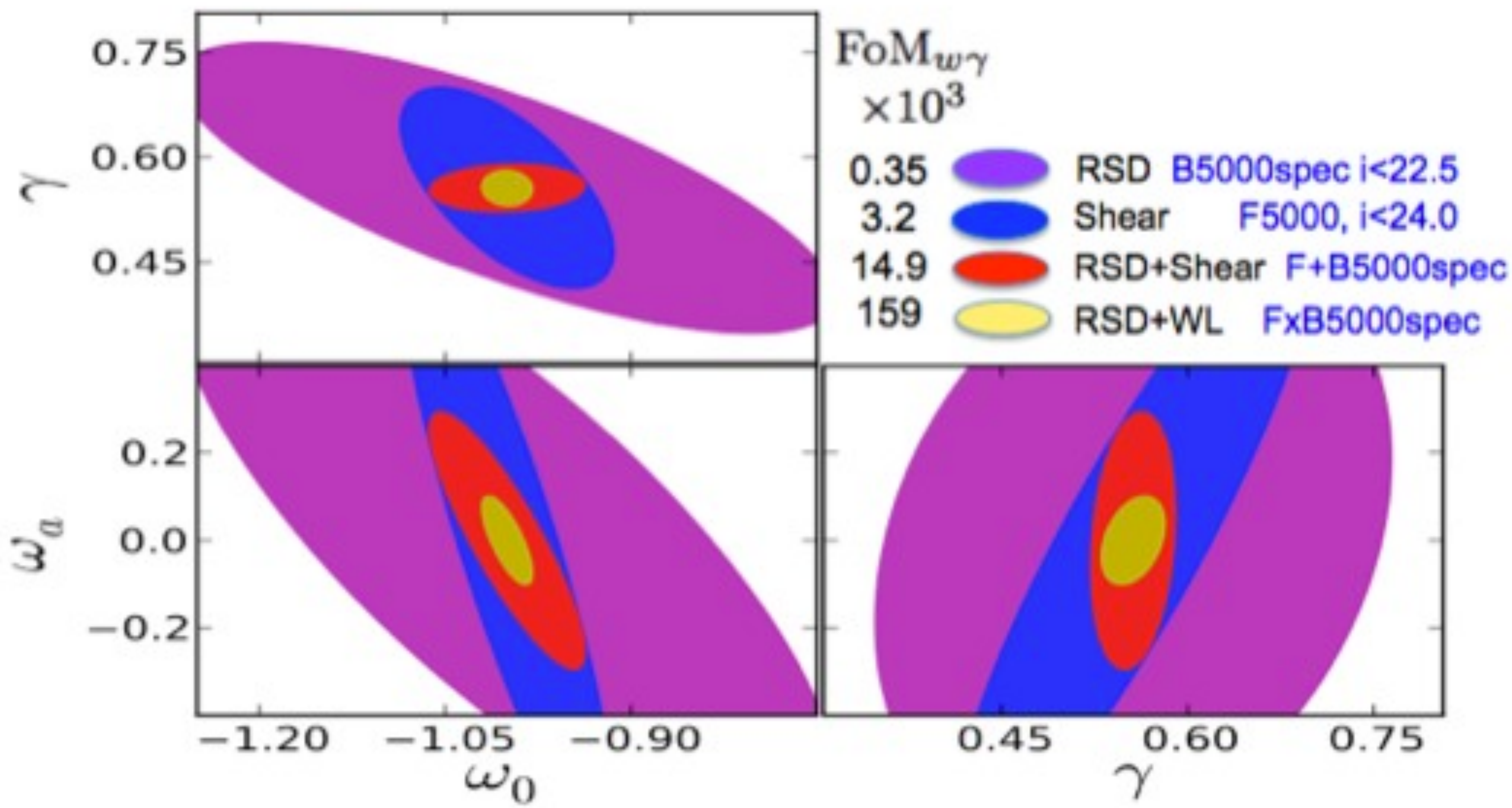
Cross talk in Cosmic Maps

Enrique Gaztañaga



Bonvin
Vernizzi
Corasaniti
Casarini
Bartelmann
Reyes

○ ○ ○ ○ ○ bottom line

astro-ph:1109.4852

WHAT DATA COULD TELL US (ON LINEAR SCALES)

MORE EFFICIENT WAY OF USING GALAXY SURVEYS:

UNDERSTANDING GALAXY BIAS CAN BRING > X100 REWARD IN COSMOLOGICAL PARAMETER MEASUREMENTS

Observing DE: H(z) & D(z) & more

1. *Expansion history:*

$$R_{\mu\nu} + \Lambda g_{\mu\nu} = -8\pi G \left(T_{\mu\nu} - \frac{1}{2} g_{\mu\nu} T \right)$$

$$H^2(z) = H^2_0 \; [\, \Omega_M (1+z)^3 + \Omega_R (1+z)^4 + \Omega_K (1+z)^2 + \Omega_{DE} (1+z)^{3(1+w)} \,]$$

matter radiation curvarure dark energy $w=p/\varrho$

- Measurements are usually integrals over H(z) $r(z) = \int dz/H(z)$
- Standard Candles (supernova) $d_L(z) = (1+z)\, r(z)$
- Standard Rulers (BAO) $d_a(z) = (1+z)^{-1}\, r(z)$ or $H(z)=c\,dz/r$ directly
- Volume Markers (clusters) $dV/dz d\Omega = r^2(z)/H(z)$

2. *Linear Growth history:*

$$\delta T^{\mu\nu}_{;\nu} = 0$$

$$\frac{d^2\delta_k}{d\tau^2} + \mathcal{H} \frac{d\delta_k}{d\tau} - \left(\frac{3}{2}\, \mathcal{H}^2\, \Omega_m - k^2\, v_s^2 \right) \delta_k = 0$$

$$\delta = D(z)\, \delta_0$$

3. *Non-linear Growth history*

- Higher order correlations, Cluster abundance, profiles

4. *Solar & Astro test of gravity*

DARK ENERGY (DE)

Challenge for Observational Cosmology:

Can we use data to confirm
or falsify the cosmological constant model?

-> show IF w (DE equation of state) is different from -1

If deviations are found, can we distinguish between
models? DE and modified gravity (why is G so weak)?

-> consistency of relation between
H(z) expansion history & linear growth D(z) -> gamma

$$\ddot{\delta}(a,k) + 2H(a)\dot{\delta}(a,k) - \frac{g(k)}{\eta(k)} 4\pi G \bar{\rho} \delta(a,k) = 0,$$

Modified:
Poison Eq. & Metric potentials

-> non-linear and local test (more complex)

Figure of Merit $\mathrm{FoM}_{w\gamma} \times 10^3$: Expansion x Growth

$$H = H(w)$$

w(z) -> Expansion History (background metric)
we will use w0 and wa

$$f \equiv \frac{d\ln D}{d\ln a} = \frac{\dot{\delta}}{\delta} \equiv \Omega_m^{\gamma}(a)$$

γ -> Growth History (metric perturbations)
probably need one more parameter here

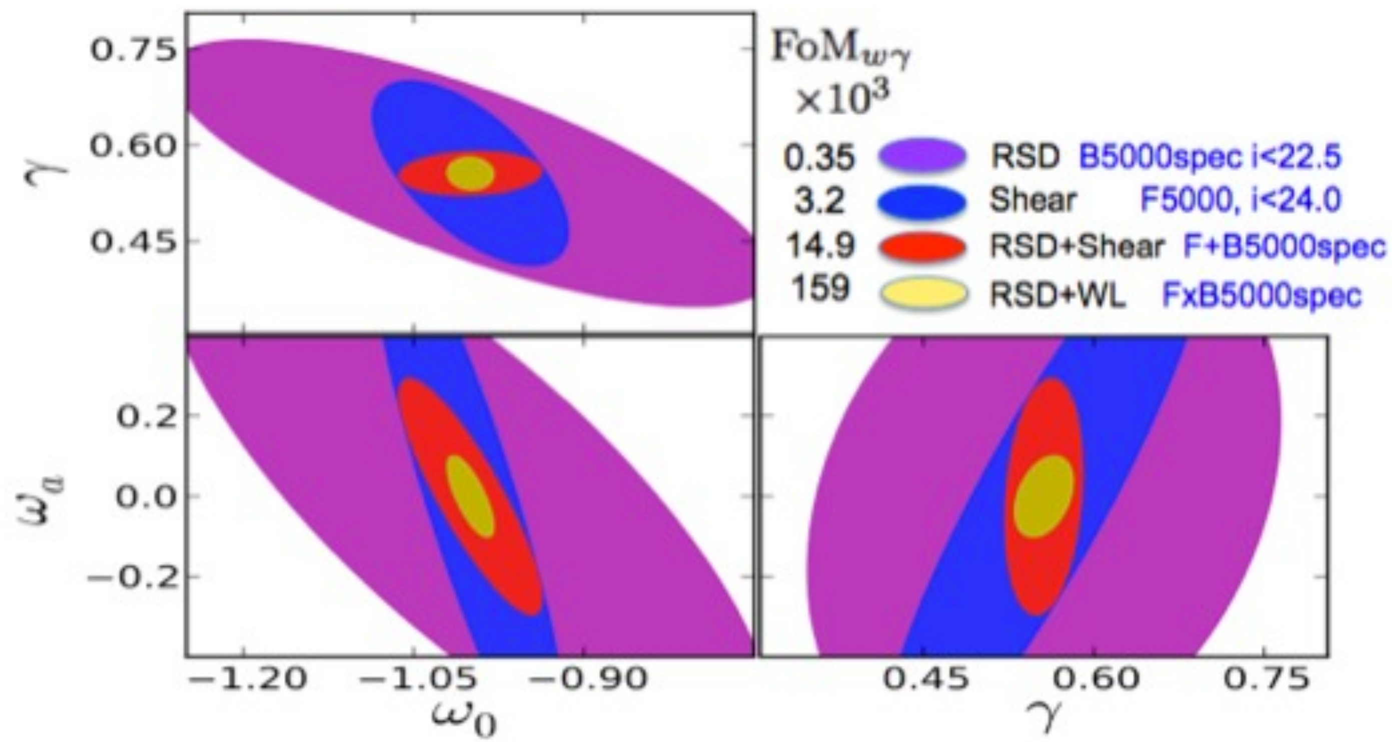
$$\delta = D(a)\delta(0)$$

Linear Theory: $P(k,z) \sim D^2(z)\, P(k,0)$
+
mass conservation

$$\dot{\delta} = -H\theta$$

$$\theta = -f(\Omega)\,\delta$$

f = Velocity growth factor: tell us if gravity is really responsible for structure formation!
Could also tell us about cosmological parameters or Modify Gravity



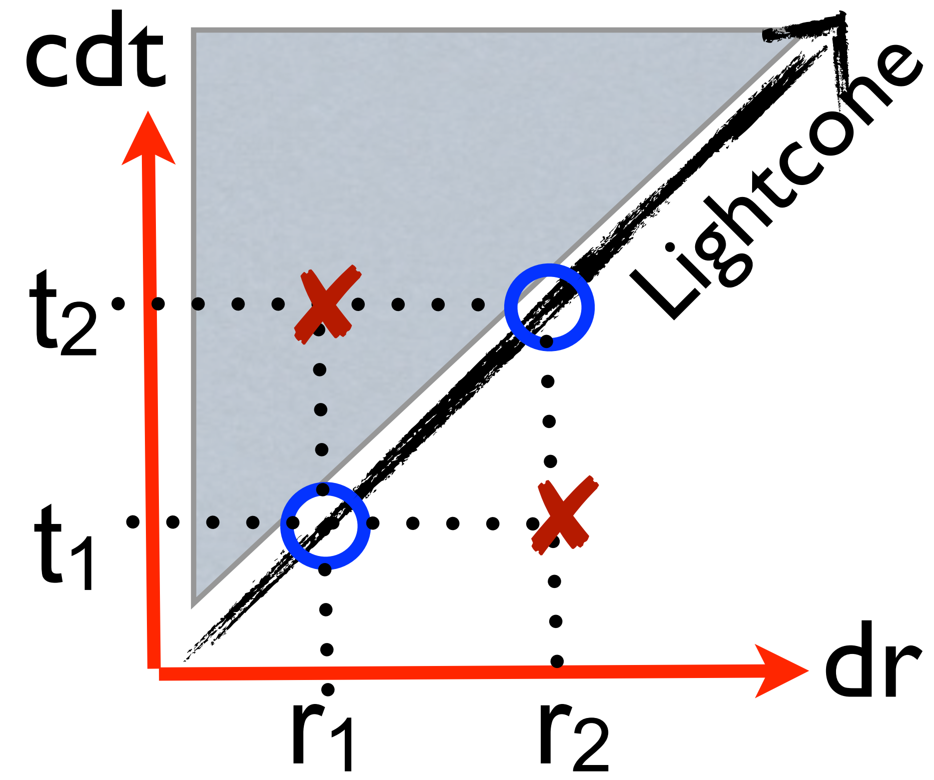
$$FoM_S = \sqrt{\frac{1}{\det[F^{-1}]_S}} = \frac{1}{\sigma(w0)\ \sigma(wa)\ \sigma(\gamma)}$$

Is this the best choice for 3 parameters?

Om - ODE - h - sig8 - Ob - **w0 - wa -**γ**-** ns - bias(z)

Need for Statistical Approach

$$\frac{d^2\delta_k}{d\tau^2} + \mathcal{H}\frac{d\delta_k}{d\tau} - \left(\frac{3}{2}\mathcal{H}^2\Omega_m - k^2 v_s^2\right)\delta_k = 0$$



This is a initial condition problem, we need:

$$\delta(r_2,t_2) = D(t_1,t_2)\,\delta(r_2,t_1)$$

$$\delta(r_1,t_2) = D(t_1,t_2)\,\delta(r_1,t_1)$$

but we can only measure: $\delta(r_1,t_1)$ & $\delta(r_2,t_2)$

Statistically this is possible (in homogeneous universe):

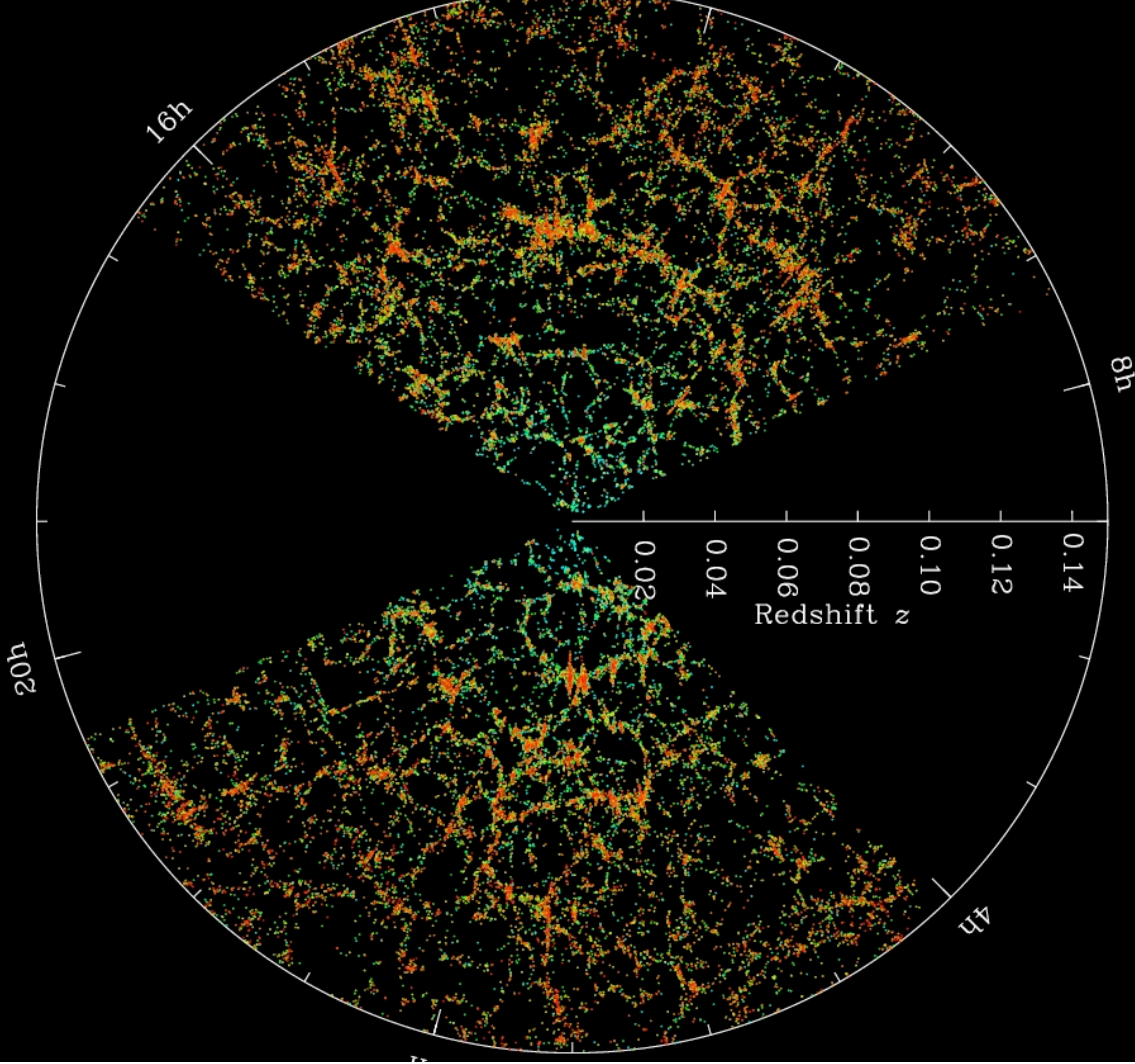
$$\xi_2(r, t_2) \equiv \langle\delta(x, t_2)\delta(y,t_2)\rangle_{xy} = D^2(t_1,t_2)\ \langle\delta(x,t_1)\delta(y,t_1)\rangle_{xy} = D^2(t_1,t_2)\ \xi_2(r, t_1)$$

