Cross-correlation Study between the Cosmological 21cm Signal and the kinetic SZ effect

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Outline

- Introduction
  - basic ideal
  - motivation
- Simulations
  - cosmological 21cm (EoR) signal
  - kSZ anisotropies
- kSZ-EoR cross-correlation
  - homogeneous vs. patchy
  - primordial CMB fluctuations
- Summary and Conclusions

Introduction: basic idea

- CMB photons scatter off the ionized bubbles produced during the EoR → secondary CMB anisotropies
- thermal SZ effect, **kinetic SZ effect** & imprint in polarization
- the kSZ – the EoR map should anti-correlate

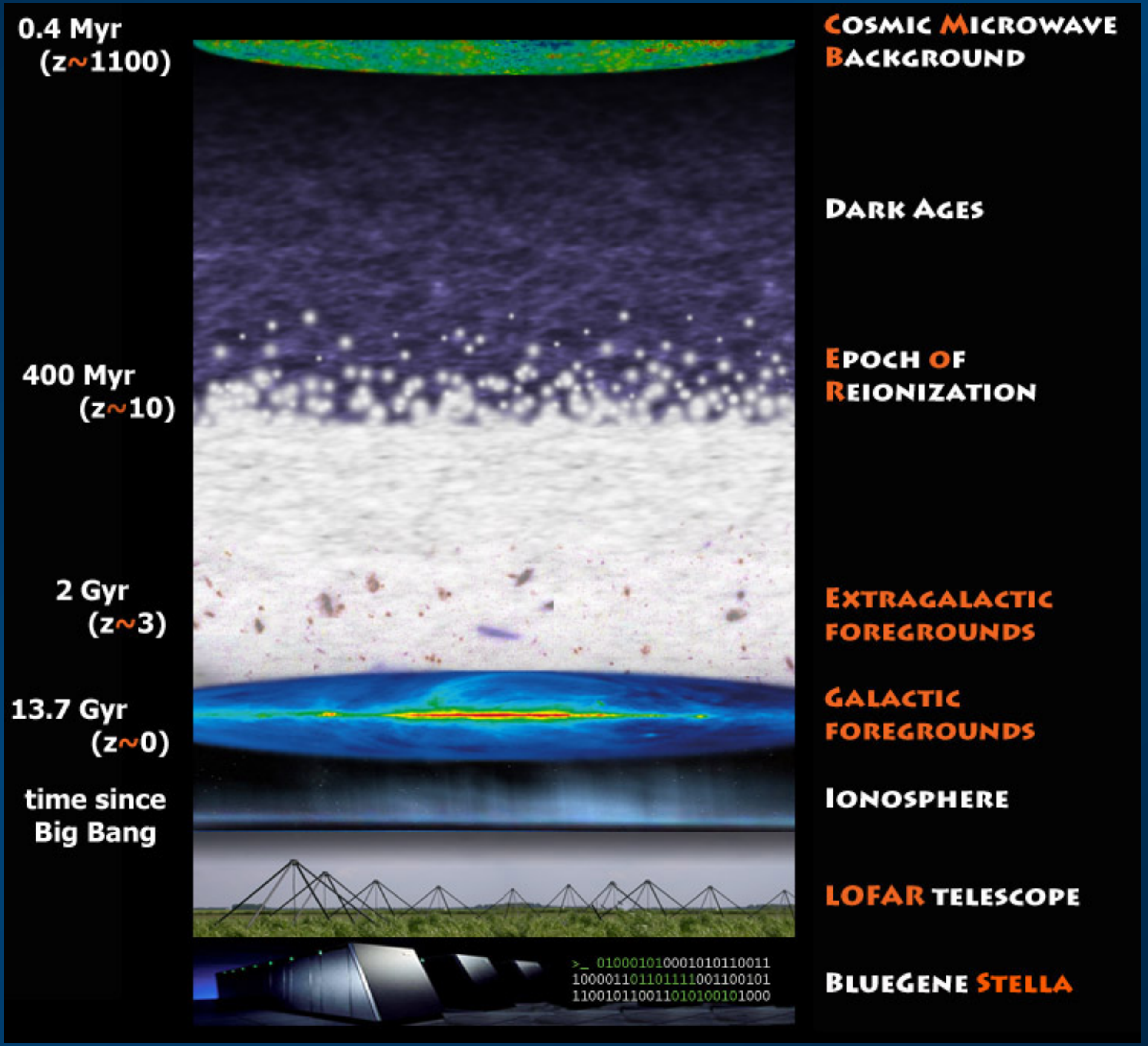
EoR map **kSZ map**

$$\delta T_{EoR} \sim n_H \qquad (\delta T/T)_{kSZ} \sim n_e$$

$$n_e \cong 1 - n_H$$

anti-correlation

Introduction: motivation



- number of planned EoR experiments (e.g. LOFAR, MWA)

