Correlation Between Galaxies and 21cm emission

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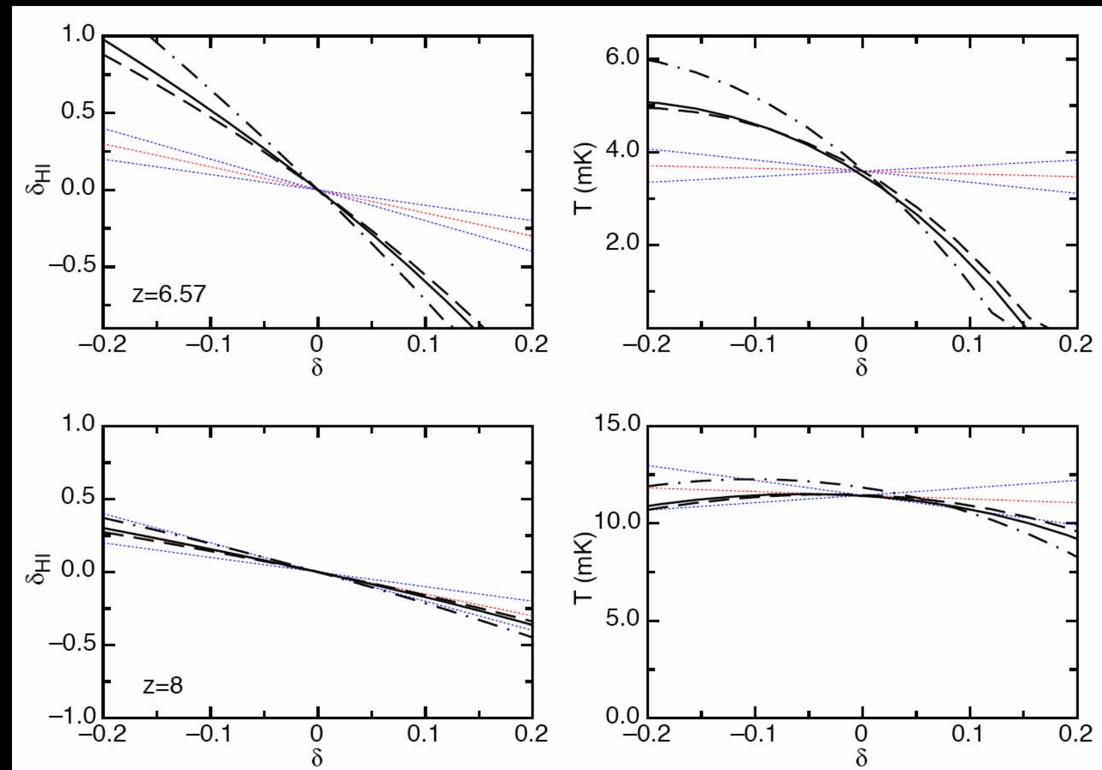
See also recent work from Steve Furlanetto and Adam Lidz

Outline

- Semi-analytic model of density dependent reionization.
- Angular auto-correlation function of brightness temp.
- Mass of Subaru Deep Field Lyα emitters.
- Cross correlation of galaxies with 21cm emission.
- Subaru Deep Field galaxies as tracers of overdense regions of the IGM.
- Detectibility of the cross-correlation between galaxies and 21cm emission using first generation surveys.

Density Dependent Reionization

Inside-out or outside-in?