$r=|x-y|$

$$P(k,z)= D^2(z)\ P(k,0)$$

This is limited by *sampling variance*: need large Volume (3D)

Can produce ***biases*** in statistical measures


16h
8h
20h
4h
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z

Galaxy Surveys

Photometric:

poor radial (redshift) resolution (~300 Mpc/h) but more Volume

DES, VISTA, Pan-STARRS, Subaru/HSC, Skymapper, LSST

PAU

Spectroscopic:

good or very good radial resolution (1-20Mpc/h), smaller Volume

WiggleZ, BOSS, e-BOSS, Subaru/Sumire, BiggBOSS, DESpec, HETDEX, SKA, VISTA/Spec

DES= Dark Energy Survey

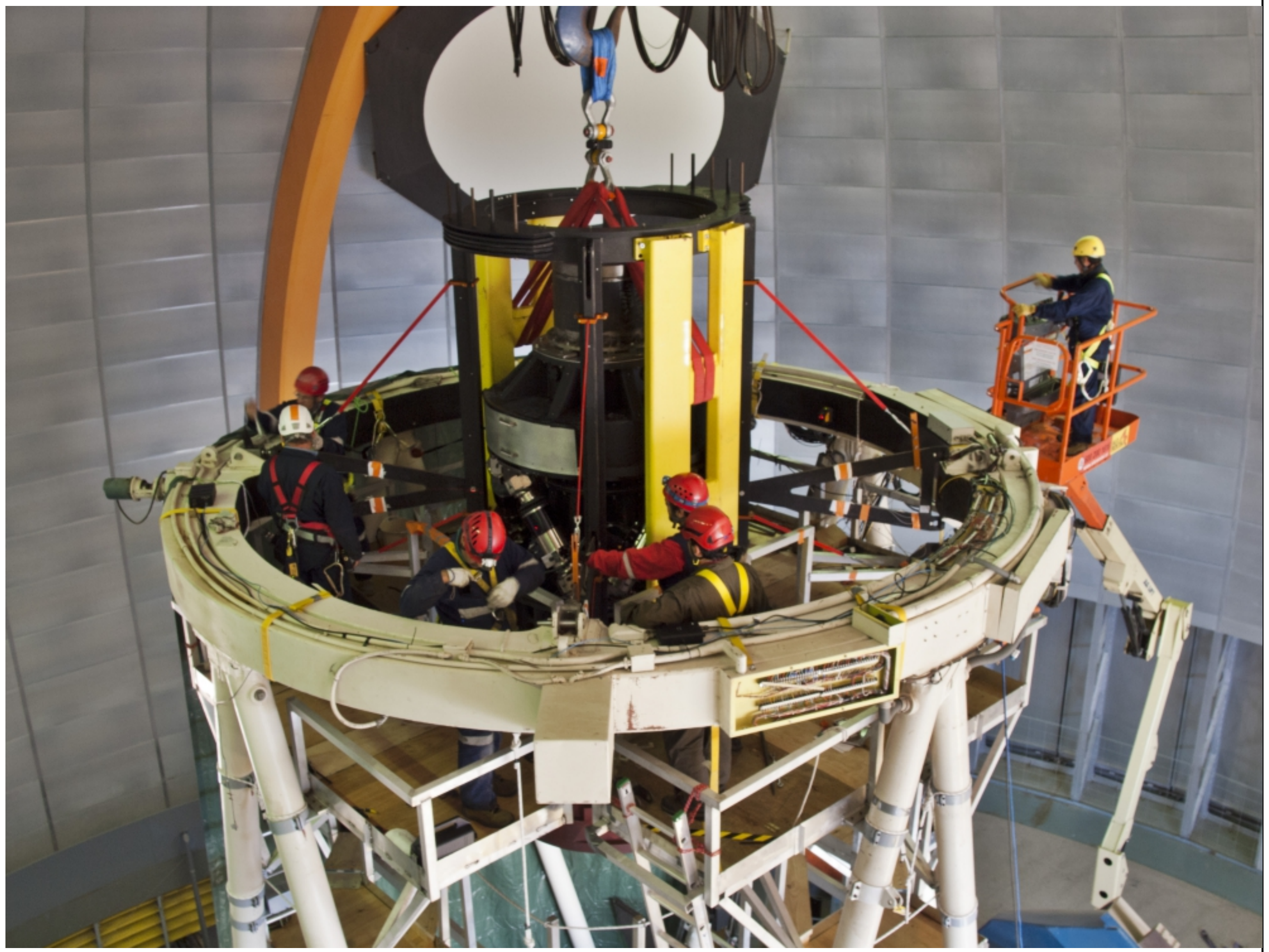
Spain: CIEMAT, ICE/IEEC, IFAE, UAM

DARK ENERGY SURVEY

- Study Dark Energy using 4 complementary techniques:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Baryon Acoustic Oscillations
  - IV. Supernovae

- Two multiband surveys:
  - 5000 deg^2 *g, r, i, Z, Y* to *i~24*
  - 9 deg^2 repeat (SNe)

- Build new 3 deg^2 camera and Data management system
  - Survey 30% of 5 years
  - Response to NOAO AO



DES Forecast: FoM =4.6x   FIRST LIGHT in a month!

NCSA

IEEC

IFAE

UCL

Photometric Redshifts

DARK ENERGY SURVEY

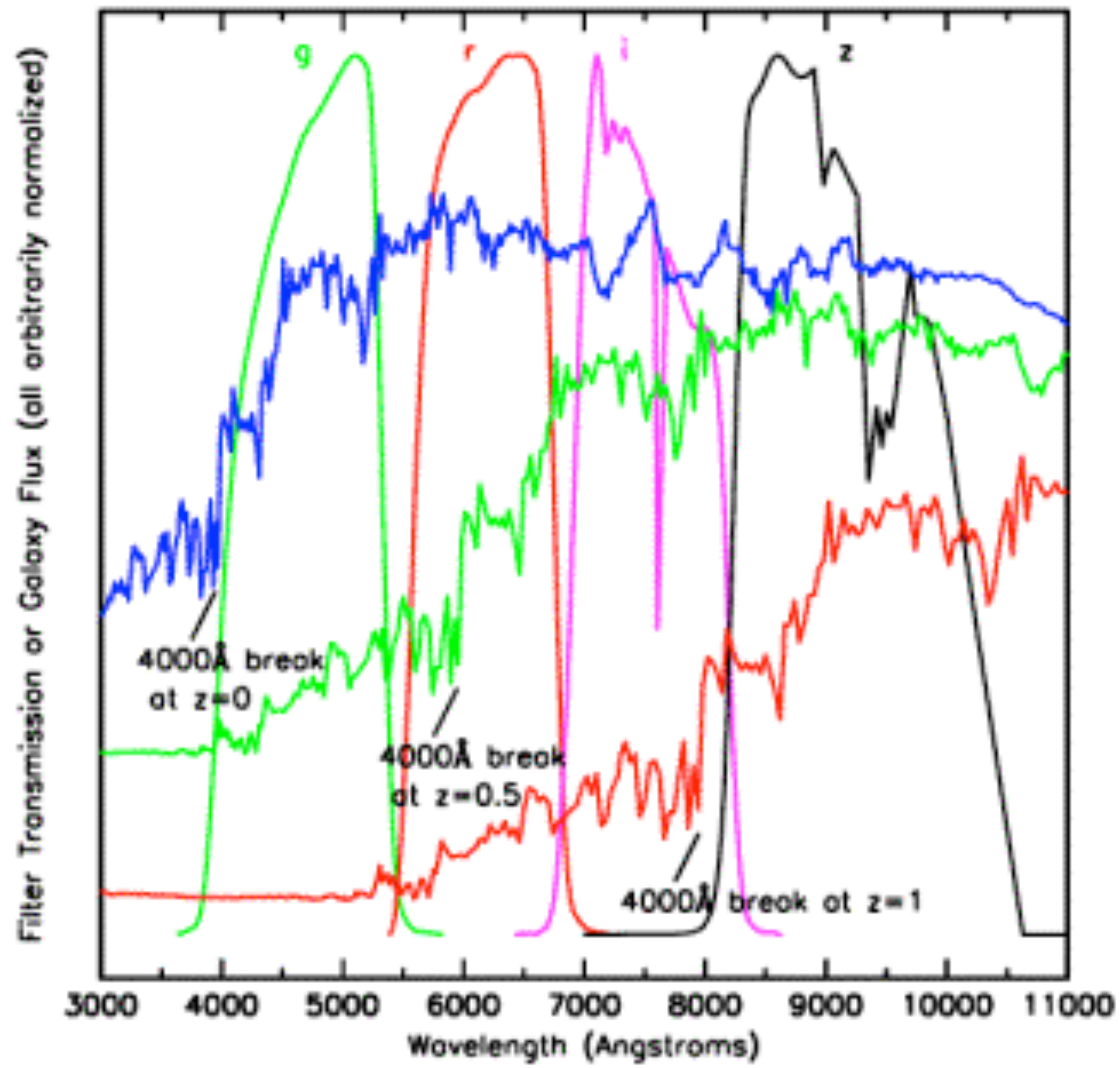
- Measure relative flux in multiple filters: track the 4000 A break

- Estimate individual galaxy redshifts with accuracy $\sigma(z) < 0.1$ (~0.02 for clusters)

- Precision is sufficient for 2D Dark Energy probes, provided error distributions well measured.

- Good detector response in *z* band filter needed to reach z>1

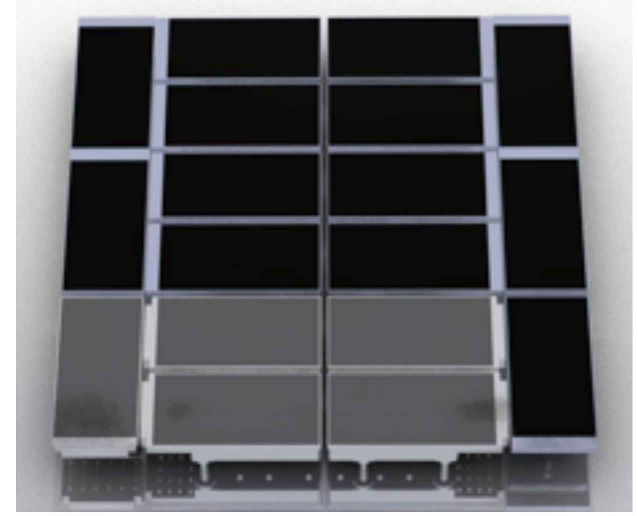
Elliptical galaxy spectrum

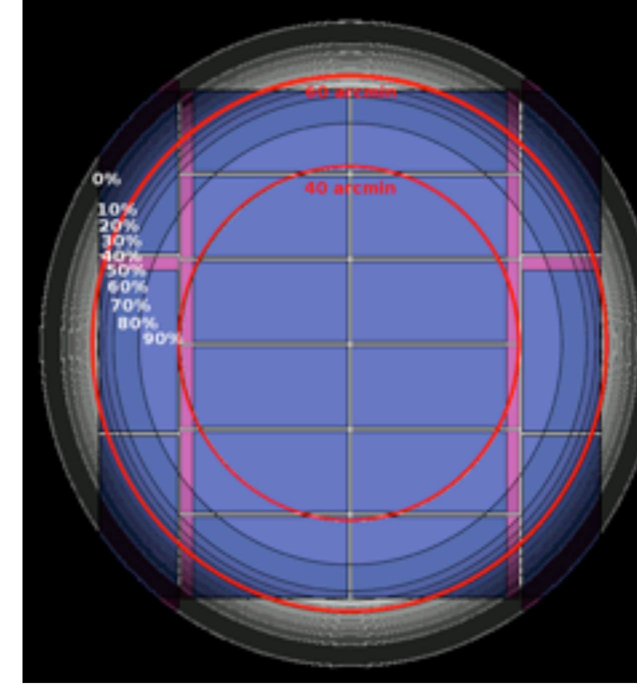


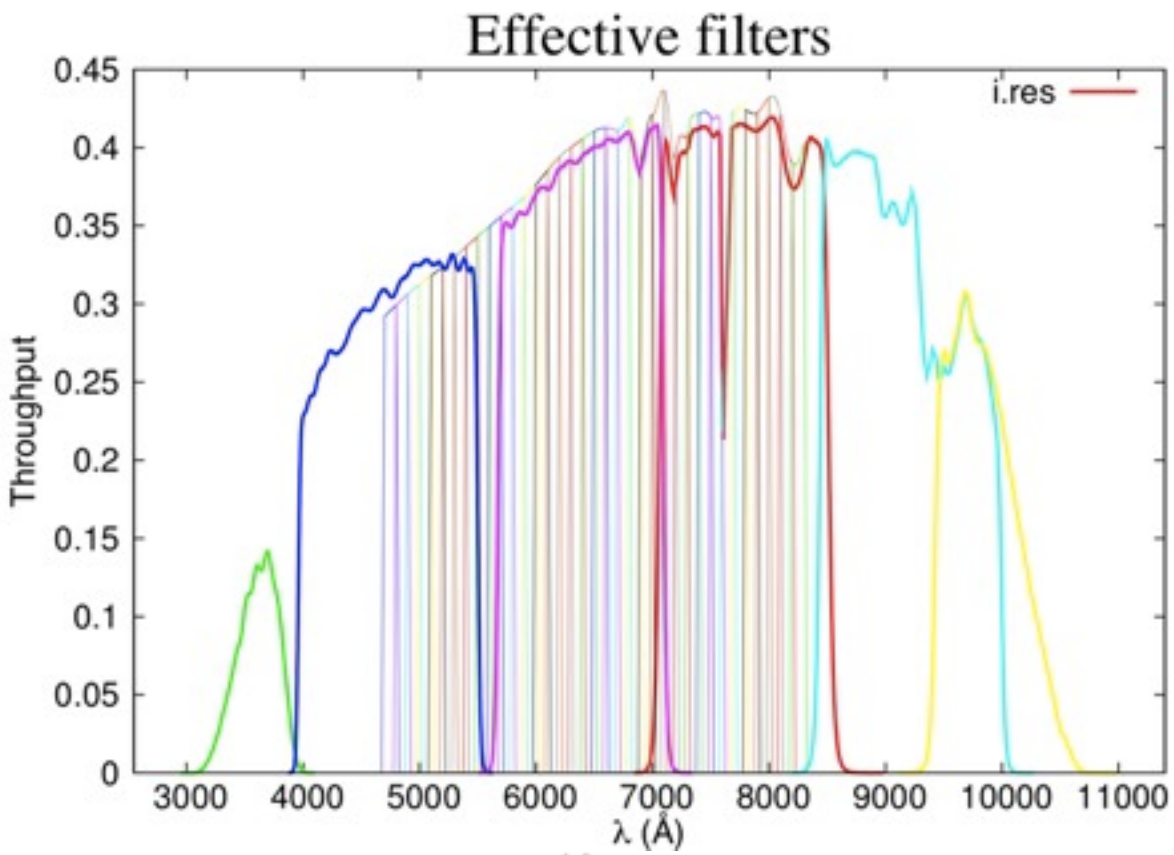
Motivation:

PAU Survey @WHT

18+4 Hamamatsu CCD





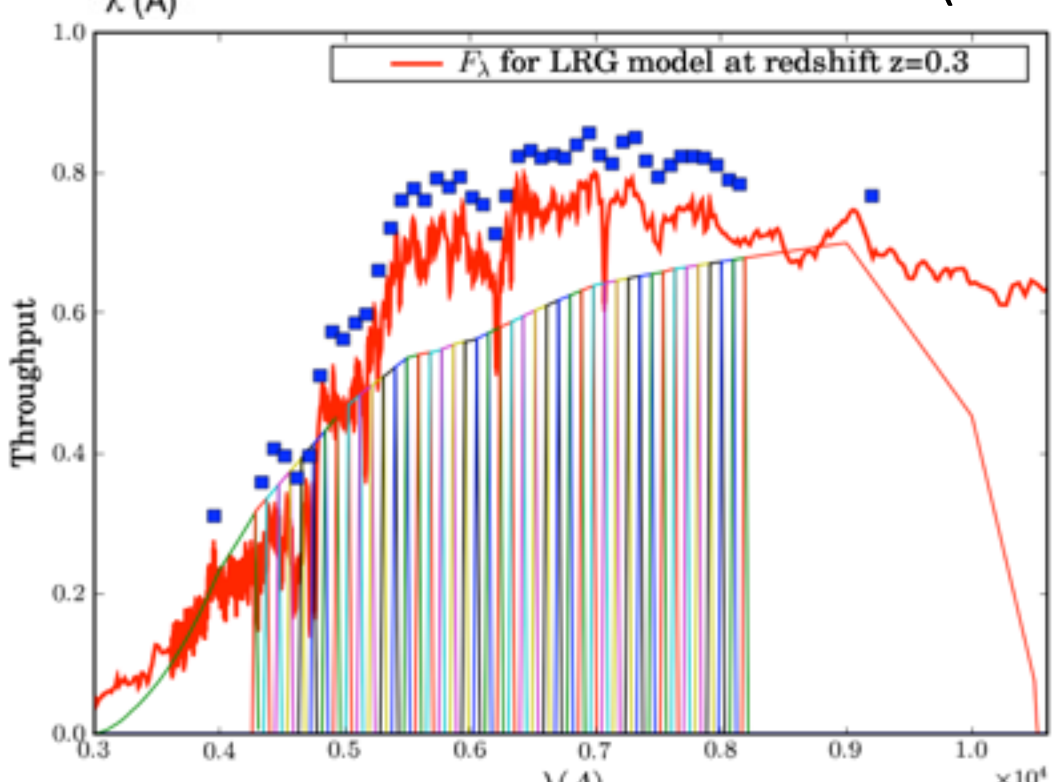


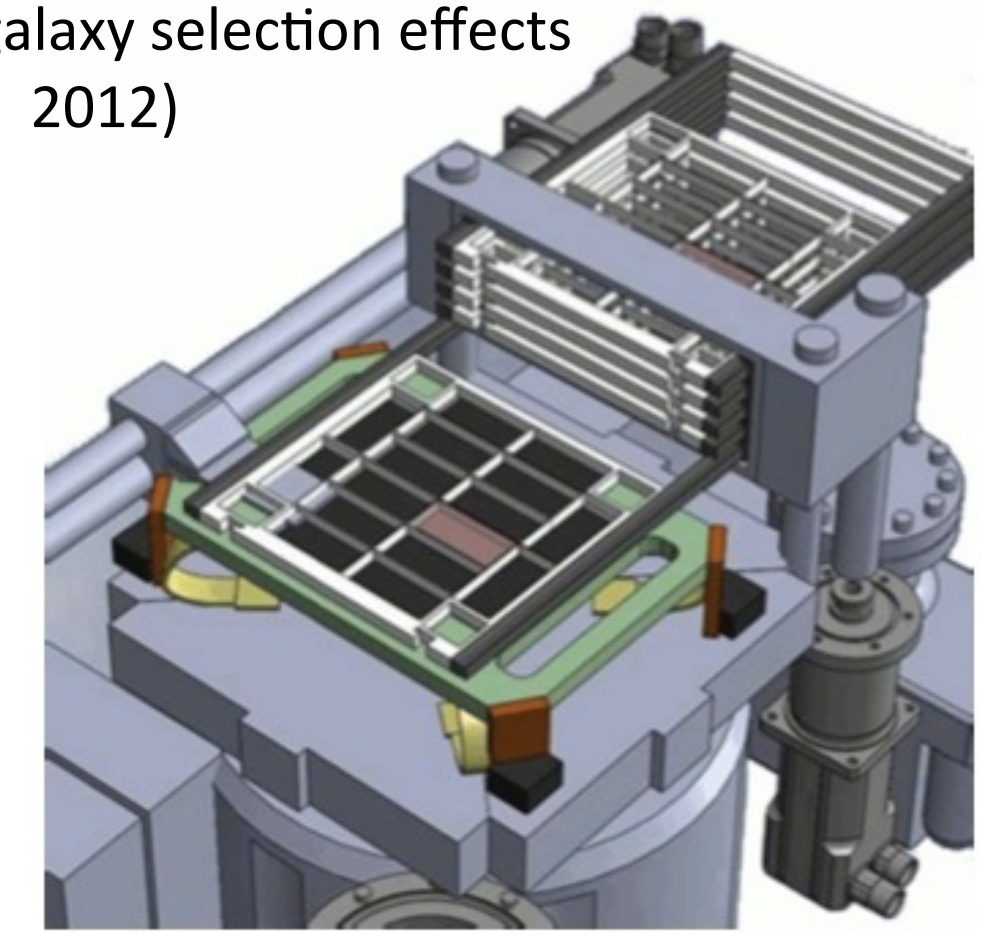
In 1 night can do 2(4) sqr.deg. to i~22.5
in 36 narrow + 6x2 broad (i~24 survey)
To get R=1/100 spectra (900 Km/s)
for 30,000 galaxies (15,000/sd)
And R=1/10 photo-z for 120,000 galaxies
No galaxy selection effects
(end 2012)

Simultaneous
Photometric (i~24)
& Spectroscopic (i~22.5
Surveys

Photo-z of 0.03/0.003
(10/100Mpc)

For linear P(k)
reconstruction





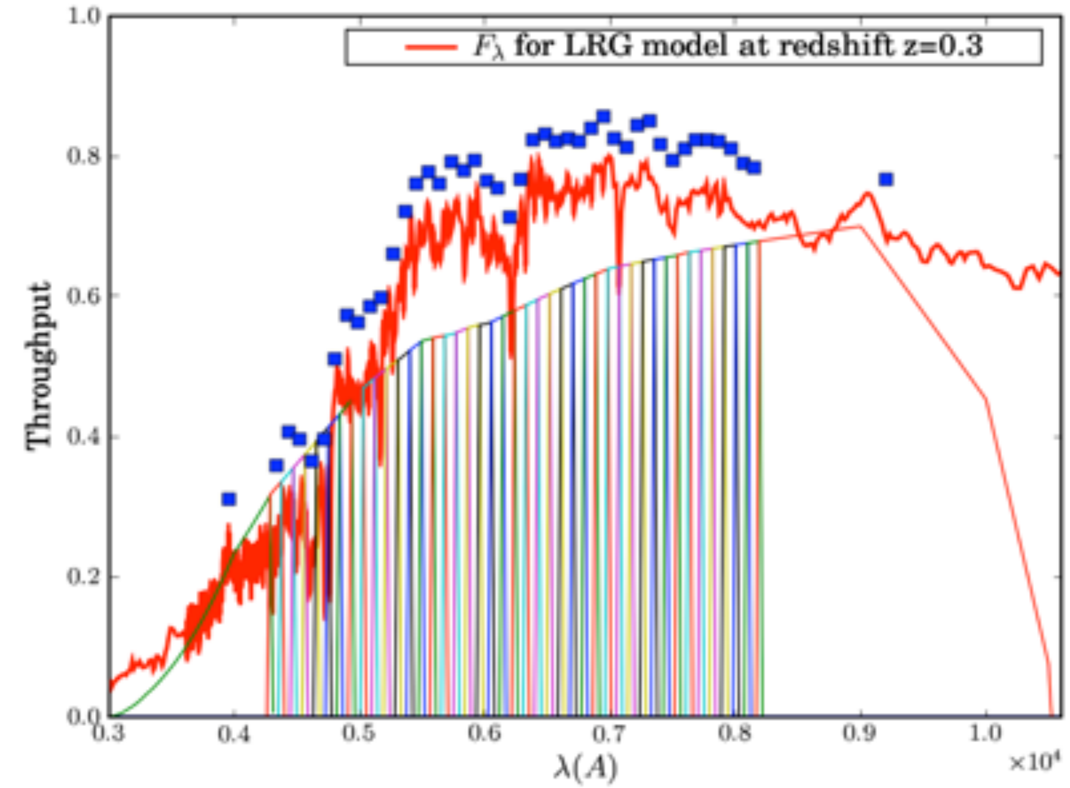
PAU photo-z:

Δz = 0.0035(1+z)

Corresponds to

c Δz/H(z)=12.5Mpc/h at z~0.5

i.e. 3D for linear scales



Spectroscopic

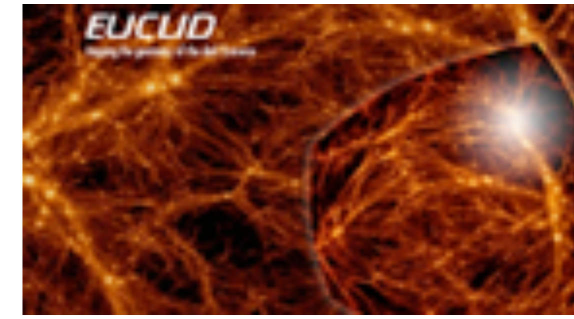
Photo-z 40-filter

Photo-z 5-filter

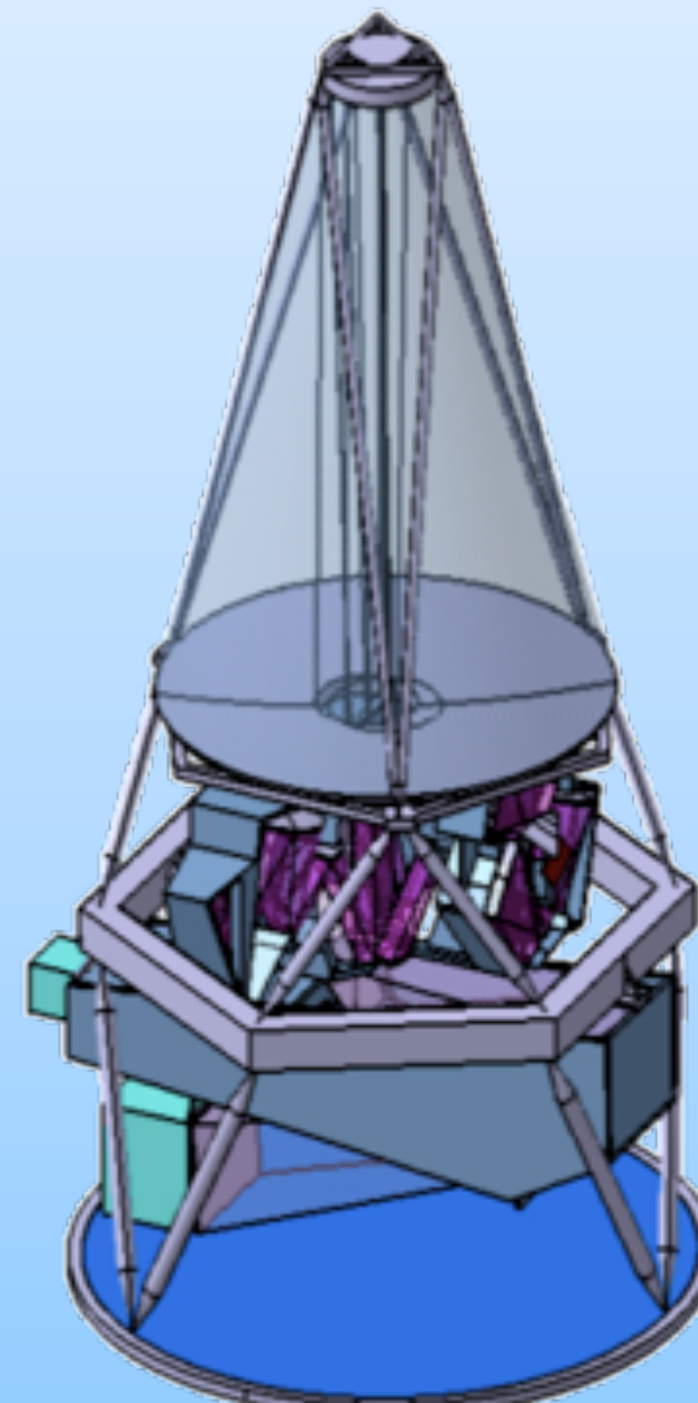
Project	Redshift	Area (deg^2)
WiggleZ	0.4-1.0	1000
HETDEX	2.0-4.0	350
WFMOS	0.5-1.3 2.3-3.3	2000 300
BOSS LRG + QSO	0.1-0.8 2.0-3.0	10000 8000
PAU-BAO	0-1	10000
Pan-STARRS*	0-1?	20000
DES*	0-1.5?	4000
LSST*	0-1.5?	20000

BAO Surveys Padmanabhan

Euclid

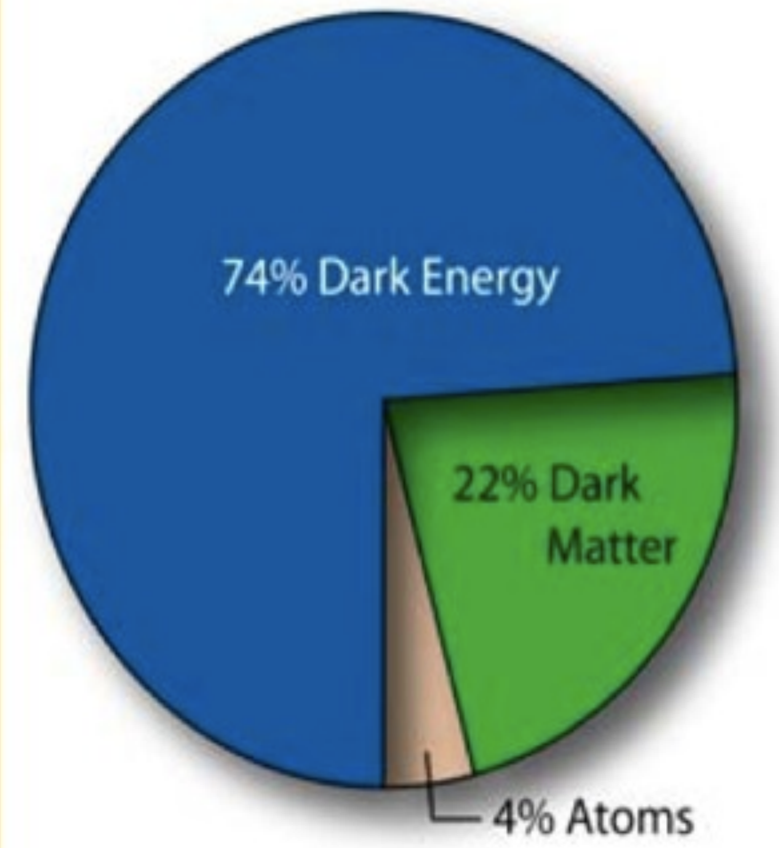


- ESA Cosmic Vision satellite proposal (600M€, M-class mission)
- 5 year mission, L2 orbit
- 1.2m primary mirror, 0.5 sq. deg FOV
- Ω = 20,000deg^2 imaging and spectroscopy
- slitless spectroscopy:
  - 100,000,000 galaxies (direct BAO)
  - ELGs (H-alpha emitters): z~0.5-2.1
- imaging:
  - deep broad-band optical + 3 NIR images
  - 2,900,000,000 galaxies (for WL analysis)
  - photometric redshifts
- Space-base gives robustness to systematics
- Final down-selection due mid 2011
- nominal 2017 launch date
- See also: LSST, WFIRST



Problem Using Galaxy Surveys:

light could be a biased tracers of DM



Possible Solutions

*Avoid **bias**:*

CMB, SNIa
Clusters, BAO
Use redshift space distortions <= only sensitive to ratios
Do weak lensing (to avoid bias) <= is 2D

