Tsinghua Center for Astrophysics

Signatures of Cosmic Reionization on the 21cm 3-Point Correlation

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Motivation

Why going beyond second-order statistics?

3-point correlations are sensitive to additional information on

- **Non-Gaussianity** and **shape of fluctuations** in 21cm brightness temperature
- coming from **bubble morphology** and the underlying **large scale structure** (see Suman Majumdar et al. 2017, arXiv:1708.08458)

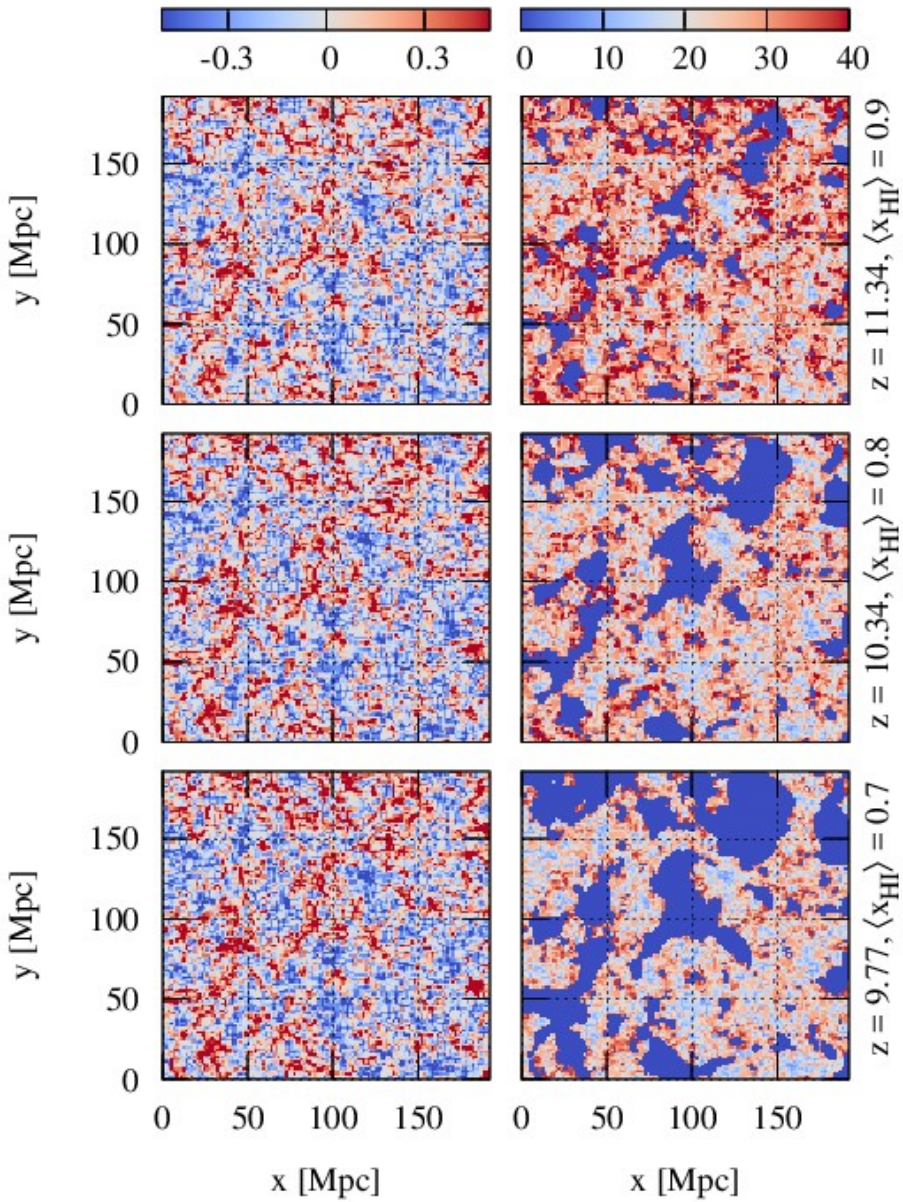
→ **21cm 3pc can tighten constraints**

- on Reionization models *(see Shimabukuro et al. 2017, 1608.00372)*
- possibly on cosmological models (see conclusions)

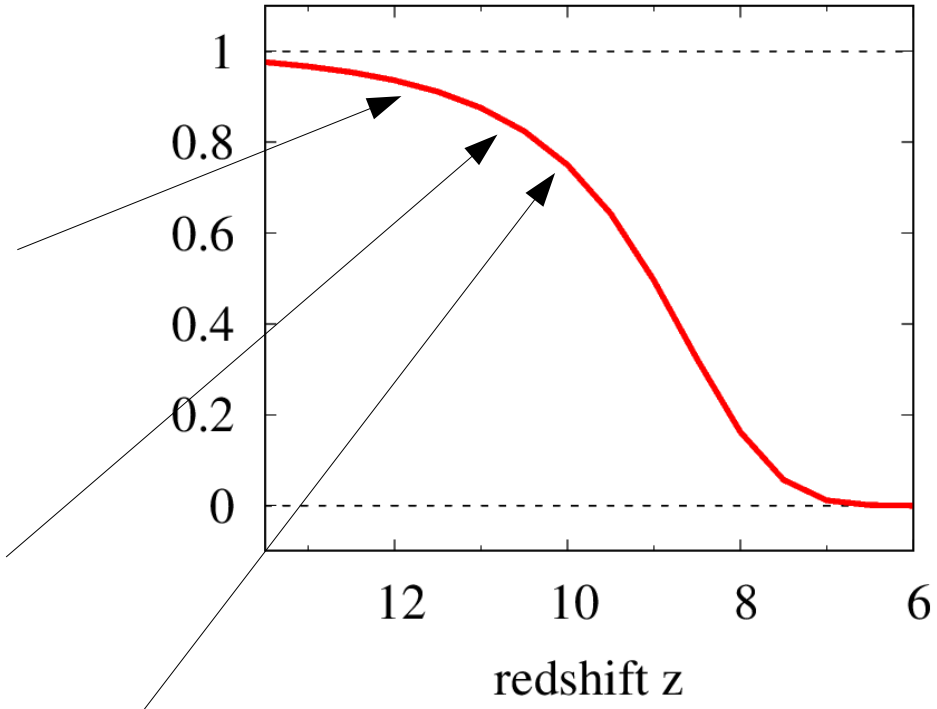
21cmFast simulations

matter fluctuations

21cm brightness Temperature [mK]



Global neutral fraction



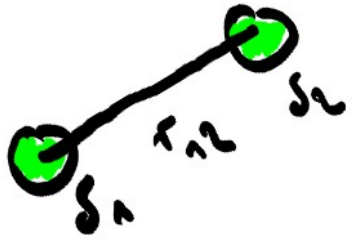
- $(768\ \mathrm{Mpc})^3$ box
- 200 realizations

2- and 3-point correlations

fluctuations: $\delta \stackrel{\text{def}}{=} \frac{\rho - \bar{\rho}}{\bar{\rho}}$

2-point correlation (2pc):

