Galaxy bias — enemy of clustering cosmology?

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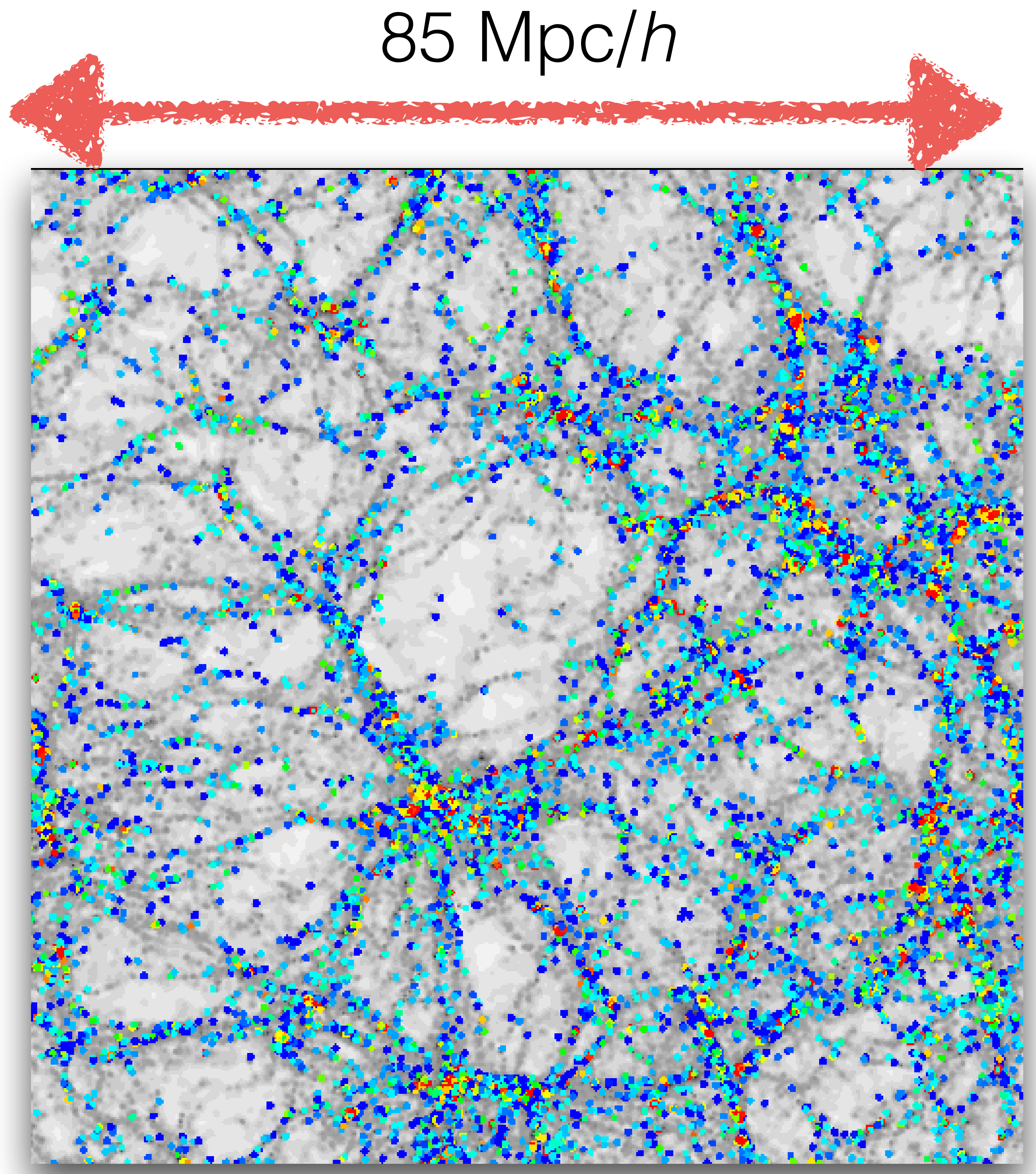
KiDS busy week / beer seminar
Royal Observatory, Edinburgh, 22/02/2018

from nuisance to stardom

- simulation slice at $z = 0$; LCDM
- gray: dark matter
- dots: *B*-*V* colours of galaxies



J. Colberg and A. Diaferio; GIF simulations (1998) density fluctuations

$$\delta(\mathbf{x}) := \frac{\rho(\mathbf{x})}{\bar{\rho}} - 1$$

$$\delta_{\rm g}(R) = b_1\, \delta_{\rm m}(R) + O(\delta_{\rm m}^2) \quad |\delta| \ll 1$$

smoothing scale

galaxy biasing is information on galaxy physics modes of density fluctuations (random fields):

$$\tilde{\delta}(\boldsymbol{k}) = \int \mathrm{d}^3x\, \delta(\boldsymbol{x})\, \mathrm{e}^{-\mathrm{i}\boldsymbol{x}\cdot\boldsymbol{k}} \, .$$

complete second-order statistics of fluctuations:

$$\begin{aligned}
\langle \tilde{\delta}_\mathrm{m}(\boldsymbol{k}) \tilde{\delta}_\mathrm{m}(\boldsymbol{k}') \rangle &= (2\pi)^3 \delta_\mathrm{D}(\boldsymbol{k}+\boldsymbol{k}') P_\mathrm{m}(k) \, ; \\
\langle \tilde{\delta}_\mathrm{m}(\boldsymbol{k}) \tilde{\delta}_\mathrm{g}(\boldsymbol{k}') \rangle &= (2\pi)^3 \delta_\mathrm{D}(\boldsymbol{k}+\boldsymbol{k}') P_\mathrm{gm}(k) \, ; \\
\langle \tilde{\delta}_\mathrm{g}(\boldsymbol{k}) \tilde{\delta}_\mathrm{g}(\boldsymbol{k}') \rangle &= (2\pi)^3 \delta_\mathrm{D}(\boldsymbol{k}+\boldsymbol{k}') \left(P_\mathrm{g}(k) + \bar{n}_\mathrm{g}^{-1} \right) \, ,
\end{aligned}$$