*Measure **bias***

learn about galaxy formation => put priors on bias
higher order correlations

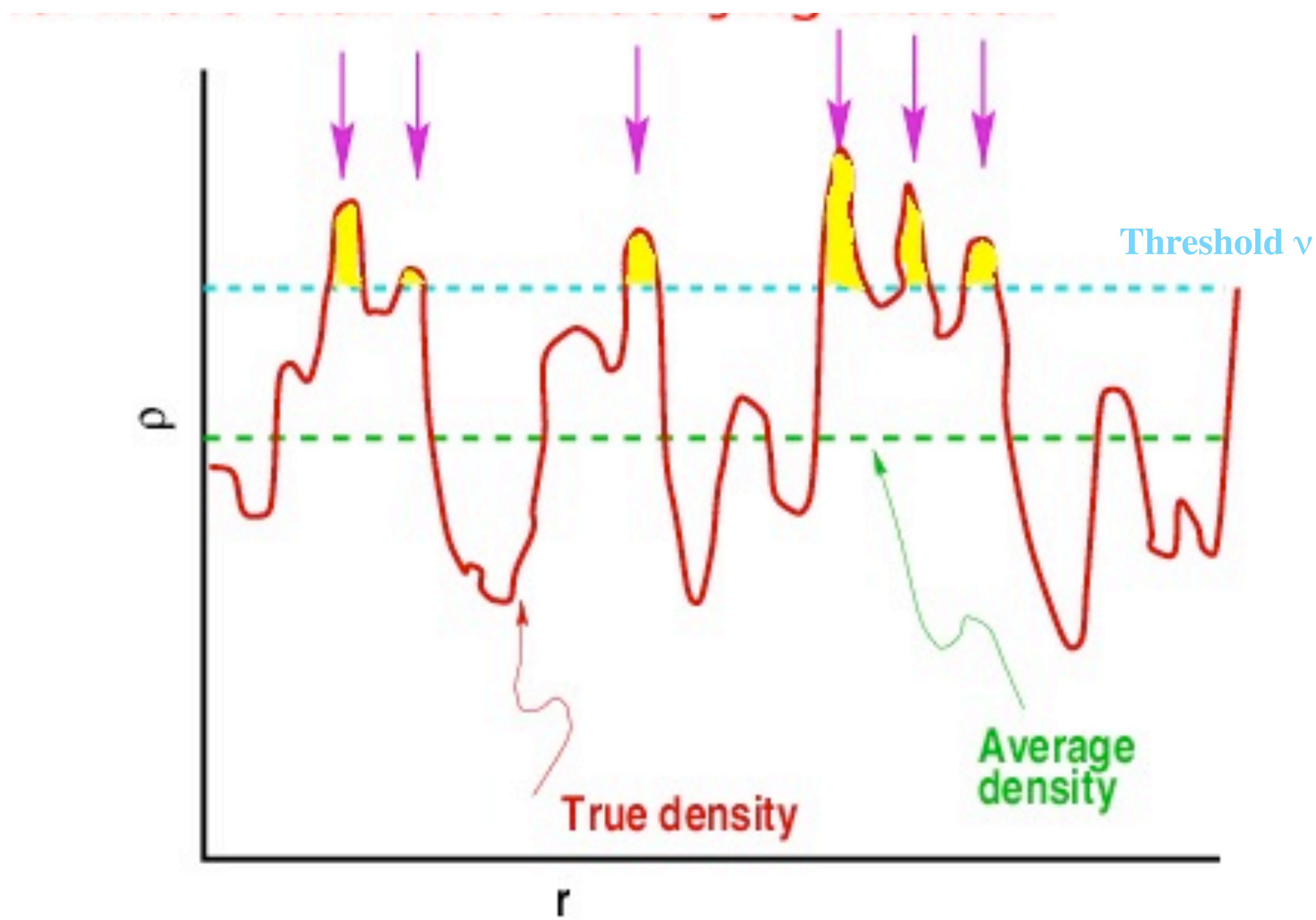
Combine the best of both: Do cross-correlations

Bias: lets take a very simple model.

rare peaks in a Gaussian field (Kaiser 1984, BBKS)

Linear bias "b": $\delta\,(\mathrm{peak}) = b\;\; \delta(\mathrm{mass})$ with $b = \nu/\sigma$ (SC: $\nu=\delta_c/\sigma$)

$$\rightarrow \xi_2\,(\mathrm{peak}) = b^2\, \xi_2\,(m)$$



Biasing: does light trace mass?

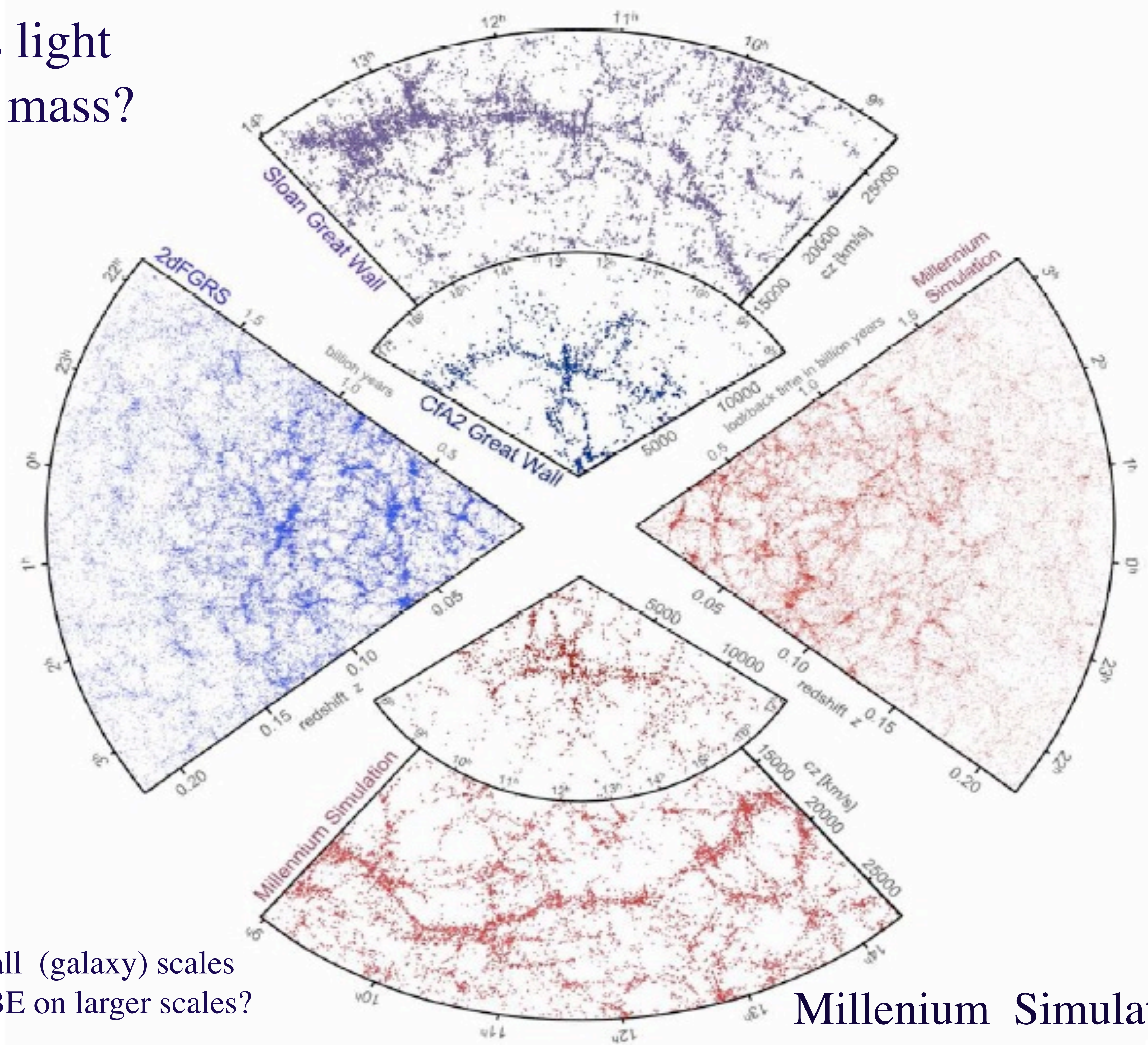
On large scales 2-pt Statistics is linear

$$\left.\begin{aligned} \delta_g &= b\,\delta_m \\ \delta_m &= \delta_L = D\,\delta_0 \end{aligned}\right\}$$

$$< \delta_g^2 > = b^2 < \delta_m^2 >^2 = b^2 D^2 < \delta_0^2 >^2$$

Gravity (D) or Cosmology
is DEGENERATE WITH
Galaxy formation (b)

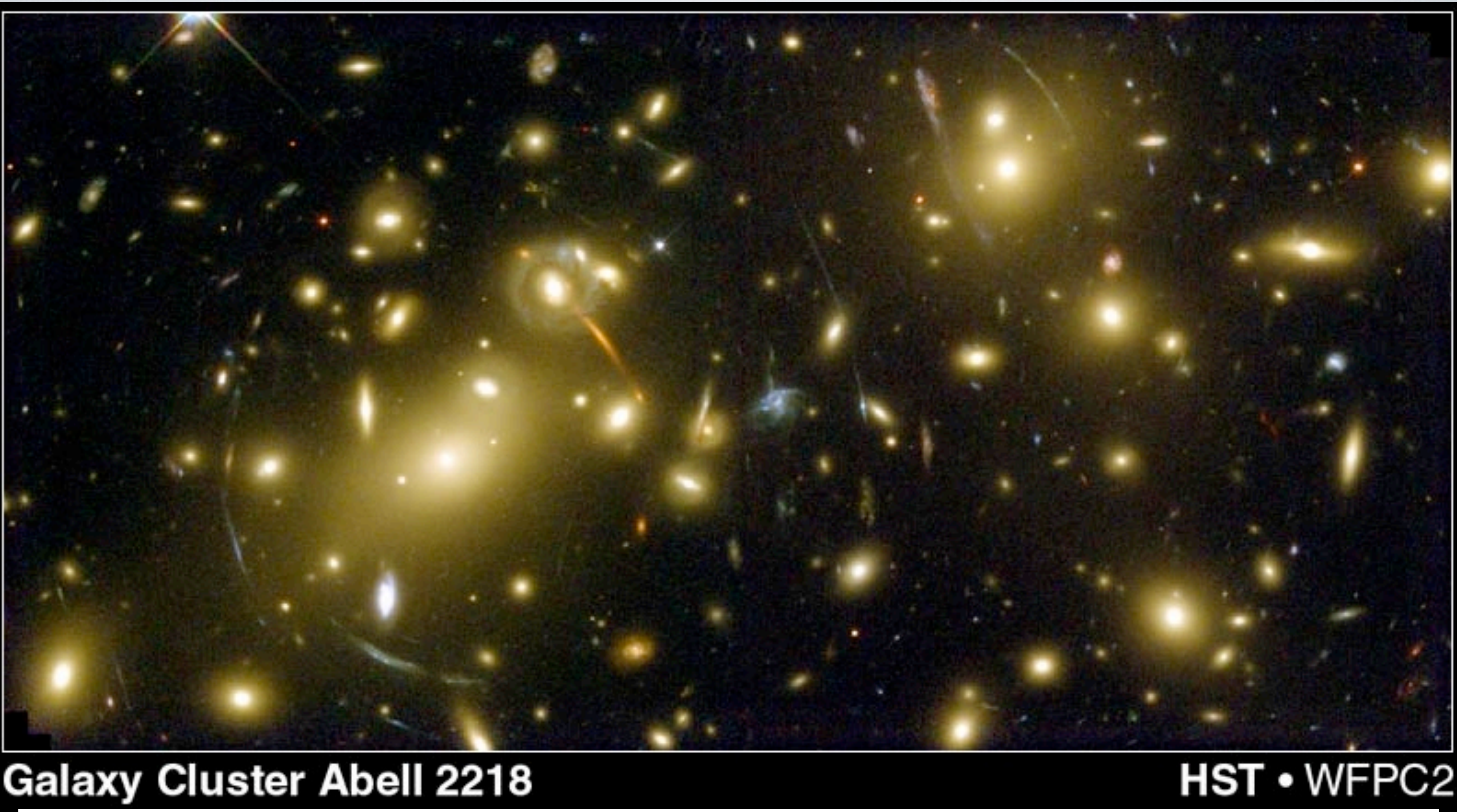
Does light traces mass?



Not on small (galaxy) scales
but MAY BE on larger scales?

Millenium Simulation

Strong and Weak Gravitational Lenses



Can be used to measure distances and growth history in the universe but is 2D

astro-ph:1109.4852

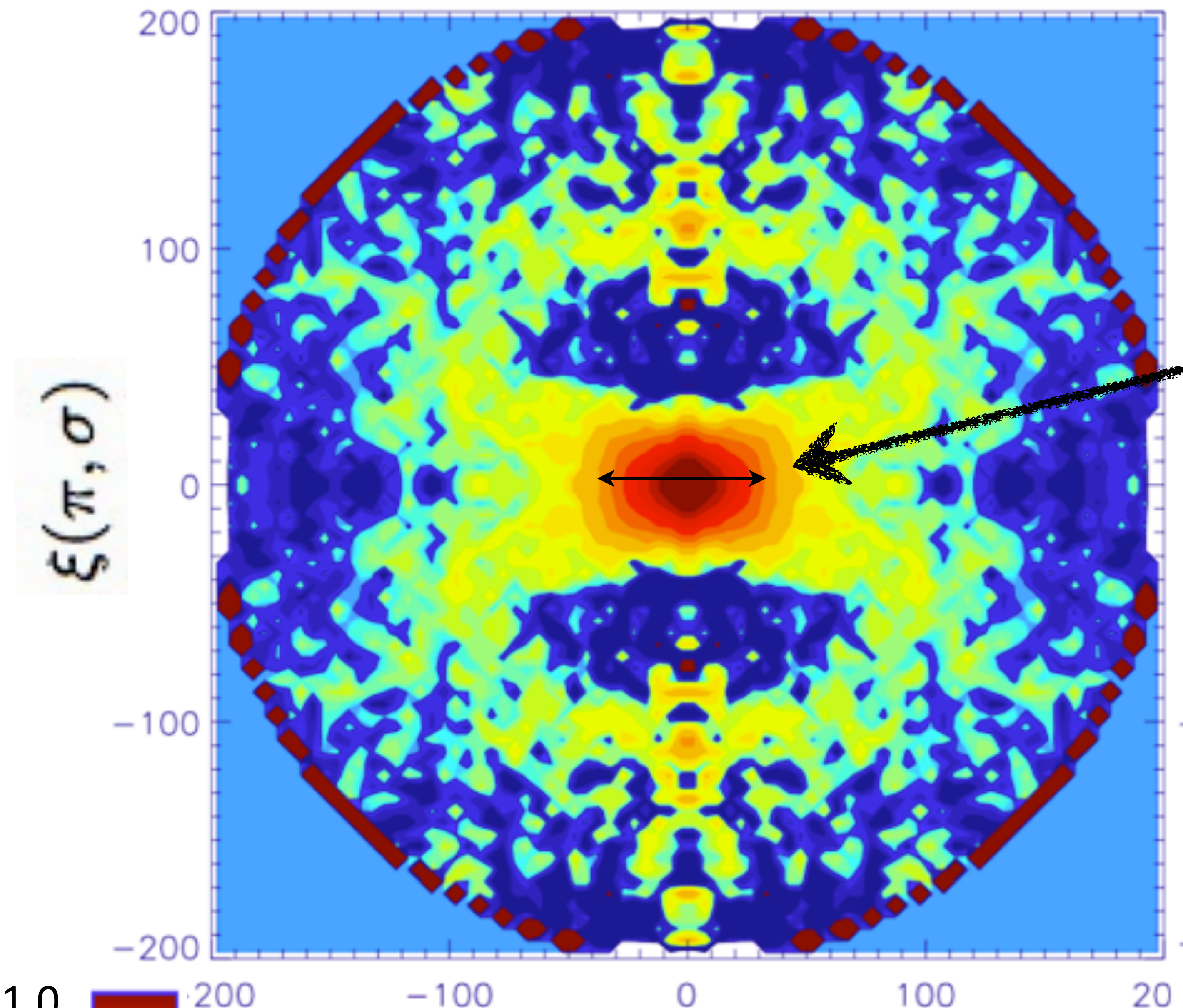
Forecast: Planck+SNII priors

5000 sq.deg.

