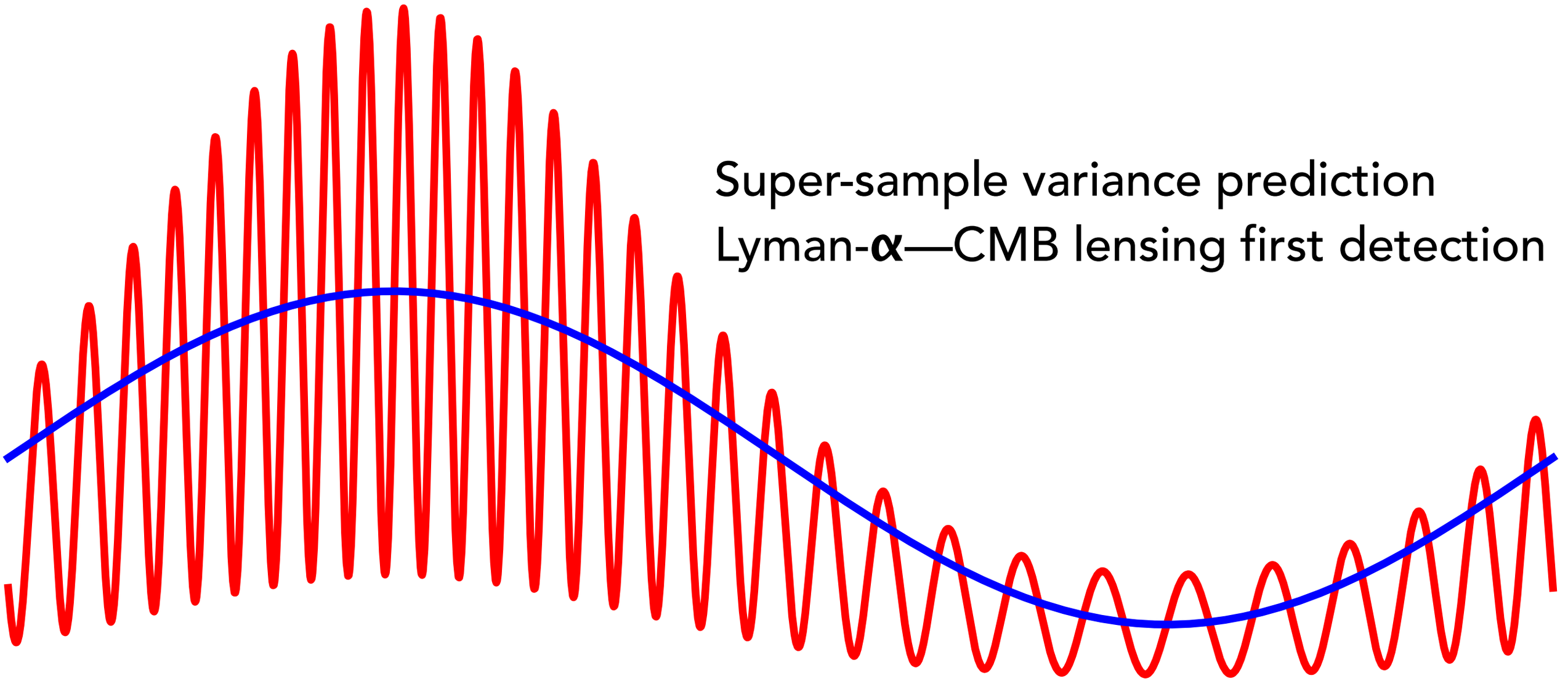
Non-linearities in the LSS: Noise and signal



Super-sample variance prediction

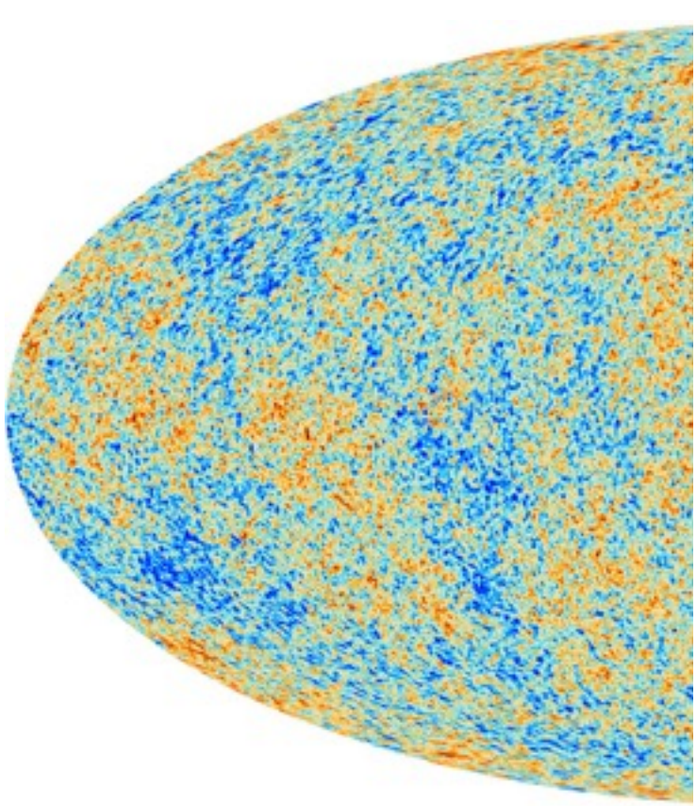
Lyman-**α**—CMB lensing first detection

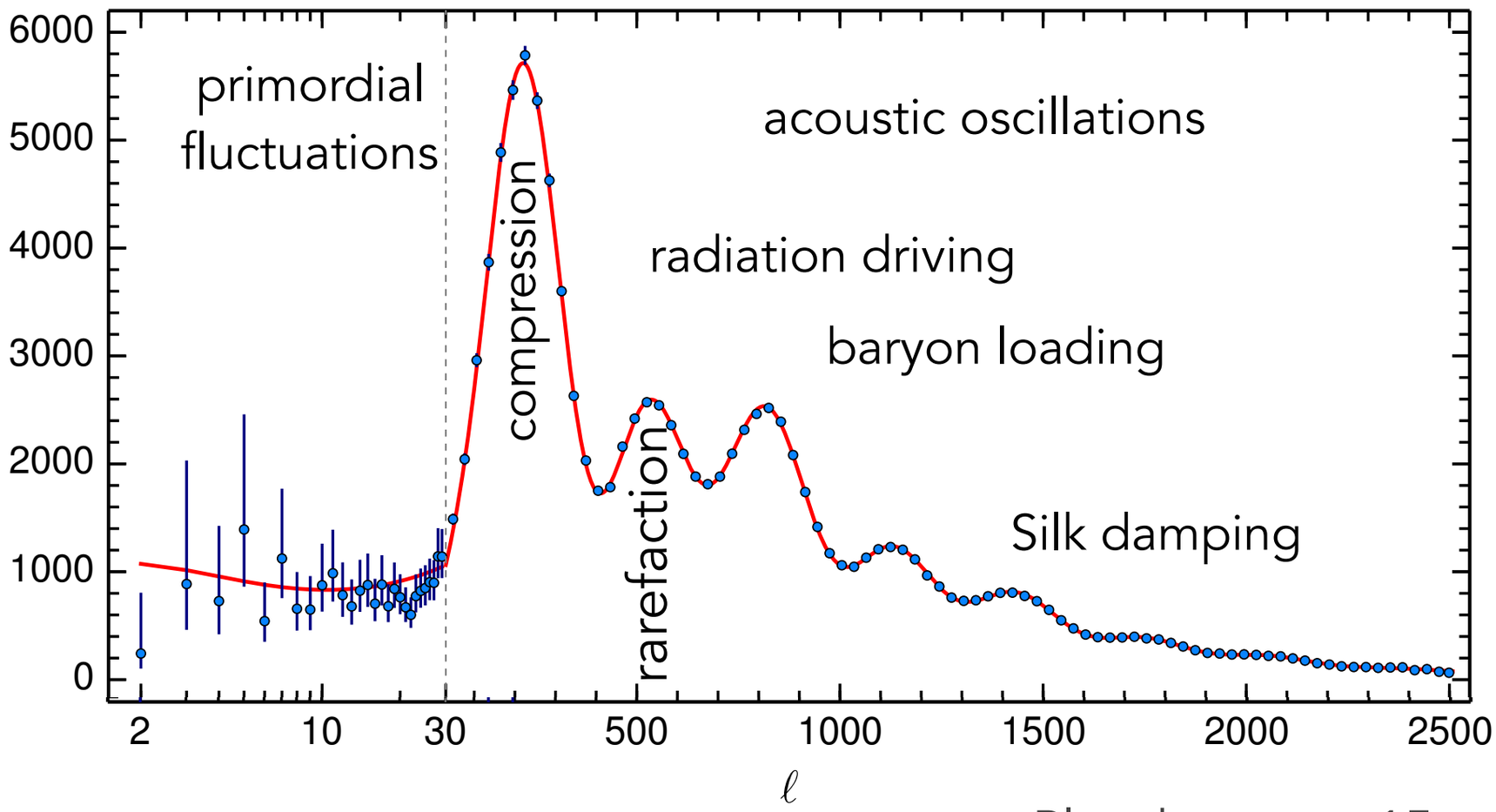
Emmanuel Schaan, Princeton

Lawrence Berkeley National Laboratory, Nov 2016

Primary anisotropies — Only one CMB sky

- **Linear physics:** acoustic waves





Planck param. 15

- **Gaussian statistics** (deviations<~10^{-3}, Planck)

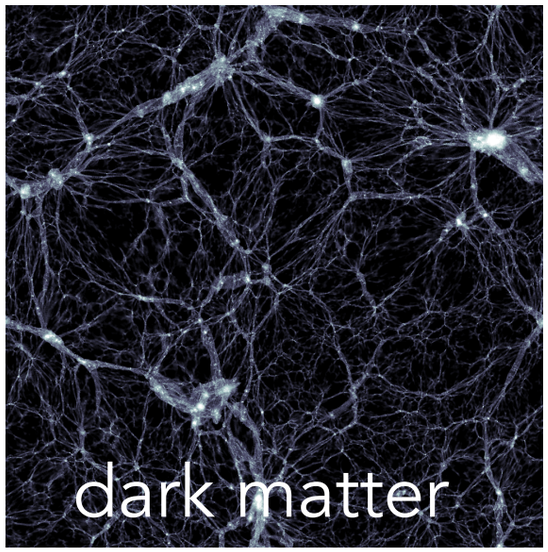
- **Primary anisotropies measured to ~ cosmic variance** with Planck
  (But primordial gravitational waves, number of relat. species!)

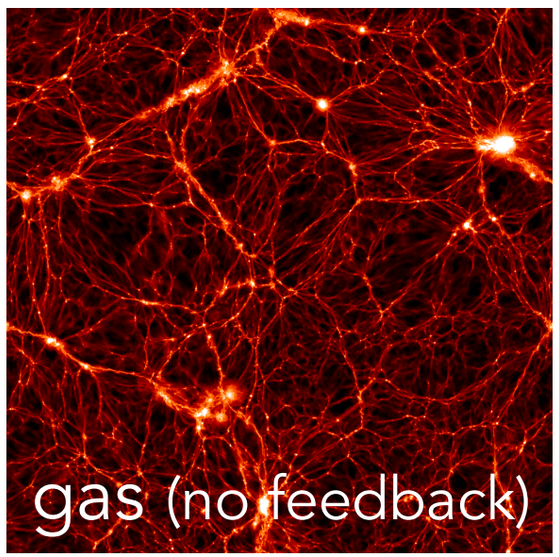
Dark energy? Dark matter? Neutrinos?