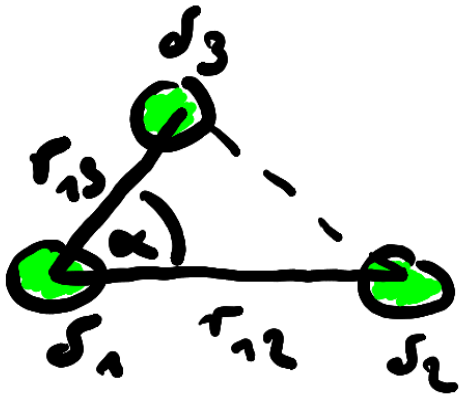
$$\xi \stackrel{\text{def}}{=} \langle \delta_1 \delta_2 \rangle (r_{12})$$



- spherically symmetric → not sensitive to shape of fluctuations

3-point correlation (3pc):

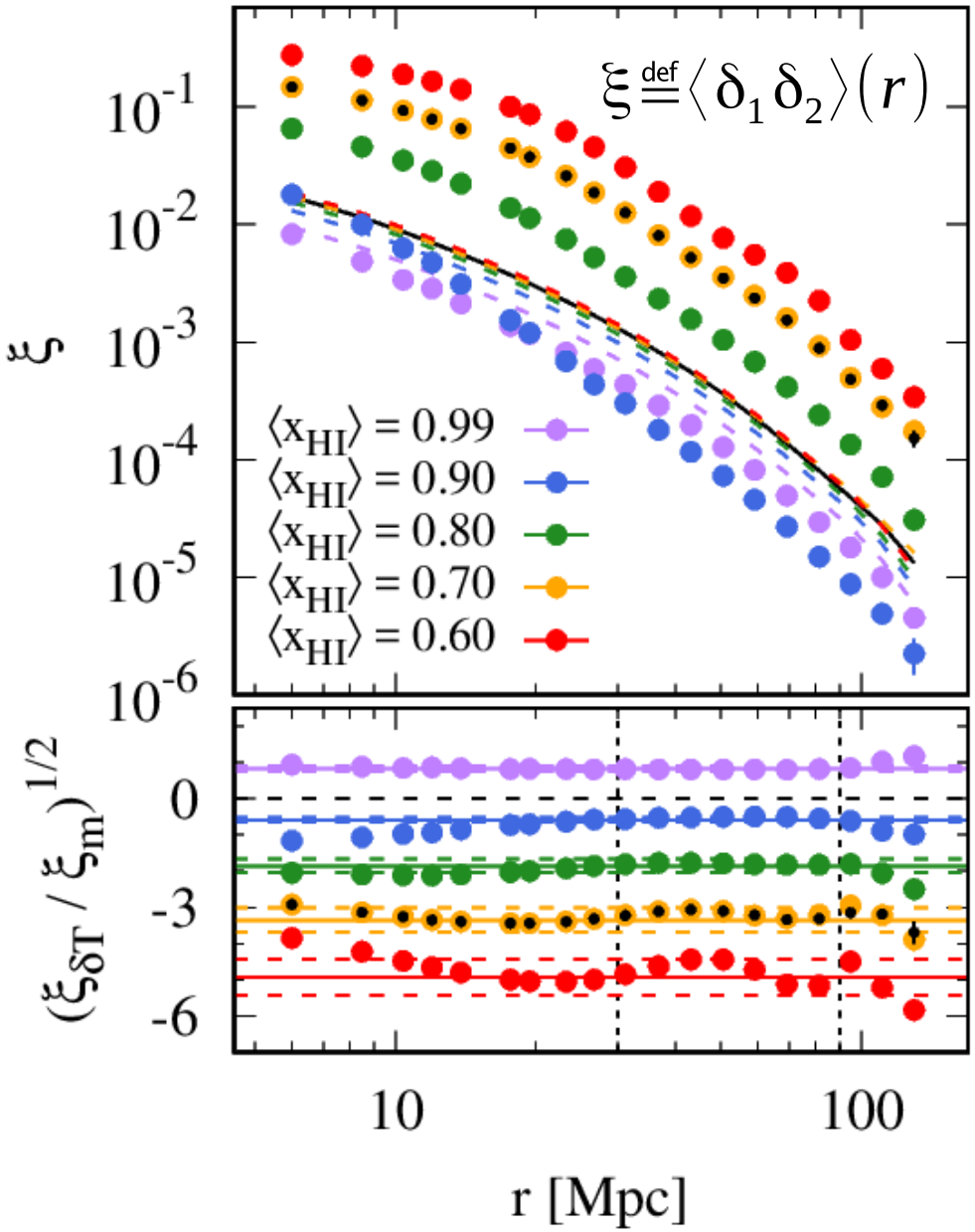
$$\zeta \stackrel{\text{def}}{=} \langle \delta_1 \delta_2 \delta_3 \rangle (r_{12}, r_{13}, \alpha)$$



- provides additional shape info

2pc measurements - 21cm vs matter

means over 200 realizations



Lines: matter

Dots: 21cm brightness temperature

large scale approximation at early times:

$$b_1 \approx \sqrt{\xi_m / \xi_{\delta T}}$$

Linear bias b1:

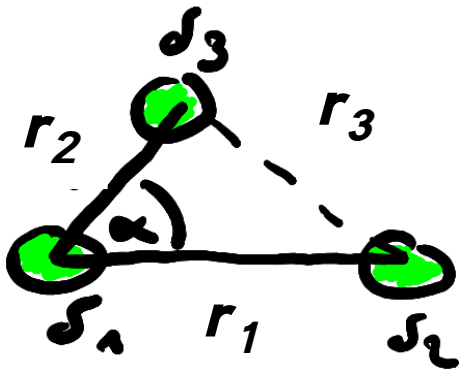
-positive at early times

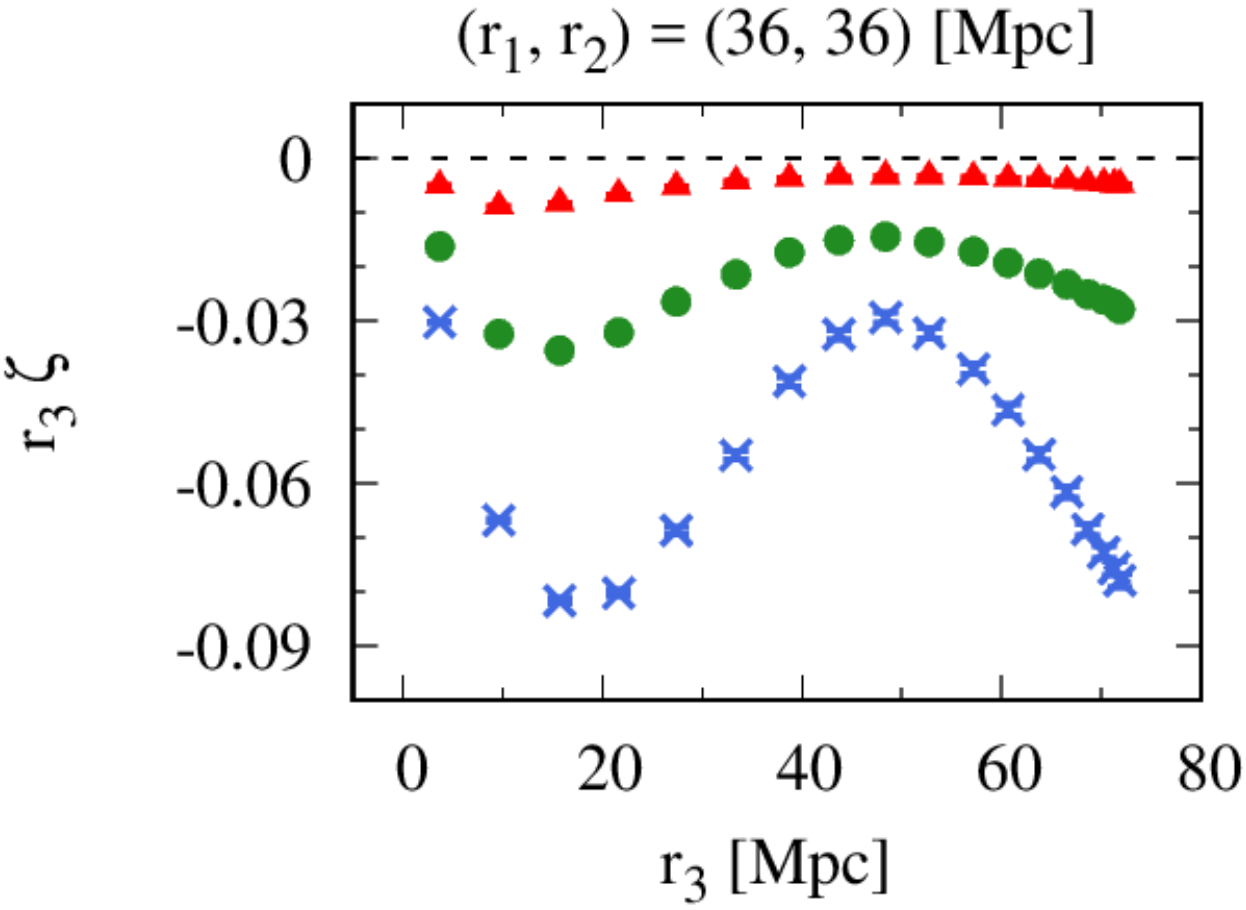
-negative at late times

fits between 30 < r < 90 Mpc

21cm 3pc scale and z dependence

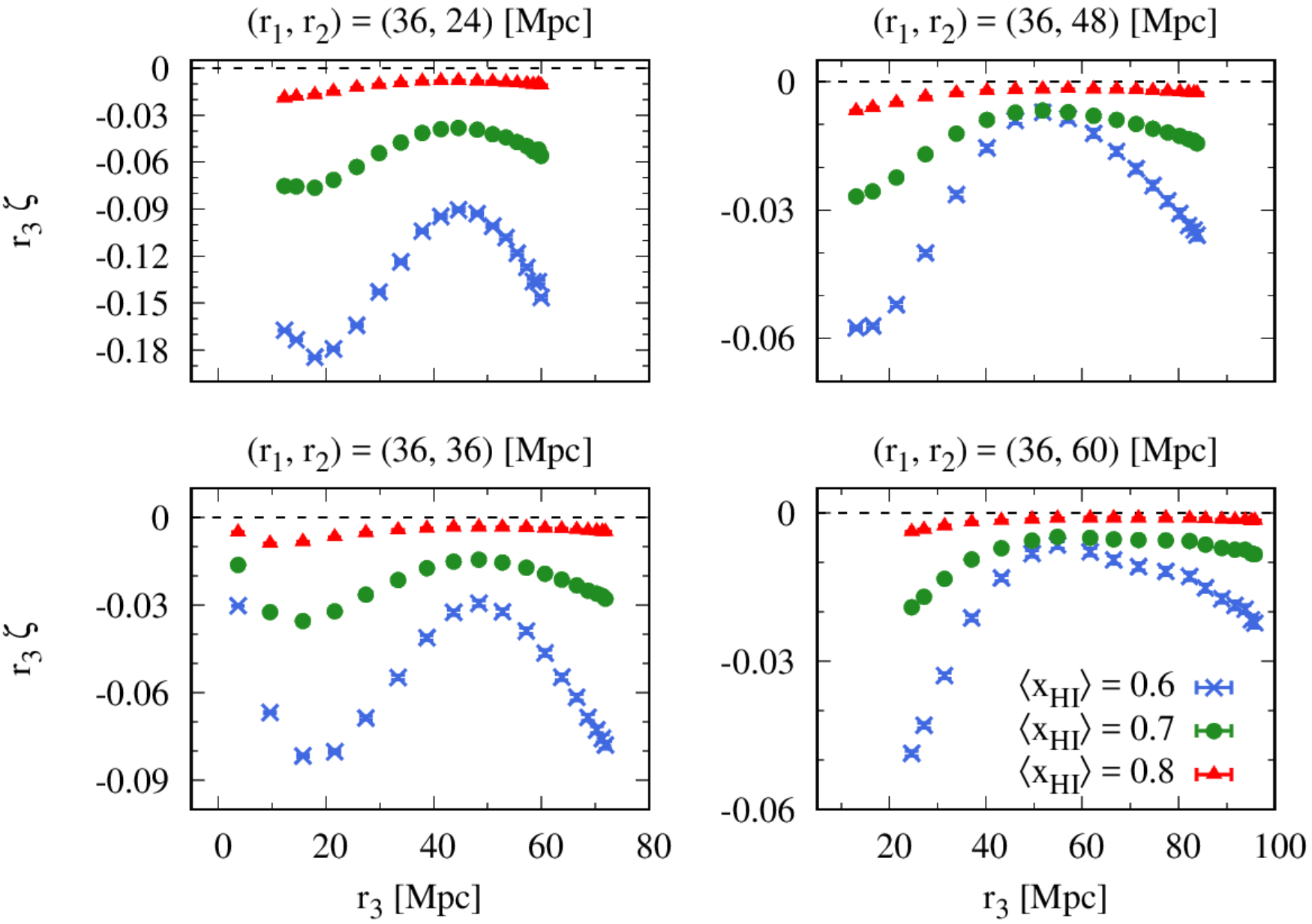
$$\zeta \overset{\text{def}}{=} \langle \delta_1 \delta_2 \delta_3 \rangle$$