- EoR experiments are a big challenge

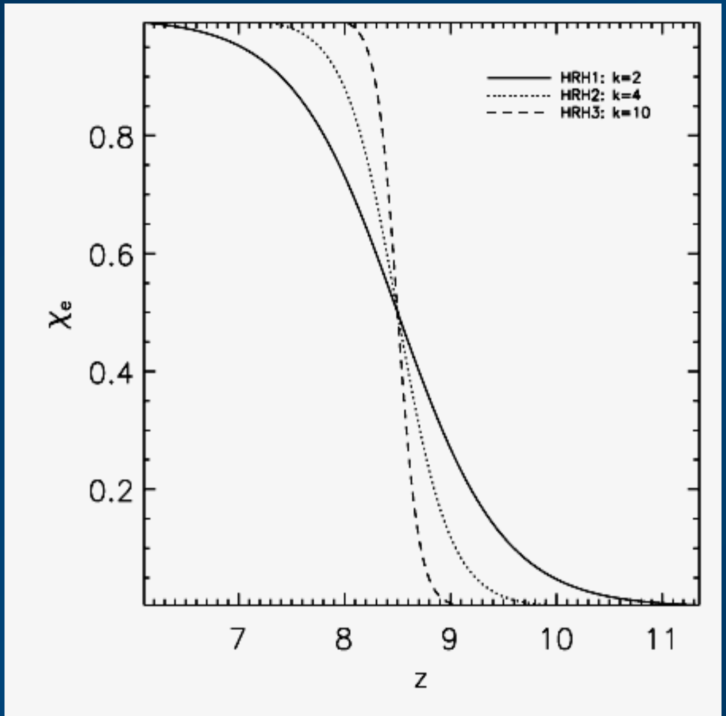
Introduction: motivation

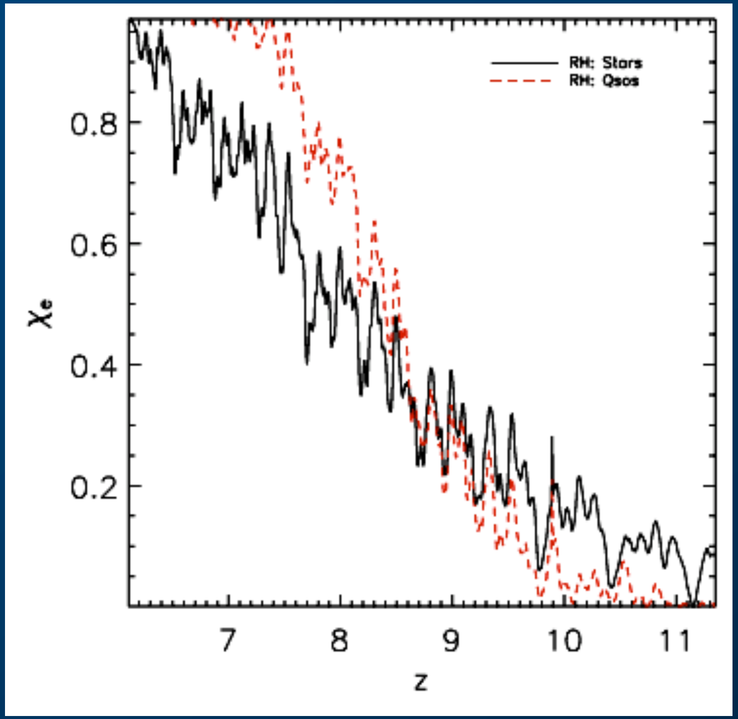
- planned cosmological 21-cm experiments (e.g. LOFAR-EoR, MWA & SKA) and CMB experiments (e.g. Planck)

- kSZ-EoR cross-correlation
  - additional probe of the EoR
  - the measurable statistics sould suffer less from the foregrounds and systematics as in the case of autocorrelation studies

Simulations: EoR & kSZ maps

- **BEARS algorithm (*Thomas et al. 2009*)**
  - N-body DM simulation along with a 1-D radiative transfer code
  - density, neutral fraction & velocity cubes
  - 100 Mpc/h comoving in size
  - 3 homogeneous and 2 patchy reionization history models





Simulations: kSZ maps

- **BEARS:** density, neutral fraction & velocity cubes

$$\tau = c\sigma_{\mathrm{T}} \int_0^z n_{\mathrm{e}} \frac{(1+z)^2}{H} \mathrm{d}z$$

$$\left(\frac{\delta T}{T}\right)_{\mathrm{kSZ}} = -\sigma_{\mathrm{T}} \int_0^{t_0} \mathrm{e}^{-\tau} n_{\mathrm{e}} (\hat{r} \cdot \vec{v}) \mathrm{d}t$$

$$n_{\mathrm{e}} = \bar{n}_{\mathrm{H}} \bar{\chi}_{\mathrm{e}} (1 + \delta + \delta_{\chi_{\mathrm{e}}} + \delta\delta_{\chi_{\mathrm{e}}})$$

$$\chi_{\mathrm{e}} = 1 - \chi_{\mathrm{n}}$$

$$\left(\frac{\delta T}{T}\right)_{\mathrm{kSZ}} = -\sigma_{\mathrm{T}} \bar{\mathrm{n}}_{\mathrm{H}(0)} \int \frac{(1+z)^2}{H} \mathrm{e}^{-\tau} \bar{\chi_e} \cdot (1 + \delta + \delta_{\chi_e} + \delta\delta_{\chi_e}) v_{\mathrm{r}} \mathrm{d}z$$

homogenous reionization term

patchy reionization term

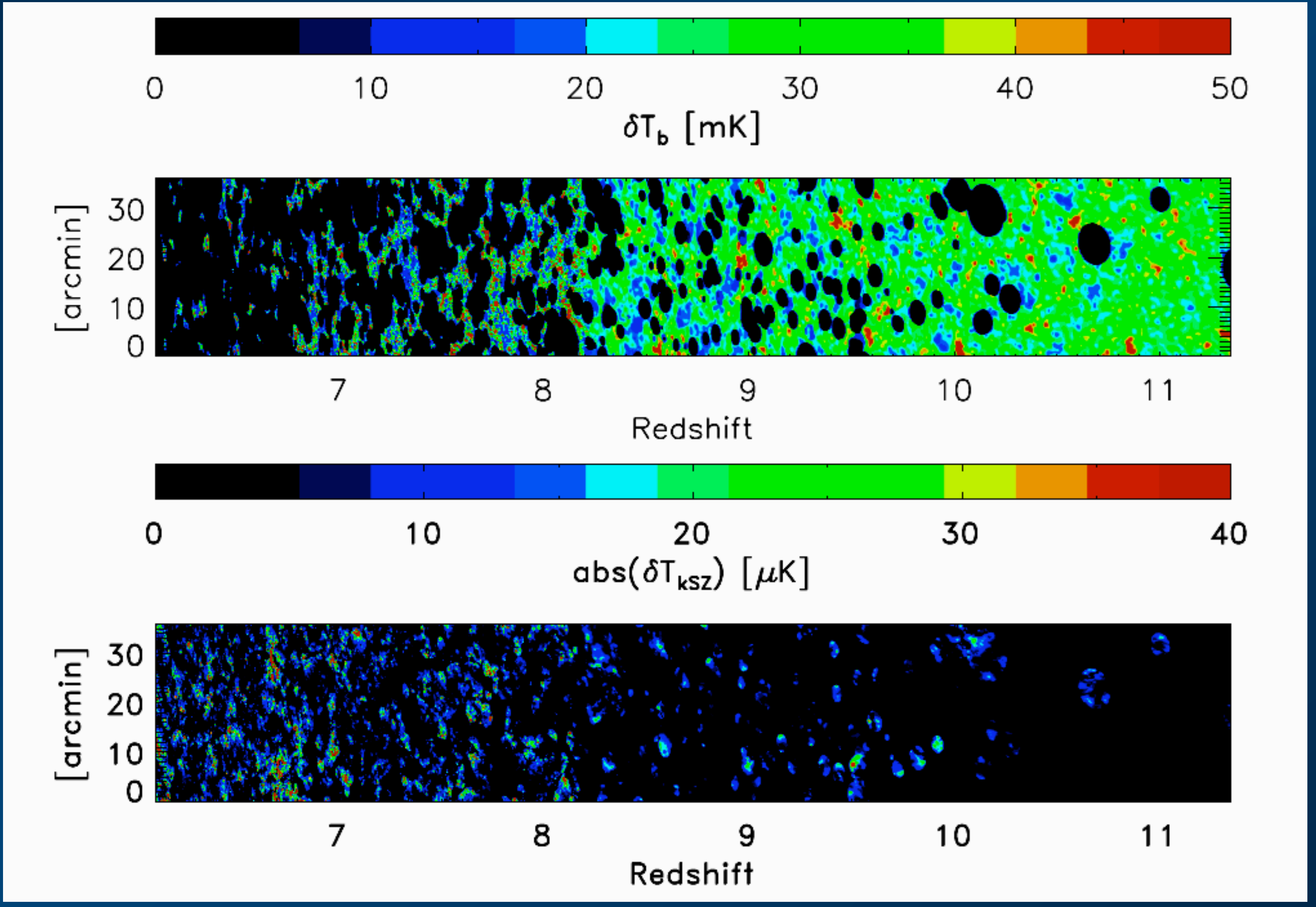
mixed term

Simulation: patchy RH

"Stars"