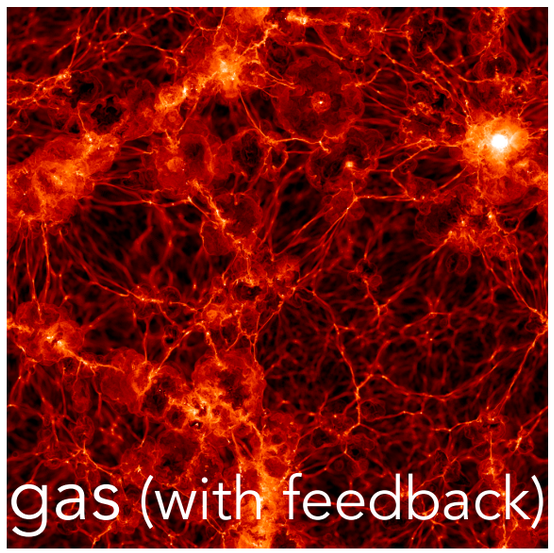
- **Laboratory experiments:** SuperCDMS, LUX/LZ; CUORE, MAJORANA, KATRIN, IceCube and many more
- **Standard candles:** Supernova Cosmology Project, SNfactory
- **LSS:** BOSS, eBOSS, DESI, LSST
  Enormous statistical power
  …**But:** astrophysics? systematics? **non-linearities**?

Localizing the baryons with the CMB

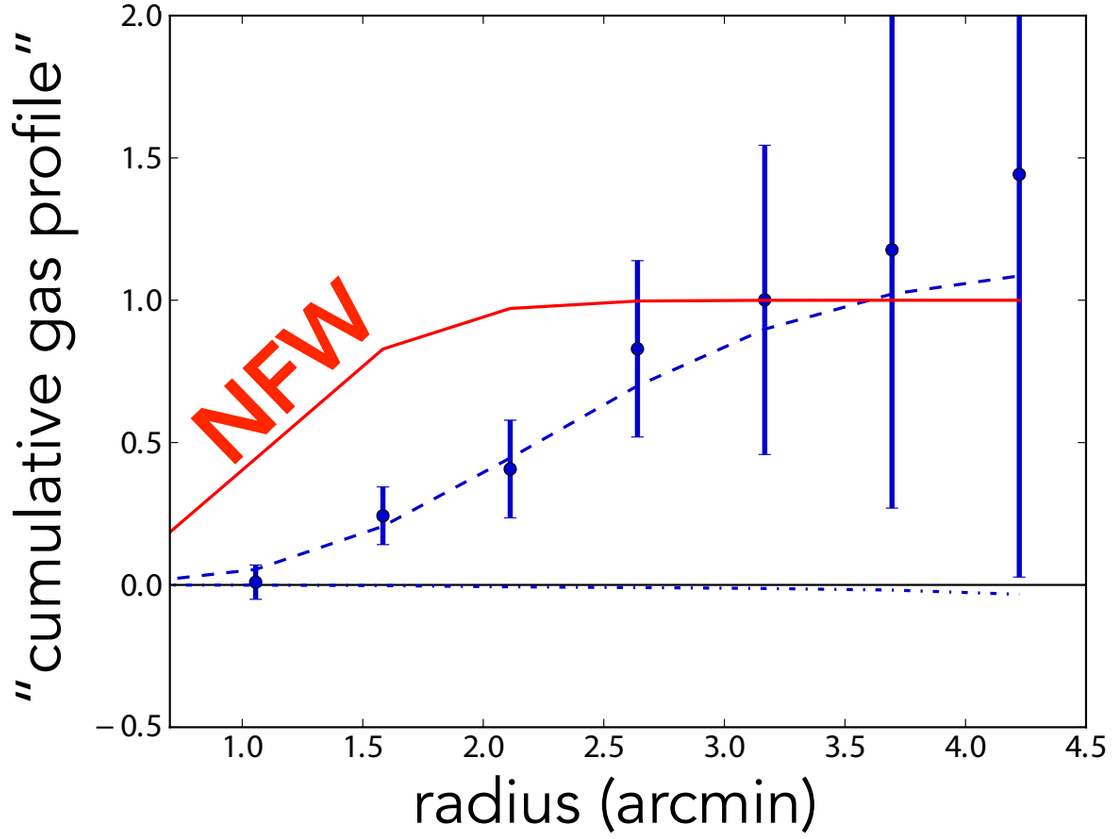
Schaan Ferraro Vargas Smith Ho Spergel & ACTPol, PRD, arxiv:1510.06442







Haider+16, Illustris simulation



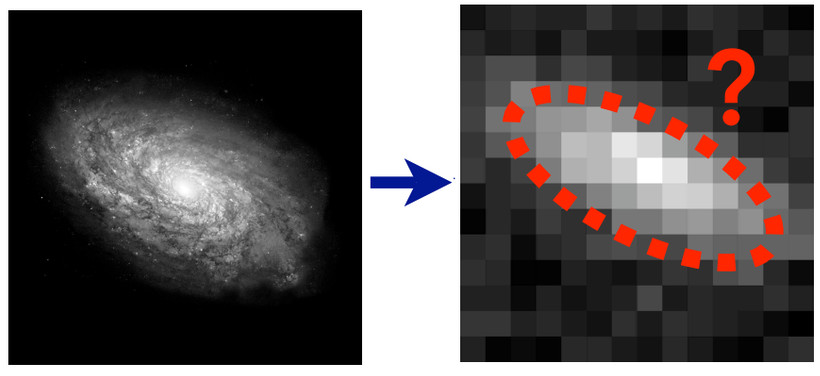
Schaan Ferraro+Ho+15

Baryons = 20% of total matter,
and spatial distribution is uncertain!
→ **limiting for lensing surveys**

But baryons imprinted on CMB
→ **major progress with BOSS/ eBOSS/DESI with SO/S4**

Controlling systematics

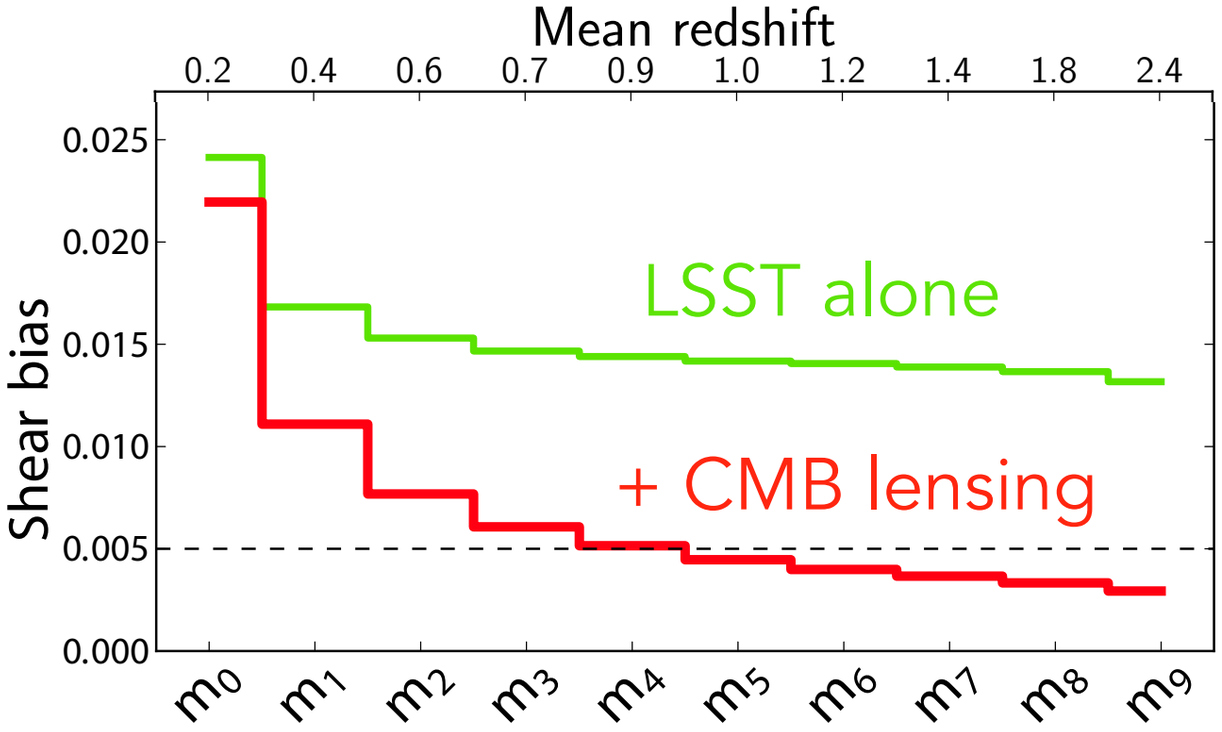
Schaan Krause Eifler Doré Miyatake Rhodes Spergel, PRD, arxiv:1607.01761



Heymans, Euclid Science Book 2010

Current optical lensing is systematics-limited at 5% (DES, KiDS)

→ **degenerate with dark energy and neutrinos**



Schaan+16

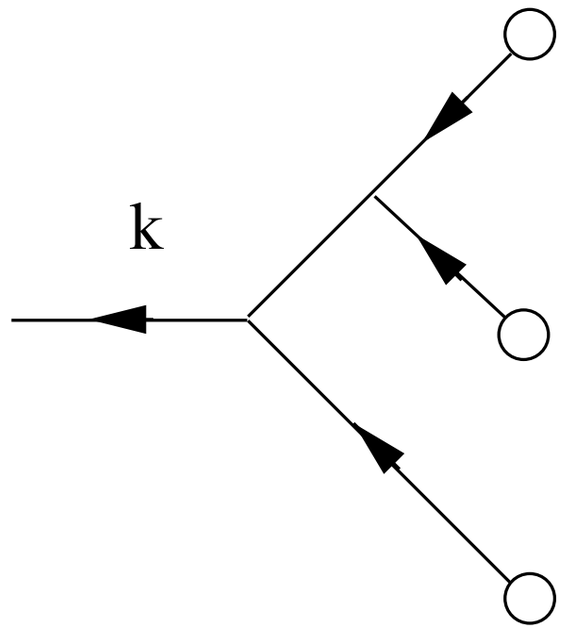
Future experiments require 0.5% (LSST, Euclid, WFIRST)

→ **achievable with SO/CMB S4 lensing!**

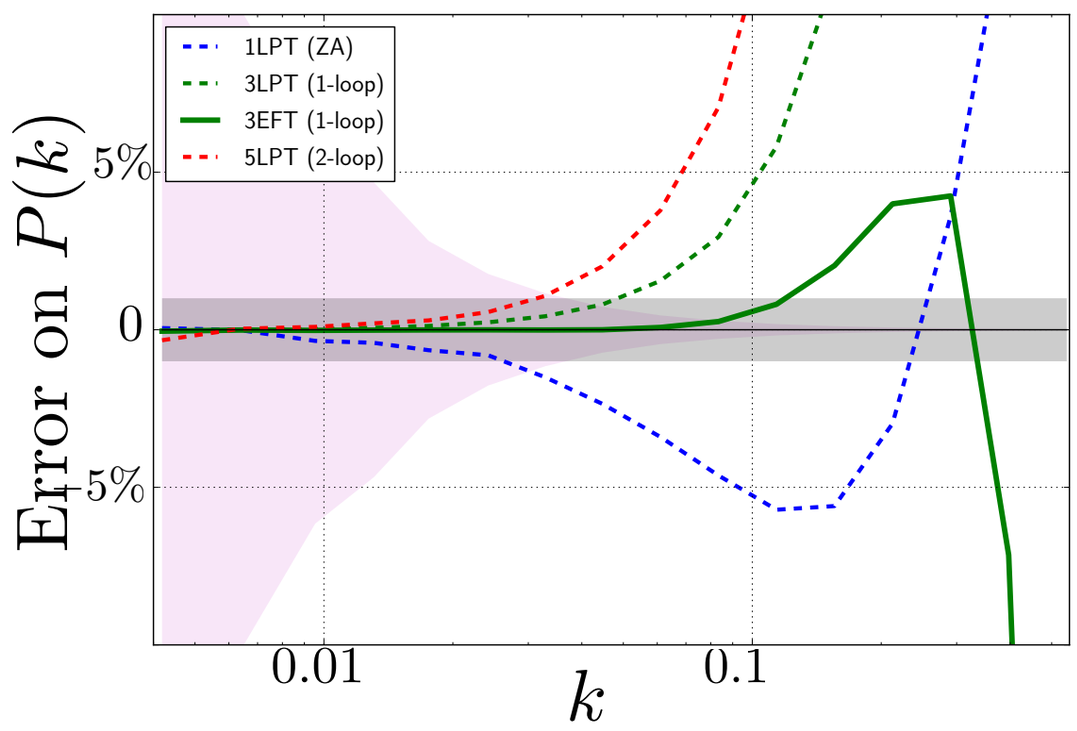
Non-linear evolution under gravity

Collisionless Boltzmann - Poisson:

$$\begin{cases} \partial_t f + \dfrac{p}{ma^2}\nabla_x f - m\nabla_x\phi\cdot\nabla_p f = 0 \\ \Delta\phi = \dfrac{4\pi\mathcal{G}m}{a}\displaystyle\int f\,dp \end{cases}$$