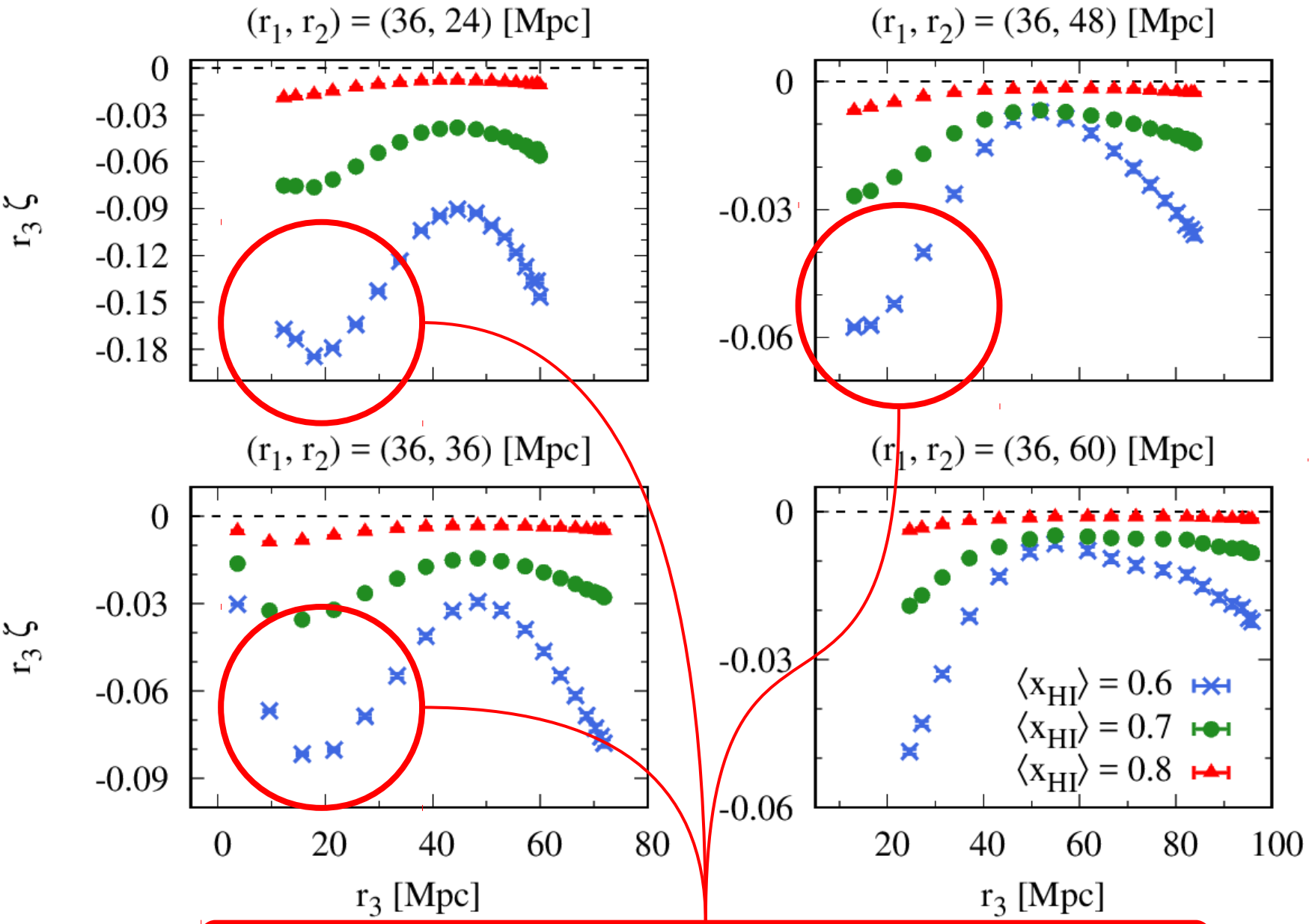


(means over 200 realizations)

21cm 3pc scale and z dependence

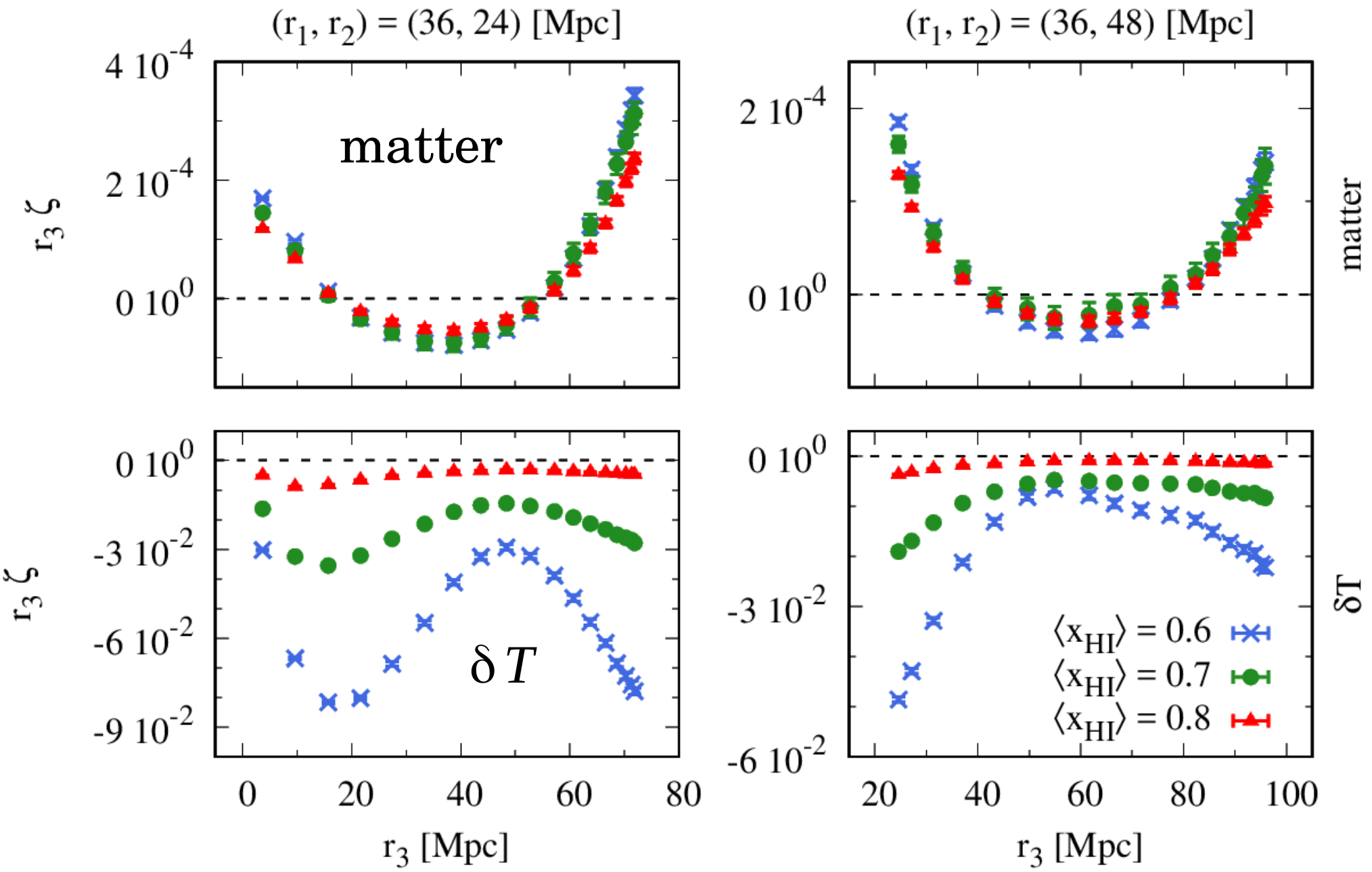


21cm 3pc scale and z dependence



signitures of HII bubbles at r < 20 Mpc

3pc - 21cm vs matter



quadratic bias model

$$\delta_{\delta T} = F(\delta_m) \approx b_1 \delta_m + b_2 (\delta_m^2 - \sigma_m^2)$$