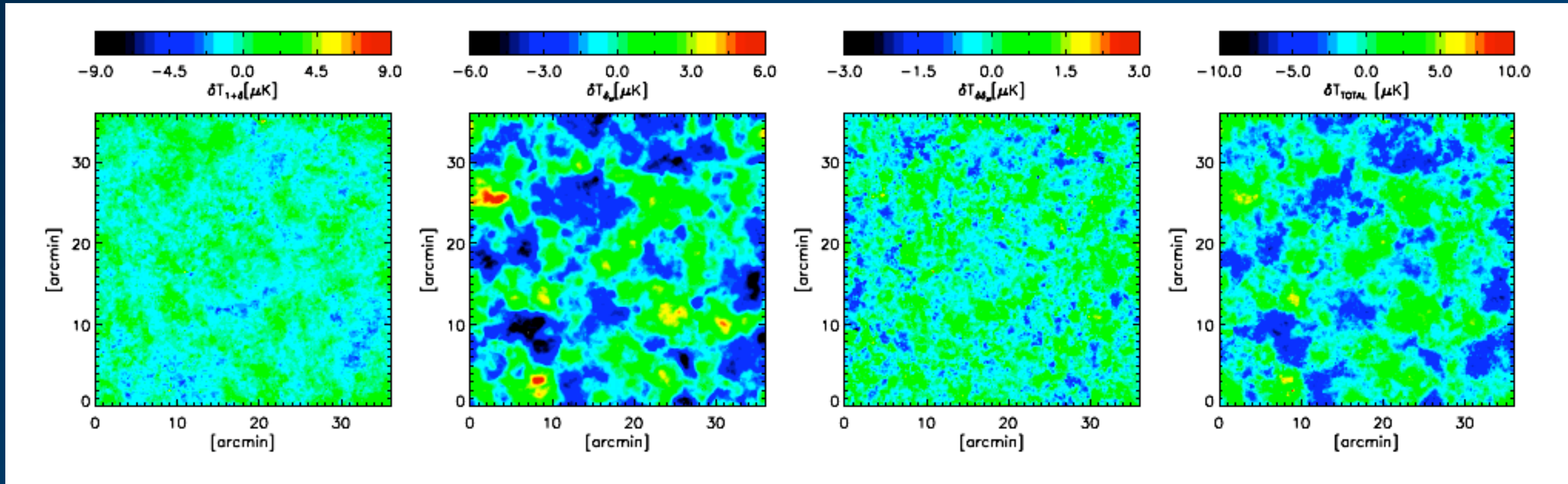
EoR

kSZ



Simulations: kSZ maps

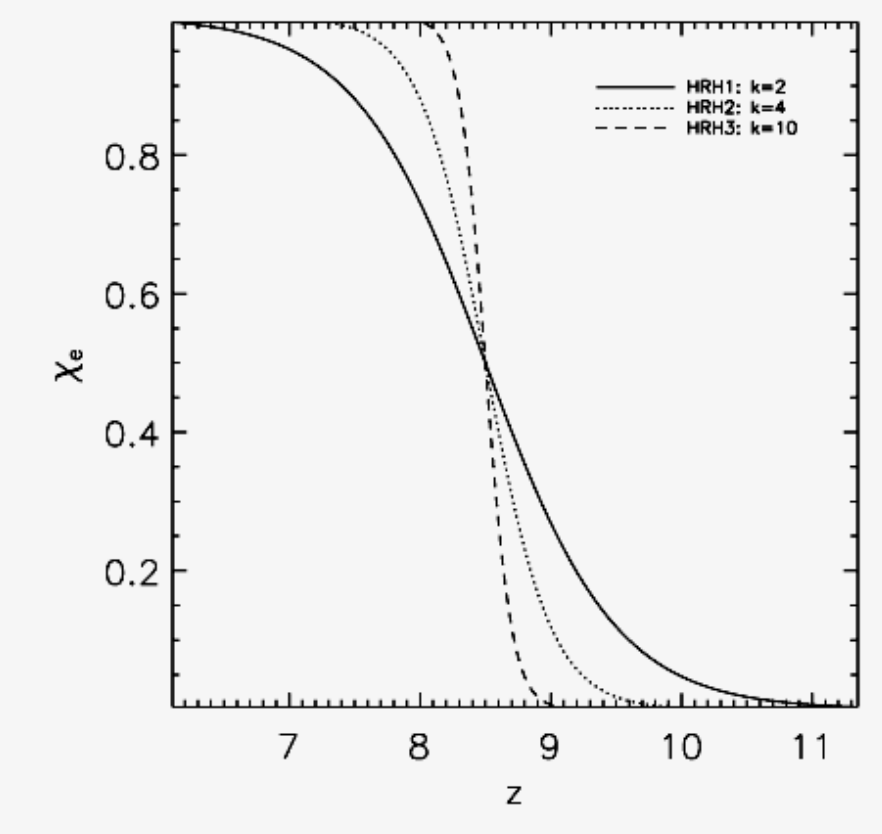
δT [μK] maps 0.6 deg x 0.6 deg



	$\delta T_{\rm kSZ}$	'$1+\delta$'	'δ_{χ_e}'	'$\delta\delta_{\chi_e}$'	TOTAL
STARS	*mean* [μK]	0.03	0.58	0.02	0.63
	rms [μK]	0.80	1.74	0.40	2.00
QSOS	*mean* [μK]	0.03	0.27	0.01	0.30
	rms [μK]	0.93	1.28	0.28	1.57

X-correlation: homogeneous RH

$$\chi_e = \frac{1}{1 + e^{k(z - z_{\rm reion})}}$$



$$C_0 = \frac{1}{n-1}\sum_{i,j}\frac{(a_{i,j}-\bar{a})(b_{i,j}-\bar{b})}{\sigma_a \sigma_b}$$