- Computationally expensive
  N-body simulations
- **Extra noise?**
- **Extra signal?**

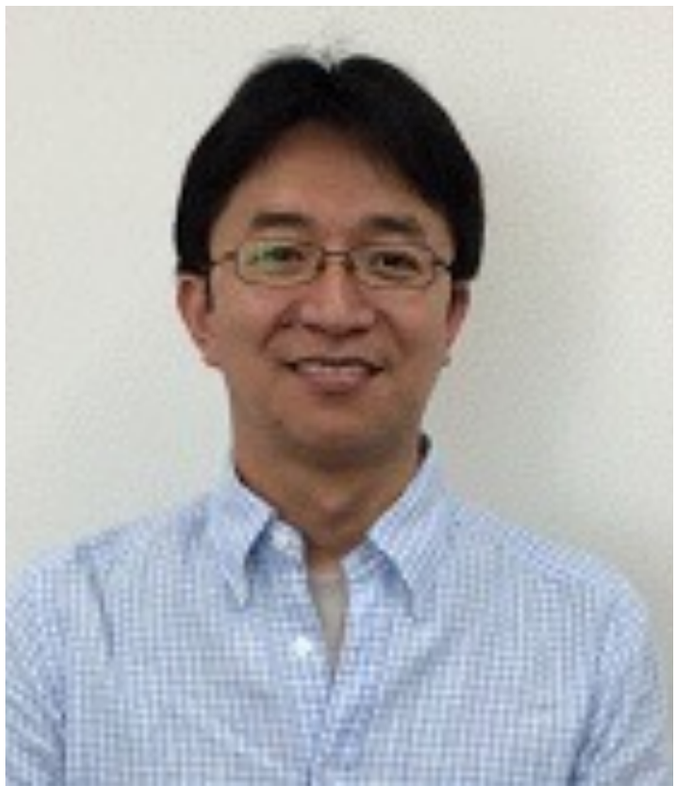


Baldauf Schaan Zaldarriaga 15
1505.07098, 1507.01583

Non-linearities as a noise: Super-sample variance

Collaborators

arxiv:1406.3330



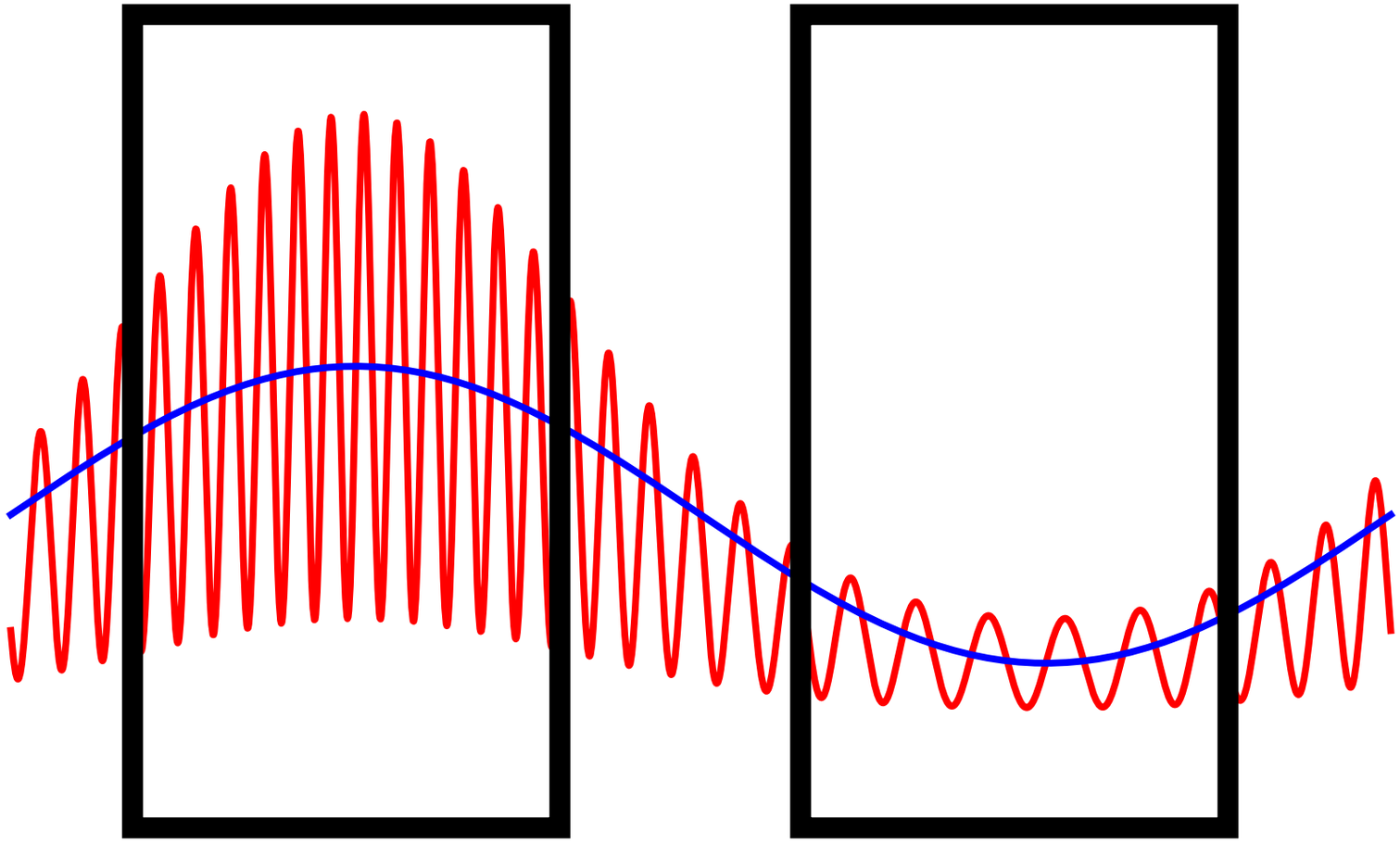
Masahiro Takada

David Spergel

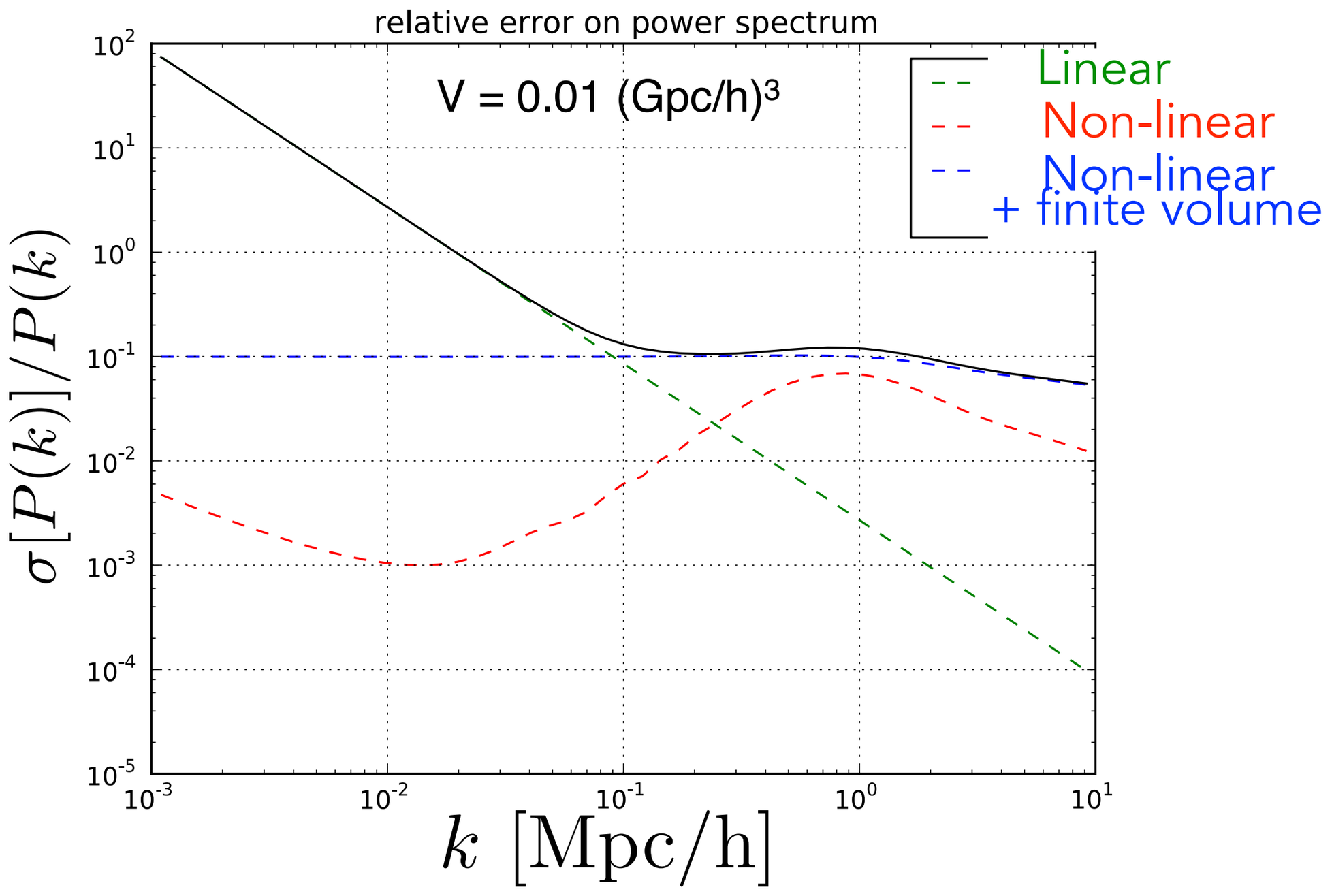
Non-linearities: beat coupling

- **Growth:** Hamilton+06, Baldauf Seljak+11, de Putter+12
- **Dilation:** Sherwin+12, Li+14, Chiang+14