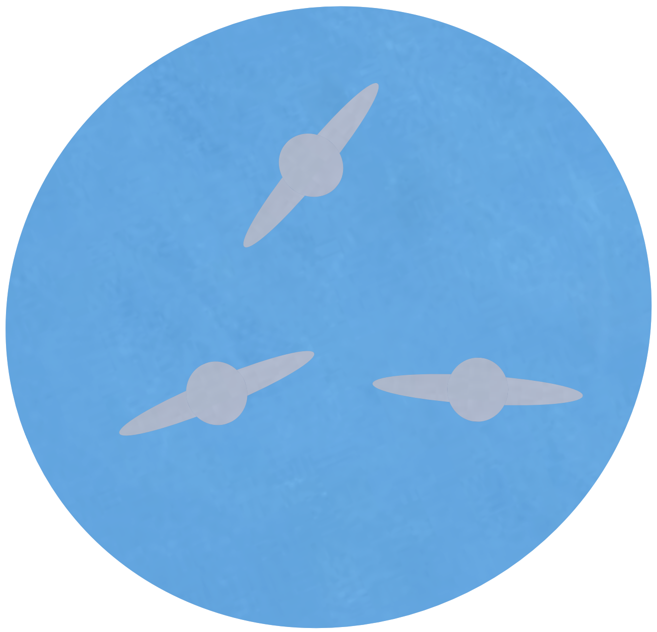
Poisson sampling noise

Biasing functions (linear stochastic bias):

bias factor

$$b(k) = \sqrt{\frac{P_\mathrm{g}(k)}{P_\mathrm{m}(k)}} \; ; \; r(k) = \frac{P_\mathrm{gm}(k)}{\sqrt{P_\mathrm{g}(k)\, P_\mathrm{m}(k)}} \, .$$

correlation factor



$N = 3$

some toy model with

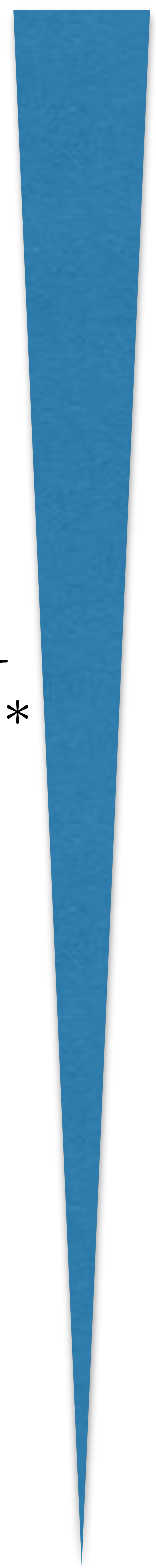
- ☑ identical halo mass-profiles
- ☑ unclustered (overlapping) halos
- ☑ no central galaxies
- ☑ galaxies trace matter density

$$r(k) = \left(1 + \frac{\sigma_{\mathrm{N}}^2 - \langle N \rangle}{\langle N \rangle^2}\right)^{-1/2} = \begin{cases} < 1 & \mathrm{super-Poisson} \\ = 1 & \mathrm{Poisson} \\ > 1 & \mathrm{sub-Poisson} \end{cases}$$

$$b(k) \times r(k) = 1$$

stellar mass

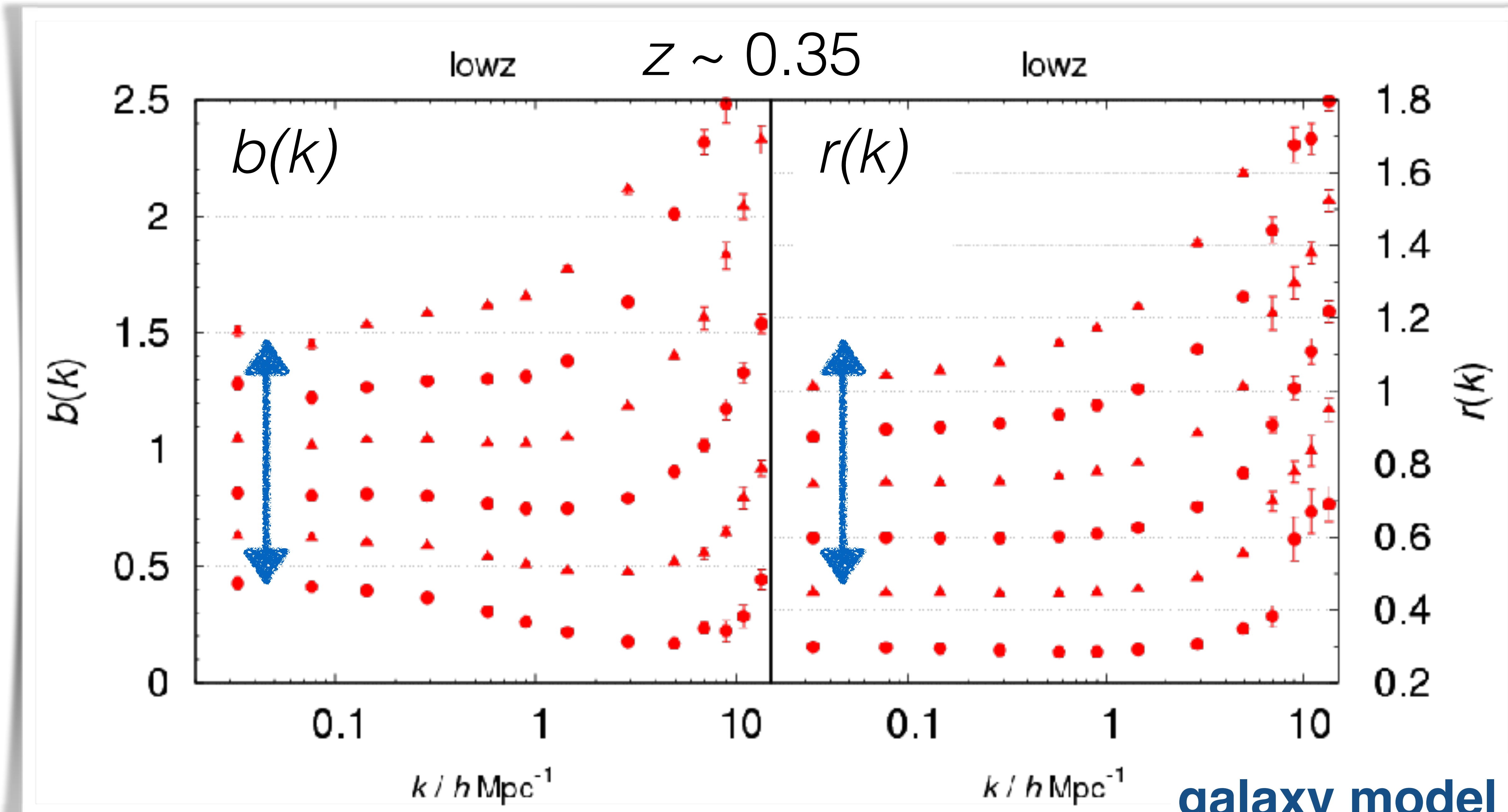
$2.1 \times 10^{11}\,\mathrm{M}_\odot$



M_*

$7.1 \times 10^{9}\,\mathrm{M}_\odot$

SAM by Henriques et al. (2015)



galaxy model

galaxy samples mimick those in
Simon et al. (2013) and Saghiha et al. (2017)

