Estimating the Sunyaev-Zel'dovich signal from Quasar hosts using a Halo Occupation Distribution based approach

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Outline

- Inverse Compton scattering of CMB photons by hot electron distributions
- Departure from a blackbody [1]

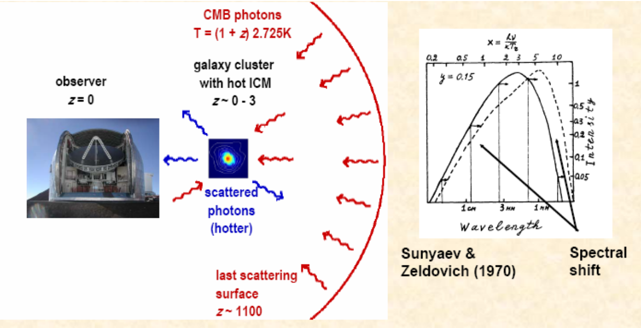

Illustration of Thermal SZ effect Photo credit: J Glenn

Thermal Sunyaev-Zel'dovich (SZ) Effect

Functional Form [a]

[a] Sunyaev & Zeldovich (1970), (1972)

$$\frac{\Delta T_{SZ}}{T_{CMB}} = \left(x \frac{e^x + 1}{e^x - 1} - 4 \right) y$$

- Spectral dependence $x = \frac{h\nu}{k_b T_e}$
- Compton y-parameter

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$$y = \frac{k_b \sigma_T}{m_e c^2} \int n_e \, T_e \, dl$$

- Electron Number density
- Electron distribution Temperature

SZ Signal from Quasar Feedback

- Feedback heats up ISM electrons of the quasar host galaxy
- Potential source of SZ signal[2]

Problem

- Quasars surrounded by halo ICM of virialised electron gas
- Total detected SZ signal likely to be a combination from both sources[3]

To detect SZ signal from feedback effects, the host halo ICM signal needs to be theoretically estimated

[2] e.g., Natarajan & Sigurdsson (1999)
[3] e.g., Chatterjee et al. (2007), (2008)

Outline

2 Modelling the Intracluster (ICM) Gas

Basic Assumptions

- Polytropic gas model with a self-similar profile in hydrostatic equilibrium
- Gas tracing dark matter (NFW profile) in halo outskrits

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Analytic universal gas density $\rho_{gas}(M, z)$ and temperature profile $T_{gas}(M, z)$

Gas Density and Temperature Profile

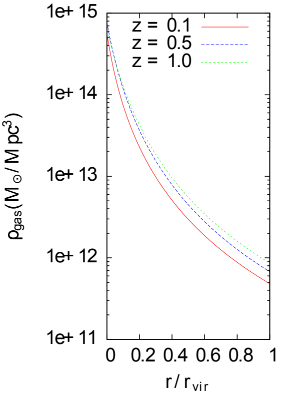


Figure : Density profile for $10^{14} M_\odot$ halo

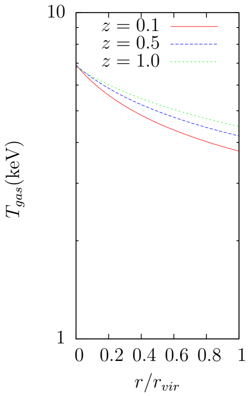


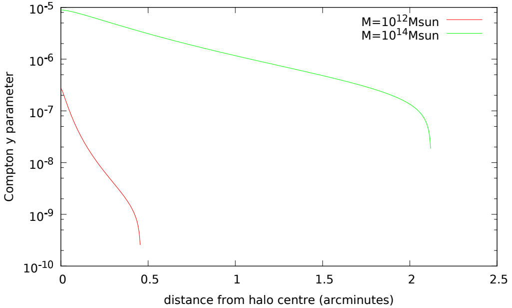
Figure : Temperature profile for $10^{14} M_\odot$ halo