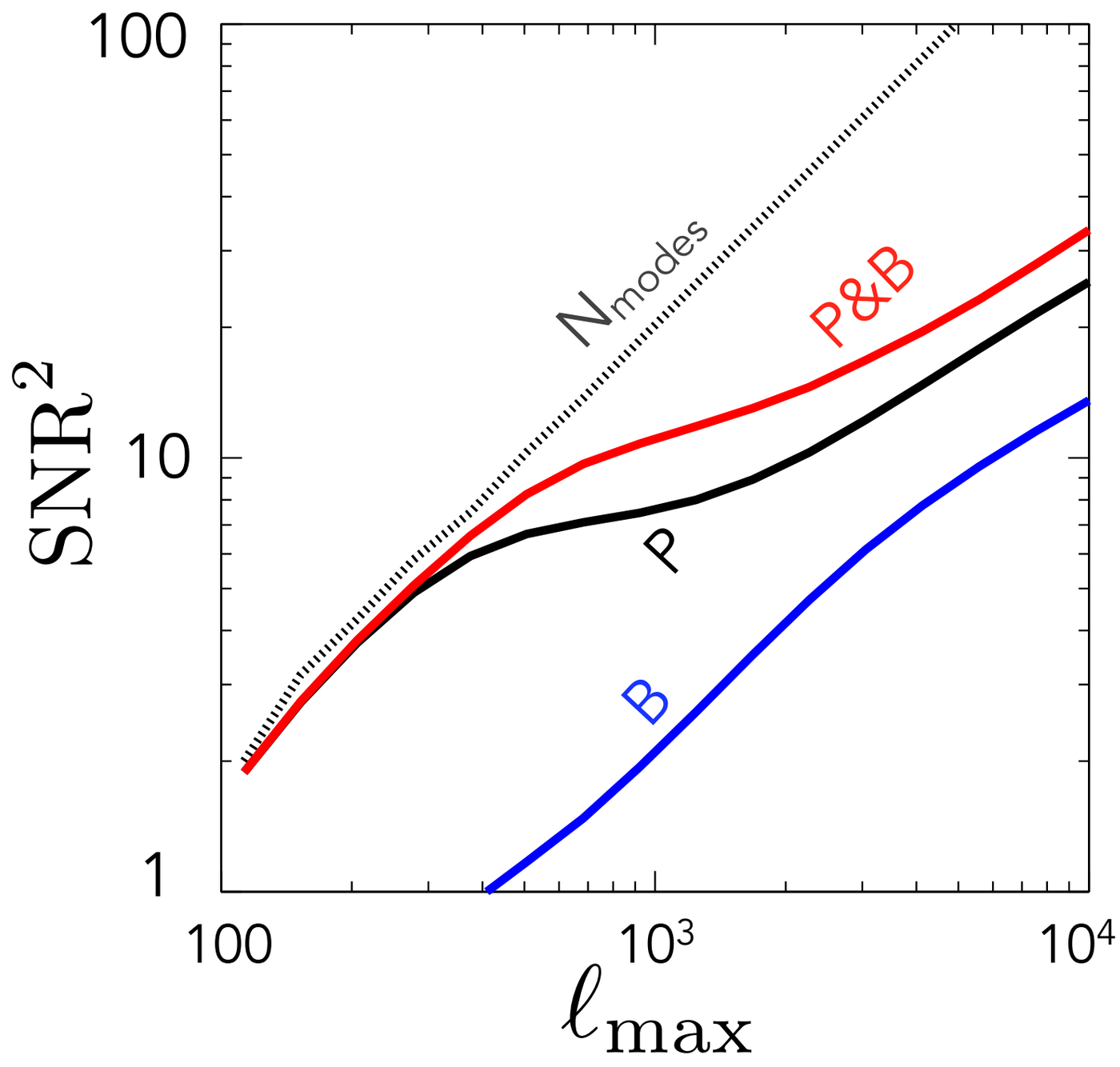
$$P(k) = \bar{P}(k)\,[1 + (\underbrace{\frac{68}{21}\,\delta_L}_{\text{growth}}]\underbrace{\frac{1}{3}\frac{d\ln k^3 \bar{P}}{d\ln k}}_{\text{dilation}})\delta_L]$$



A dominant noise!

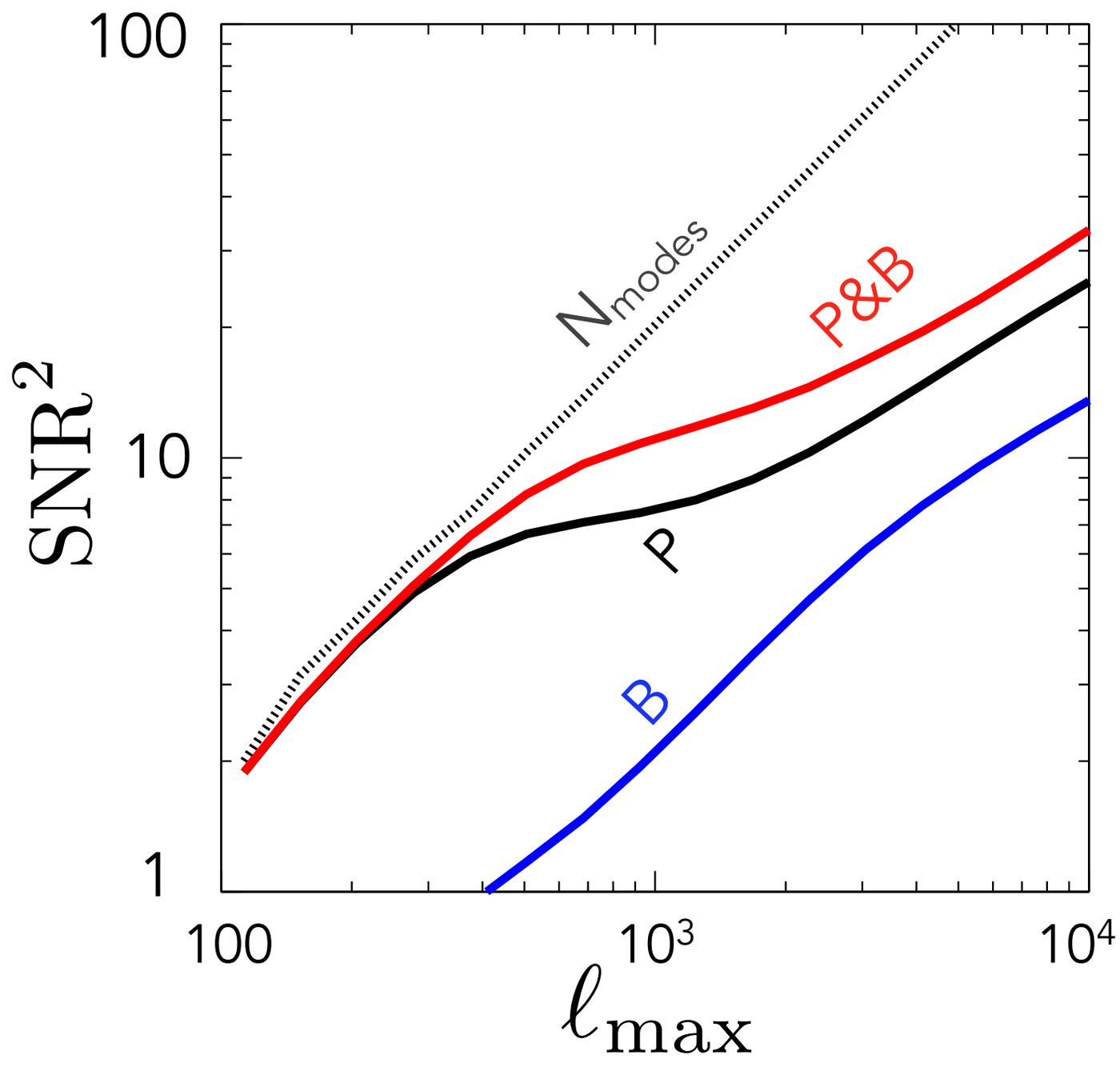


Where did the information go?



Kayo Takada Jain 12
Schaan+14

Where did the information go?

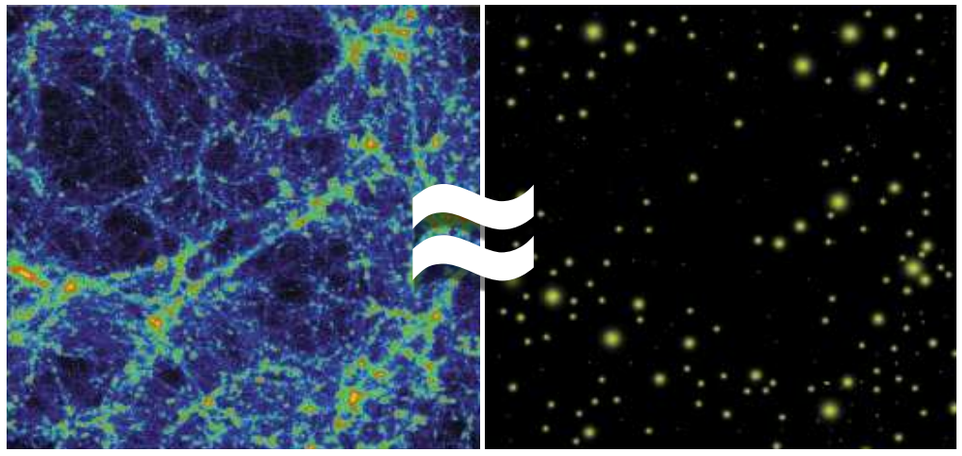


Kayo Takada Jain 12
Schaan+14

Recover even more info?

Describe the highly non-linear scales?

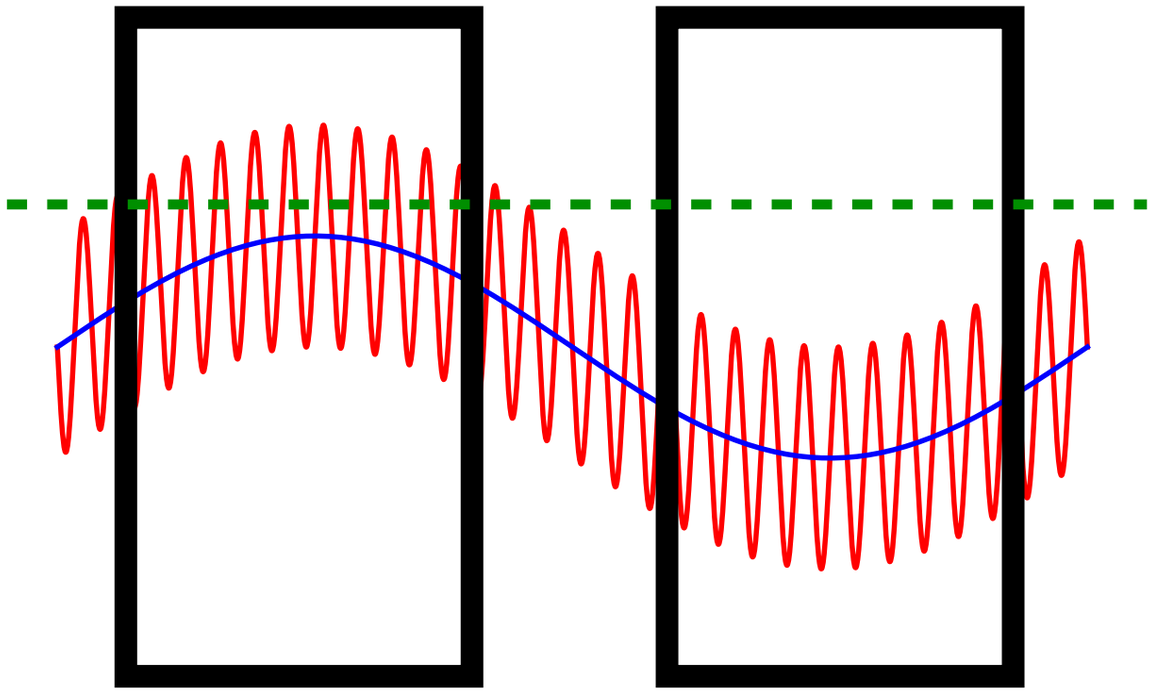
Non-linearities: halo model



Cooray Sheth 02

$$\delta_{\text{non-lin}}(k) = \underbrace{\int dm\, \frac{dn}{dm}}_{\text{how many halos}} \underbrace{\left(\frac{m}{\bar{\rho}}\right) u(k,m)}_{\text{what profile}} \underbrace{b(m)\delta_{\text{lin}}(k)}_{\text{where}}$$