lensing is a natural way to measure galaxy bias

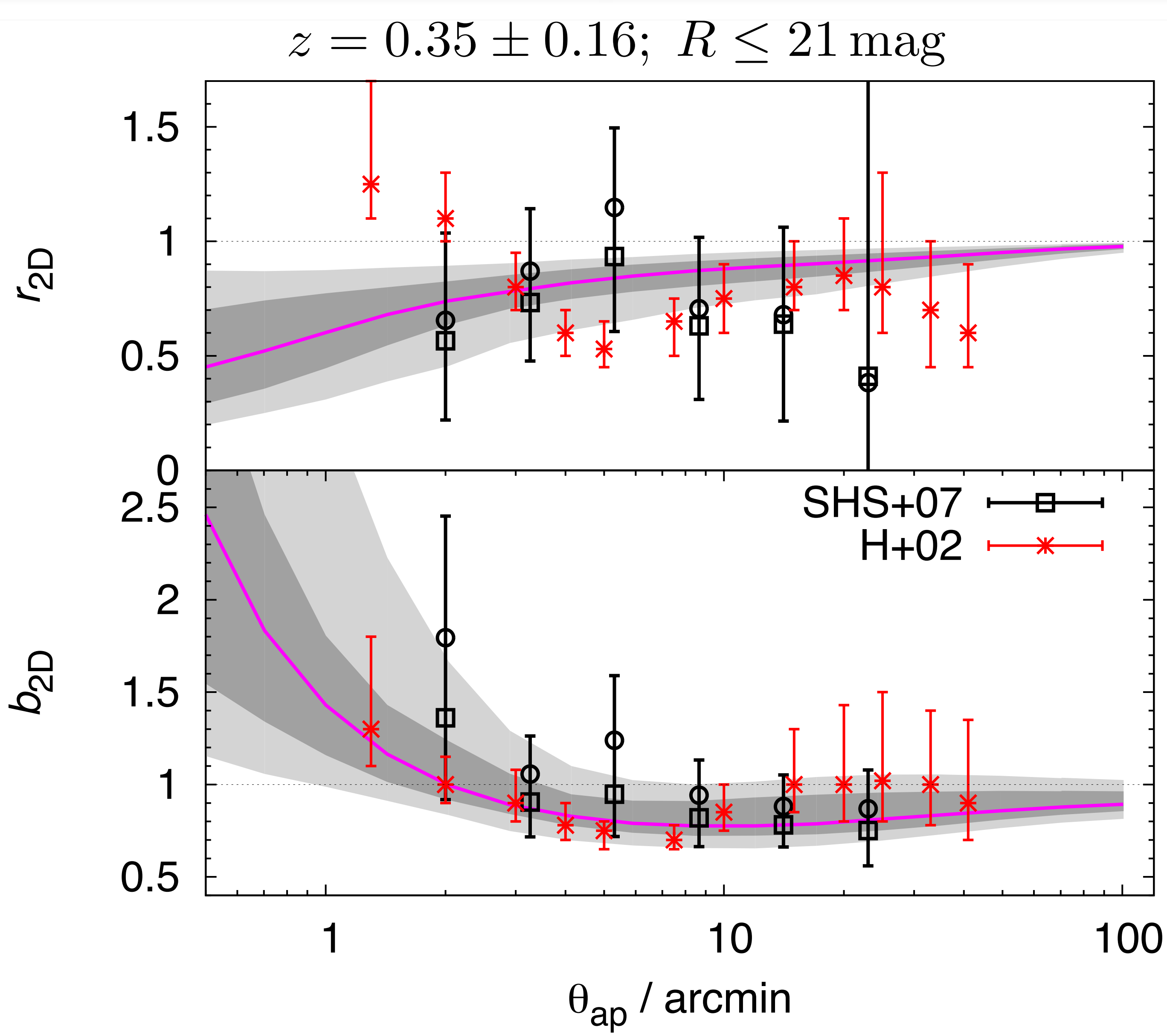
van Waerbeke, L., 1998, A&A, 334, 1
Schneider, P., 1998, ApJ, 498, 43

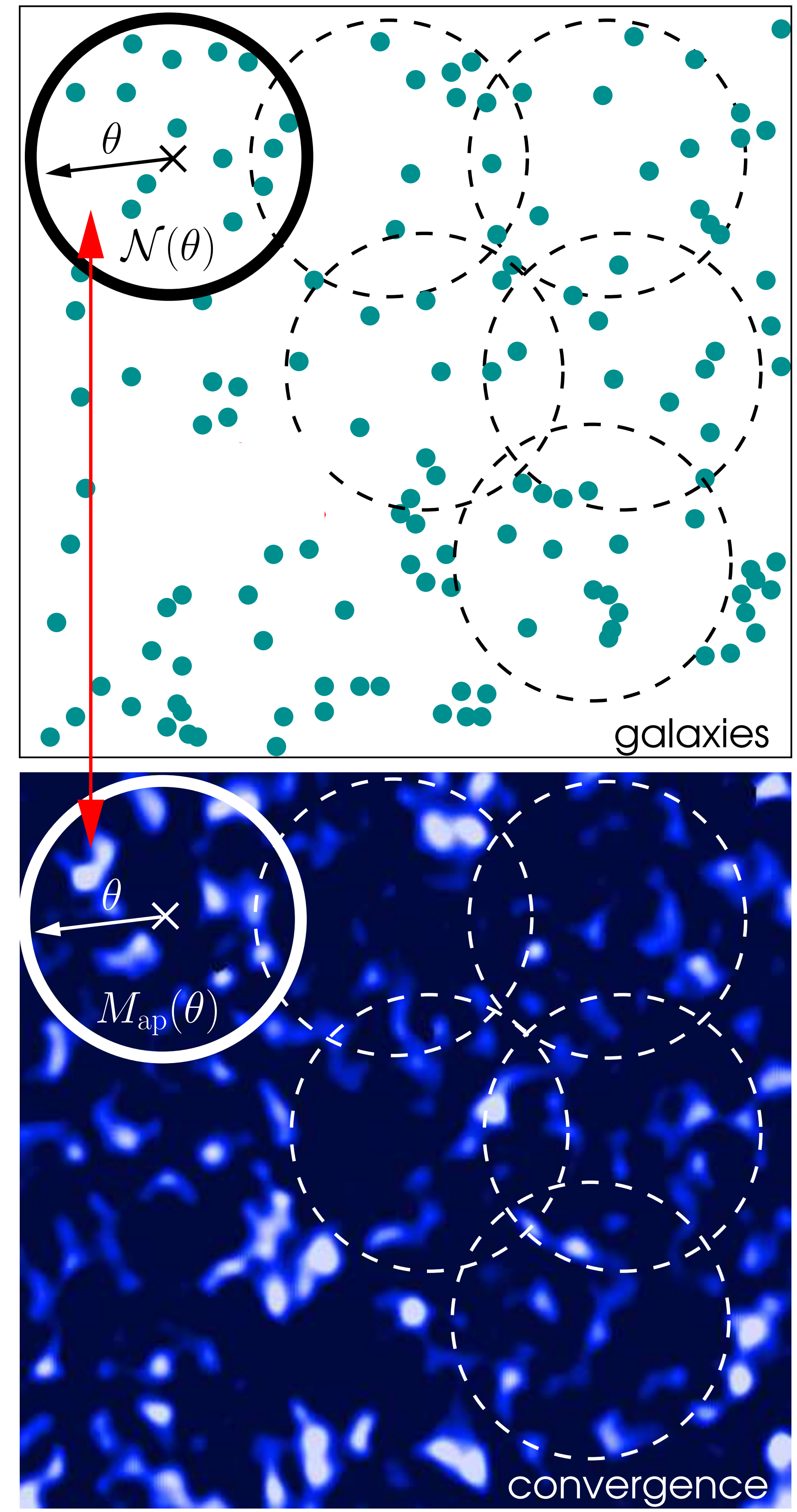
Hoekstra et al., 2001, ApJ, 558, 11
Hoekstra et al., 2002, ApJ, 577, 604