introduced for LSS tracers by Fry&Gaztanaga 93

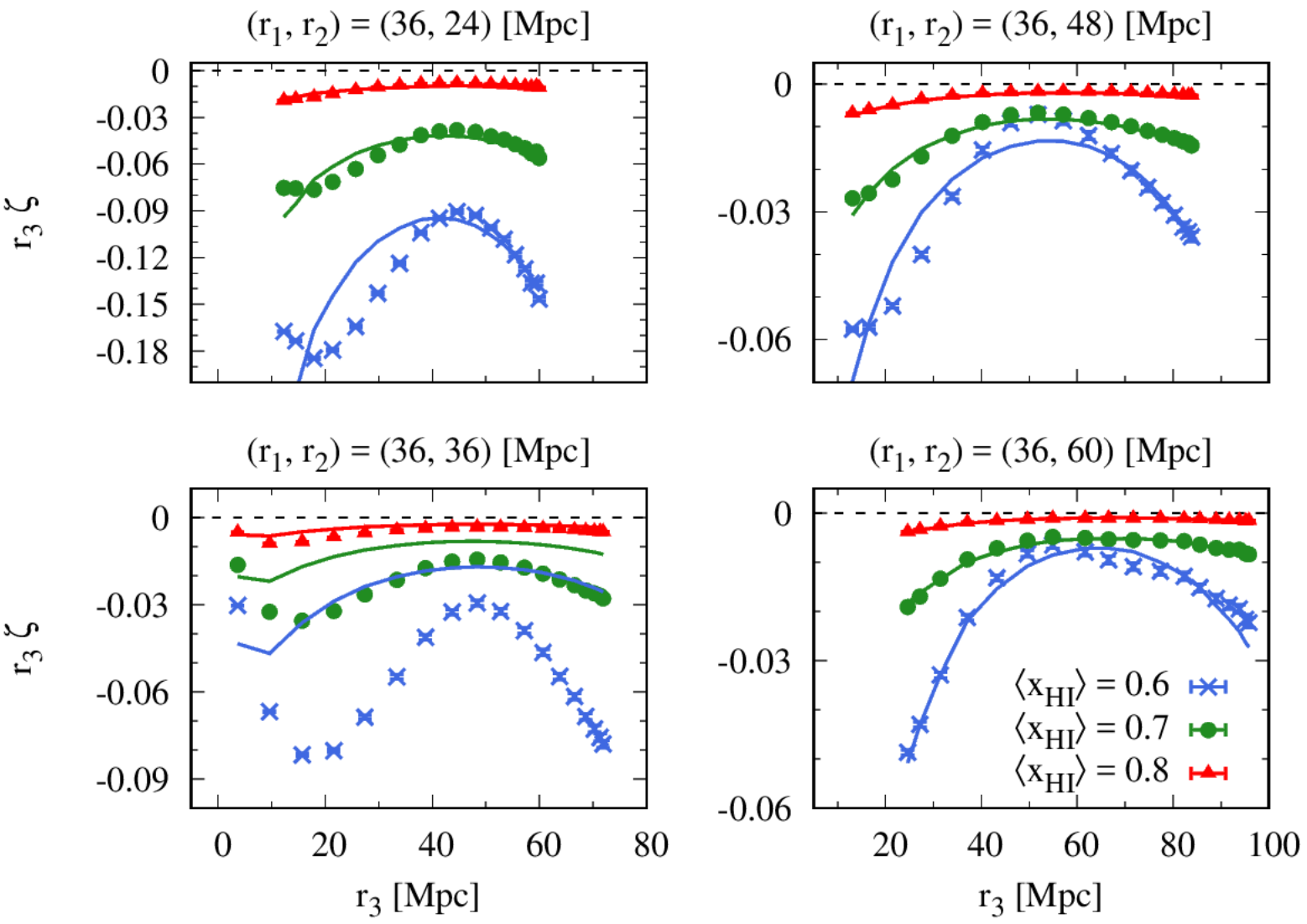
Assumption: 21cm brightness temperature is deterministic function of underlying matter density

Leading order approximations of correlation functions:

2pc $$\xi_{\delta T}^{(12)} \approx b_1^2 \xi_m^{(12)}$$

3pc $$\zeta_{\delta T}^{(123)} \approx b_1^3 \zeta_m^{(123)} + b_1^2 b_2 (\xi_m^{(12)} \xi_m^{(13)} + 2\, perm.)$$