Outline

3. SZ Distortion from Quasar Host Halo ICM

SZ Distortion from Quasar Host Haloes

Compton y-Parameter Profile



For different halo masses at redshift 1.0

Line of Sight signal

$$y = \frac{k_b \sigma_T}{m_e c^2} \int n_e \, T_e \, dl$$

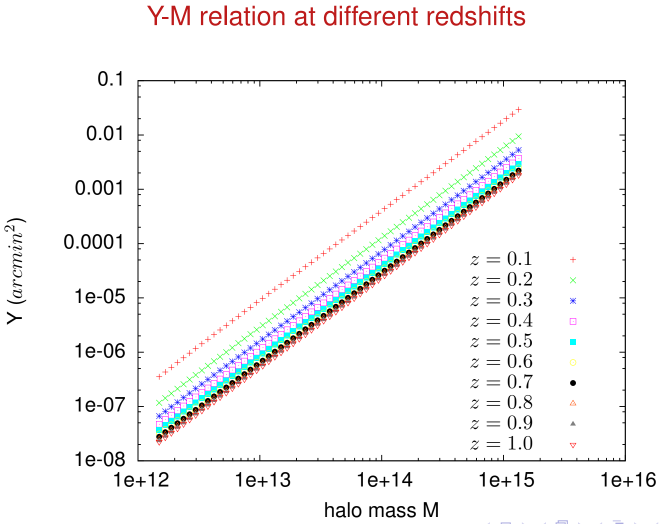
Total SZ Signal

$$Y(M, z) = \int_\Omega y \, d\Omega$$

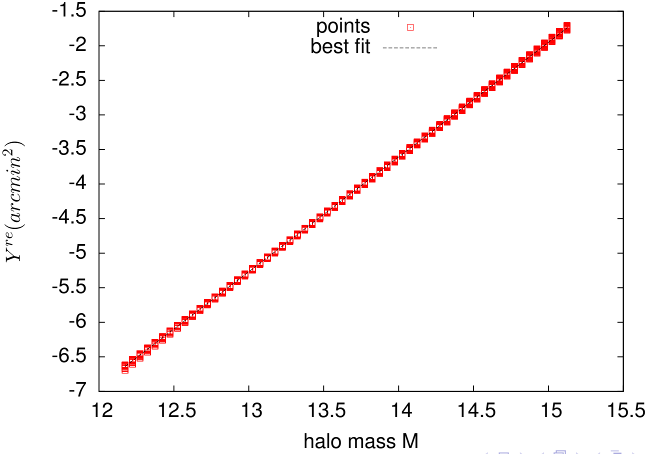
$$d\Omega = ds / D_A^2$$

SZ Distortion from Quasar Host Haloes

Total SZ signal



SZ signal rescaled to common angular diameter distance of 500 Mpc[4]



Rescaled SZ Signal

- Self similar scaling relation from linear fit of data

$$Y^{re} = 1.55 \times 10^{-3} \left(\frac{M}{3 \times 10^{14} M_{\odot}} \right)^{1.66}$$

- Validated by *Planck* observations from locally bright galaxies[4]

[4] Planck Collaboration XI (2013)

Outline

4. Average SZ signal from quasar hosts

Estimating the average SZ signal from Quasar Hosts

$$\langle Y^{re}(z)\rangle = \frac{\int_{M_1}^{M_2} Y_{re}(M)\ N_q(M,z)\ dM\ dV}{\int_{M_1}^{M_2} N_q(M,z)\ dM\ dV}$$

- Comoving number density of quasar hosts
- Comoving volume between z to z+dz

$$N_q(M,z) = \langle N(M)\rangle\ \frac{dn}{dM}(M,z)$$

Halo Mass Function[5]