$\mathrm{FoM}_{w\gamma} \times 10^3$	RSD	RSD +BAO	WL Shear-Shear	Galaxy-Galaxy WHEN BIAS IS KNOWN
Photometric (i<24)			**3.2**	**8.4**
Spectroscopic (i<22.5)	**0.5**	**2.7**		**17**

Motivation to learn about bias

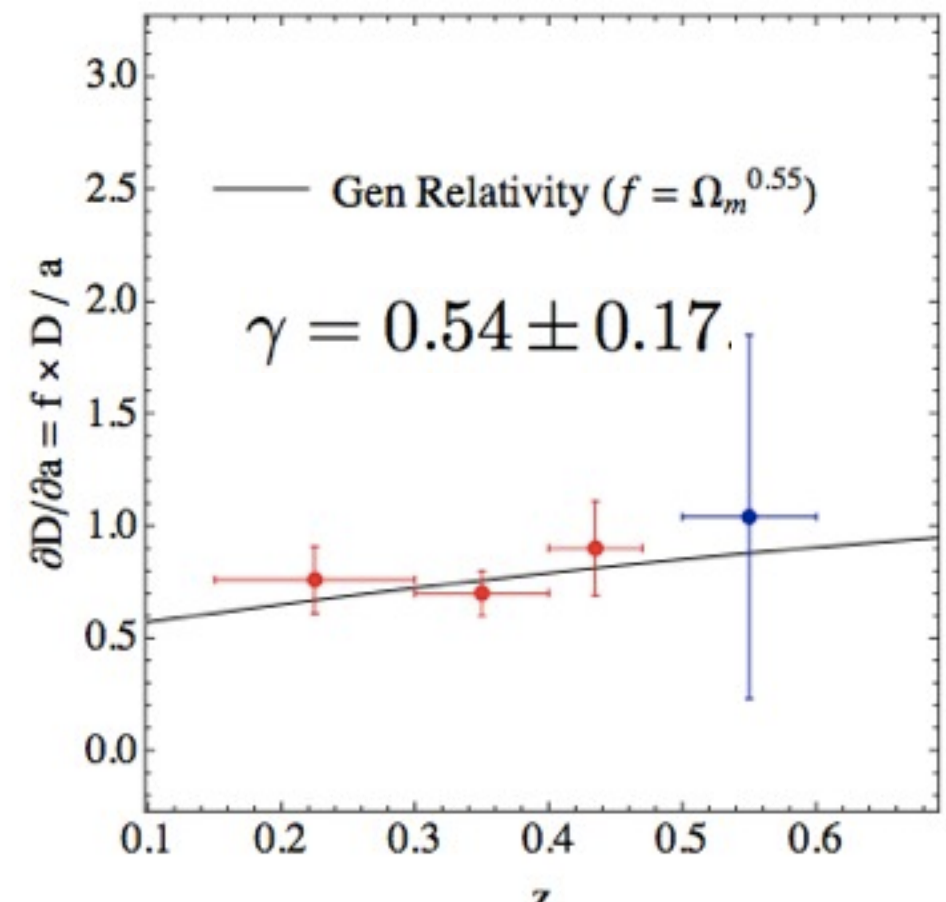
Redshift Space Distortions (RSD)



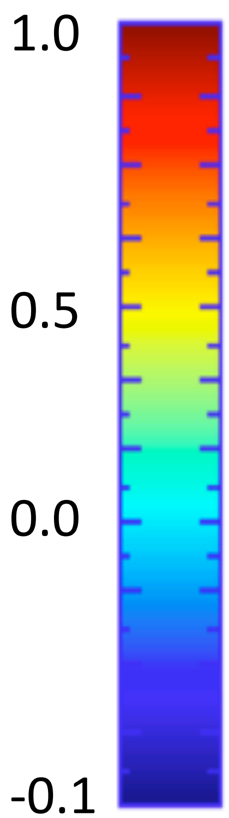
μ=0
π=0

$$\delta_g(k,\mu) = (b + f\mu^2)\delta(k)$$

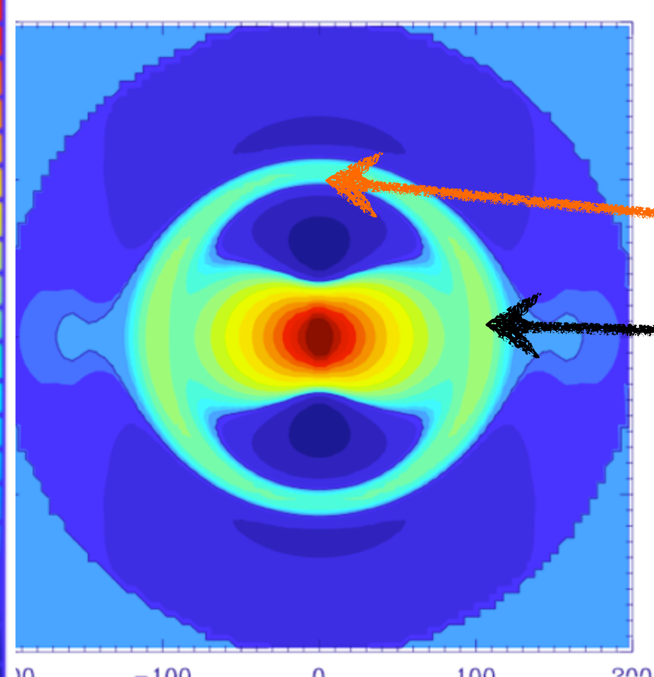
Measure both bias and growth!



FoMγ= 6 Crocce etal 2011
(Forecast for DES: Ross etal 2011)



Anna Cabré's PhD Thesis arXiv:0807.3551



BAO: $\xi(\pi,\sigma)$

radial H(z)

H(z=0.34) = 83.8 ±3.0± 1.6

EG, Cabre & Hui (2009)

Transverse $\int$ cdz/H(z)

θ(z=0.34) = 3.90 ± 0.38

Carnero etal 2011

Non-linear bias (galaxy formation, unknown?)
+ Non Linear matter growth (gravity, known?)

$$\nu_2 = \frac{34\omega + 56}{21\omega + 36}$$

astro-ph/0303526 & 0307034

$$\left.\begin{aligned} \delta_g &= b\,\delta_m + b_2\,\delta_m^2 \\ \delta_m &= \delta_L + \nu_2\,\delta_L^2 \end{aligned}\right\}$$

$$<\delta_g^2> = b^2 <\delta_m^2>^2 = b^2 <\delta_L^2>^2$$

$$<\delta_g^3> = b^3 <\delta_m^3> + 3\,b_2 b^2 <\delta_m^4> + \ldots$$

$$<\delta_g^3> = b^3\,(3\,\nu_2 + 3\,b_2/b) <\delta_g^2>^2 + \ldots$$

Gravity vs Galaxy formation

Hierarchical ratios ratios

$$Q = \frac{\xi_3(\mathbf{x}_1, \mathbf{x}_2 \mathbf{x}_3)}{\xi(x_{12})\xi(x_{23}) + \xi(x_{23})\xi(x_{31}) + \xi(x_{31})\xi(x_{12})},$$

are independent of growth, time or expansion history:

$$S_{g,3} = b^{-1}(S_3 + 3c_2)\,,$$

$$S_{g,4} = b^{-2}(S_4 + 12c_2 S_3 + 4c_3 + 12c_2^2)\,,$$

Can be used to separate bias from gravity

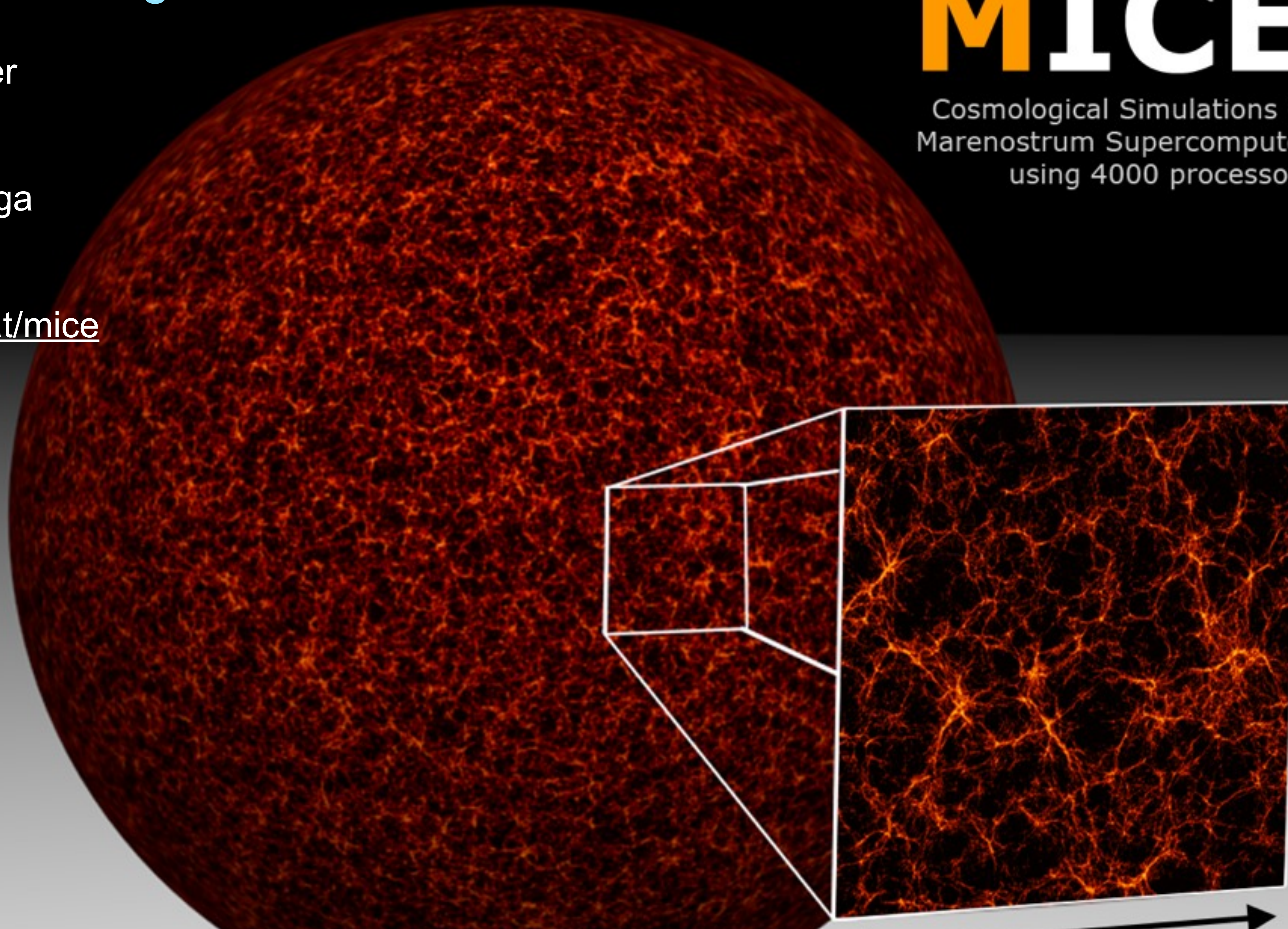
Grand Challenge Sim

F.Castander
M.Crocce
P.Fosalba
E.Gaztanaga

www.ice.cat/mice

MICE

Cosmological Simulations @
Marenostrum Supercomputer
using 4000 processors



Box Size (Mpc/h)	Number of Particles	Particle Mass ($x10^{10}$ Msun/h)	PMGrid size	Initial conditions	Initial redshift	l_{soft} (kpc/h)	MaxSize Timestep
3072	4096^3	2,927	4096^3	ZA	100	50	0,02

Galaxy DES-MICE simulations

DES-MICE v0.3r2.0

ice.cat/mice

Components/Validations:

A very large and high resolution DM sim: clustering

Box Size (Mpc/h)	Number of Particles	Particle Mass ($x10^{10}$ Msun/h)	PMGrid size	Initial conditions	Initial redshift	l_{soft} (kpc/h)	MaxSize Timestep
3072	4096^3	2,927	4096^3	ZA	100	50	0,02

Find halos: validate mass function & clustering of halos

Make Weak Lensing (WL) maps

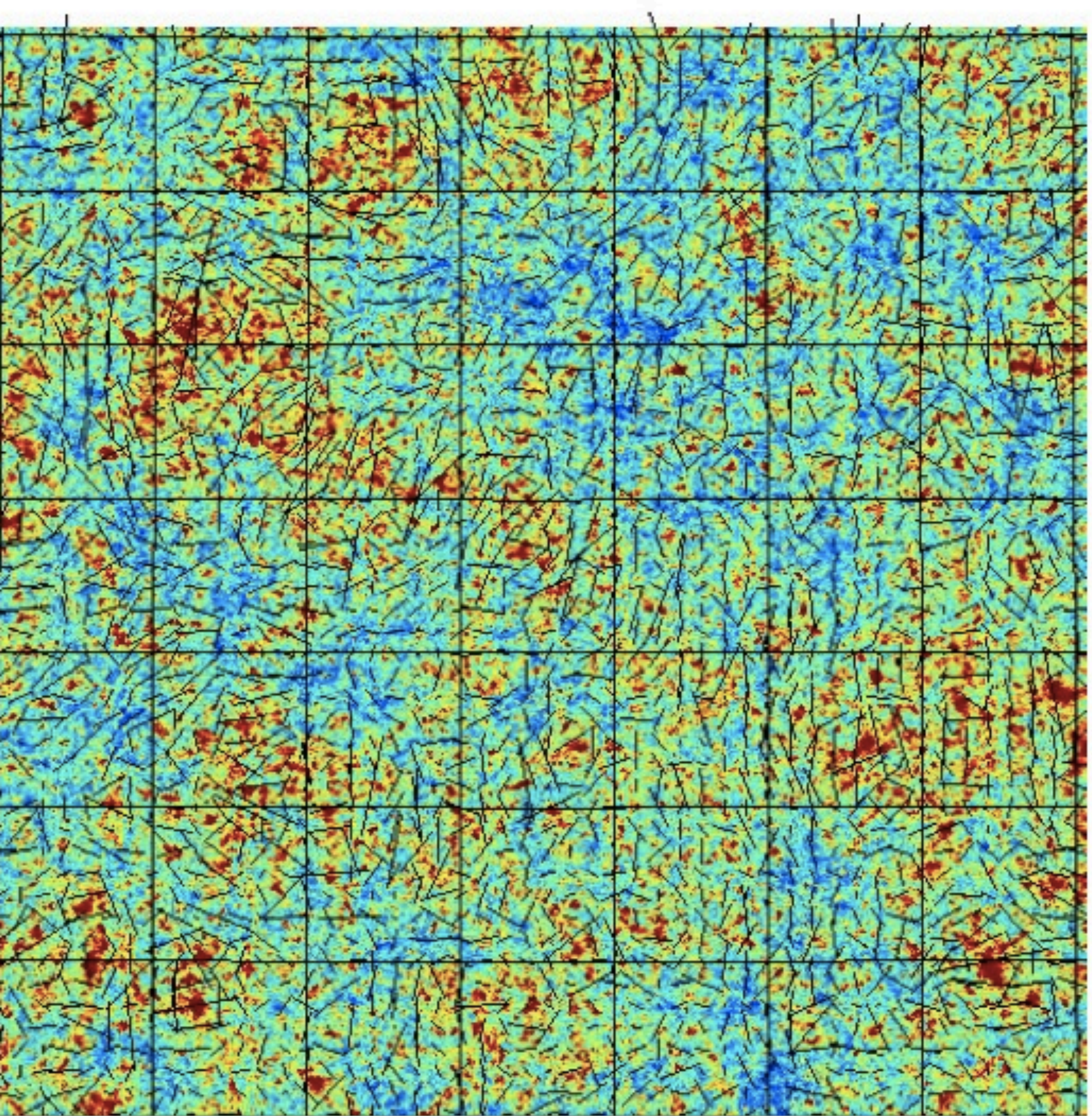
Assing galaxies to halos (HOD)