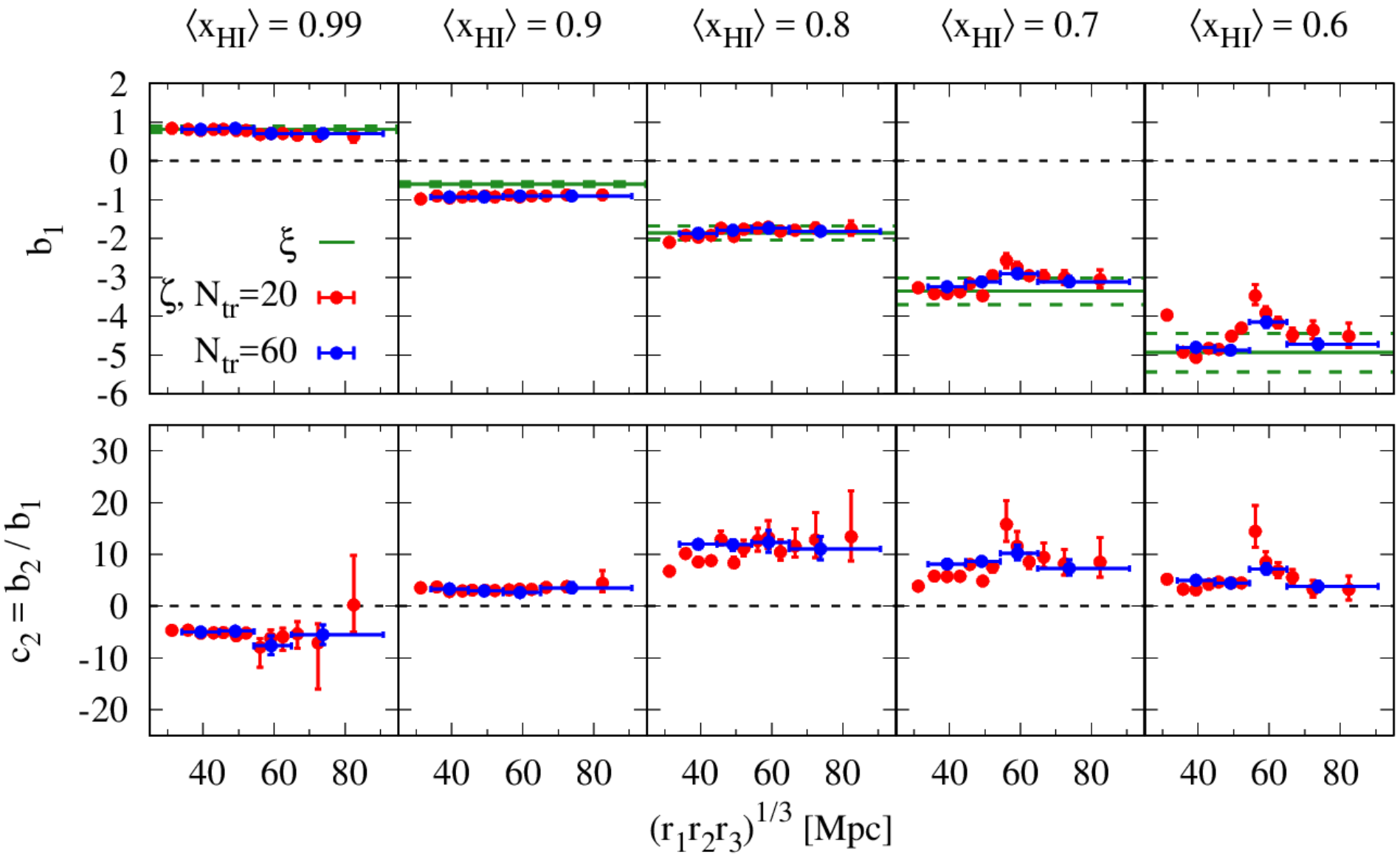
21cm 3pc fits



Fitting model $\zeta_{\delta T}^{(123)} \approx b_1^3 \zeta_m^{(123)} + b_1^2 b_2 \left(\xi_m^{(12)} \xi_m^{(13)} + 2\, perm. \right)$