[5] e.g., Press & Schechter (1974); Sheth & Tormen (1999); Jenkins et al. 2001

Estimating the average SZ signal from Quasar Hosts

$$\langle Y^{re}(z)\rangle = \frac{\int_{M_1}^{M_2} Y_{re}(M)\; N_q(M,z)\; dM\; dV}{\int_{M_1}^{M_2} N_q(M,z)\; dM\; dV}$$

$$N_q(M,z) = \langle N(M)\rangle \; \frac{dn}{dM}(M,z)$$

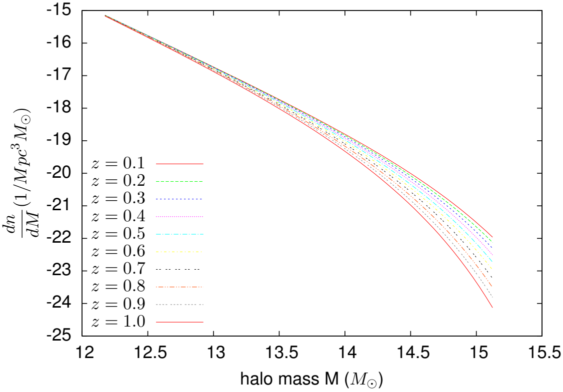
Halo Mass Function[5]

- Comoving Density of dark matter haloes at a given redshift
- Obtained from analytic prescriptions or simulations

[5] e.g., Press & Schechter (1974); Sheth & Tormen (1999); Jenkins et al. 2001

Estimating the average SZ signal from Quasar Hosts

Sheth & Tormen (1999) HMF at different redshifts



Estimating the average SZ signal from Quasar Hosts

$$\langle Y^{re}(z) \rangle = \frac{\int_{M_1}^{M_2} Y_{re}(M) \; N_q(M,z) \, dM \; dV}{\int_{M_1}^{M_2} N_q(M,z) \, dM \, dV}$$

$$N_q(M,z) = \langle N(M) \rangle \; \frac{dn}{dM}(M,z)$$

Halo Occupation Distribution (HOD)[5]

- Conditional probability, $P\,(N\,|M)$ that a halo of mass M contains N quasars
- $\langle N(M) \rangle \rightarrow$ average occupanancy of quasar hosts

[5] e.g., Ma & Fry (2000); Seljak (2002)

Estimating the average SZ signal from Quasar Hosts

- Five-parameter HOD model of Chatterjee et al. (2012) is used.
- Parameters obtained by Richardson et al. (2012) through fitting two-point correlation function of SDSS quasars at $z = 1$.
- Parameters assumed to be redshift independent.

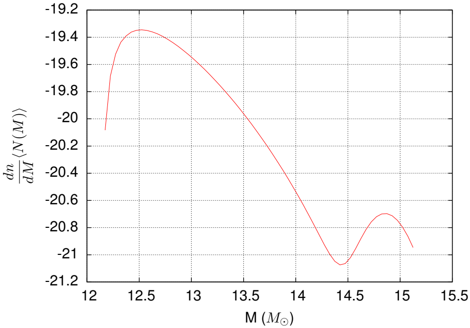
$$\langle N^c(M)\rangle = \frac{1}{2}\left[1 + erf\left(\frac{\log M - \log M_{min}}{\sigma_{\log\ M}}\right)\right]$$

$$\langle N^s(M)\rangle = \left(\frac{M}{M_1}\right)^{\alpha} exp\left(-\frac{M_{cut}}{M}\right)$$

$$\langle N(M)\rangle = \langle N^c(M)\rangle + \langle N^s(M)\rangle$$

Estimating the average SZ signal from Quasar Hosts

Comoving density of quasar hosts per unit mass at $z = 1.0$



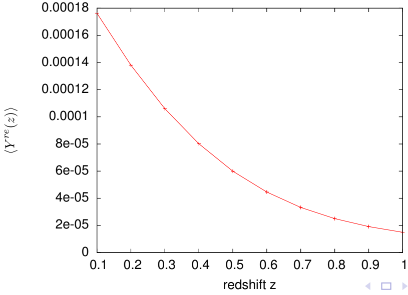
Host mass distribution peaks at around $M = 10^{12.5} M_\odot$ and $M = 10^{14.8} M_\odot$ for central and satellite satellite quasars respectively.