galaxy bias on the sky

$$b_{2D}(\theta_{ap}) = \sqrt{\frac{\langle \mathcal{N}^2\rangle(\theta_{ap})}{\langle M_{ap}^2\rangle(\theta_{ap})}} \times f_b(\theta_{ap}) ,$$

$$r_{2D}(\theta_{ap}) = \frac{\langle \mathcal{N} M_{ap}\rangle(\theta_{ap})}{\sqrt{\langle \mathcal{N}^2\rangle(\theta_{ap})\,\langle M_{ap}^2\rangle(\theta_{ap})}} \times f_r(\theta_{ap}) ,$$





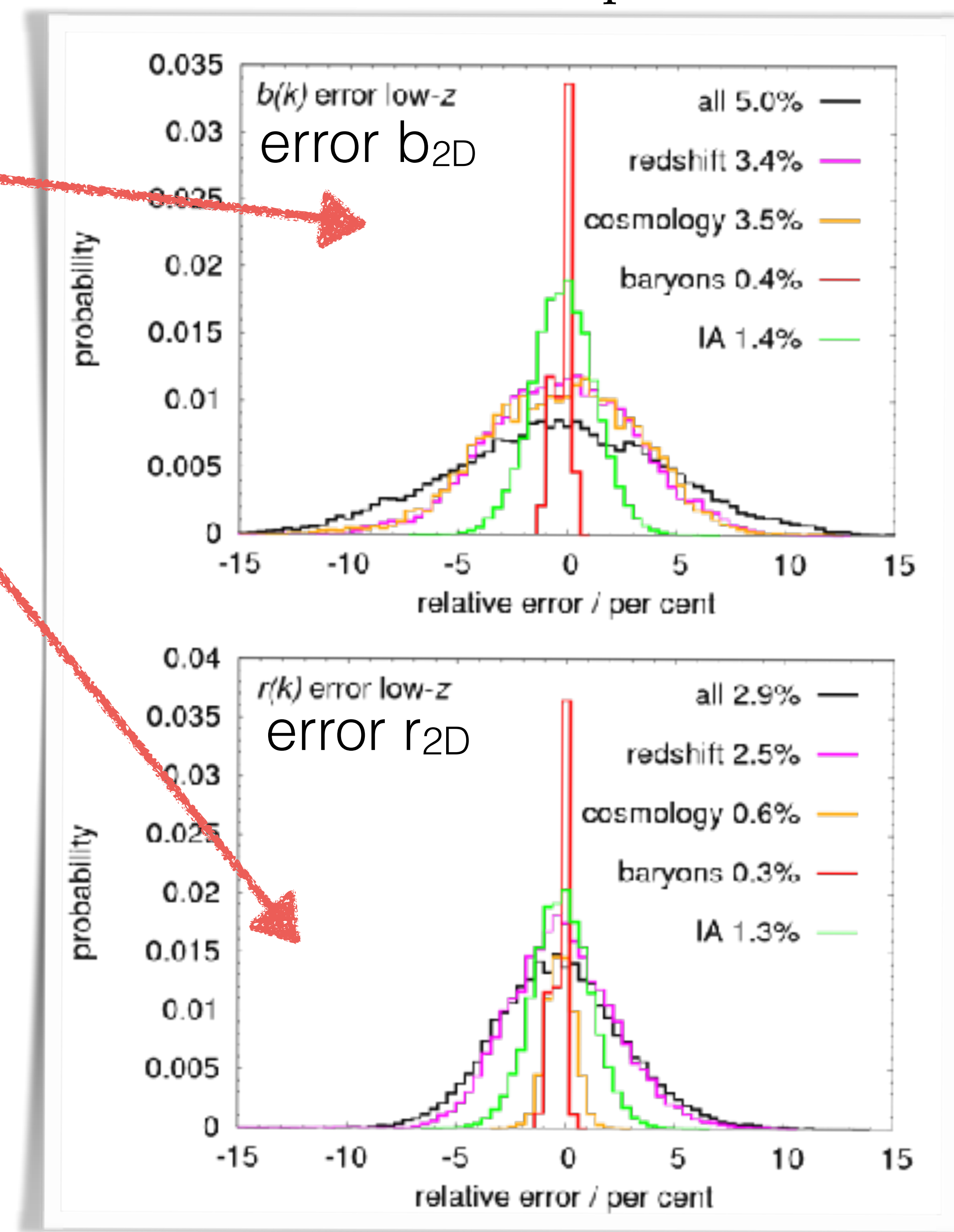
normalisation of projected galaxy bias is only weakly model dependent (ratio statistics)

$$1' \lesssim \theta_{\rm ap} \lesssim 2^\circ$$

$$b_{\rm 2D}(\theta_{\rm ap}) = \sqrt{\frac{\langle \mathcal{N}^2\rangle(\theta_{\rm ap})}{\langle M_{\rm ap}^2\rangle(\theta_{\rm ap})}} \times f_{\rm b}(\theta_{\rm ap}) \,,$$

$$r_{\rm 2D}(\theta_{\rm ap}) = \frac{\langle \mathcal{N} M_{\rm ap}\rangle(\theta_{\rm ap})}{\sqrt{\langle \mathcal{N}^2\rangle(\theta_{\rm ap})\,\langle M_{\rm ap}^2\rangle(\theta_{\rm ap})}} \times f_{\rm r}(\theta_{\rm ap}) \,,$$

Parameter	RMS Error	
redshift bias	2.0%	
$p(z)$ width	5.0%	
$\Omega_{\rm m}$	4.3%	*Planck* TT TE EE +BAO (k=0)
$\Omega_{\rm b}$	4.8%	*Planck* TT TE EE +BAO (k=0)
w	6.2%	*Planck* TT TE EE +BAO (k=0)
H_0	2.3%	*Planck* TT TE EE +BAO (k=0)
$n_{\rm s}$	0.5%	*Planck* TT TE EE +BAO (k=0)
σ_8	2.6%	*Planck* TT TE EE +BAO (k=0)
$A_{\rm ia}(=-3.6)$	40.0%	Joudaki et al. (2016)
$M_{\rm c}, k_{\rm g}, \eta_{\rm b}, z_{\rm c}$	20.0%	Chisari et al. (2018)