integ. kSZ & integ. EoR

HRH1: k=2
C_0=0.10

HRH2: k=4
C_0=0.21

HRH3: k=10
C_0=0.25

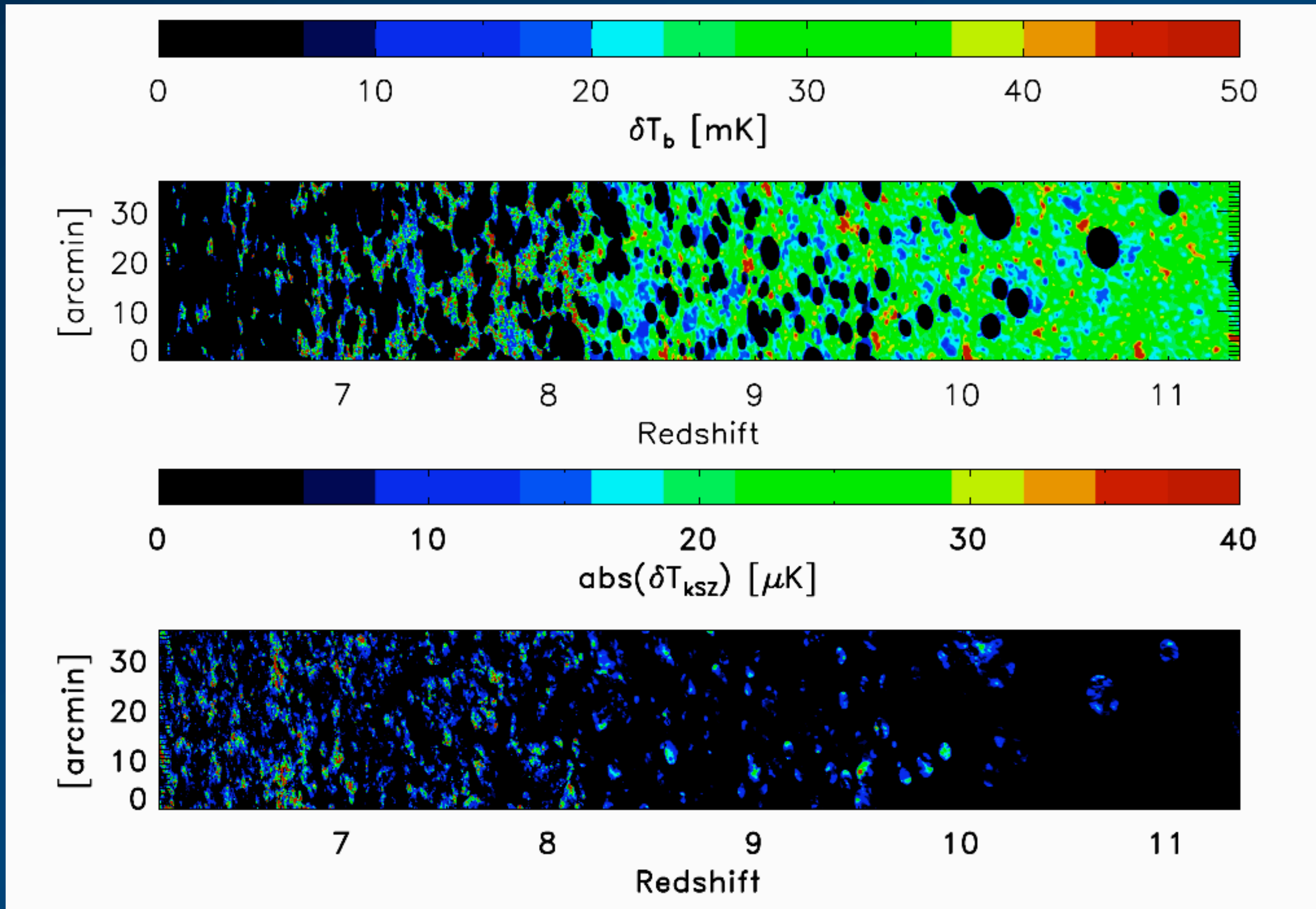
- **for HRH: kSZ & EoR map correlate and correlation is strongest for sharp reionization history (*Alvarez et al. 2006*)**

X-correlation: patchy RH

"Stars"