Neyman Scott 1952, Seljak 00

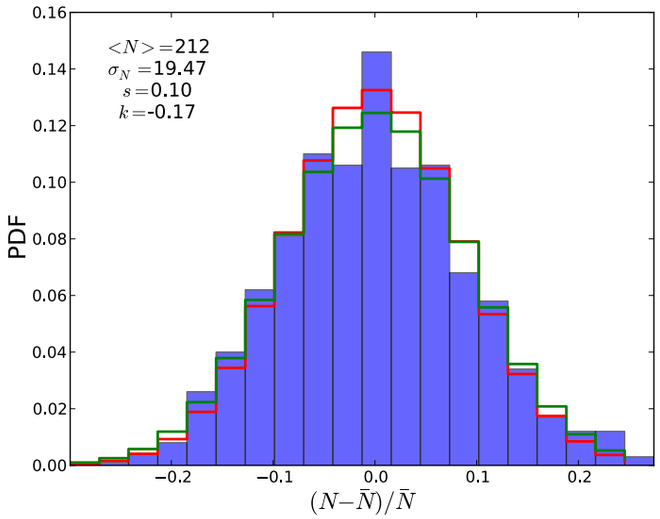


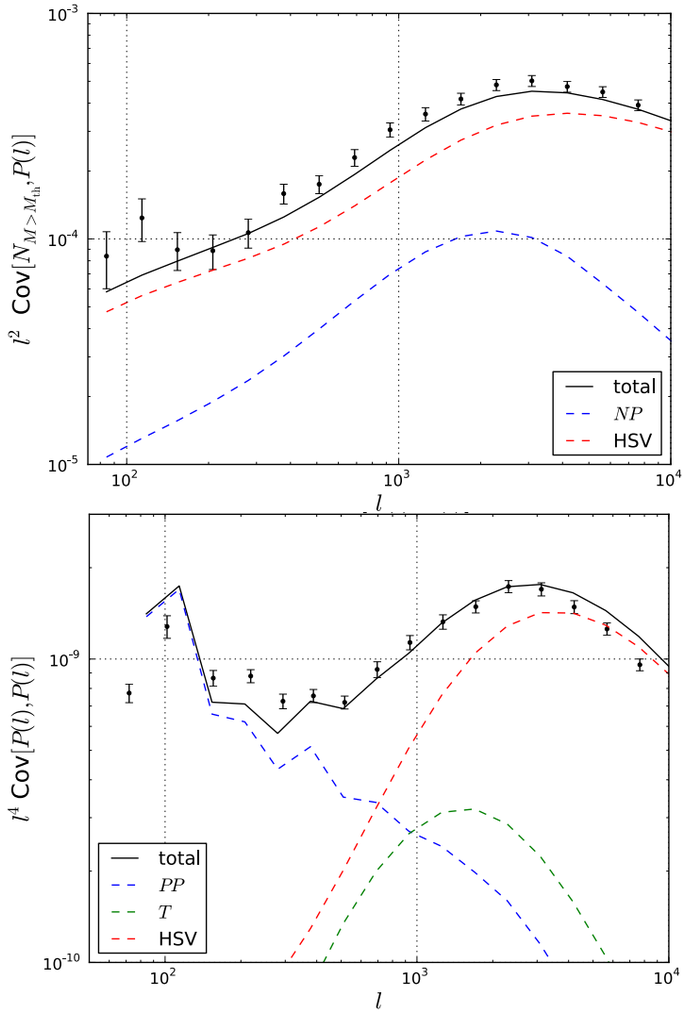
- "Halo sample variance"
  Hu Kravtsov 02, Hu Cohn+06, Sato+09
- Correlation between P, B and number of halos
  Kayo+12, Takada Spergel 13, Schaan+14

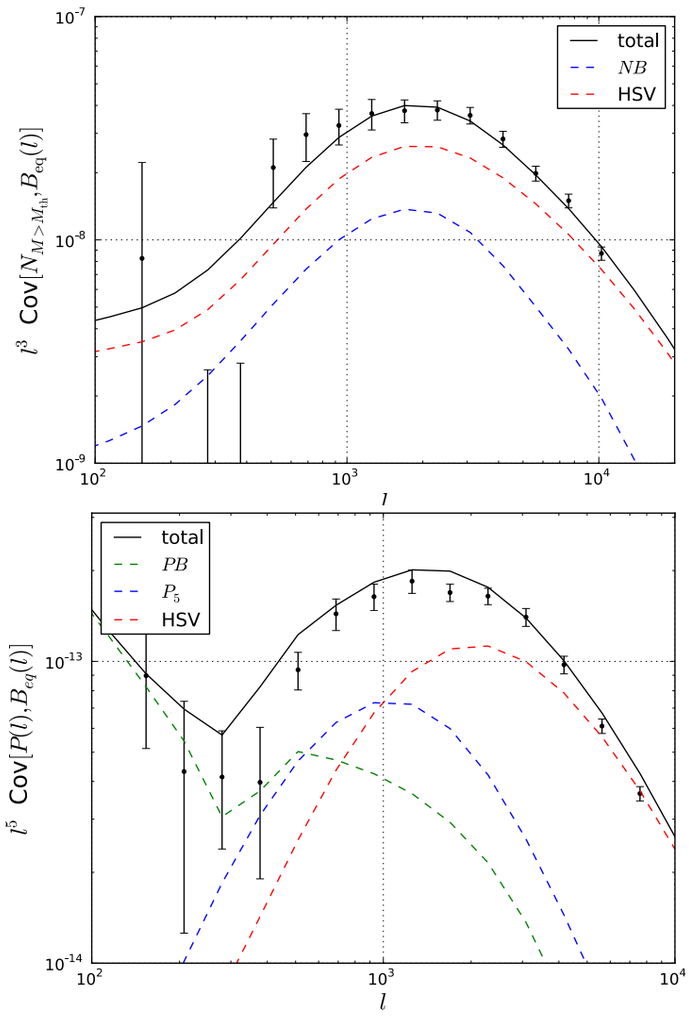
Covariance predictions

N P B

N





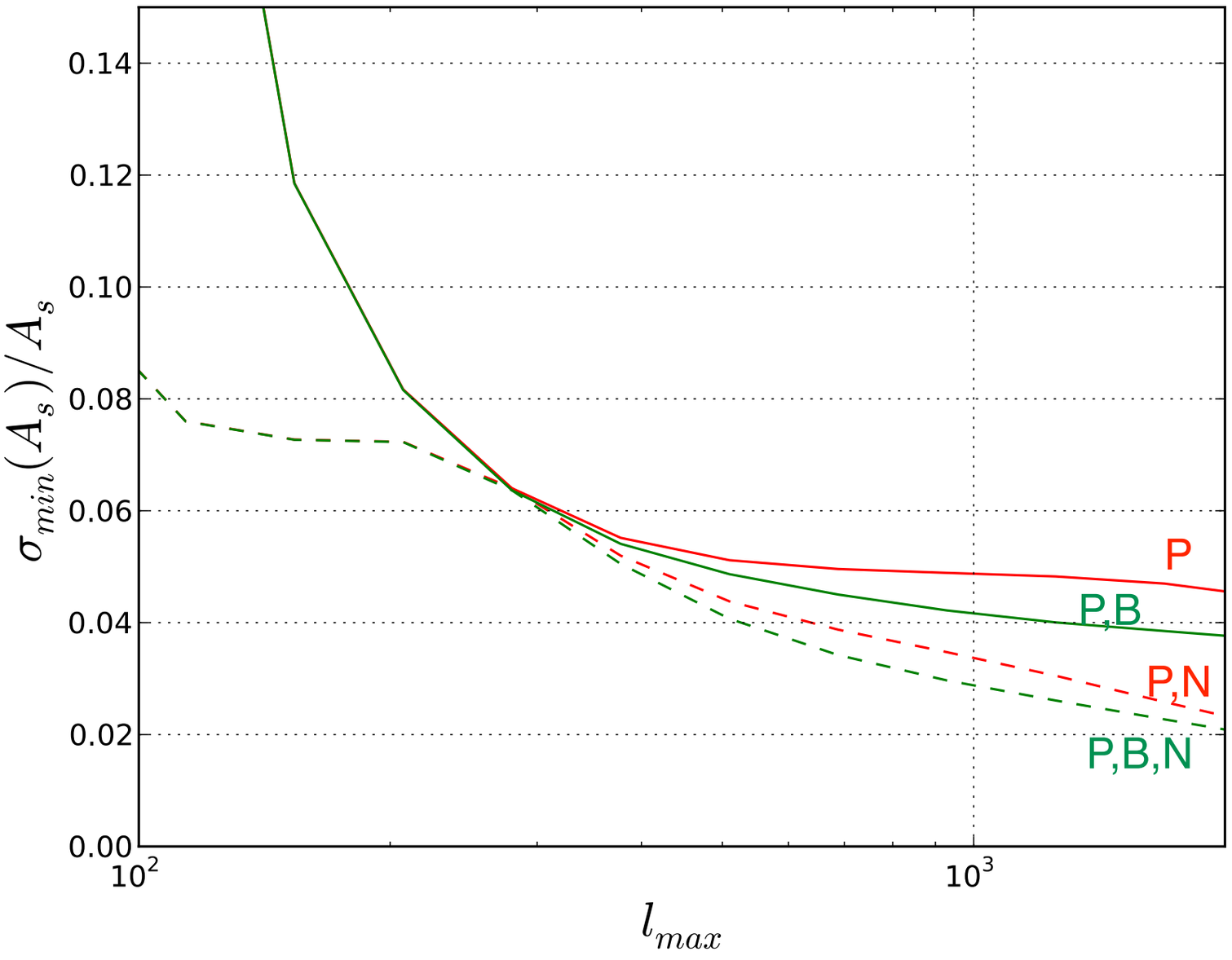


P

B

Schaan Takada Spergel 14

Gain from a Joint Analysis



n_g = 20 arcmin^{-2}

σ_ε = 0.22

area = 15000 deg^2

$\langle z_s \rangle$ = 1

Schaan, Takada, Spergel 2014

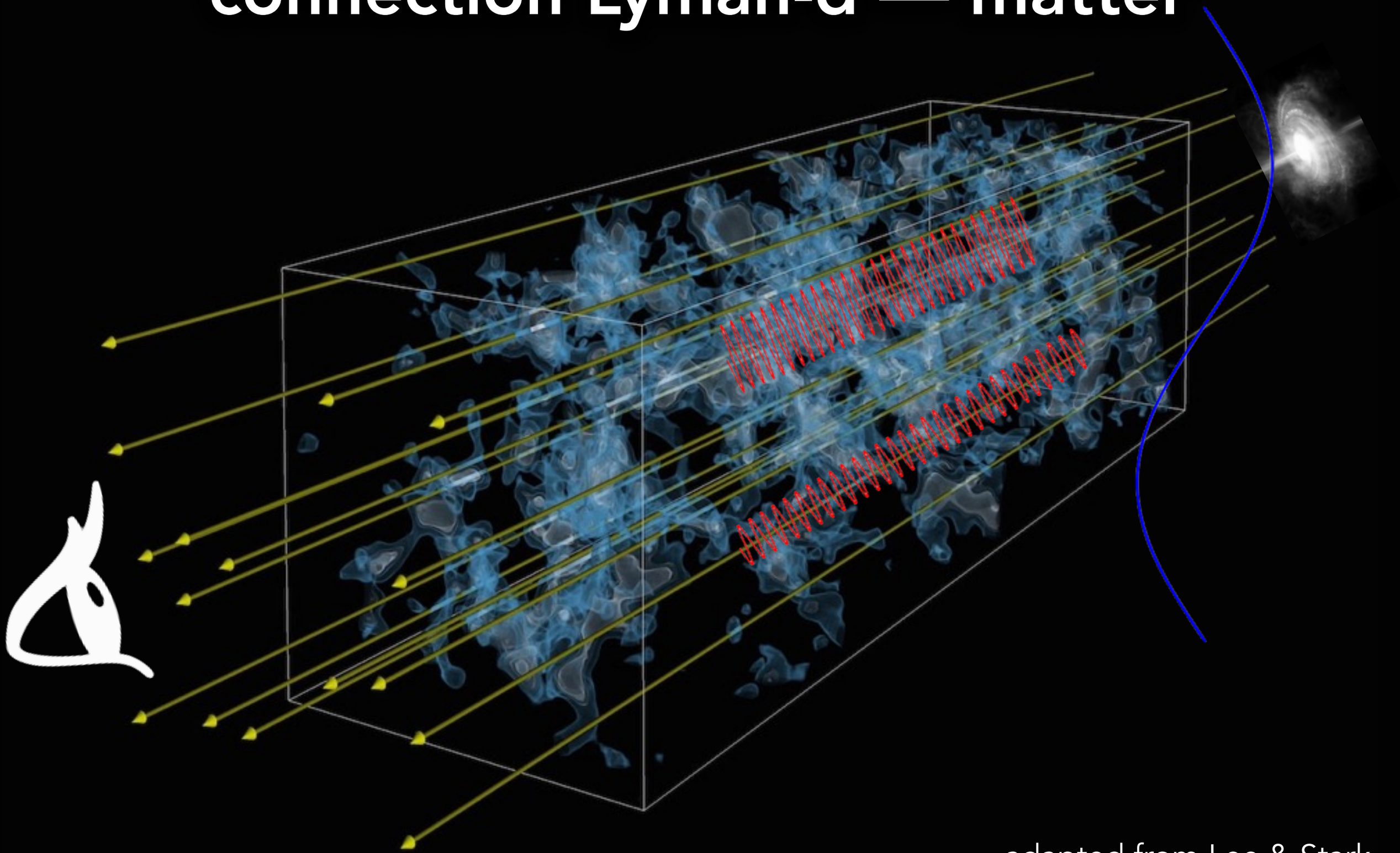
→ Precision on Ω_m and A_s improved by ~40%