Estimating the average SZ signal from Quasar Hosts

Average Integrated SZ Signal

$$\langle Y^{re}(z)\rangle = \frac{\int_{M_1}^{M_2} Y_{re}(M)\ N_q(M,z)\ dM\ dV}{\int_{M_1}^{M_2} N_q(M,z)\ dM\ dV}$$

Average integrated host halo signal decreasing with increase in redshift



Estimating the average SZ signal from Quasar Hosts

Average Integrated SZ Signal

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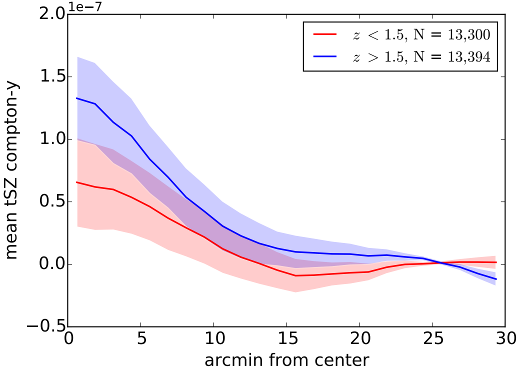
Average Line of Sight SZ Signal

$$\langle y(p,z) \rangle = \frac{\int_{M_1}^{M_2} y(M,p,z)\ N_q(M,z)\ dM\ dV}{\int_{M_1}^{M_2} N_q(M,z)\ dM\ dV}$$

Outline

Comparison with Observations

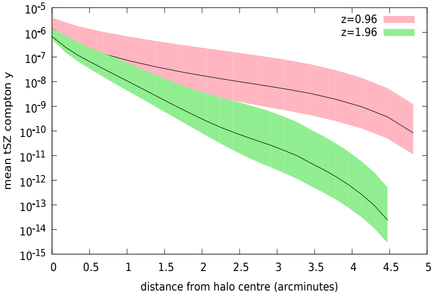
Stacked Compton y-maps correlated with high and low redshift quasars. Ruan et al. 2015



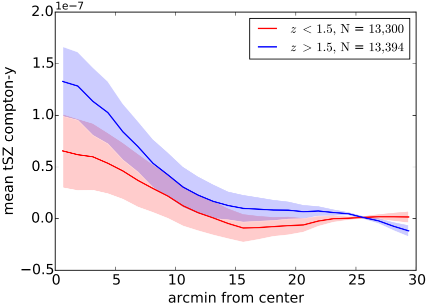
- high redshift → No massive clusters. SZ signal only due to quasar feedback
- low redshift → Quasar feedback + Halo ICM signal

Comparison with Observations

Average host halo signal



Ruan et al. 2015 signal



Comparison with Observations

Median Redshift	Observed Y^{re} $(10^{-6}\text{arcminute}^2)$	Modeled Host Halo Y^{re} $(10^{-6}\text{arcminute}^2)$
0.96	74 ± 30	$22 \ -16/+193$
1.96	115 ± 19	$4 \ -2/+14$

Table : Comparison of integrated SZ signal detected by Ruan et al. 2015 with our theoretical model for host halo signal

Conclusions

Preliminary Results:

- Modeled halo signal without including feedback falls off very rapidly with distance from halo centre.
- Observed signal is strong upto comparatively larger distance and falls off only slowly.
- Indicative of strong quasar feedback and modification of host halo signal at high redshift if the Ruan et al. 2015 is correct.
- At low redshift ($z \sim 1$), the observed signal and the host halo signal overlap. So detection of quasar feedback is not feasible.

Scope for further Work

- Modeling halo gas including gas cooling, star-formation and non-gravitational heating processes. (Shaw et al. 2010)
- Comparing the redshift integrated signals.
- Redshift evolution of HOD parameters.