C=2

C=10

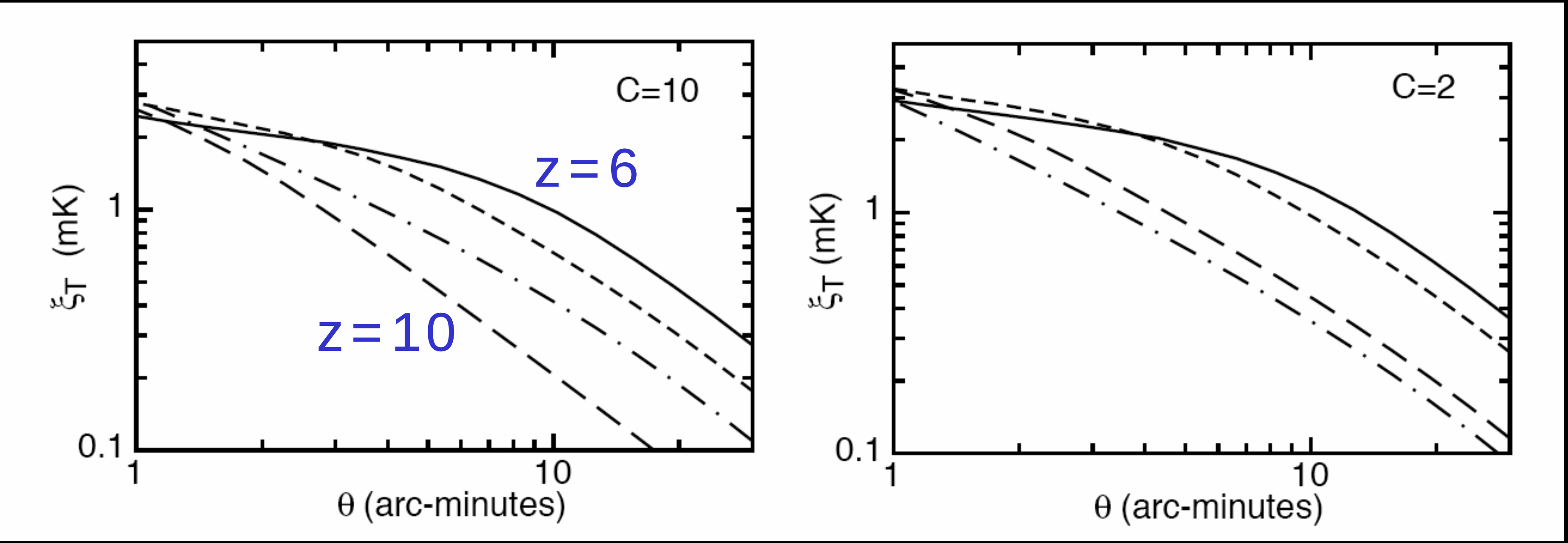
C=20

Standard Expression has $\delta=0$ and $R=\infty$.

$$\begin{aligned}\frac{dQ_{\delta,R}}{dt} &= \frac{N_{\rm ion}}{0.76}\left[Q_{\delta,R}\frac{dF_{\rm col}(\delta,R,z,M_{\rm ion})}{dt}\right.\\ &\left.\qquad + (1-Q_{\delta,R})\,\frac{dF_{\rm col}(\delta,R,z,M_{\rm min})}{dt}\right]\\ &- \alpha_{\rm B} C n_{\rm H}^0\left(1+\delta\frac{D(z)}{D(z_{\rm obs})}\right)(1+z)^3\,Q_{\delta,R},\end{aligned}$$

$$F_{\rm col}(\delta,R,z) = {\rm erfc}\left(\frac{\delta_{\rm c}-\delta(z)}{\sqrt{2\left([\sigma_{\rm gal}]^2-[\sigma(R)]^2\right)}}\right)$$