EoR

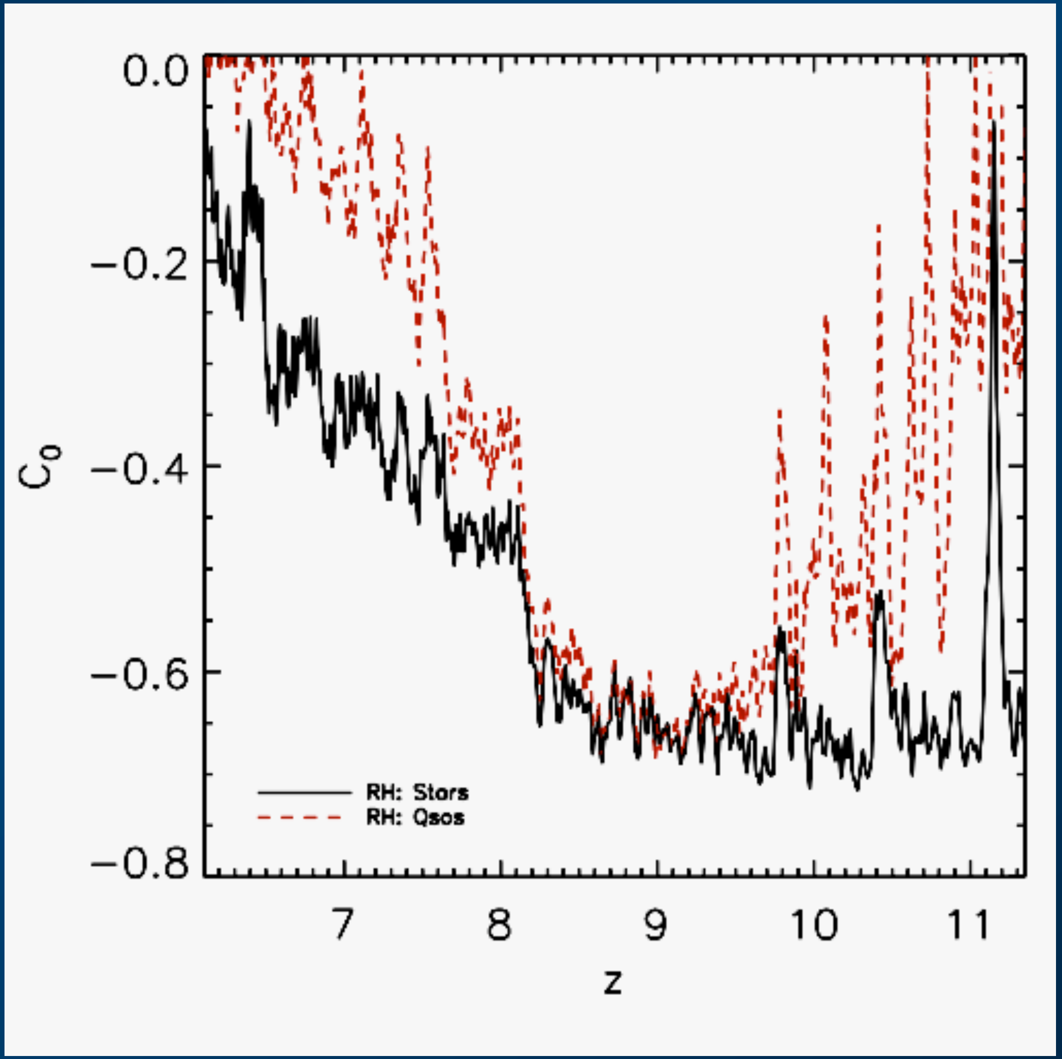
kSZ



X-correlation: patchy RH

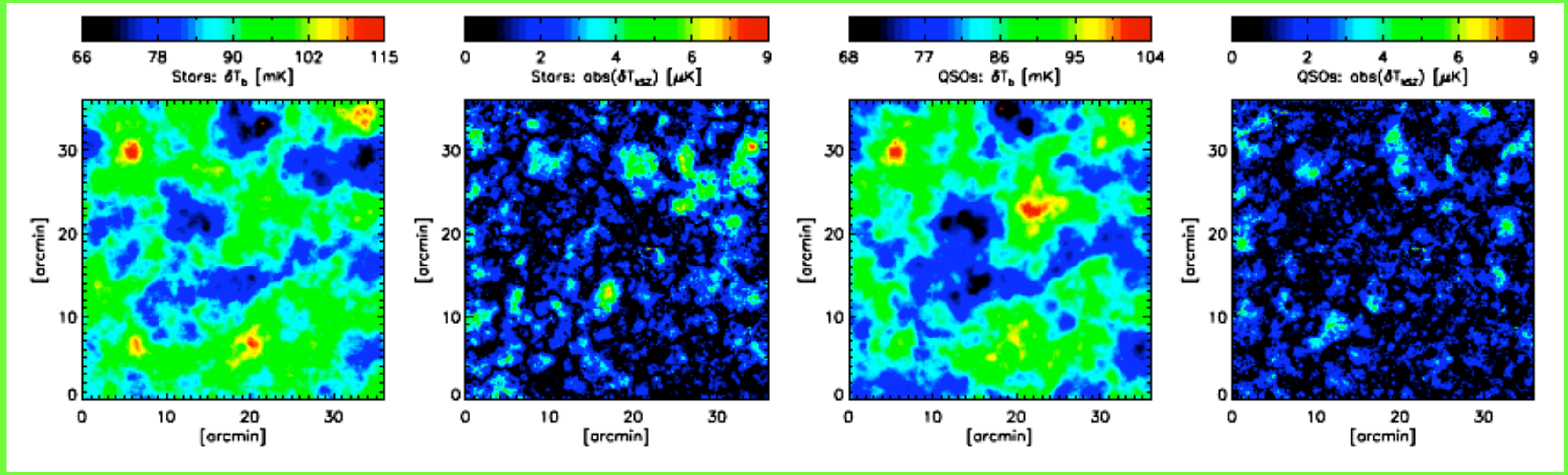
kSZ (z) & EoR (z)

- **for PRH:** kSZ & EoR map as a func. of redshift anti-correlate and strongest signal we get around z~8.5 (half of the reionization)



X-correlation: patchy RH

- integ. EoR & integ. kSZ maps (0.6 deg x 0.6 deg)



EoR [mK] |kSZ| [μK] EoR [mK] |kSZ| [μK]

PRH: Stars

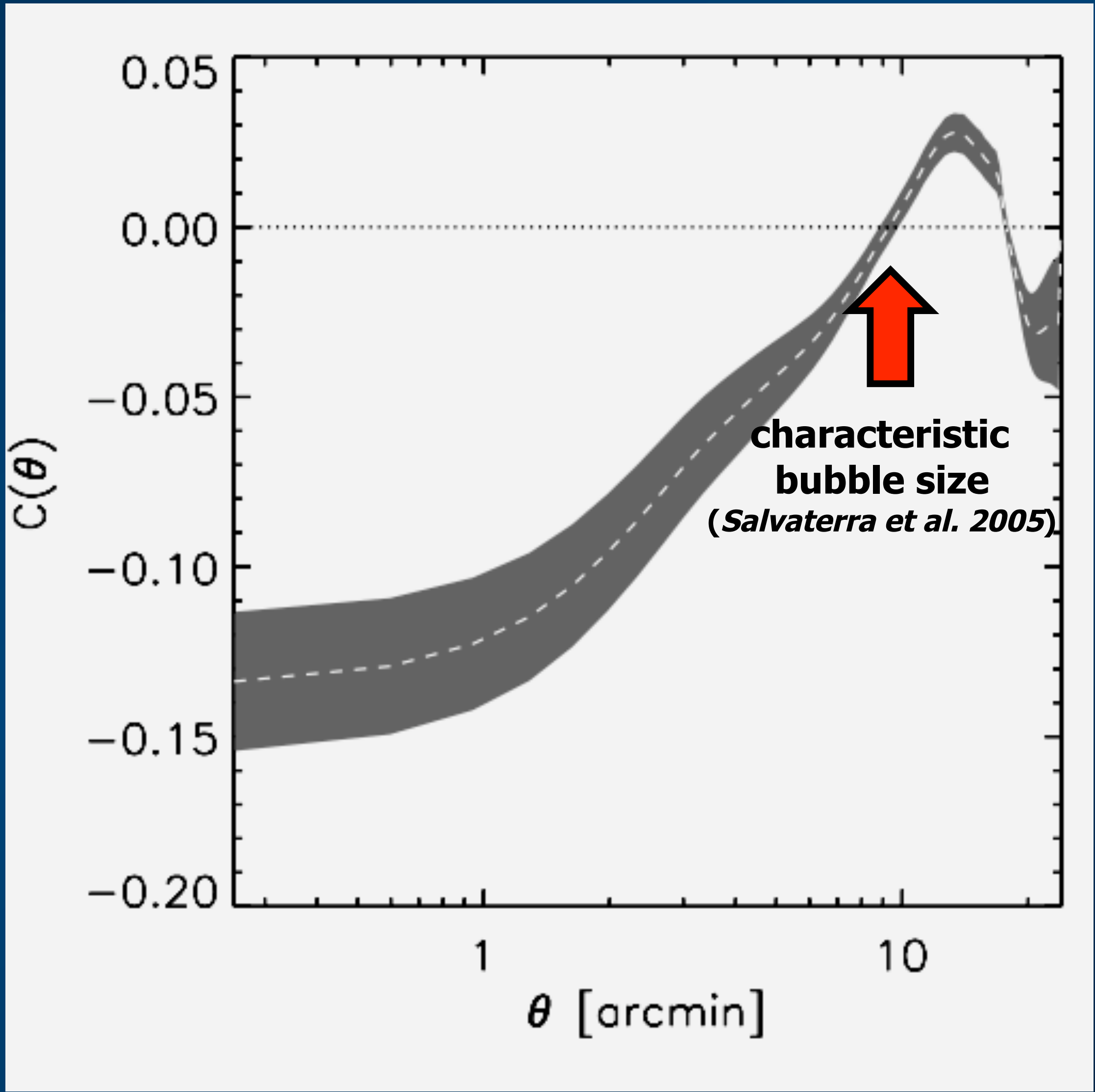
$C_0 = -0.16 \pm 0.02$

PRH: QSOs

$C_0 = -0.05 \pm 0.02$

- **Stars**: patchy term dominates over the other terms
- **QSOs**: homog. & patchy term have the same order and tend to cancel each other; bubbles larger ➔ more noise in correlation