Assing WL information to galaxies

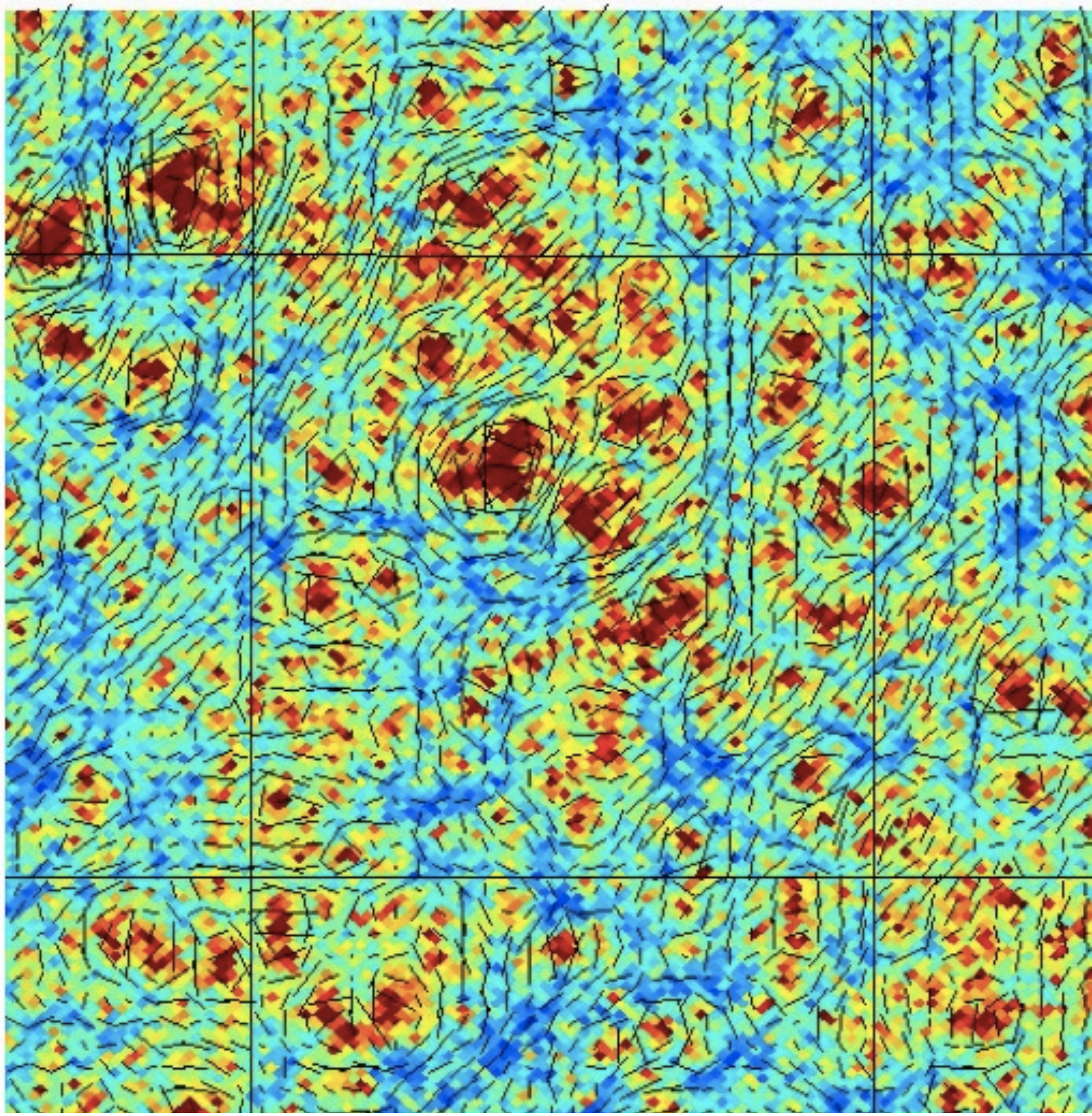
DES-MICE v0.3r2.0

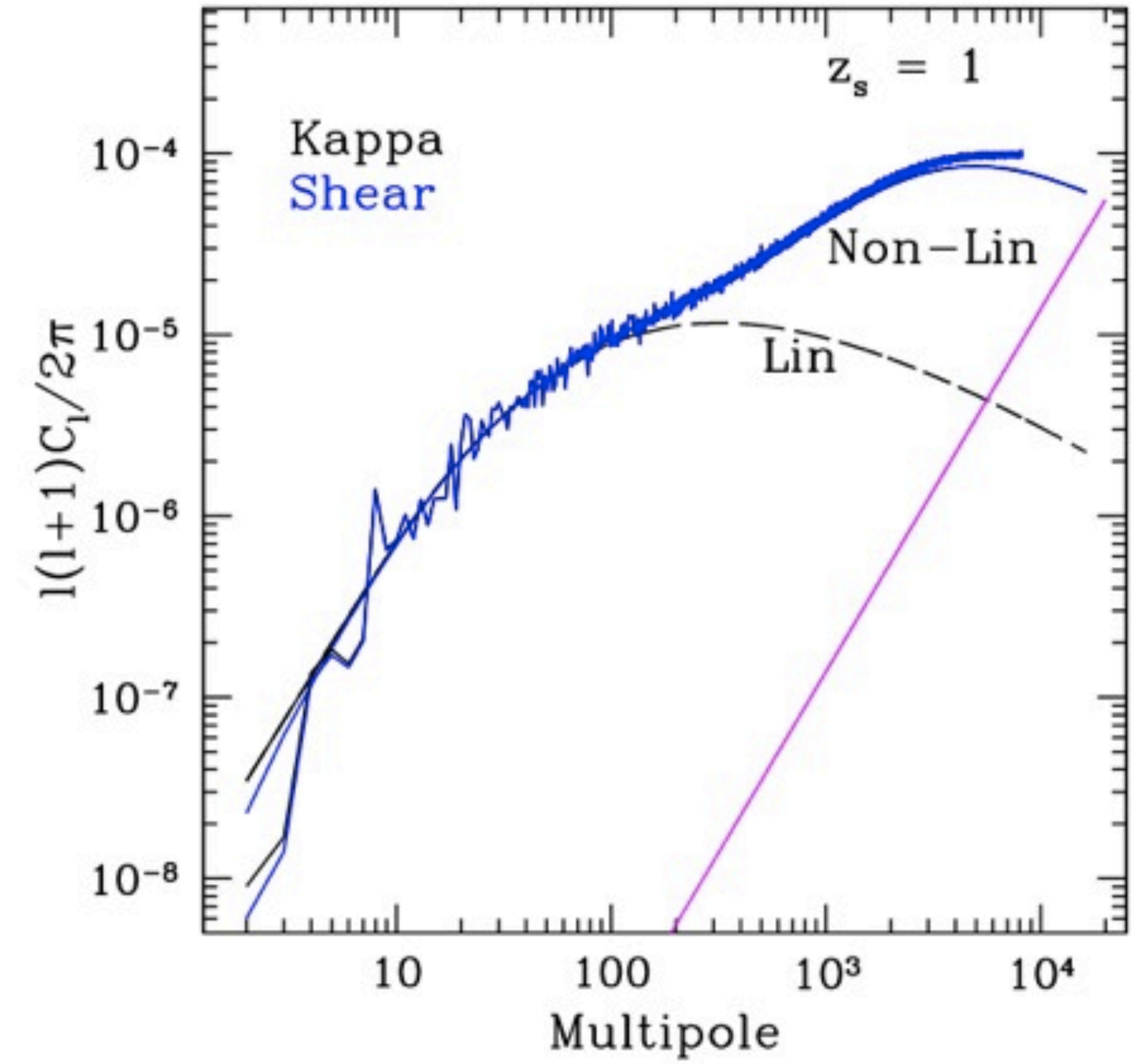
ice.cat/mice

Matter Kappa/Shear MICE-GC, z=1.4

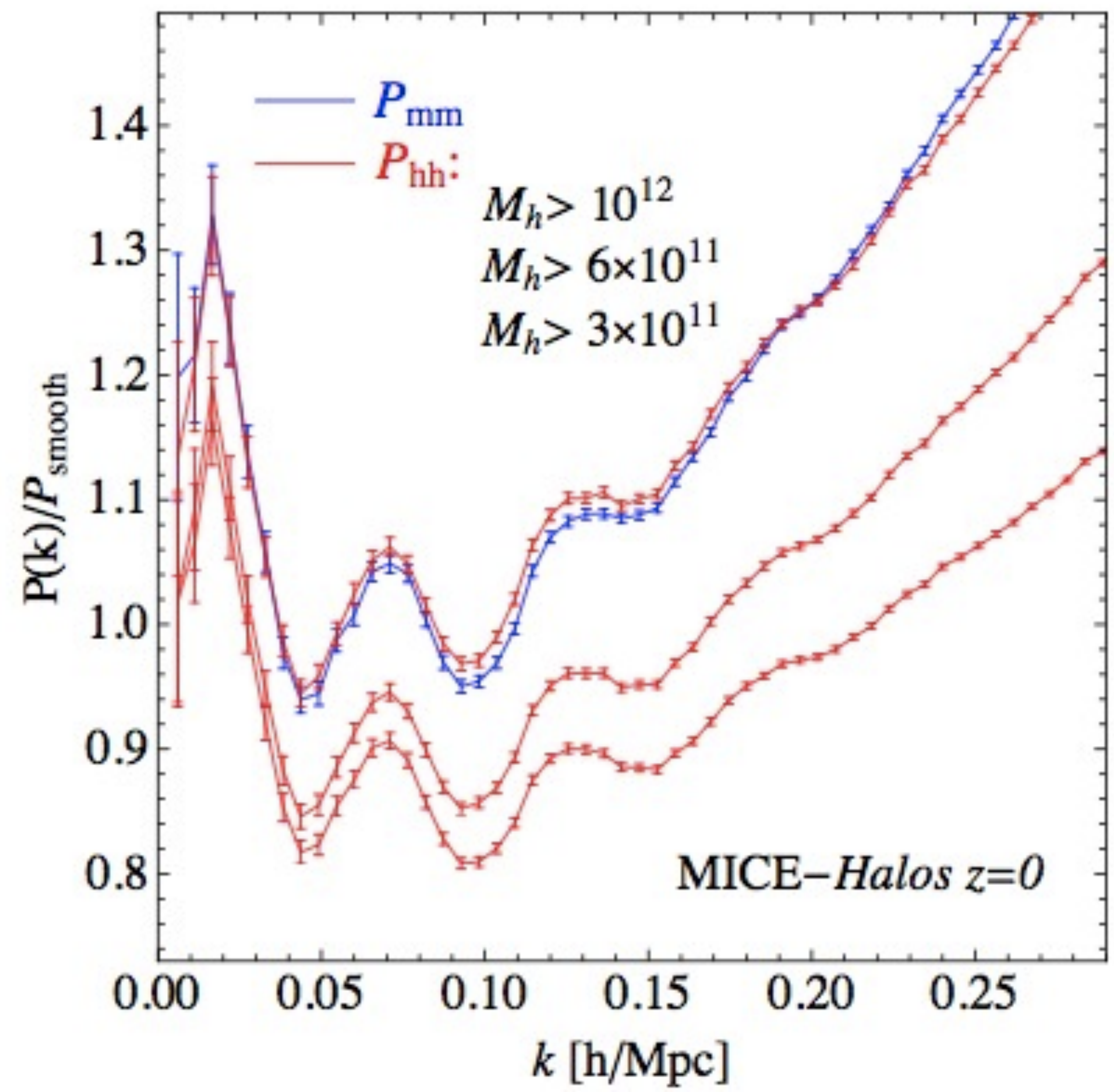


Zoom-in of Matter Kappa/Shear MICE-GC, z=1.4

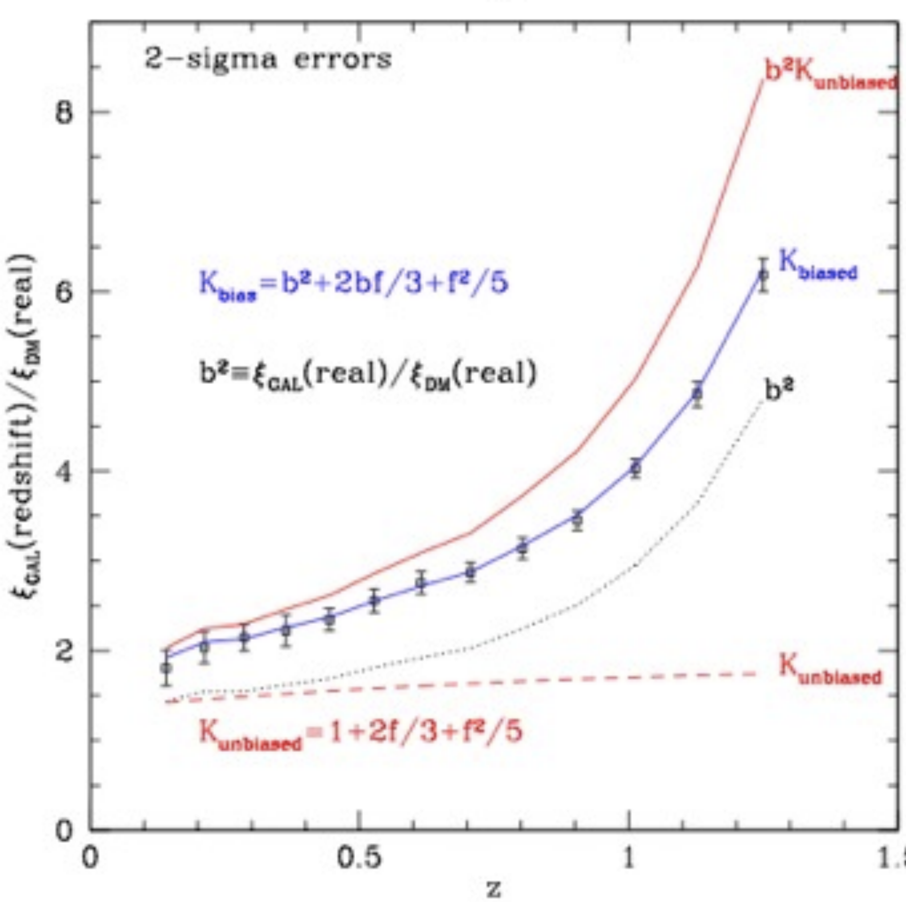




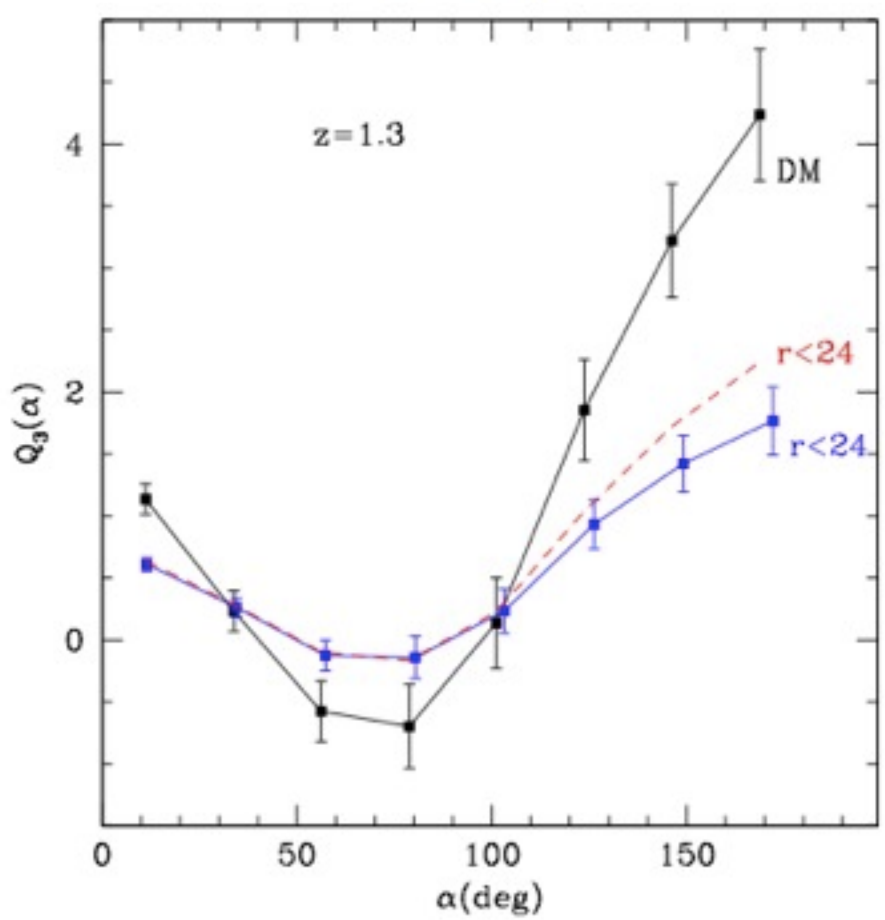
$z_s = 1$
Kappa
Shear
Non−Lin
Lin
$l(l+1)C_l/2\pi$
Multipole



P_{mm}
P_{hh}:
$M_h > 10^{12}$
$M_h > 6\times10^{11}$
$M_h > 3\times10^{11}$
MICE−*Halos z=0*
$P(k)/P_{smooth}$
k [h/Mpc]



2-sigma errors
$b^2K_{unbiased}$
$K_{bias}=b^2+2bf/3+f^2/5$
K_{biased}
$b^2=\xi_{GAL}(real)/\xi_{DM}(real)$
b^2
$K_{unbiased}$
$K_{unbiased}=1+2f/3+f^2/5$
$\xi_{GAL}(redshift)/\xi_{DM}(real)$
z



z=1.3
DM
r<24
r<24
$Q_3(\alpha)$
α(deg)

