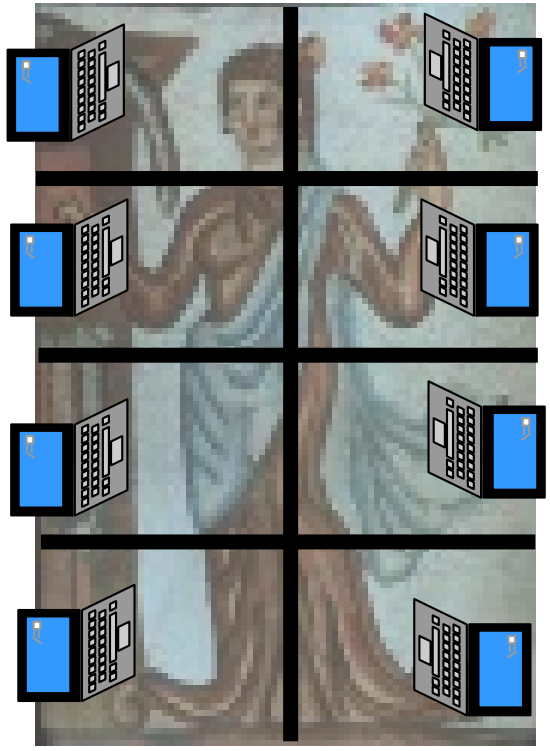




Excellent scalability.

Each tile fits into a laptop.



~ Raw skewers:

with FFTW 2 hours per DR9 mock
(140K QSOs) on 16 CPUs
(5 hours with FFTPACK).

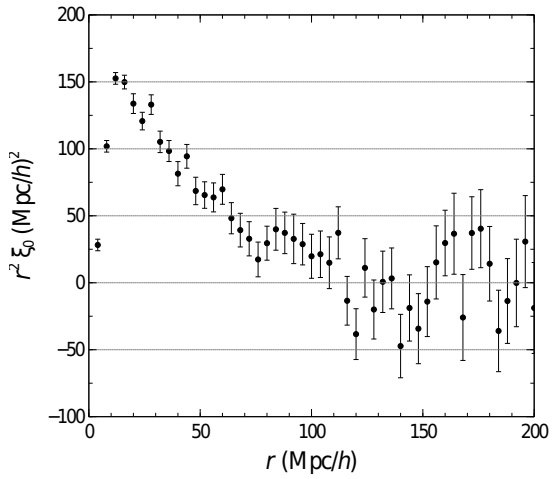
10 mins per mock on 512 CPUs

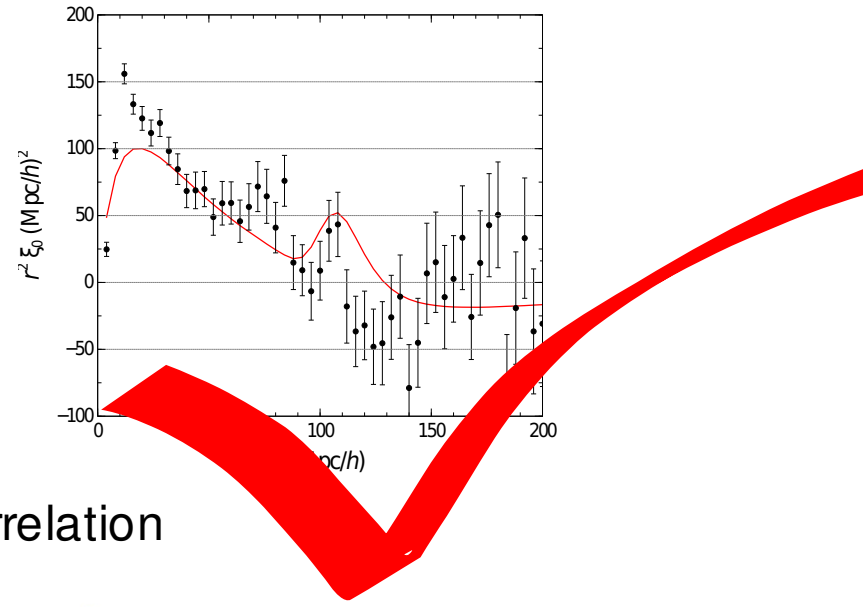
Sightlines scale linearly with quasars

May take longer in bigBOSS

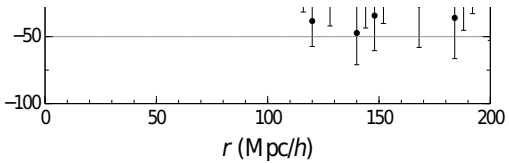
Did we do it right?

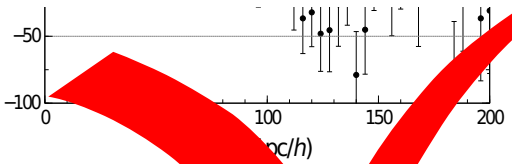
Density skewers: cross correlation





Density skewers: auto correlation





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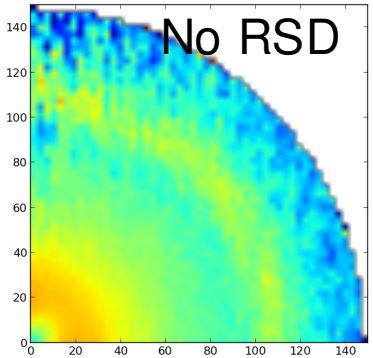
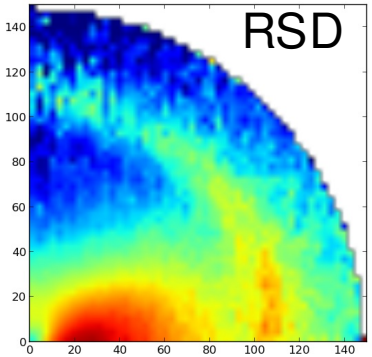


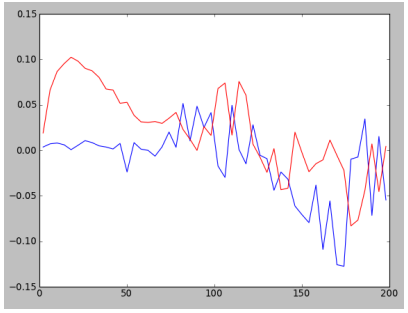


Fiducial z=2

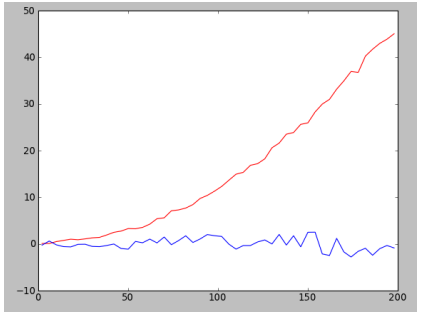
Auto correlaiton of Flux with noise?

No RSD, reasonable

Auto correlaiton of Flux with noise?



No RSD, reasonable



With RSD, off

Still investigating

Summary

Broken power spectrum + nested mesh

Does not tamper with BAO

Fast, excellent scalability

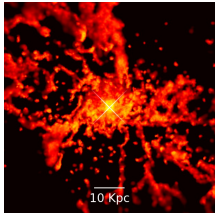
Think about bigBOSS?

Full Talk summary

Simulating Quasars

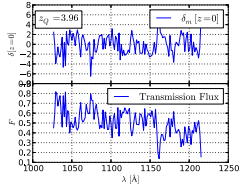
At small scales: Hydro sims

Feeding & Growth



At large scale: Linear theory

Clustering



Thanks!