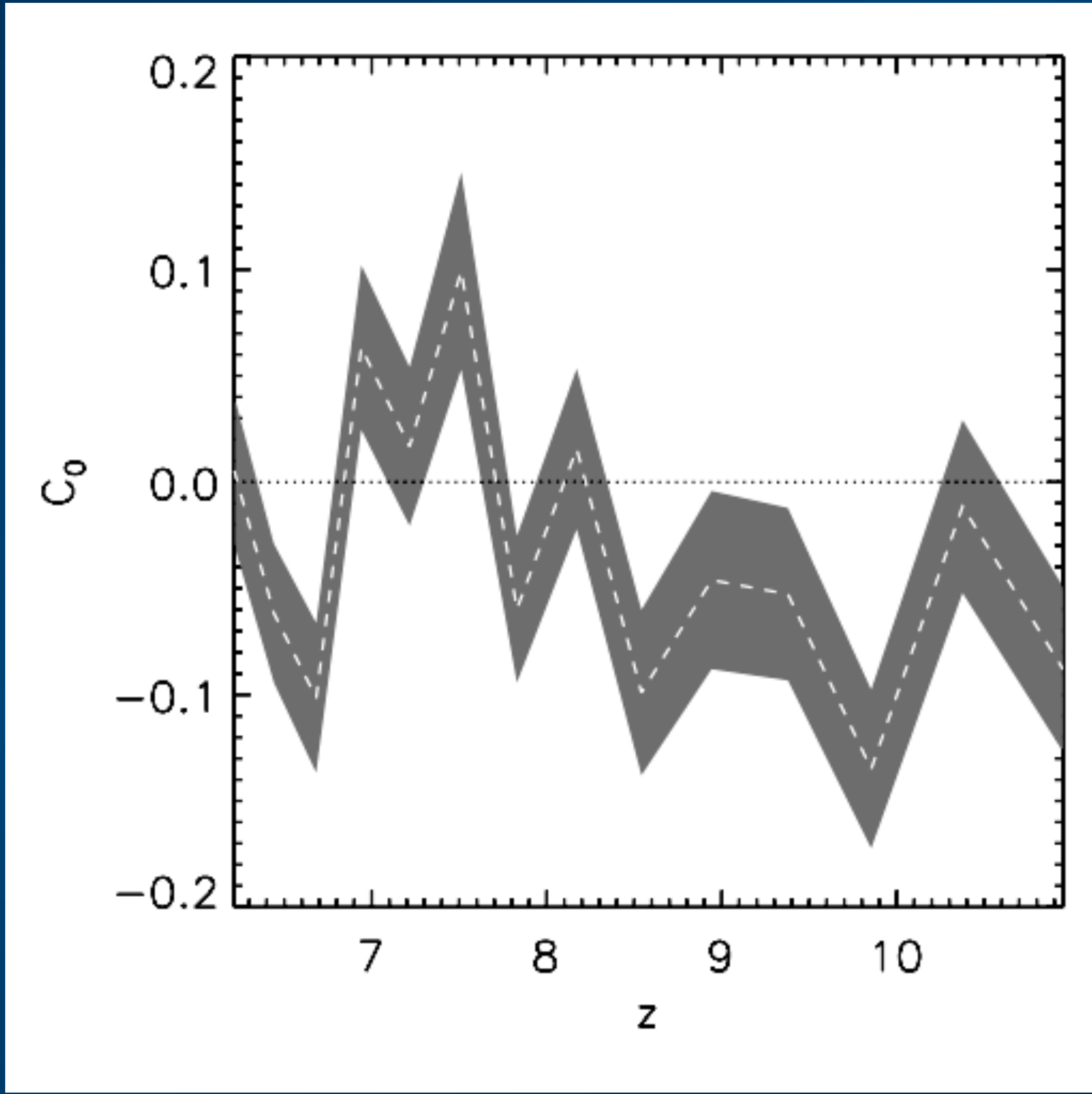
X-correlation: patchy RH



Cross-correlation as a function of lag

integ. kSZ & integ. EoR for Stars patch reion.

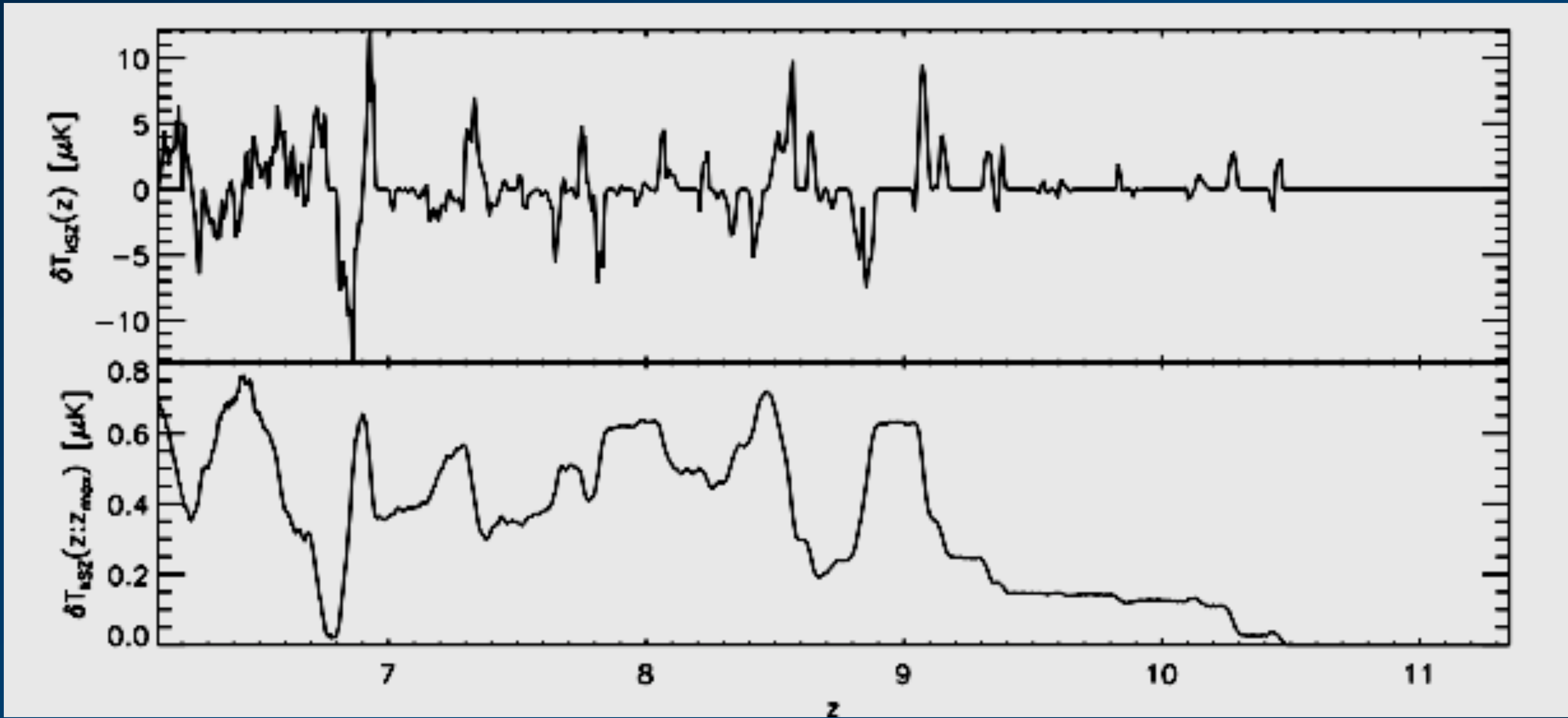
X-correlation: patchy RH



Cross-correlation
as a function of z

integ. kSZ & EoR(z)
for Stars patchy reion.