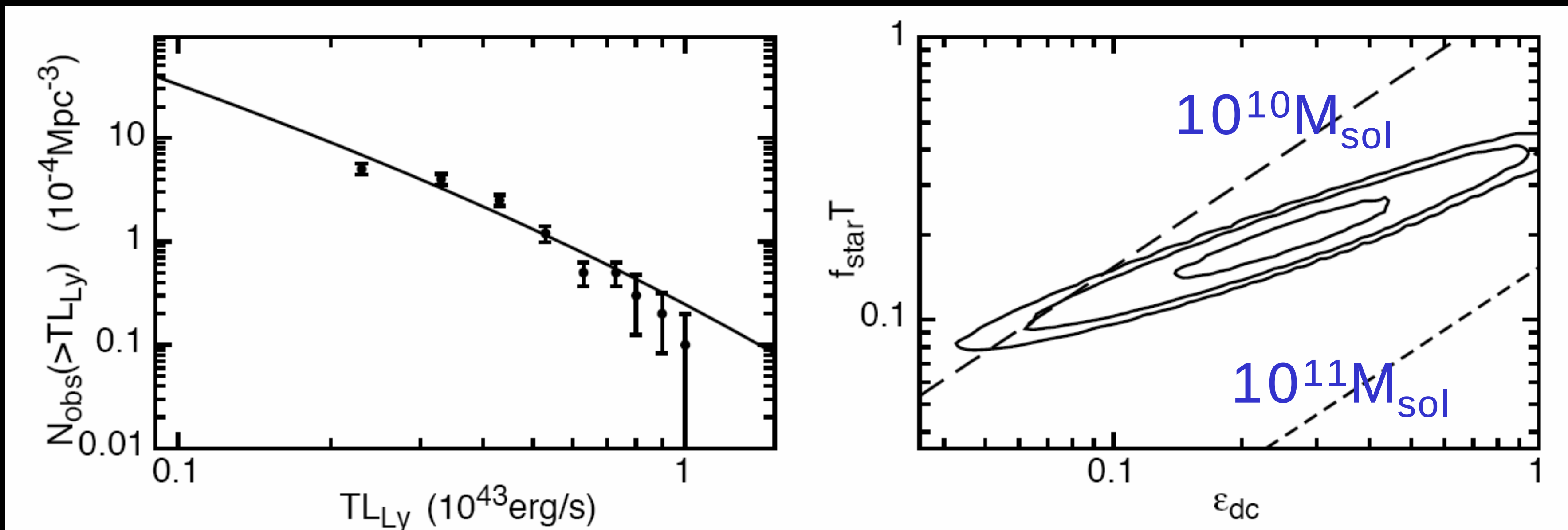
Temperature Auto-Correlation Function



Valid while bubble size smaller than θ

$$\xi_T(\theta) = \langle (T - \langle T \rangle)^2 \rangle^{1/2}$$
$$= \left[\frac{1}{\sqrt{2\pi}\sigma(R)} \int d\delta \, (T(\delta) - \langle T \rangle)^2 \, e^{-\frac{\delta^2}{2\sigma(R)^2}} \right]^{\frac{1}{2}}$$

Mass of Subaru Deep Field Lyα Emitters



$$N(>\mathcal{T}L_{\rm Ly}) = \epsilon_{\rm dc}\int_{M(L_{\rm Ly})}^{\infty} dM\,\frac{dn}{dM}$$