Simon et al., in prep.

deprojection of angular biasing functions

- direct inversion tricky: projection does smoothing; solve by forward-fitting smooth model templates

Simon & Hilbert (2018)

$b(k,z)$
$r(k,z)$
templates

$b_{2\mathrm{D}}(\theta_{\mathrm{ap}})$
$r_{2\mathrm{D}}(\theta_{\mathrm{ap}})$

$p_{\mathrm{s}}(z)$

$p_{\mathrm{d}}(z)$ A_{ia}

$P_{\mathrm{m}}(k,z)$ $D_{\mathrm{A}}(w)$

normalisation
(smoothing weights)

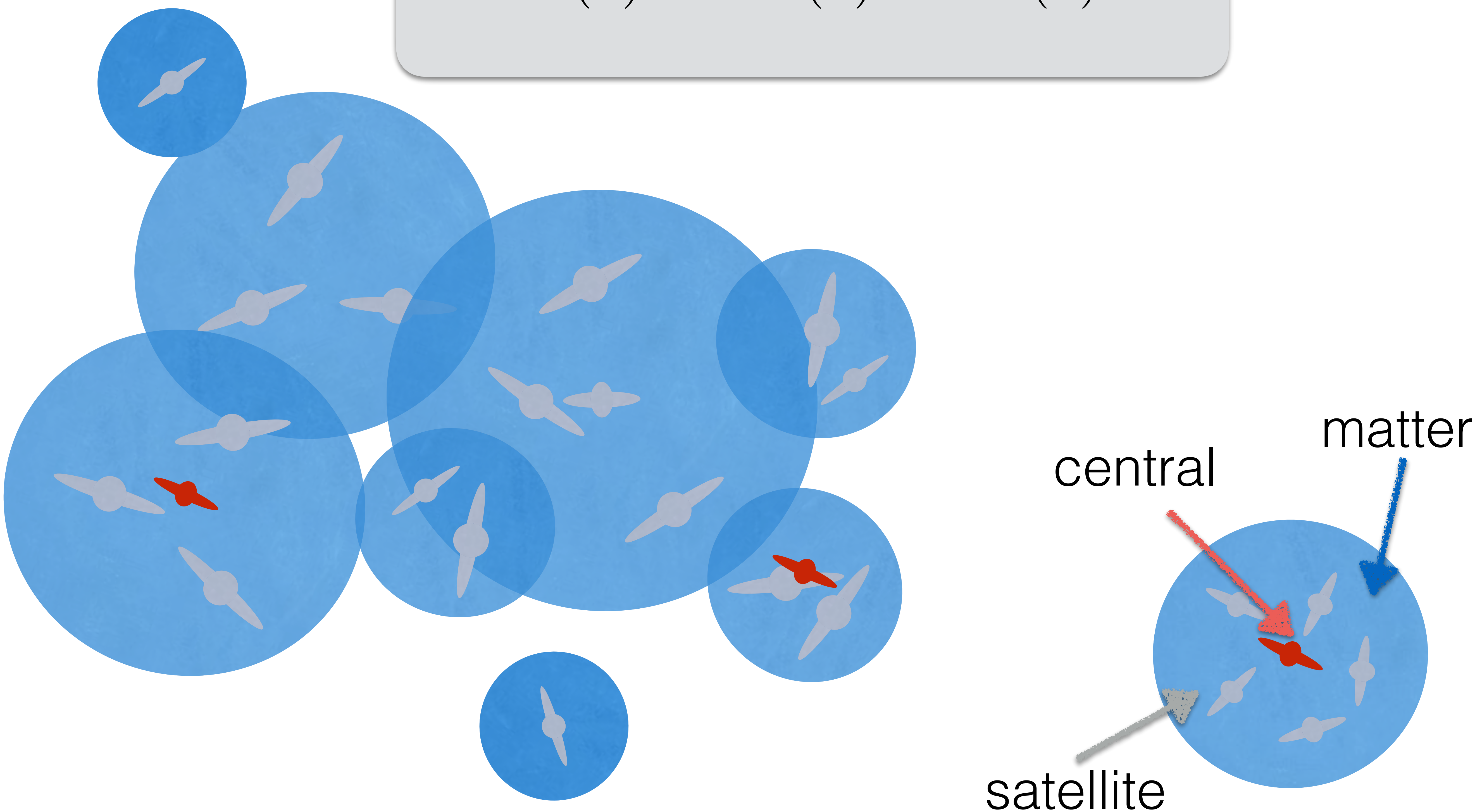
e.g., *generic* templates:

$$b(k) = \frac{b_0 + b_1\,k + b_2\,k^2}{1 + b_3\,k + b_4\,k^2}$$

$$r(k) = \frac{1 + r_1\,k + r_2\,k^2}{1 + r_3\,k + r_4\,k^2 + r_0\,k^3}$$

- *physical* models: more insight and better extrapolation towards small k

$$P(k) = P^{1\mathrm{h}}(k) + P^{2\mathrm{h}}(k)$$



- consider bias in one- and two-halo regime separately

$$b^{1\mathrm{h}}(k) := \sqrt{\frac{P^{1\mathrm{h}}_{\mathrm{g}}(k)}{P^{1\mathrm{h}}_{\mathrm{m}}(k)}}\ ;\ b^{2\mathrm{h}}(k) := \sqrt{\frac{P^{2\mathrm{h}}_{\mathrm{g}}(k)}{P^{2\mathrm{h}}_{\mathrm{m}}(k)}}$$