X-correlation: patchy RH

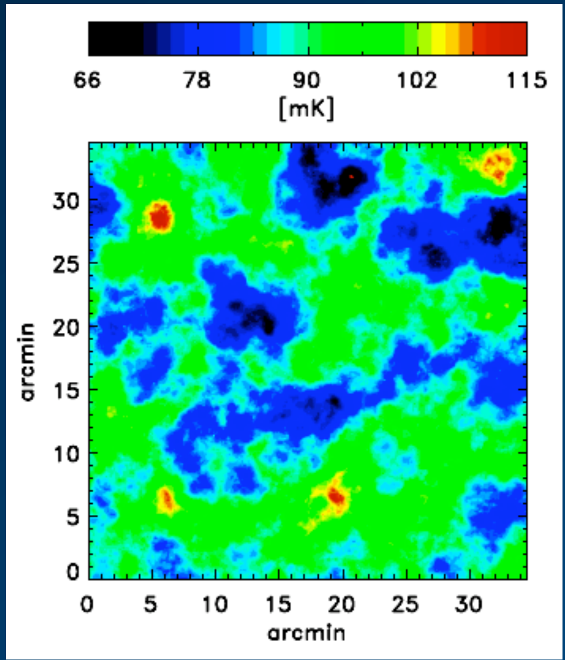


LOS through the kSZ cube

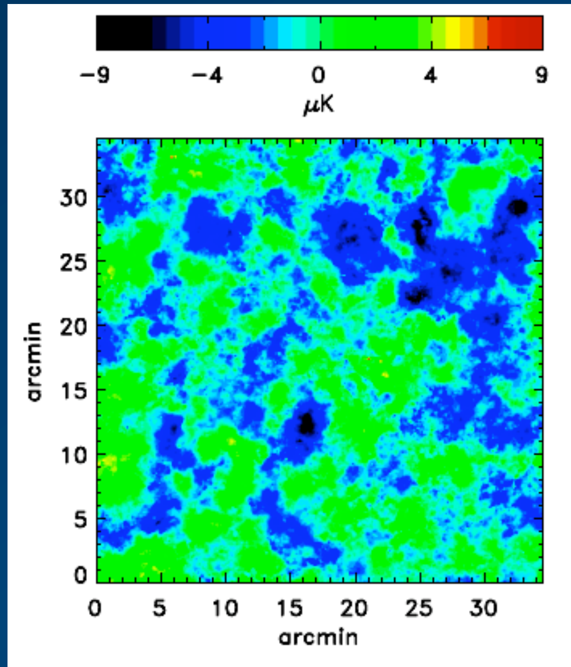
➔ **no coherent redshift evolution of the kSZ effect**

X-correlation: pCMB

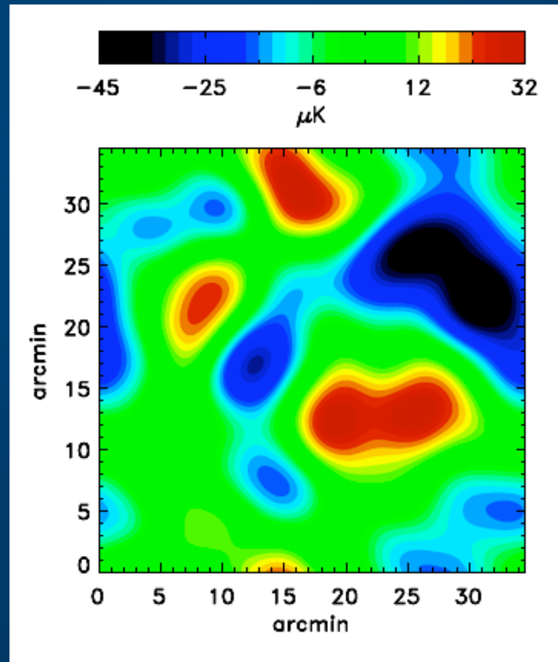
- pCMB map produced using CMBFAST power spectra