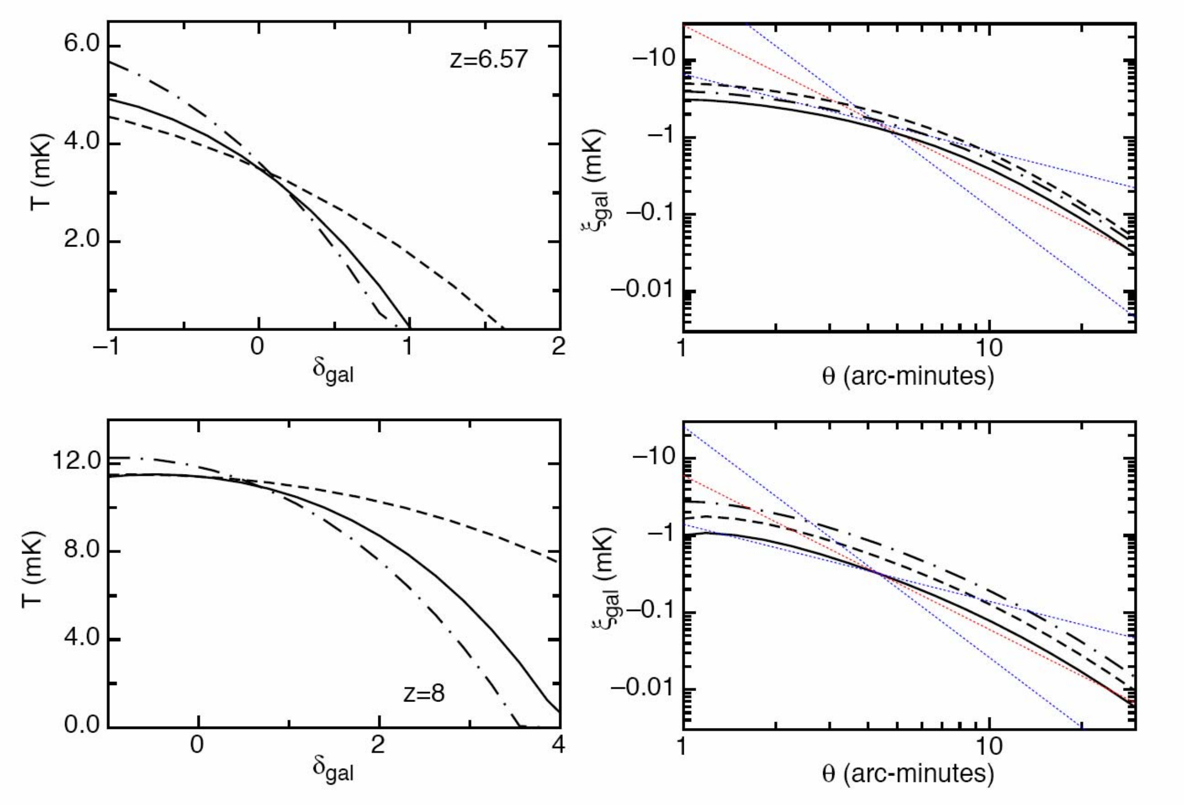
$$\mathcal{T}L_{\rm Ly} = 3\times10^{42}{\rm erg/s}\left(\frac{f_{\rm star}\mathcal{T}}{0.2}\right)\left(\frac{\epsilon_{\rm dc}}{0.1}\right)^{-1}\left(\frac{M}{10^{10}M_\odot}\right)$$