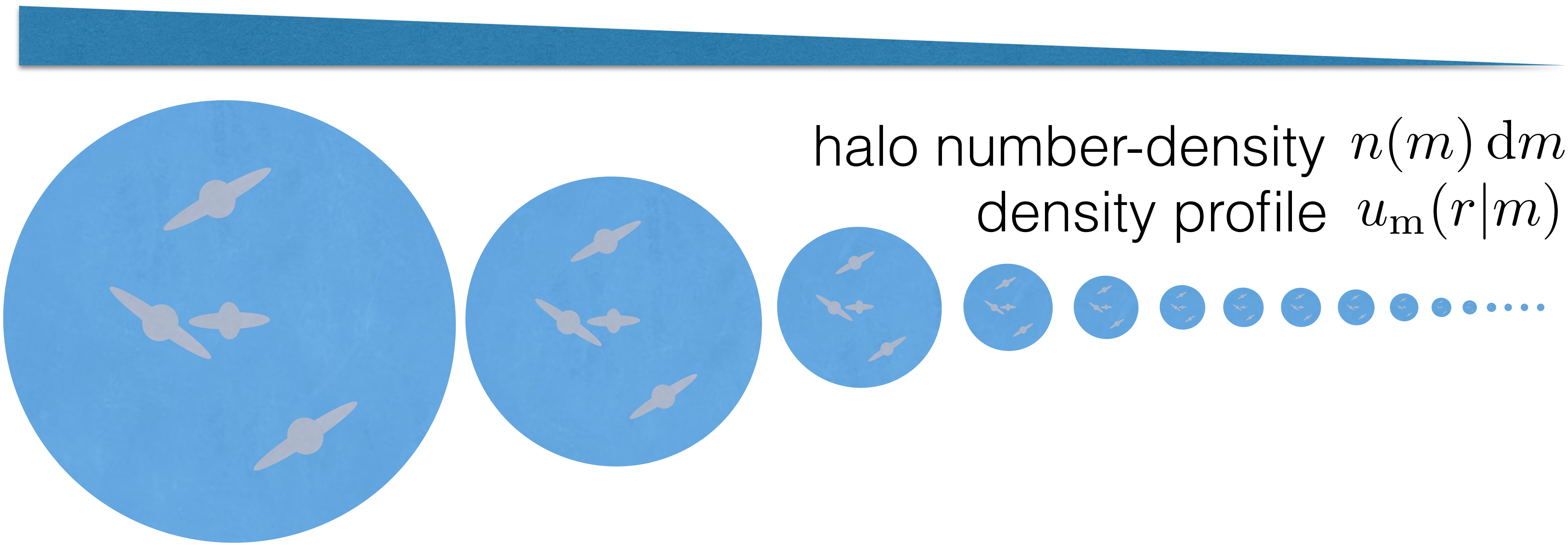
$$r^{1\mathrm{h}}(k) := \frac{P^{1\mathrm{h}}_{\mathrm{gm}}(k)}{\sqrt{P^{1\mathrm{h}}_{\mathrm{g}}(k)\,P^{1\mathrm{h}}_{\mathrm{m}}(k)}}\ ;\ r^{2\mathrm{h}}(k) := \frac{P^{2\mathrm{h}}_{\mathrm{gm}}(k)}{\sqrt{P^{2\mathrm{h}}_{\mathrm{g}}(k)\,P^{2\mathrm{h}}_{\mathrm{m}}(k)}}\ ,$$

- turns out: *two-halo regime* is essentially k-independent; use as parameters in templates; b_{ls} $r_{\mathrm{ls}} = 1$

- halo model predicts $r_{ls} = 1$ in the two-halo regime — but we now *can* test that!

- our ingrediens for the *one-halo regime*

halo mass m



halo number-density $n(m)\,\mathrm{d}m$

density profile $u_{\rm m}(r|m)$

$\langle N|m\rangle \propto m\, b(m)$ $\quad$ $\langle N|m_{\rm piv}\rangle = 1$ $\quad$ mean galaxy number

$$\langle N(N-1)|m\rangle = \langle N|m\rangle^2 \left(1 + \frac{V(m)}{\langle N|m\rangle}\right)$$ mean pair number

$f_{\rm cen} \in [0,1]$ $\quad$ halo fraction with centrals

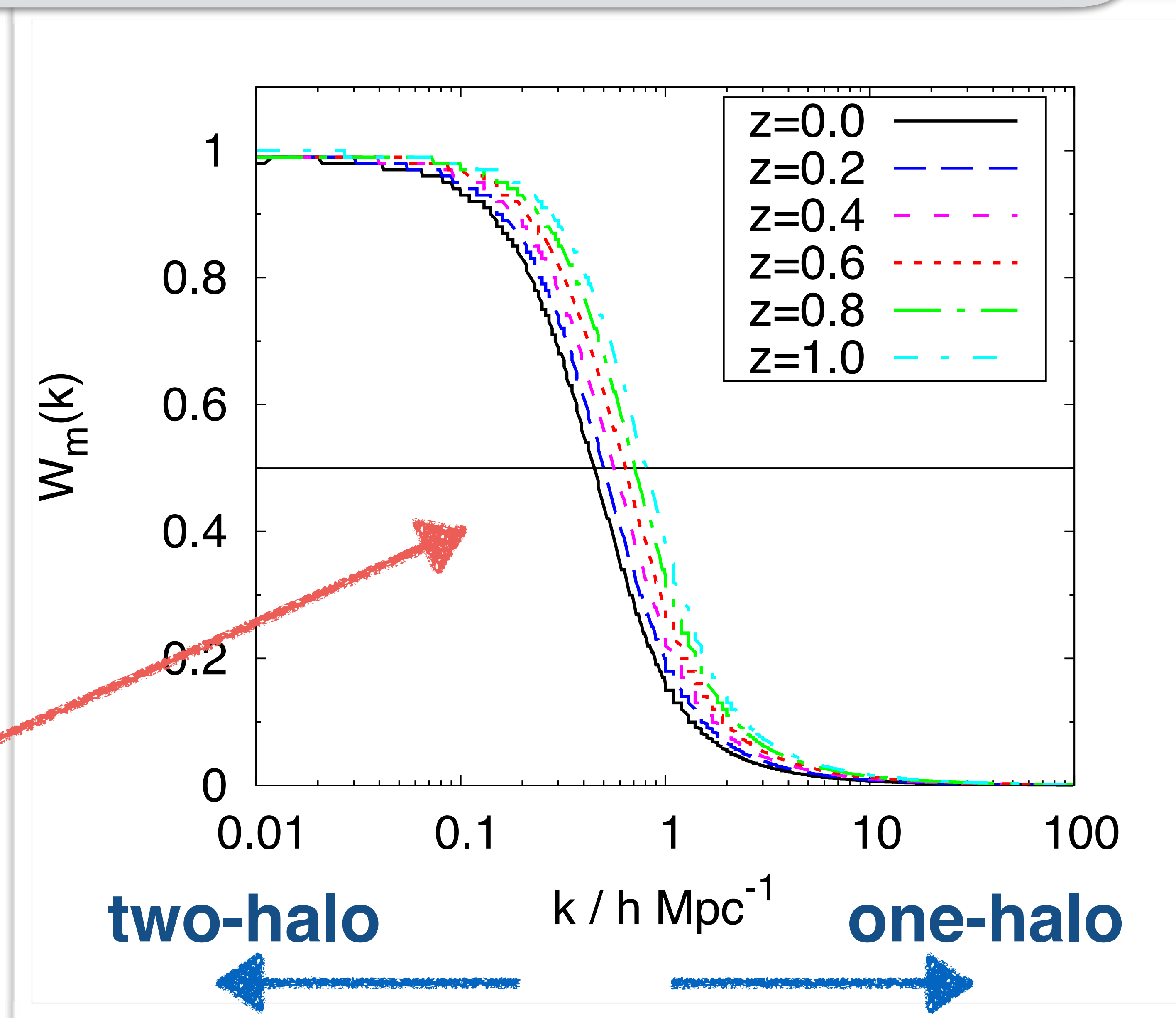
- patch both regimes together with halo weights $W(k)$:

$$b^2(k) = (1 - W_\mathrm{m}(k))\,[b^{1\mathrm{h}}(k)]^2 + W_\mathrm{m}(k)\,b_\mathrm{ls}^2$$