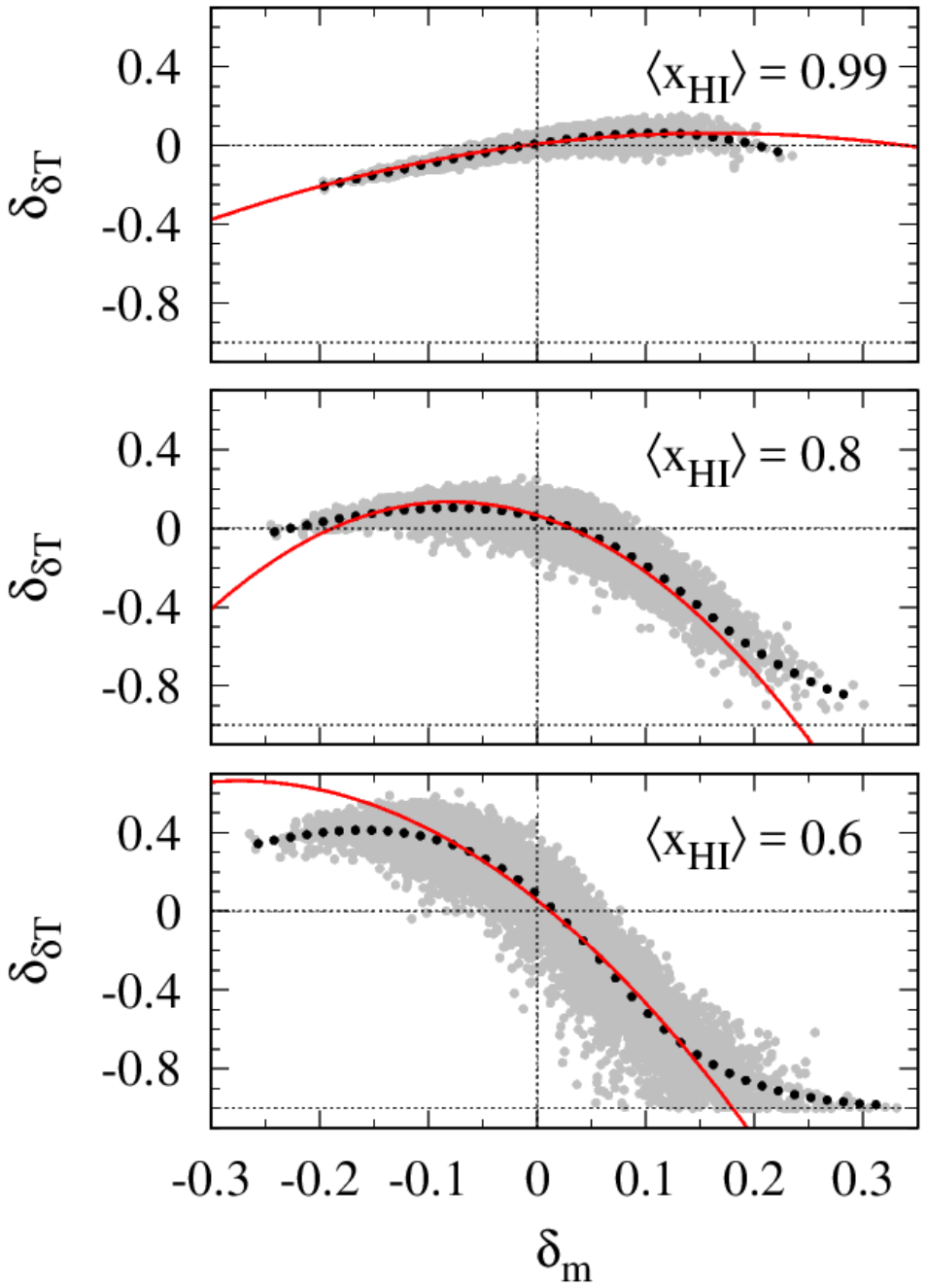
Bias comparison 3pc vs 2pc

Joint analysis of 240 striangle



Consistent linear bias measurements from 2pc and 3pc

Bias comparison



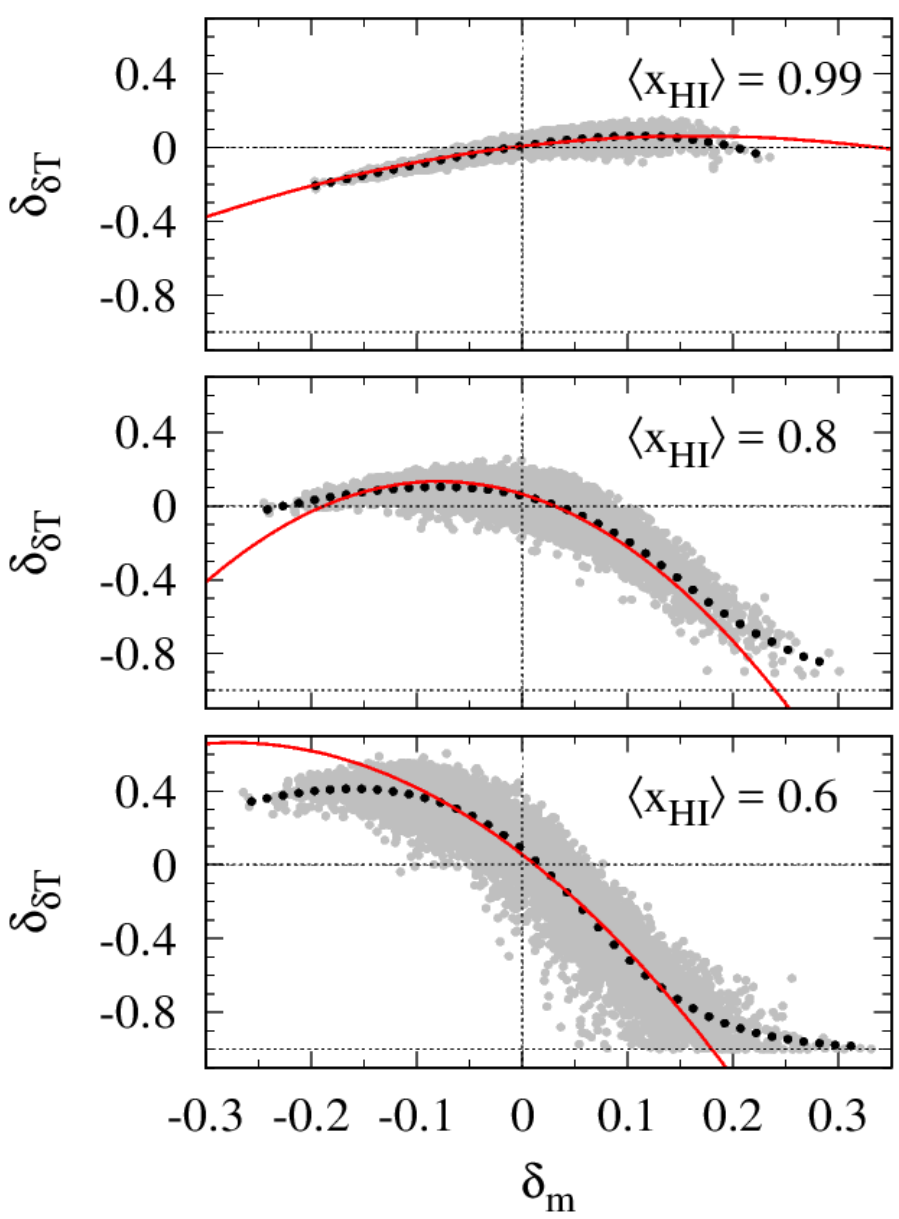
- grey dots: fluctuations in 24 Mpc cubical grid cells in one realization
- black dots show mean over 200 realizations
- red lines show predictions from quadratic bias model with b1 and b2 from 3pc measurements

$$\delta_{\delta T} \approx b_1 \delta_m + b_2 \left(\delta_m^2 - \sigma_m^2 \right)$$

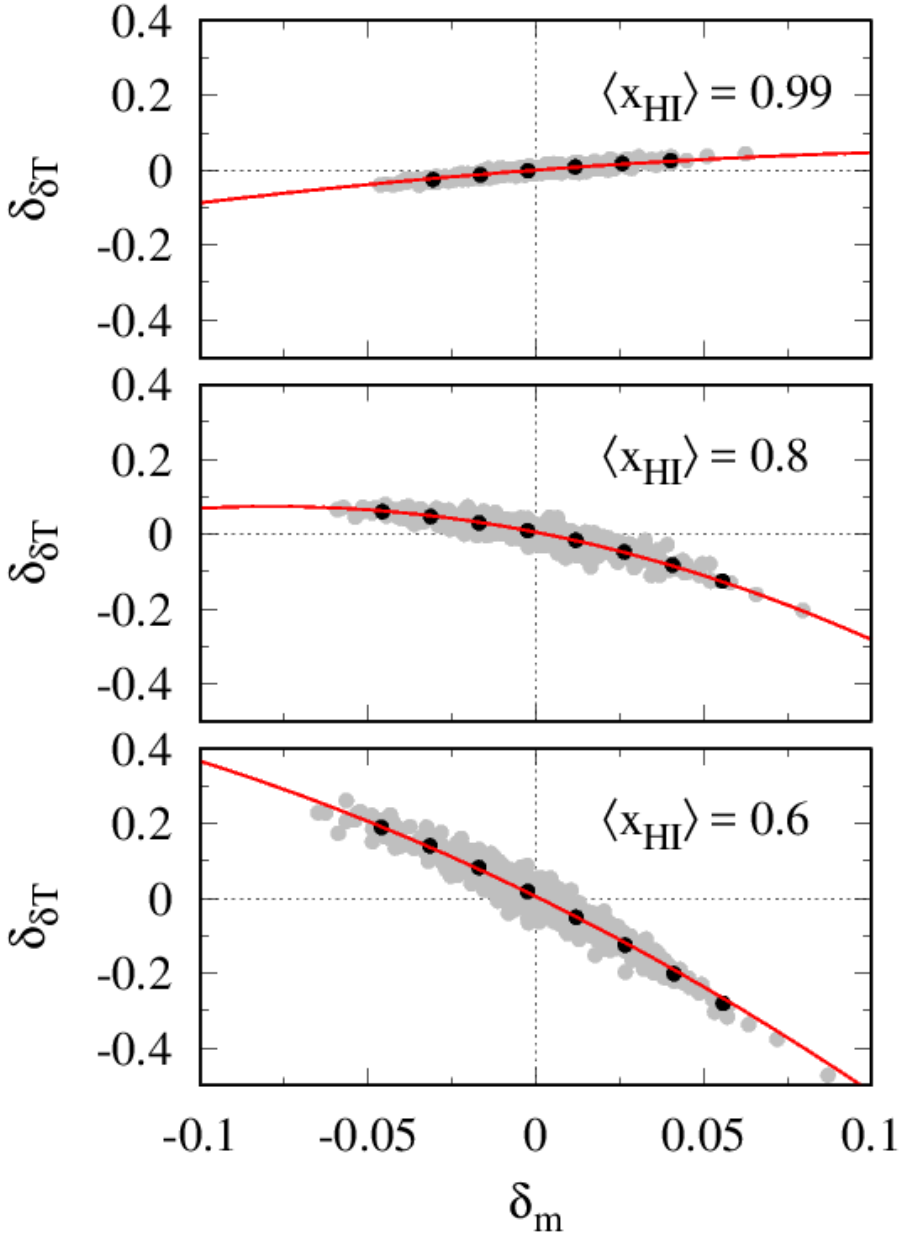
Linear bias (slope):
- positive at early times
- negative at late times