XTalks in Galaxy Clustering

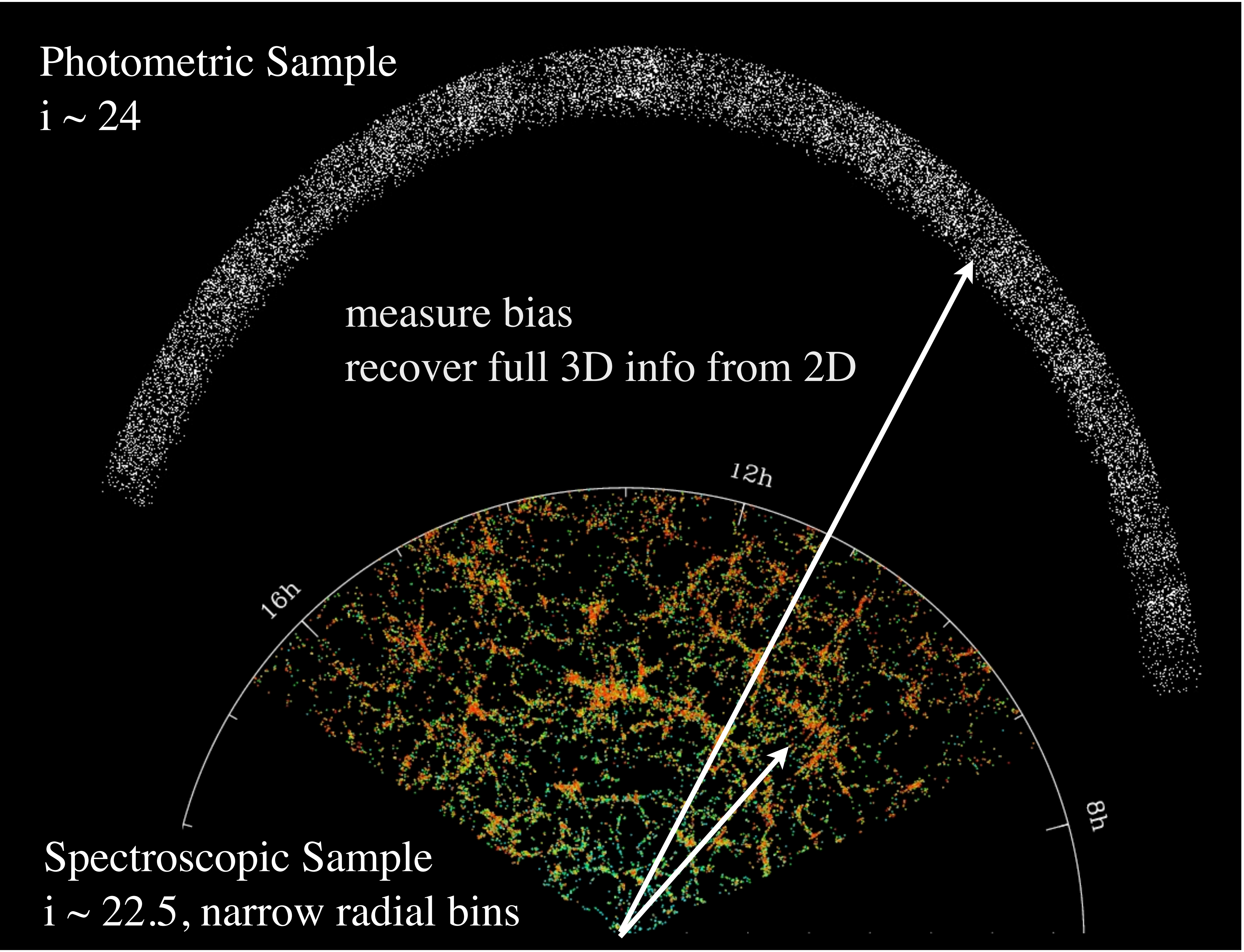
1. Galaxy Clustering 2pt: 3D, all info but biased
2. Galaxy Clustering 3pt: 3D (bias can be roughly measured)
3. Weak Lensing: 2D (unbiased but degenerate)
4. Redshift Space Distortions: ratios, (unbiased but degenerate)
5. BAO: 1.5 D (unbiased)

Combine (cross-correlate) Photometric & Spectroscopic Surveys

and all different probes (XTalks)

and all systematics (bias, photo-z, IA)

astro-ph:1109.4852


Photometric Sample
i ~ 24
measure bias
recover full 3D info from 2D
12h
16h
8h
Spectroscopic Sample
i ~ 22.5, narrow radial bins

Forecast Cross-correlations: narrow bins

$$\delta_{A_i}(\vec{\theta}) = \int dz\, p_{A_i}(z)\delta_m(r\vec{\theta}, z) \qquad C_{A_iB_j}(\ell) = \int_0^\infty dz\, p_{A_i}(z)\, p_{B_j}(z)\, \mathcal{P}(k,z)$$

Galaxy-galaxy Magnification
or
Galaxy-shear are 3D with z

$$C_{GiKj} \simeq b_{n_i} p_{ij} \mathcal{P}_i$$

$$C_{GiGj} \simeq b_{n_i}^2 \frac{\delta_{ij}}{\Delta_i} \mathcal{P}_i$$

Cross-correlation Ratios:

Measure bias, ie from Cii/Cij
Measure pij, ie from Cij/Cik
Measure P(k) ie from Cij^2/Cii

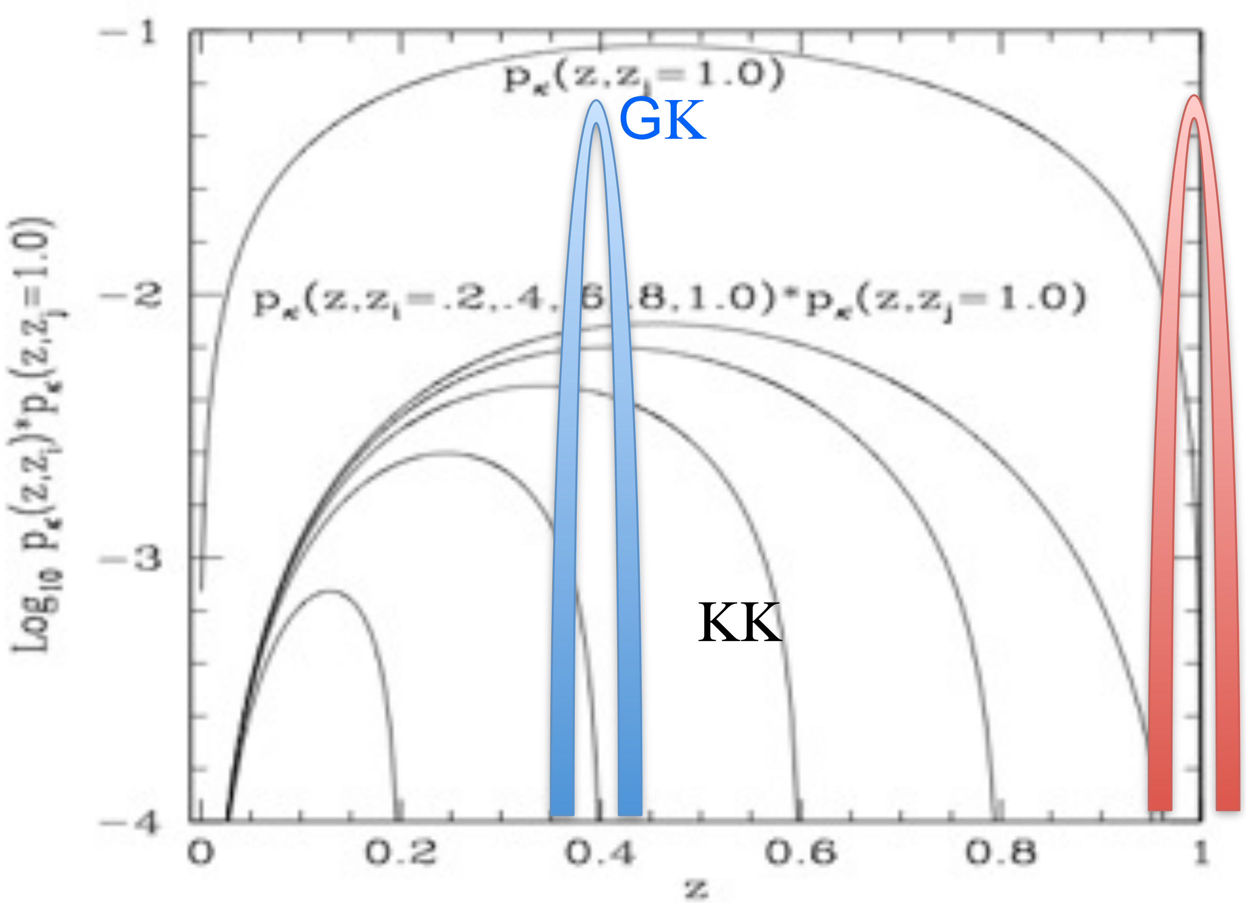


FIG. 2.— Weak lensing efficiency for shear-shear power $p_\kappa(z,\bar{z}_i)p_\kappa(z,\bar{z}_j)$ for $\bar{z}_j = 1.0$ and $\bar{z}_i = 0.2, 0.4, 0.6, 0.8$ and 1.0. Top line corresponds to $p_\kappa(z,\bar{z}_j = 1.0)$, for galaxy-shear lensing.

$$\mathcal{P}_i \equiv \frac{P(k_i, \bar{z}_i)}{\chi_i^2 \chi_{H_i}}$$

$k_i = l/\chi_i$

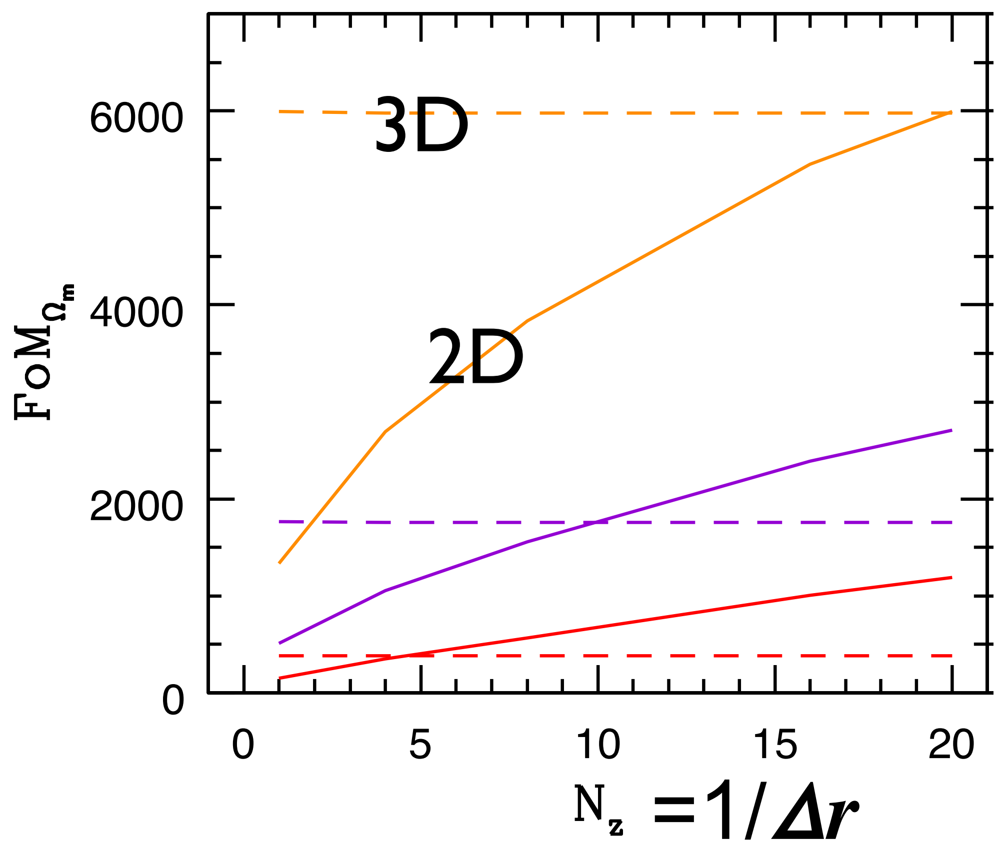
$$p_{ij} \equiv p_{\kappa_j}(z_i) \simeq \begin{cases} \frac{3\Omega_m H_0}{2H(z_i)a_i} \frac{\chi_i(\chi_j - \chi_i)}{\chi_{H0}\chi_j} & \text{for} \quad i < j \\ 0 & \text{for} \quad i \geq j \end{cases}$$