integ. EoR map



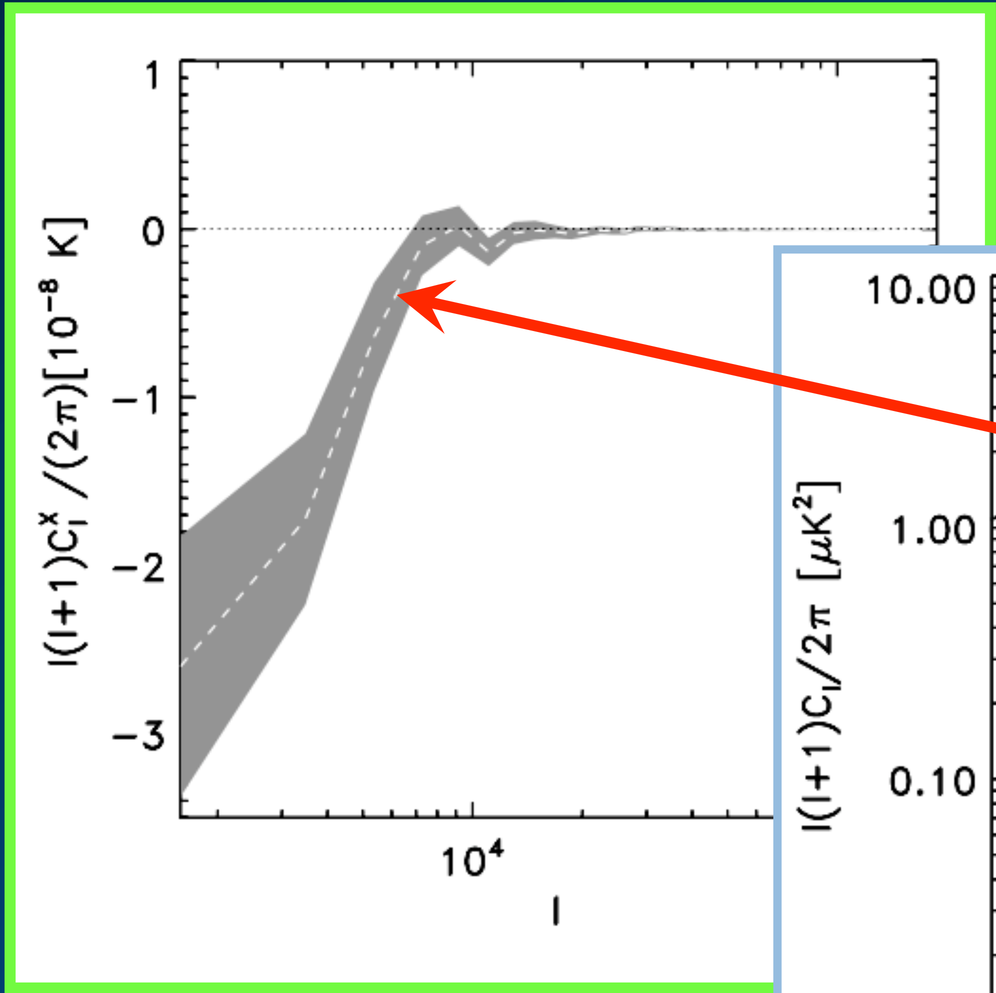
kSZ map

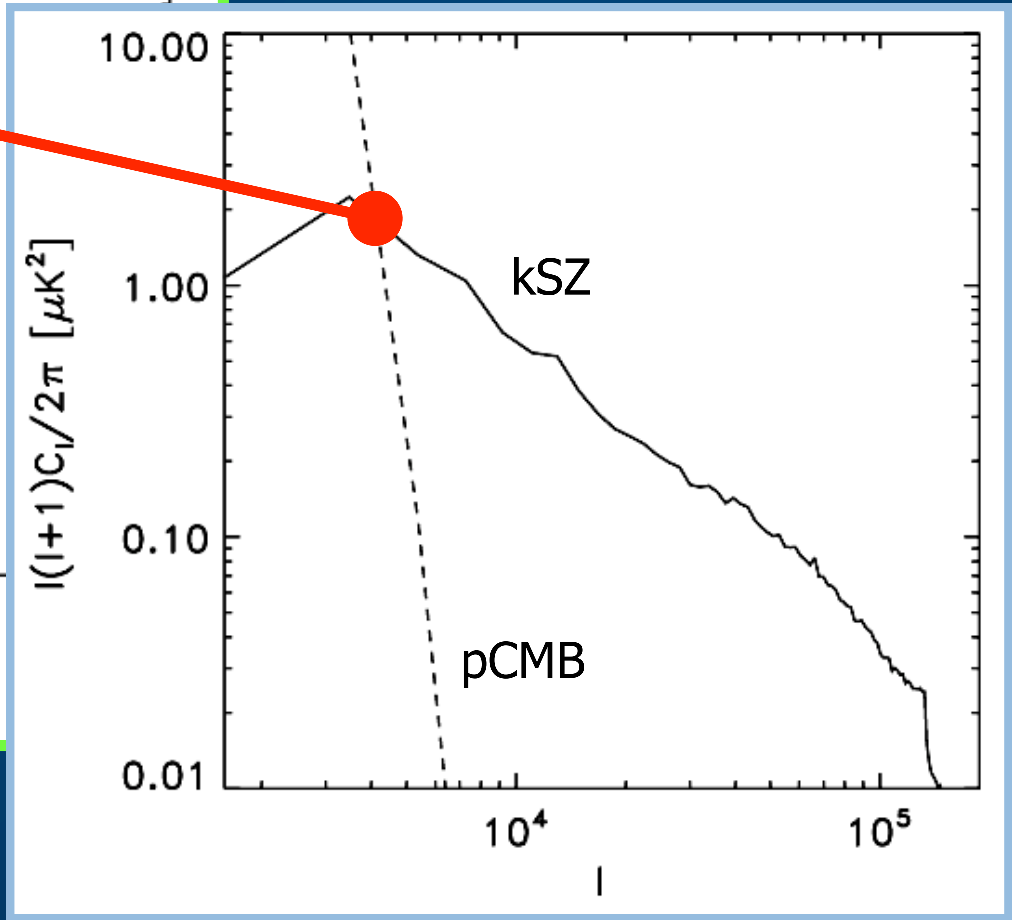


pCMB map

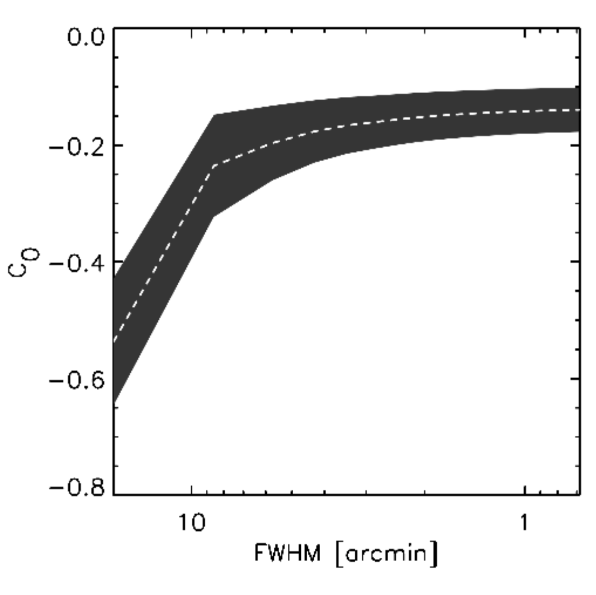
➢ once the pCMB fluctuations are included the correlation between the kSZ-EoR maps is not significant any more **(C_0=-0.0±0.2)**

X-correlation: pCMB

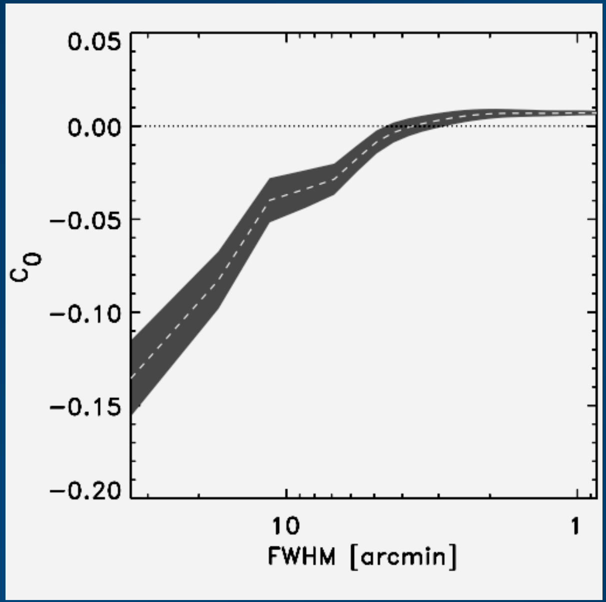


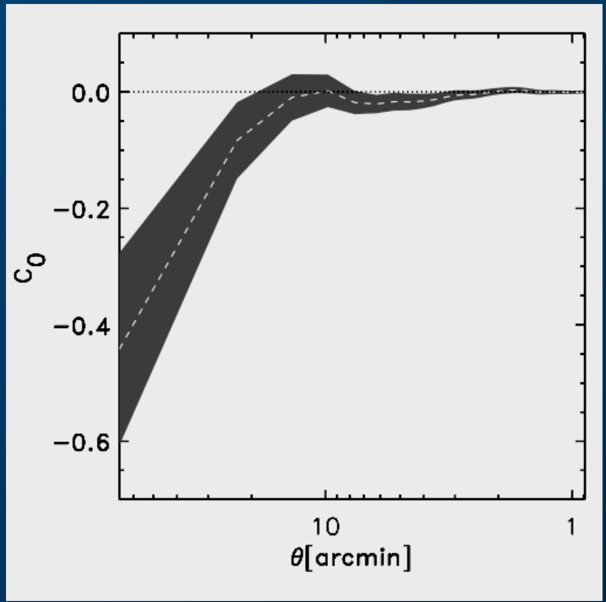


X-correlation: pCMB



• different filtering procedures





• once the pCMB included: no significant X-correlation

Summary & Conclusions

- the kSZ anisotropies from the homogeneous and patchy reionization are calculated based on radiative transfer EoR numerical simulations and then cross-correlated with cosmological 21-cm maps

- **for HRH:** kSZ & EoR map correlate and correlation is strongest for sharp reionization history

- **for PRH: integrated kSZ & EoR maps**
  - extended history: patchy term dominates ➔ -0.16 ± 0.02
  - sharper history: homog. & patchy term have the same order and tend to cancel each other; larger bubbles introduce more noise in the correlation (-0.05 ± 0.02)

- **once the pCMB fluctuations are included the correlation between the kSZ-EoR maps is not significant any more**

Jelic et al. 2009, astro-ph 0907.5179