→ Factor of 2 in survey volume

Summary

- Finite survey volume degrades information
  Schaan, Takada & Spergel 2014
- Missing information partially recovered by joint analyses
- (Cheaper covariance matrix estimation possible)
- ...noise or signal?
  “Super sample signal”, Li, Hu, Takada 2014

Non-linearities as a signal: connection Lyman-α — matter



adapted from Lee & Stark

Collaborators

arxiv:1406.3330

Cyrille Doux

Eric Aubourg

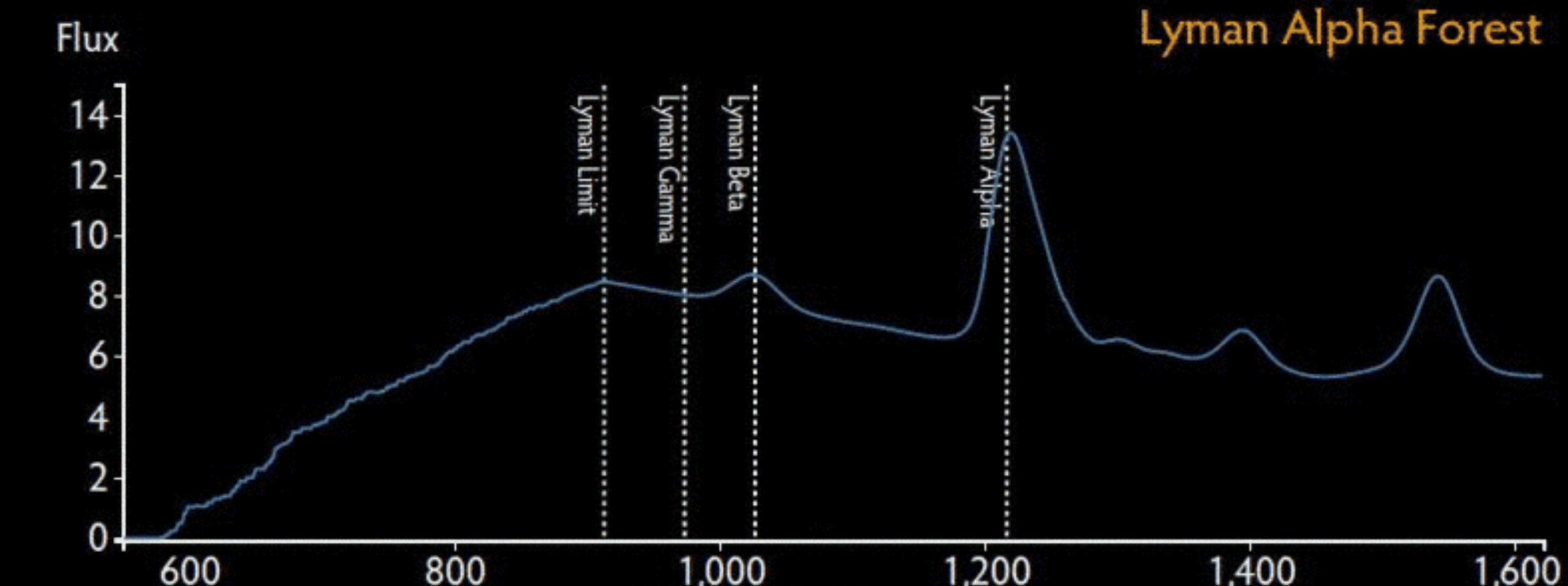
Ken Ganga

Khee-Gan Lee

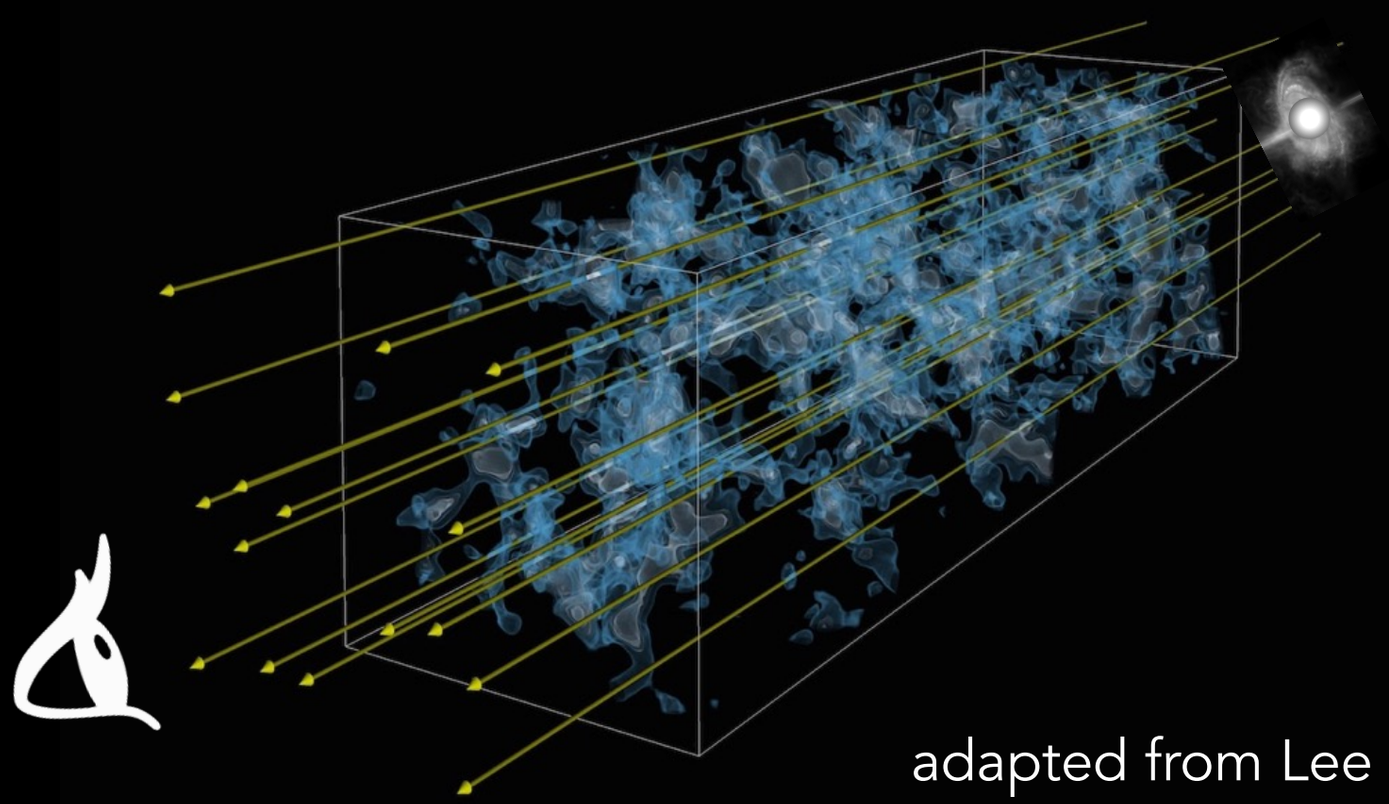
David Spergel

Julien Treguer

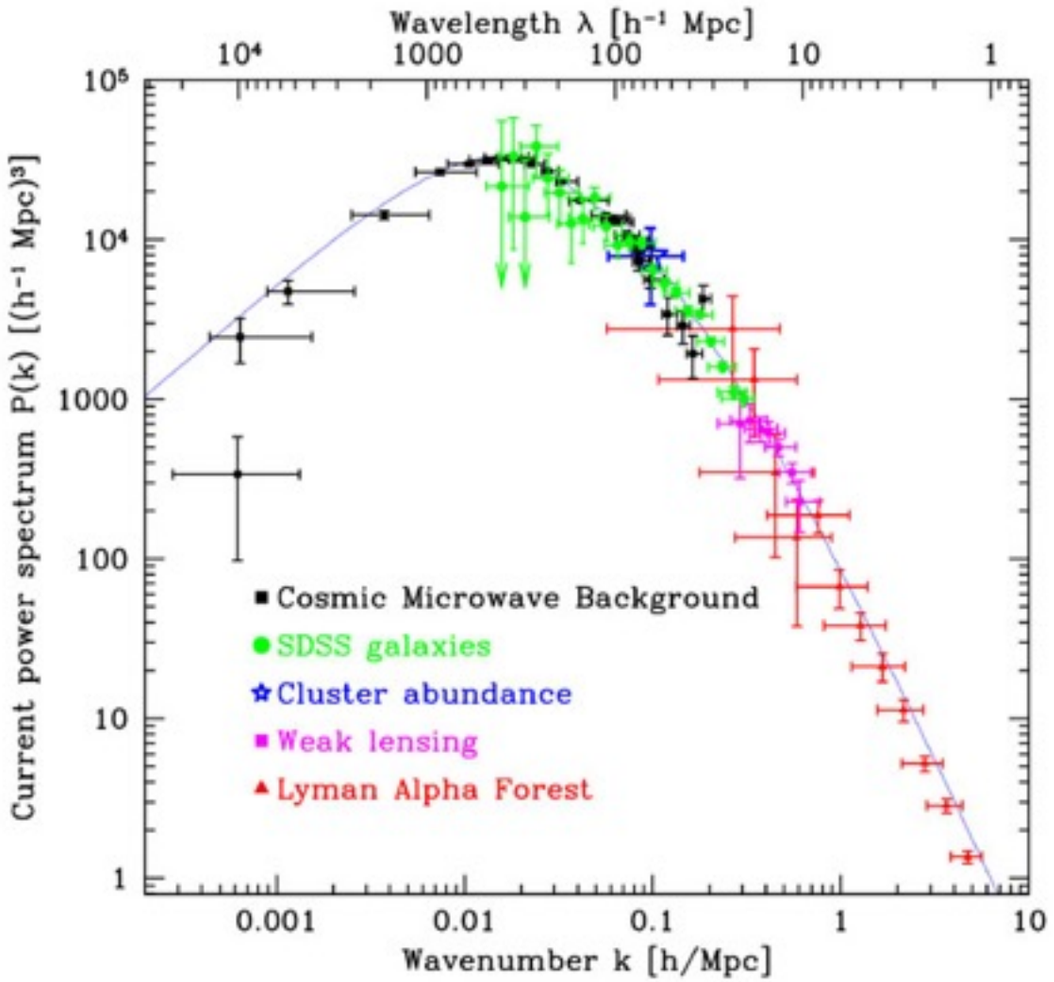
Lyman Alpha Forest



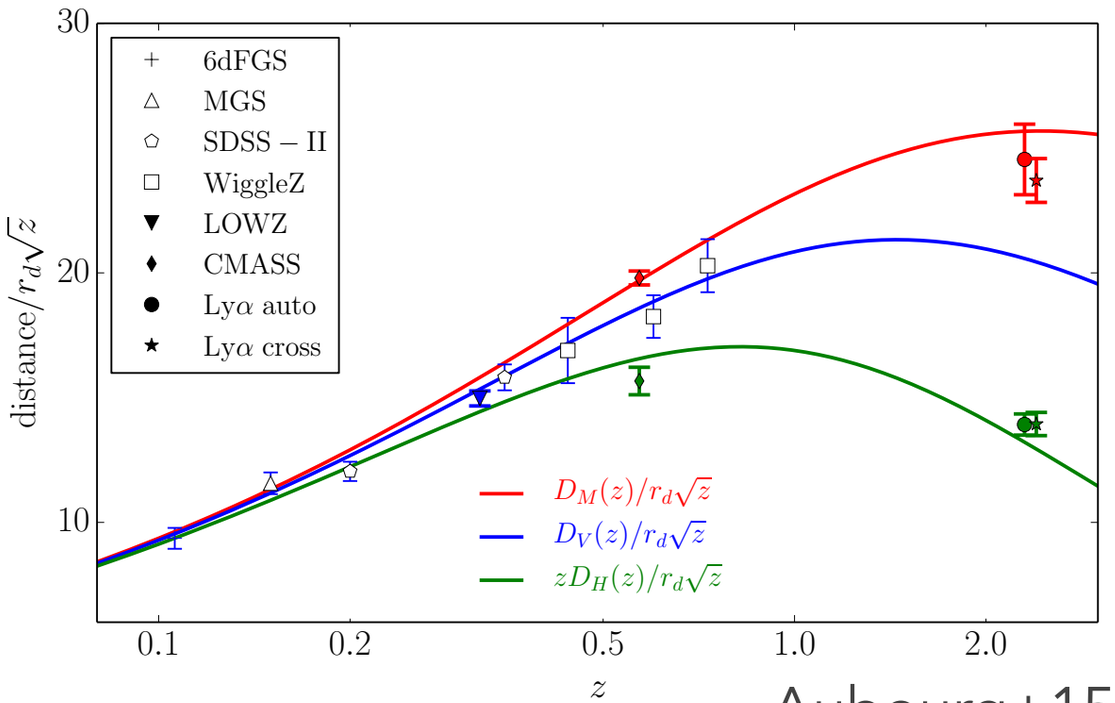
https://www.cfa.harvard.edu/~yuan-sen.ting/Lyman_Alpha_Module/HTML/lyman_alpha2.html



adapted from Lee & Stark



Tegmark+03



Aubourg+15

Cosmology from Lyman-α forest

- Ionization and thermal history
  line width, transmission pdf, Gunn-Peterson trough