Bias comparison

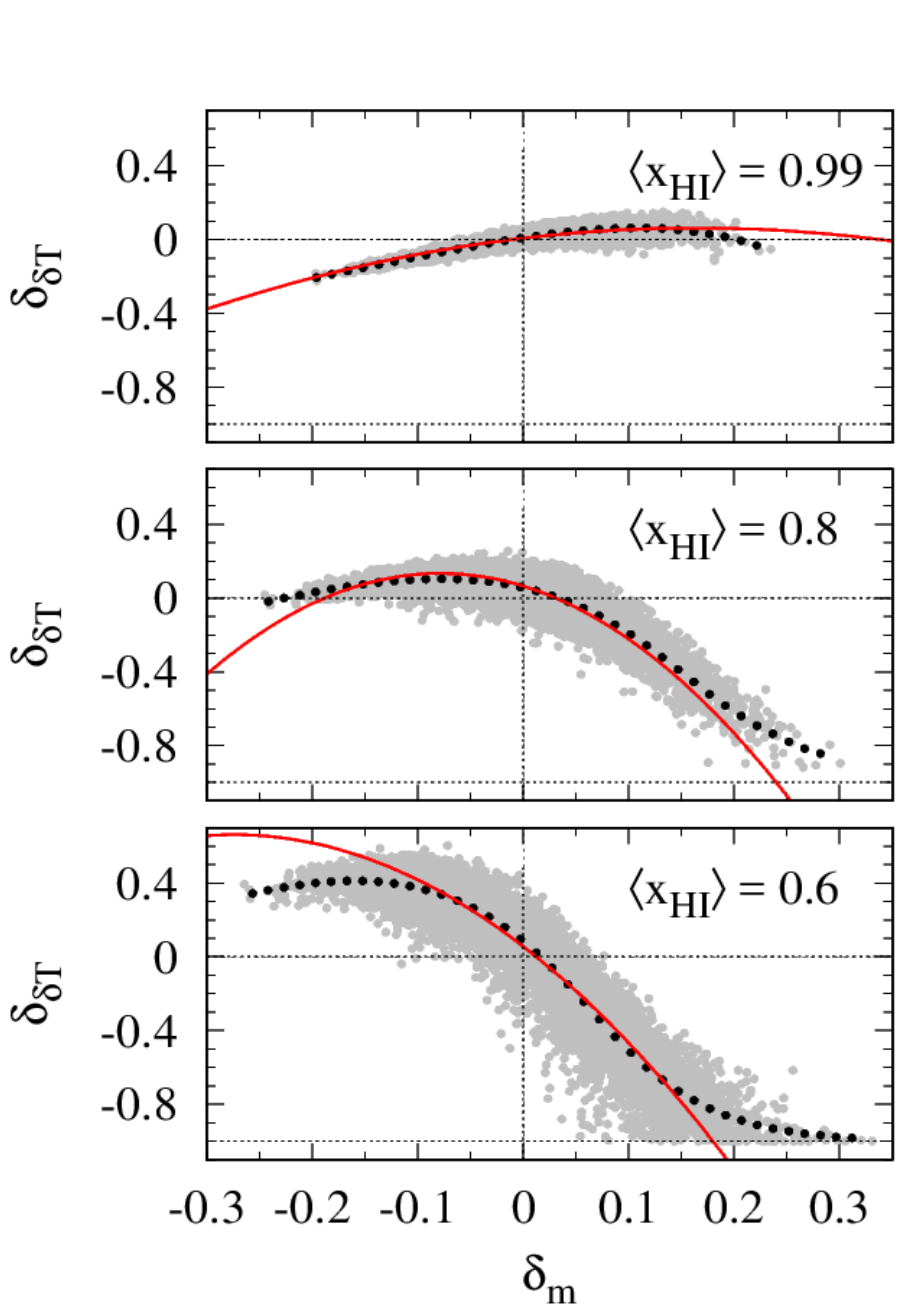
24 Mpc smoothing

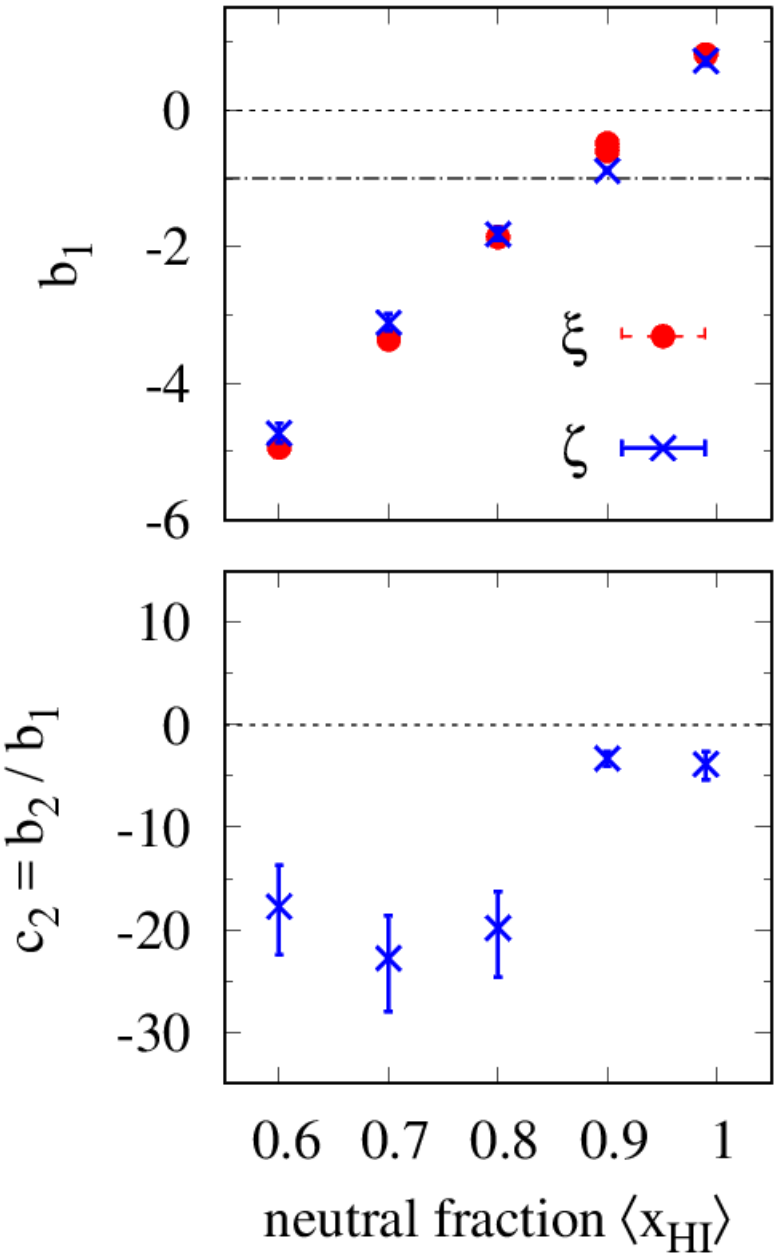


96 Mpc smoothing



Bias comparison





Summary & conclusions

- Quadratic bias model provides explanation for shape of 21cm 3pc at large scales and early times of reionization (neutral fraction > 60%, r> 20 Mpc)
- Linear bias from 2pc and 3pc model fits to measurements consistent at 10% level, accept for |b1| ~ 0, where b1 switches sign
- b1 and b2 measurements might allow for extracting physical information on EoR from 21cm observations
- Combining 21cm 2pc and 3pc can break growth-bias degeneracy

  → new possibility for cosmological constraints at high z

growth-bias degeneracy: $\xi_m^{(z)} = \xi_m^{(z_0)} D^2(z)/D^2(z_0)$

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growth-bias degeneracy:

$$\frac{D(z)}{D(z_0)} = \frac{b(z_0)}{b(z)} \sqrt{\frac{\xi_{\delta T}^{z}}{\xi_{\delta T}^{z_0}}}$$