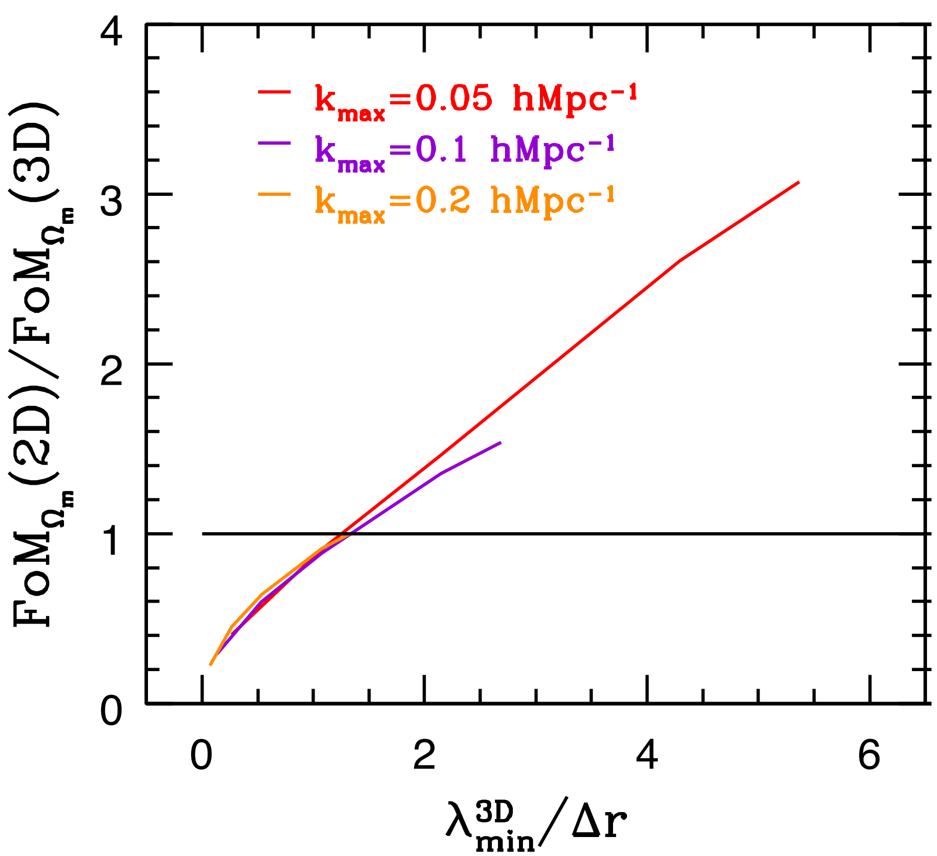
$$\chi_H(z) \equiv c/H(z)$$

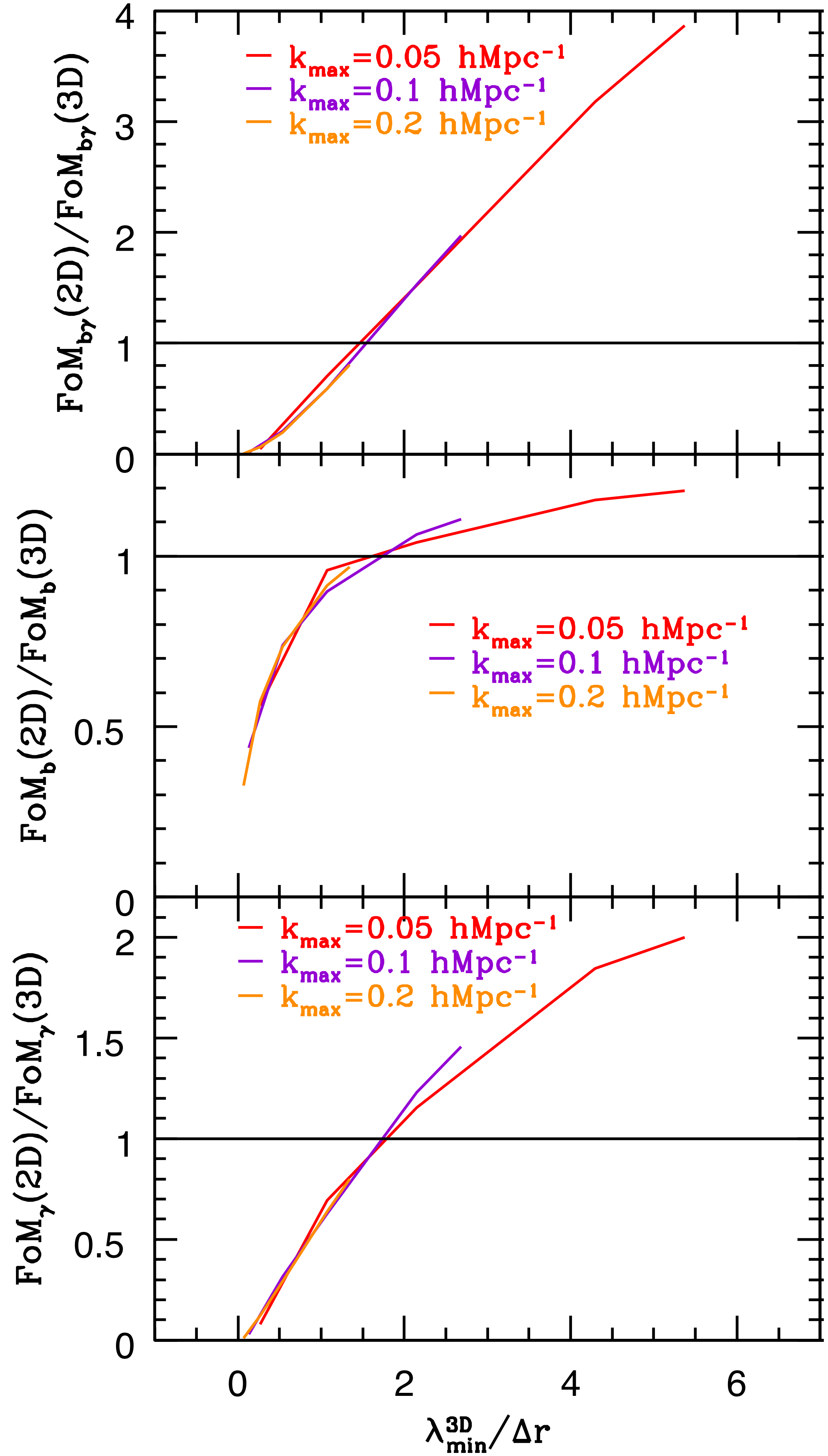
WE IGNORE RSD HERE

$$F_{\mu\nu} = \sum_{\ell \text{ or } k_i} \sum_{ij,mn} \frac{\partial C_{ij}}{p_\mu} \Theta^{-1}_{ij;mn} \frac{\partial C_{mn}}{p_\nu}$$

- Narrow-band filters photometric survey

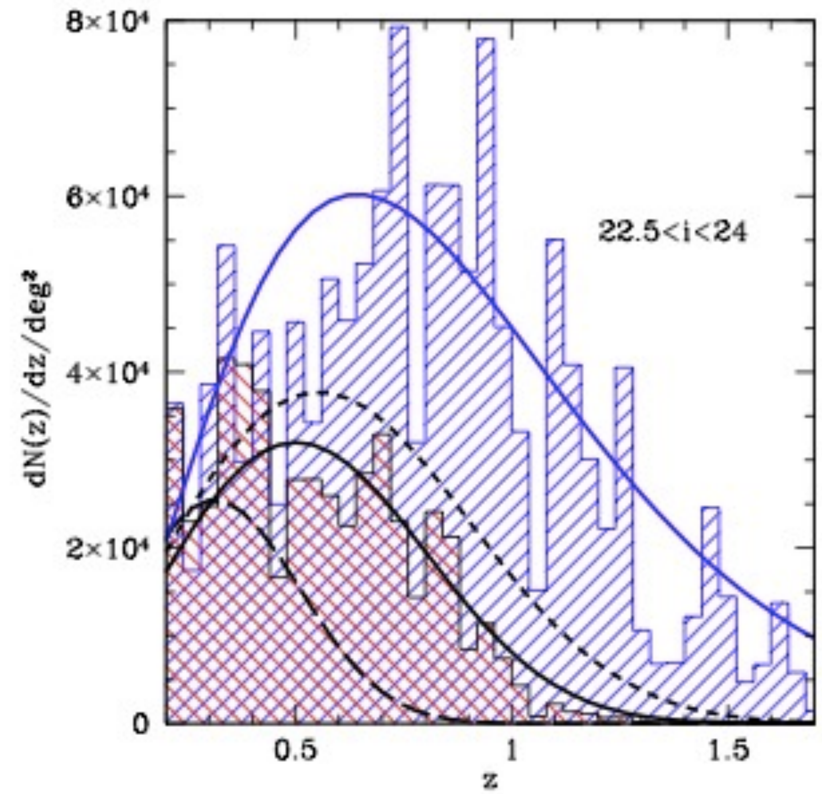






Jacobo Asorey

Forecast	RSD(BAO)	WLxG
Spectroscopic (B=Bright)	✔	✘
Photometric (F=Faint)	✘	✔
Combined as independent: B+F	B	F
Cross-correlate same Area: BxF	B (+F)	BxF



Observables:

WLxG: Angular clustering of Shear-Shear; Galaxy-Shear; Galaxy-Galaxy

RSD: f(z)D(z); b(z)D(z) from P(k,z) in 3D with

Fisher Matrix of RSD and WLxG are added: transverse modes+radial ratios

Nuisance parameters: bias (4 for each B & F), photo-z transitions (rij, can be measured), noise (σ/n)

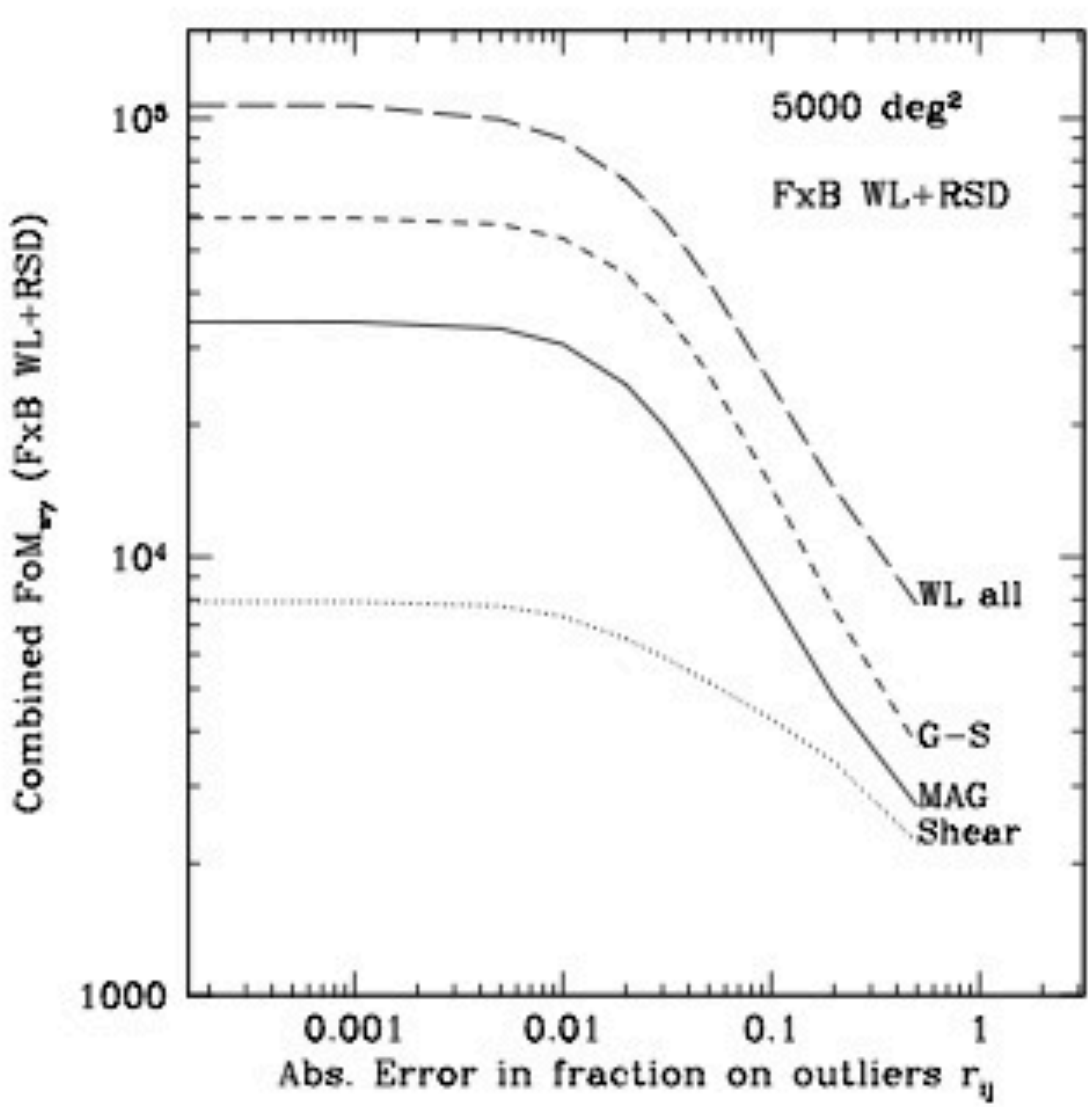
Cosmological: Om - ODE - h - sig8 - Ob - **w0 - wa - γ** - ns - bias(z)

$$FoM_{w\gamma} \simeq 2700\ \bar{A}^{0.89}\ \eta^{0.22}\ 1.4^{m_l-22.5}\ e^{-\bar{\sigma}_z^2-\bar{\Delta}_r\bar{A}^{0.05}}$$

astro-ph:1109.4852

Transition Probabilities

$$\bar{C}_{ij} = \sum_{kl} r_{ik}\, r_{jl}\, C_{kl}$$



astro-ph:1109.4852

Forecast: Planck+SNII priors 5000 sq.deg.

$FoM_{w\gamma} \times 10^3$	RSD	RSD + BAO	WL Shear-Shear	WLxG + RSD + BAO	**RSD + WLxG or just MAG (den/mag)**	**RSD + WLxG or just MAG (den/mag)**	**RSD+ WLxG + BIAS IS KNOWN** (eg 3pt)
Photometric DES (i<24)			**3.2**				
Spectroscopic eBOSS+ (i<22.5)	**0.5**	**2.7**					
Combine both as Independent				**40**			
PAU: Cross Correlated over same Area					**251** **30/72**	**5.2** **1.8/2.5**	**26** **7.7/10**

5000 sq.deg. (RSD to RSD + WLxG or just MAG columns) ←→ 200 sq.deg. (last two columns)

WLxG: shear-shear, galaxy-shear, galaxy-galaxy (including MAG from counts or MAG from magnitudes and counts)

astro-ph:1109.4852

Conclusion

astro-ph:1109.4852

- Combining Spectroscopic and Photometric samples and different probes can bring a boost of x100 in FoM (roughly 2-5 times smaller errors)
  - Req: Photo-z error transitions need to be known to 1% accuracy
  - Req: Bias evolves on timescales>1Gyr
  - Thanks to measurement of galaxy bias
- Spectroscopic follow-up: is better to measure spectra of lenses than doing BAO
- Magnification can be as usefull as shear
- If more is known of bias another x5
- This is both simple and challenging: covariances, many z-bins and Xtalks

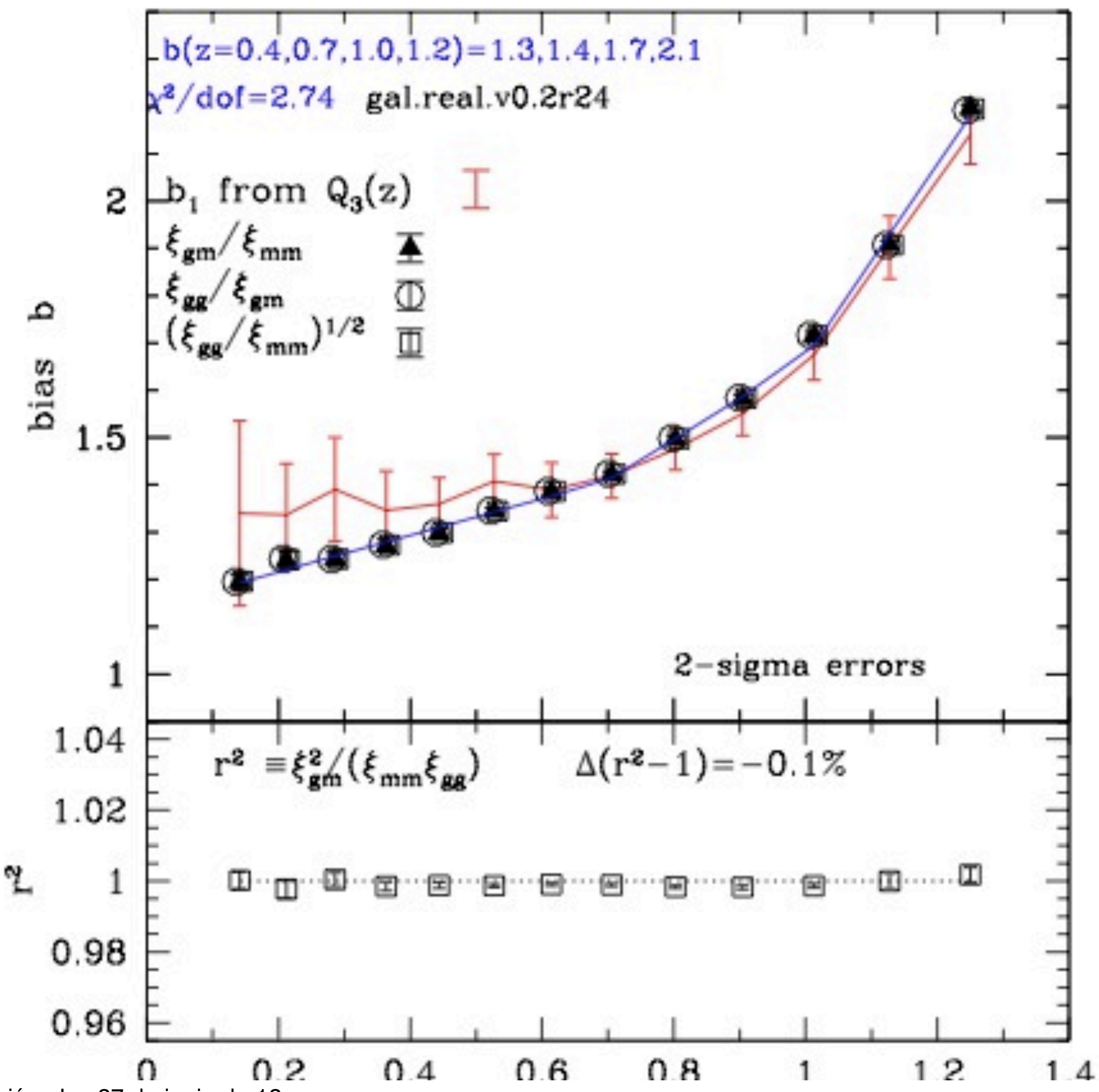
Bonvin
Vernizzi
Corasaniti
Casarini
Bartelmann
Reyes

THE END

- Additional slides

Galaxy bias evolution (~ luminosity evolution): how many parameters?

The characteristic time scales for bias evolution is $\Delta a > 0.1$, corresponding to $t > 1\text{Gyr}$, which is typical of galaxy evolution: 4-5 values between z = 0.2-1.5



$$r \equiv \frac{\xi_{gm}}{\sqrt{\xi_{gg}\xi_{mm}}}$$

$$\xi_{gg} \simeq b^2\,\xi_{mm} + \xi_\epsilon \simeq b^2\,\xi_{mm}\left(1 + \frac{\xi_\epsilon}{b^2\xi_{mm}}\right)$$

$$\xi_{gm} \simeq b\,\xi_{mm}$$

$$r \simeq \frac{1}{\sqrt{1+\xi_\epsilon/b^2\xi_{mm}}} \simeq 1 - \frac{\xi_\epsilon}{2b^2\xi_{mm}}$$

$$\xi_\epsilon(r) \equiv <\delta_m \epsilon> \sim 0$$

Simulations show that 4 values (between z=0.2-1.4) of b(z) are enough for 1% accuracy