- Small-scale power: WDM, FDM, neutrino masses
  McDonald+06, Viel+13, Hui+16, Palanque-Delabrouille+15
- BAO from auto & cross with QSOs
  Delubac+14 , Font-Ribera+14
- 3d tomography
  Lee 14, Lee+14,15, Lee White 16

Modeling the Lyman-a forest

- Assume photoionization equilibrium in uniform UV background:

$$\tau_{\rm Ly\alpha}(z) = 1.3\,\Delta_b \left(\frac{x_{\rm HI}}{10^{-5}}\right)\left(\frac{1+z}{4}\right)^{3/2}\left(\frac{dv/dx}{H(z)/(1+z)}\right)^{-1}$$

McQuinn 16

  - But Jeans' smoothing, thermal broadening, proximity, extra sources of entropy?

→ test the neutral gas—matter connection?

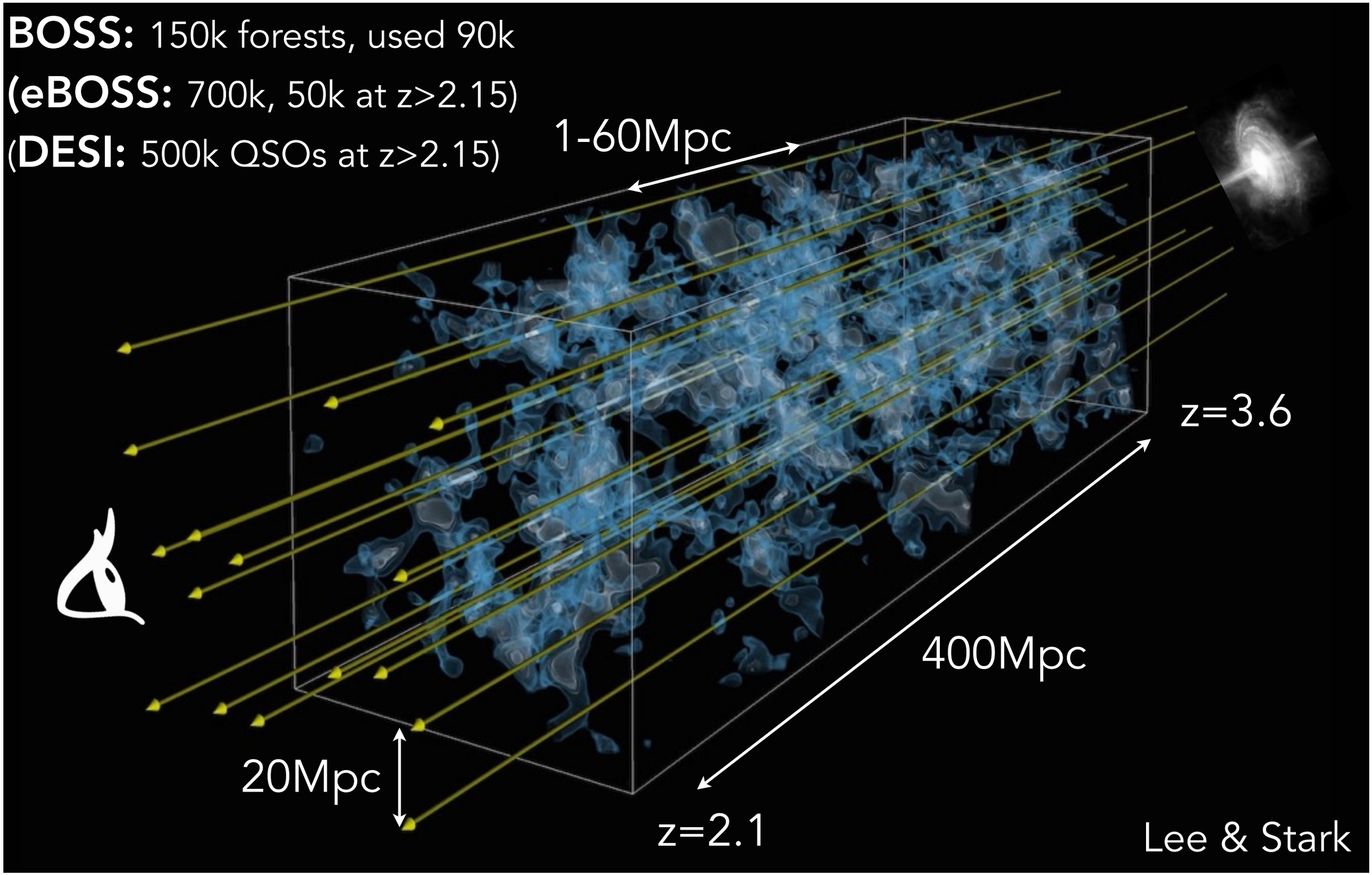
Testing connection LyA-matter

- Zaldarriaga Seljak Hui 01:
  constrain non-gravitational sources of fluctuations in Lyman-α, e.g. continuum fitting errors

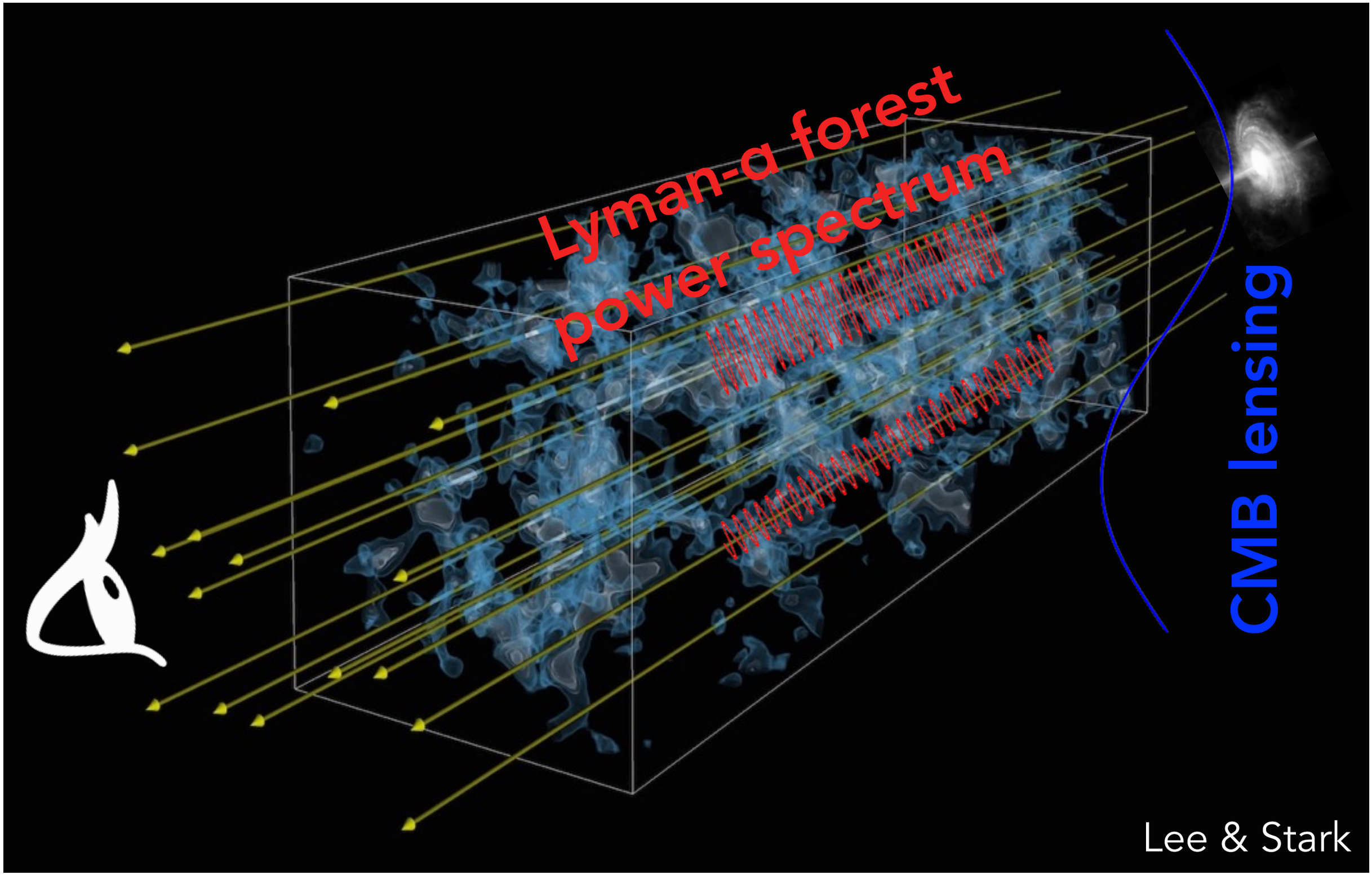
- Meiksin White 03:
  constraining fluctuations in UV background from the Lyman-α transmission pdf