Cross Correlation of Galaxies with 21cm Emission

- · - · - · - · - C=2 M=10^{10}

——————— C=10 M=10^{10}

- - - - - - C=10 M=10^{11}



Weak clumping leads to greater variation of T with δ

Galaxies correlate negatively with T since overdense regions reionize first

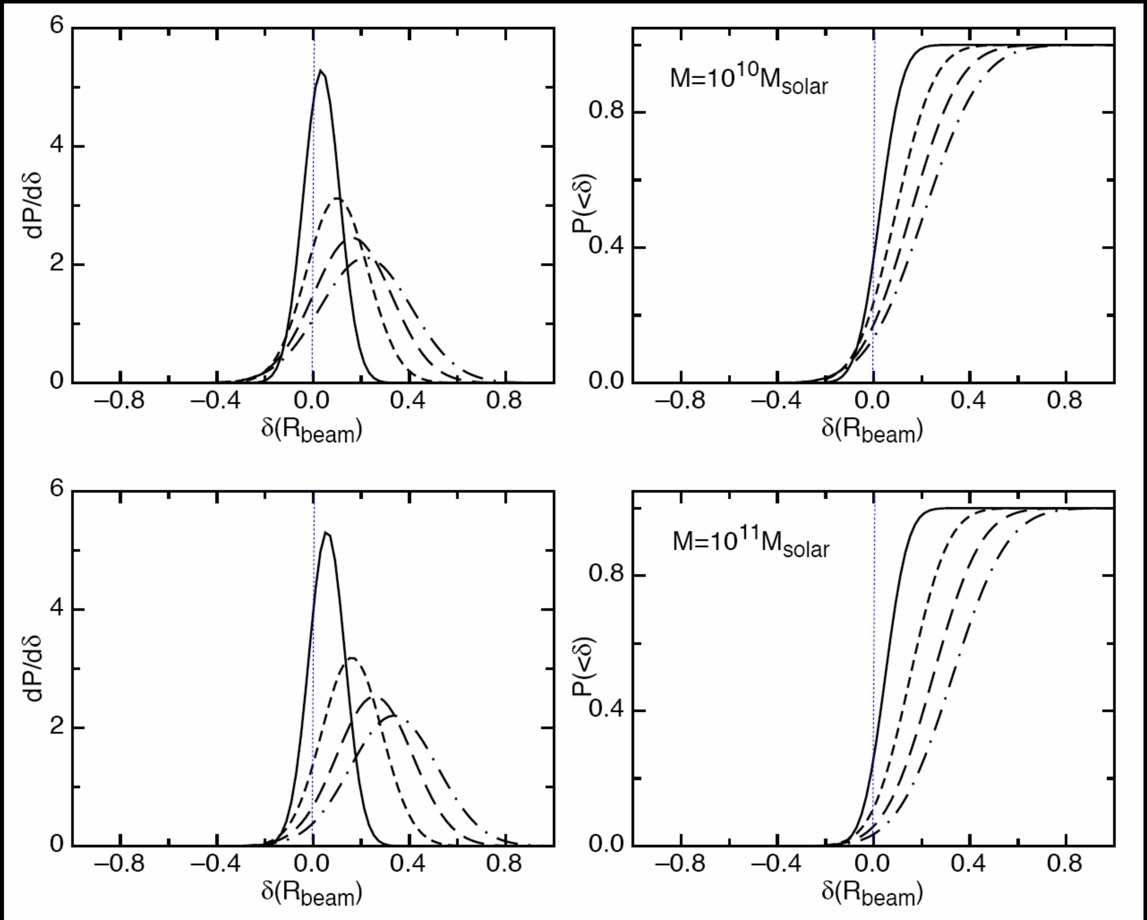
$$\delta_{\rm gal} = 4/3 \times b(M,z)\delta$$

$$\begin{aligned}\xi_{\rm gal}(\theta) &= \langle \delta_{\rm gal} \times (T - \langle T \rangle)\rangle \\ &= \frac{1}{\sqrt{2\pi}\sigma(R)} \int d\delta\, (\delta_{\rm gal} \times (T - \langle T \rangle))\, e^{\frac{-\delta^2}{2\sigma(R)^2}}\end{aligned}$$