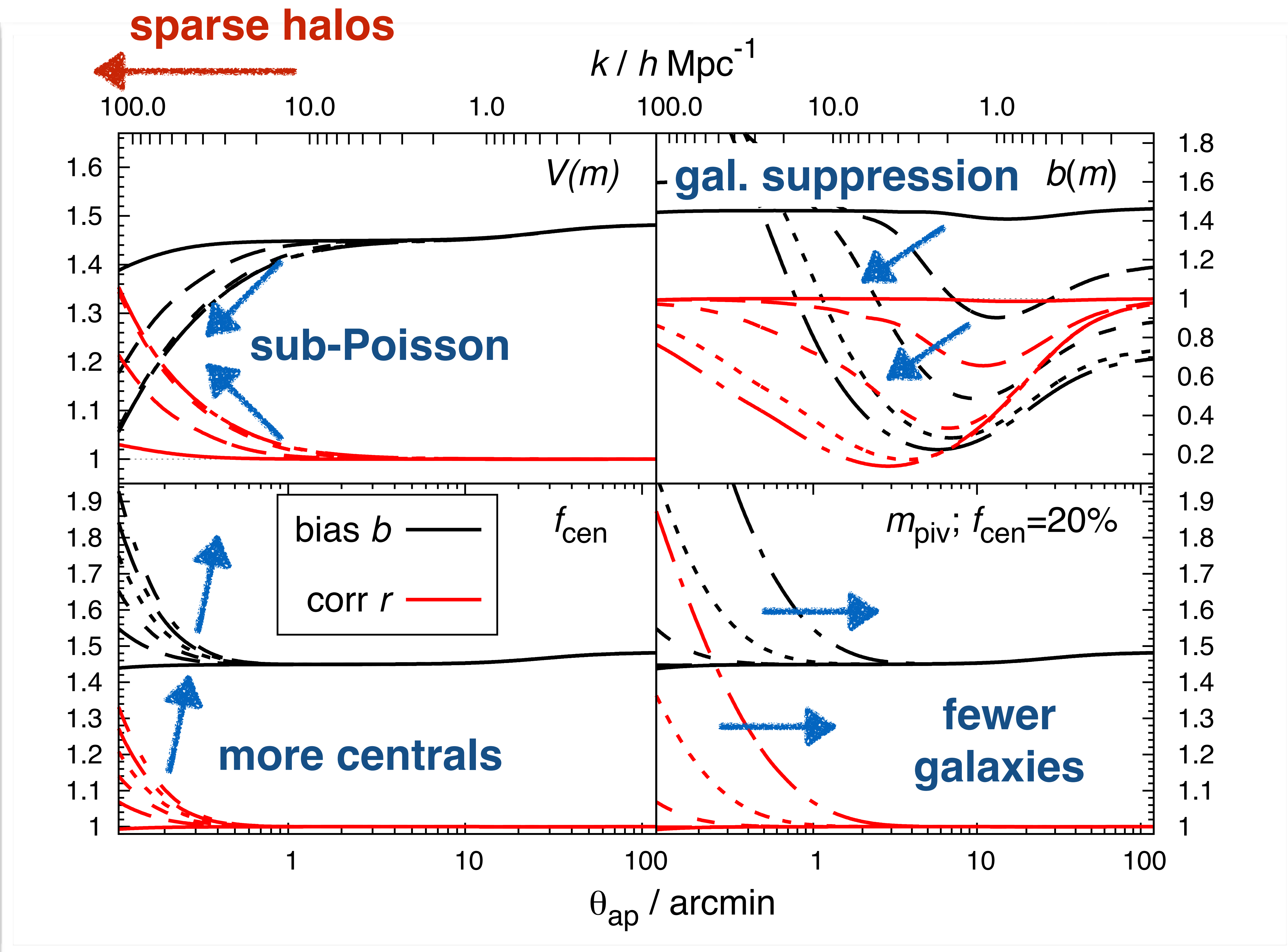
$$r(k) = \sqrt{(1 - W_\mathrm{m}(k))(1 - W_\mathrm{g}(k))}\,r^{1\mathrm{h}}(k) + \sqrt{W_\mathrm{m}(k) W_\mathrm{g}(k)}\,r_\mathrm{ls}$$

$$W_\mathrm{g}(k) := \left(\frac{b_\mathrm{ls}}{b(k)}\right)^2 W_\mathrm{m}(k)$$

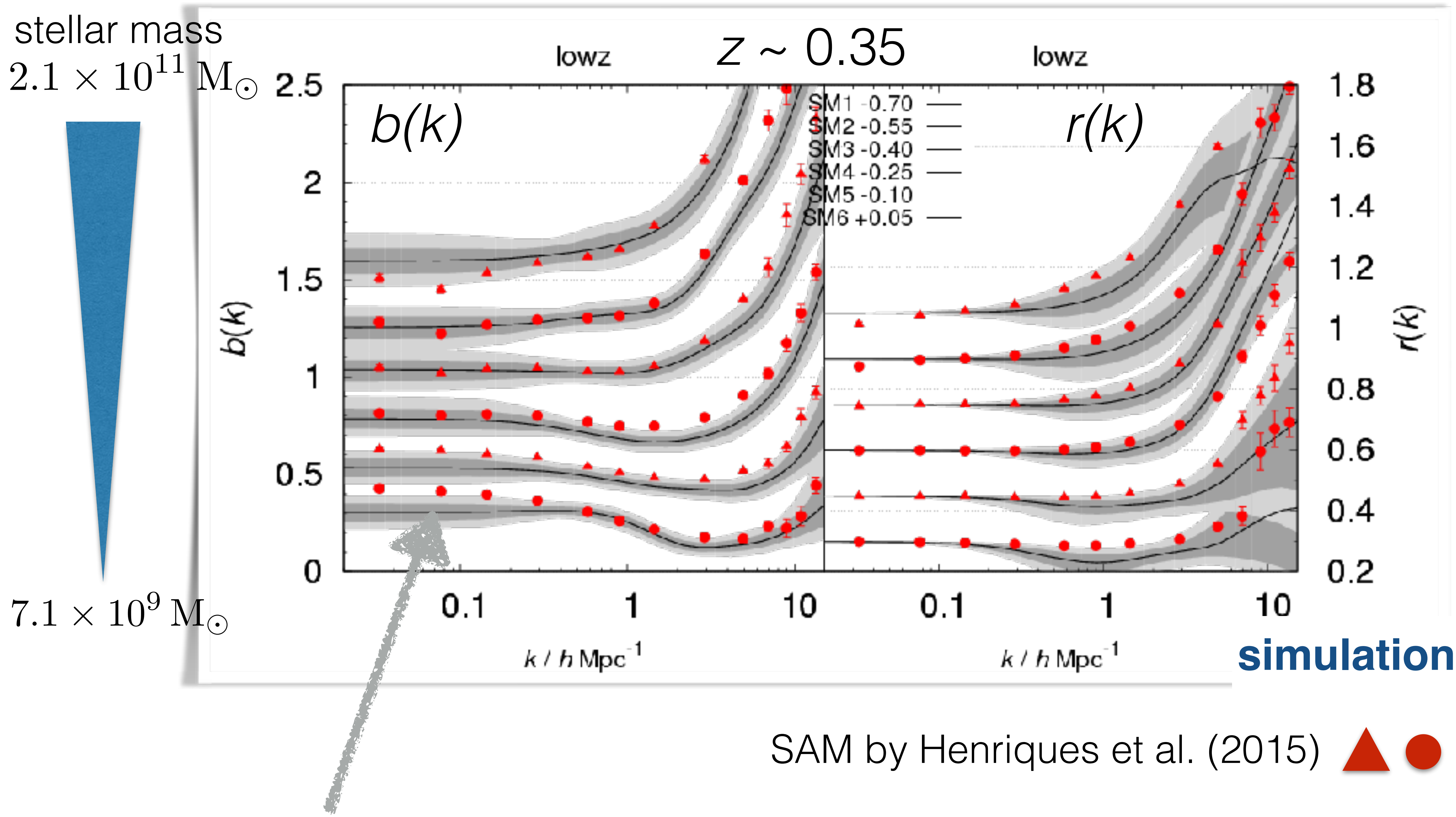
$$W_\mathrm{m}(k) := \frac{P_\mathrm{m}^{2\mathrm{h}}(k)}{P_\mathrm{m}(k)}$$