Acknowledgements

- My thesis adviser Dr. Suchetana Chatterjee for her academic insights, discussions and constant motivation.
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- Friends and Family for their encouragement and support.

EXTRAS

$$\rho_{dm}(r) = \rho_s \; y_{dm}(r/r_s) \tag{1}$$

$$x = r/r_s \tag{2}$$

$$c = r_{vir}/r_s \tag{3}$$

$$\rho_s = \frac{c^3 M}{4\pi r_{vir}^3 m(c)} \tag{4}$$

$$r_{vir} = \left(\frac{M}{4/3\pi \Delta_c(z) \rho_c(z)} \right)^{1/3} \tag{5}$$

$$\Delta_c(z) = 18\pi^2 + 82y - 39y^2 \tag{6}$$

$$y = \frac{\Omega_m^0 (1+z)^3}{\Omega_m^0 (1+z)^3 + \Omega_\Lambda} - 1 \qquad for \; \Omega_r = 0 \tag{7}$$

EXTRAS

$$c = \frac{c_0}{1+z} \tag{8}$$

$$c_0 = 6\left(\frac{M}{10^{14} M_\odot}\right)^{-1/5} \tag{9}$$

$$y_{dm}(x) = \frac{1}{x^\alpha (1+x)^{3-\alpha}} \tag{10}$$

$$\rho_{gas}(r) = \rho_{gas}(0) y_{gas}(r/r_s) \tag{11}$$

EXTRAS

$$P_{gas}(r) \;\; \alpha \;\; \rho_{gas}(r) T_{gas}(r) \;\; \alpha \;\; \rho^{\gamma}_{gas}(r) \tag{12}$$

$$T_{gas} \;\; \alpha \;\; \rho^{\gamma-1}_{gas} \tag{13}$$

$$T_{gas}(r) = T_{gas}(0) \; y^{\gamma-1}_{gas}(r/r_s) \tag{14}$$

$$\frac{dP_{gas}}{dr} = -\frac{G \rho_{gas} M(\leq r)}{r^2} \tag{15}$$

$$\frac{d y^{\gamma-1}_{gas}}{dr} = -\left(\frac{\gamma - 1}{\gamma}\right) \frac{G \mu m_p M}{k_b T_{gas}(0) r^2} \frac{m(r/r_s)}{m(c)} \tag{16}$$

EXTRAS

$$y_{gas}^{\gamma-1}(x) = 1 - 3\eta^{-1}(0)\left(\frac{\gamma-1}{\gamma}\right)\left[\frac{c}{m(c)}\right]\int_0^x \frac{m(u)}{u^2}du \quad (17)$$

$$\eta^{-1}(x) = \frac{G\mu m_p M}{3r_{vir}k_b T_{gas}(x)} \quad (18)$$

$$\gamma = 1.15 + 0.01(c - 6.5) \quad (19)$$

$$\eta(0) = 0.00676(c - 6.5)^2 + 0.206(c - 6.5) + 2.48 \quad (20)$$

$$\rho_{gas}(c) = \rho_{gas}(0)y_{gas}(c) = \frac{\Omega_b}{\Omega_{dm}}\rho_{dm}(c) \quad (21)$$

EXTRAS

$$Y^{re} = Y \; E^{-2/3}(z) \; \left(\frac{D_A}{500Mpc} \right)^2 \tag{22}$$

where $E^2(z) = \Omega_m^0 (1+z)^3 + \Omega_\Lambda$

$$Y^{re} = (0.73 \pm 0.07) \times 10^{-3} \left(\frac{M}{3 \times 10^{14} M_\odot} \right)^{5/3} \tag{23}$$

EXTRAS

Free parameters	Best fit value
M_{min}	$10^{16.46}$
$\sigma_{\log\ M}$	1.667
M_1	$10^{12.47}$
α	0.6158
M_{cut}	$10^{15.28}$

Table : HOD