Subaru Deep Field Galaxies Trace Overdense Regions

Filter ~ 132A
~5.9Mpc > $\theta_{beam} d_A$

Divide survey into Line-of-sight bins



$N_{bin}=1$
$N_{bin}=2$
$N_{bin}=3$
$N_{bin}=4$

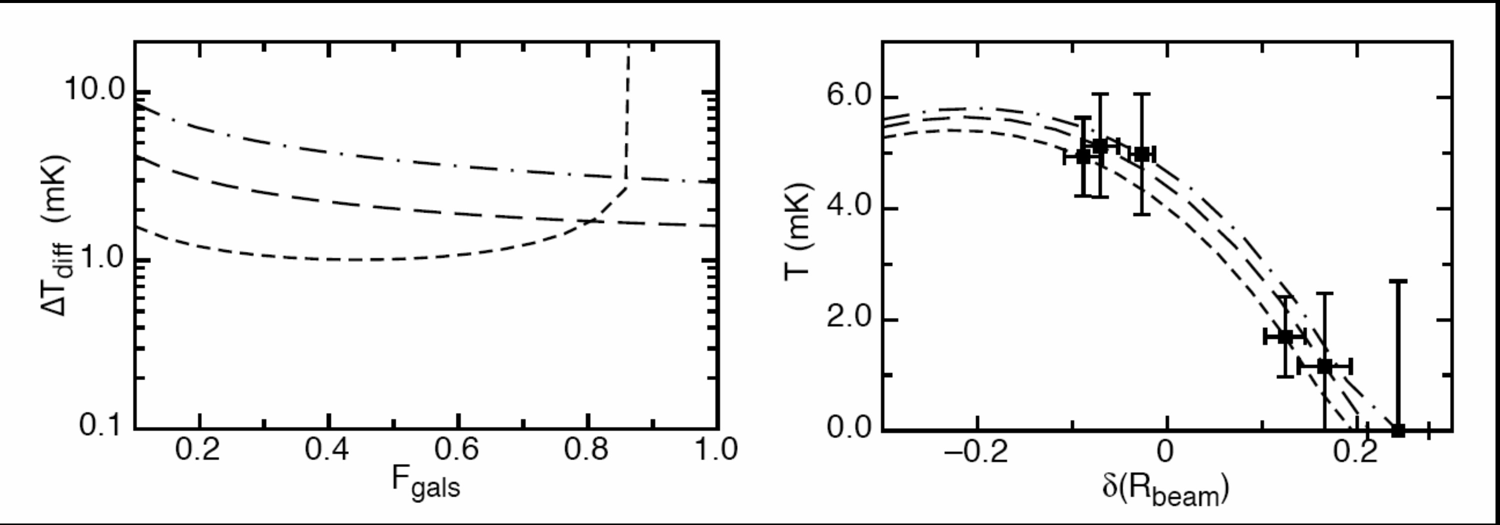
$$\left.\frac{dP}{d\delta}\right|_{\rm gal} \propto \mathcal{L}_{\rm g}(\delta)\frac{dP_{\rm prior}}{d\delta}$$

$$\mathcal{L}_{\rm g}(\delta) = \frac{(1+\delta)\nu(1+\nu^{-2p})e^{-a\nu^2/2}}{\bar{\nu}(1+\bar{\nu}^{-2p})e^{-a\bar{\nu}^2/2}},$$

Detectability of Cross-Correlation using First Generation Surveys

- The survey volume can be divided up into N regions.
- Some fraction of these regions will contain galaxies.
- The average overdensity of regions containing galaxies will be positive, and hence the average T from those areas will be below average.
- Conversely, the average overdensity of regions not containing galaxies will be negative, and hence the average T from those areas will be above average.
- The telescope noise can be averaged over the regions. If there is enough survey volume, the noise will be smaller than the difference in T.

Detectability of Cross-Correlation using First Generation Surveys



1 SDF, 1000hr LFD integration

$$\Delta T = 7.5\left(\frac{1.97}{C_{\rm beam}}\right)\mathrm{mK}\left(\frac{A}{A_{\rm LFD}}\right)^{-1} \times \left(\frac{\Delta\nu}{1\mathrm{MHz}}\right)^{-1/2}\left(\frac{t_{\rm int}}{100\mathrm{hr}}\right)^{-1/2}\left(\frac{\theta_{\rm beam}}{5'}\right)^{-2}$$

$$\Delta T_{\rm gal} = \Delta T/\sqrt{N_{\rm gal}} \qquad \Delta T_{\rm nogal} = \Delta T/\sqrt{N_{\rm nogal}}$$

$$\Delta T_{\rm diff} = \sqrt{(\Delta T_{\rm gal})^2 + (\Delta T_{\rm nogal})^2}$$

dotted	$N_{bin}=2$	$\theta_{beam}=4.2'$
dashed	$N_{bin}=3$	$\theta_{beam}=2.8'$
dash-dot	$N_{bin}=4$	$\theta_{beam}=2.1'$

$$\delta T_{\rm int} = 22\mathrm{mK}\,x_{\rm HI}\frac{4}{3}\left(\langle\delta\rangle_{\rm gal} - \langle\delta\rangle_{\rm nogal}\right) \approx 4\mathrm{mK}\left(\frac{\langle\delta\rangle_{\rm gal} - \langle\delta\rangle_{\rm nogal}}{0.3}\right)\left(\frac{x_{\rm HI}}{0.5}\right)$$