- Vallinotto+09:
  CMB lensing and LyA forest

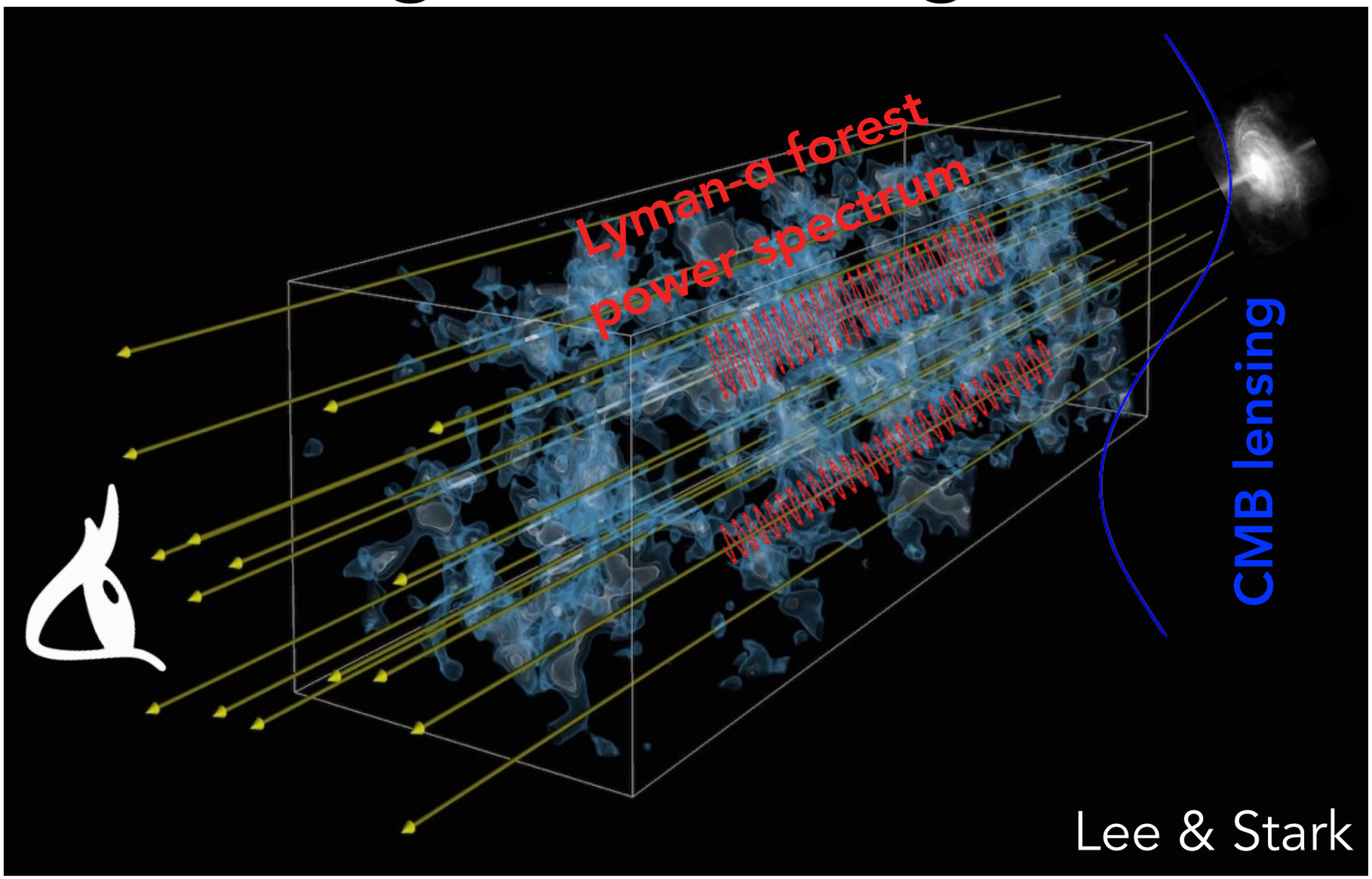
BOSS LyA forest sample



Origin of our signal



Origin of our signal



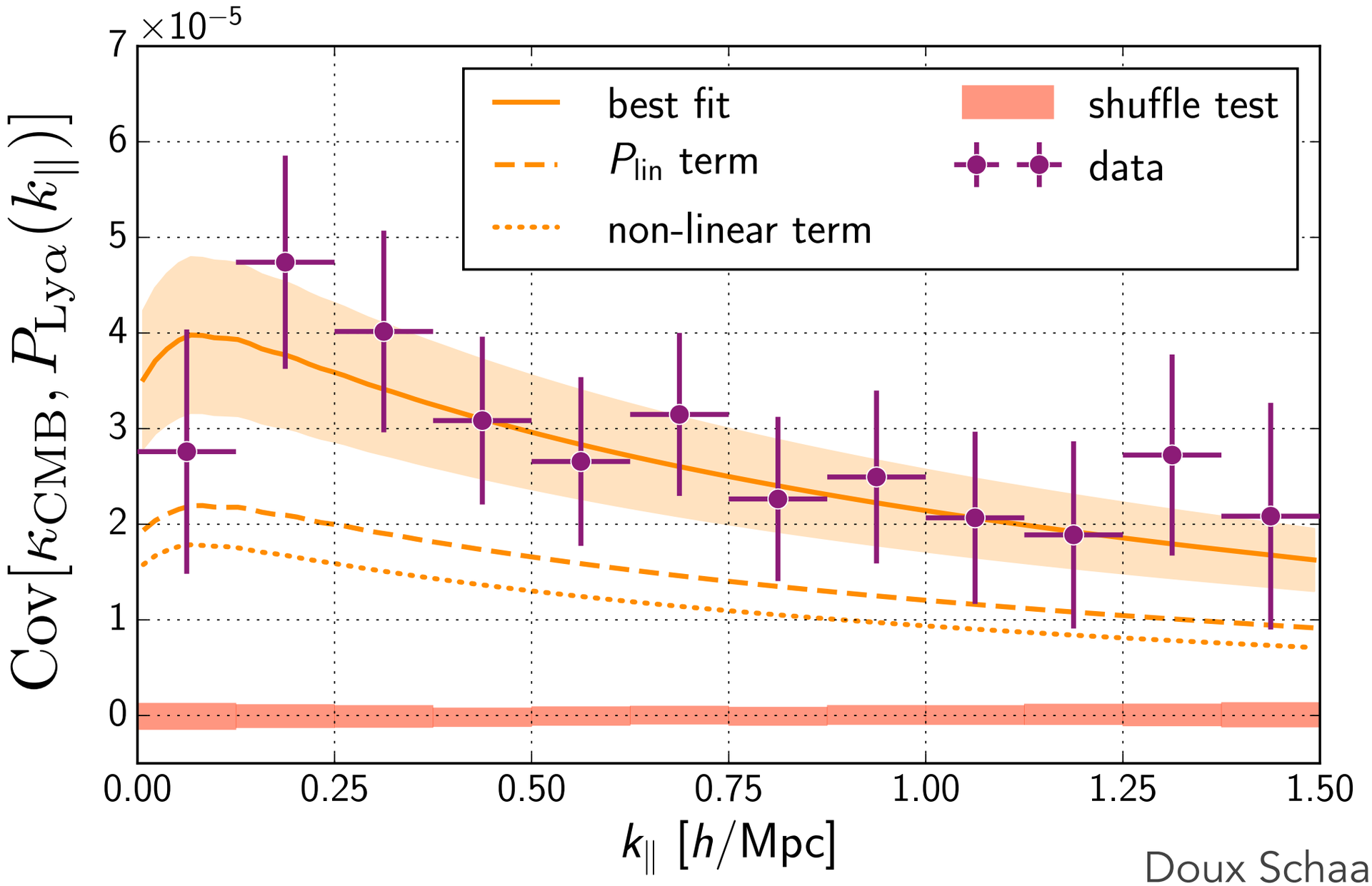
$$\mathrm{Cov}[\kappa_{\mathrm{CMB}}, P_{\mathrm{Ly}\alpha}] = \frac{d\kappa_{\mathrm{CMB}}}{d\bar{\delta}} \frac{dP_{\mathrm{Ly}\alpha}}{d\bar{\delta}} \mathrm{Var}[\bar{\delta}]$$

$$P^{3d}_{\mathrm{Ly}\alpha} = P_{\mathrm{matter}}(k)\, b^2\, (1+\beta\mu^2)^2\, D(k,\mu)/\bar{f}^2$$

bias · velocities · Non-linearities, Jeans smoothing, thermal broadening · normalization

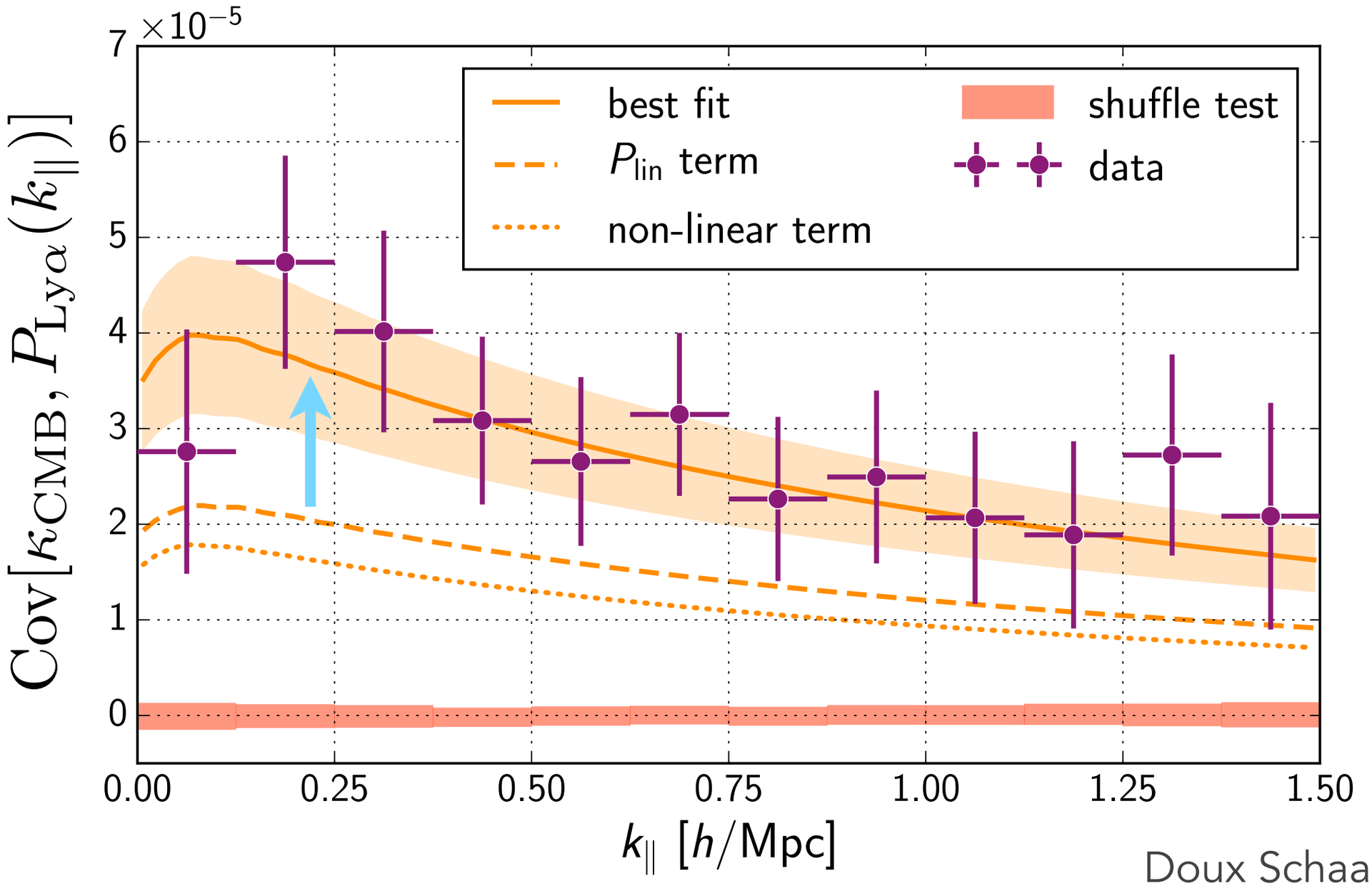
Arinyo-i-Prats+15

5σ detection



Doux Schaan+Lee+16

Probing the Lyman-α — matter connection



Doux Schaan+Lee+16

$$P^{3d}_{\mathrm{Ly}\alpha} = P_{\mathrm{matter}}(k)\, b^2\, (1+\beta\mu^2)^2\, D(k,\mu)/\bar{f}^2$$

bias · velocities · Non-linearities, Jeans smoothing, thermal broadening · normalization

Arinyo-i-Prats+15

Summary

- Lyman-α forest powerful cosmological tool
  WDM, FDM, neutrino masses
- Non-linearities test the connection Lyman-α — matter
- First detection of a correlation between CMB and Lyman-α forest