parameter dependence for lenses at $z = 0.3$



- test with CFHTLenS-like survey but 1000 square degree; source z ~ 0.93 and 5 per arcmin^2



SAM by Henriques et al. (2015)

Simon and Hilbert (2018)

Conclusions

- ☑ the reconstruction accuracy is 3-7% (3-5%) for lenses at *z*~0.35 (0.51);

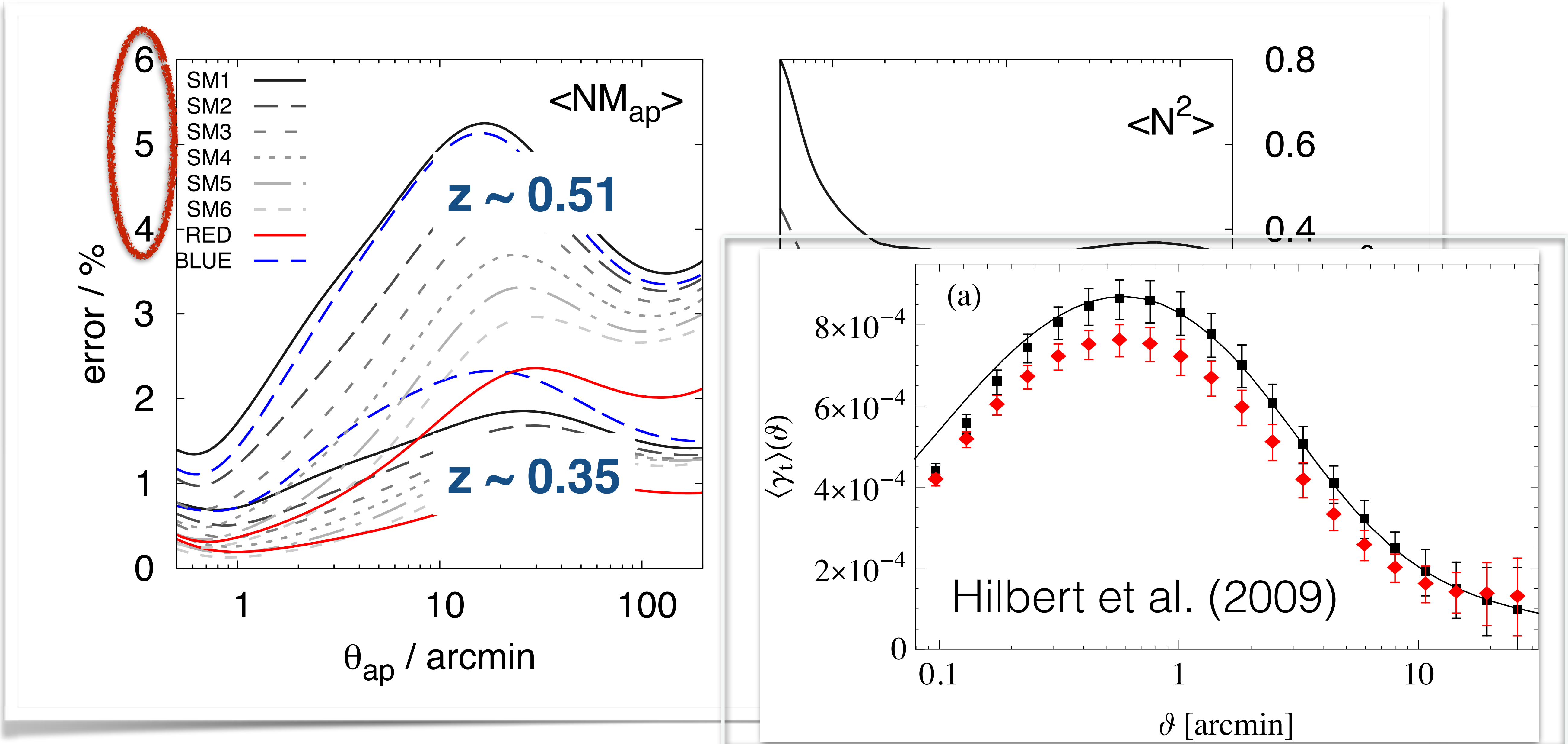
- ☐ errors in the data covariance (Jackknife) and likelihood model are included in the error budget;

- ☑ the normalisation error is around 5-8% for *b(k)* or 3-5% for *r(k)*, *if* IA error is controlled to around 40% and baryon physics to 20% (*Planck*+BAO prior);

- ☐ magnification bias of lenses is relevant for lenses at high redshift and low clustering (affects *r(k)* and GGL)?

- ☐ constraints from one-halo regime can be used to predict the galaxy bias factor at large scales and test halo model;

magnification bias may be important for GGL!



see Sect. 3.4 in Simon and Hilbert (2018);
Ziour and Hui (2008), Hilbert et al. (2009), PhD thesis of J. Hartlap (2009)