Detecting Baryons from gravitational lensing X tSZ

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Y.Z. Ma et al , arxiv:1404.XXXX

L. Van Waerbeke et al, PRD 89, 023508 (arxiv: 1310.5721)

Baryons

- ~ 10 % in compact objects , ~ 90 % in diffuse form
- Understanding of baryonic processes ?
- Baryons missing on all scales !
- Useful probe: thermal Sunyaev-Zeldovich (tSZ) effect
- Gravitational lensing: unbiased tracer of projected mass
- Weak lensing (CFHTLens) X tSZ (Planck):
  - Van Waerbeke, Hinshaw & Murray, PRD (2013)

Thermal Sunyaev-Zeldovich (tSZ) effect

- Inverse Compton scattering of CMB photons by hot electrons

$$\frac{\Delta T}{T_0} = y\, S_{\rm SZ}(x)$$

- SZ spectral dependence :

$$S_{\rm SZ}(x) = x \coth(x/2) - 4$$

- y: Comptonization parameter :

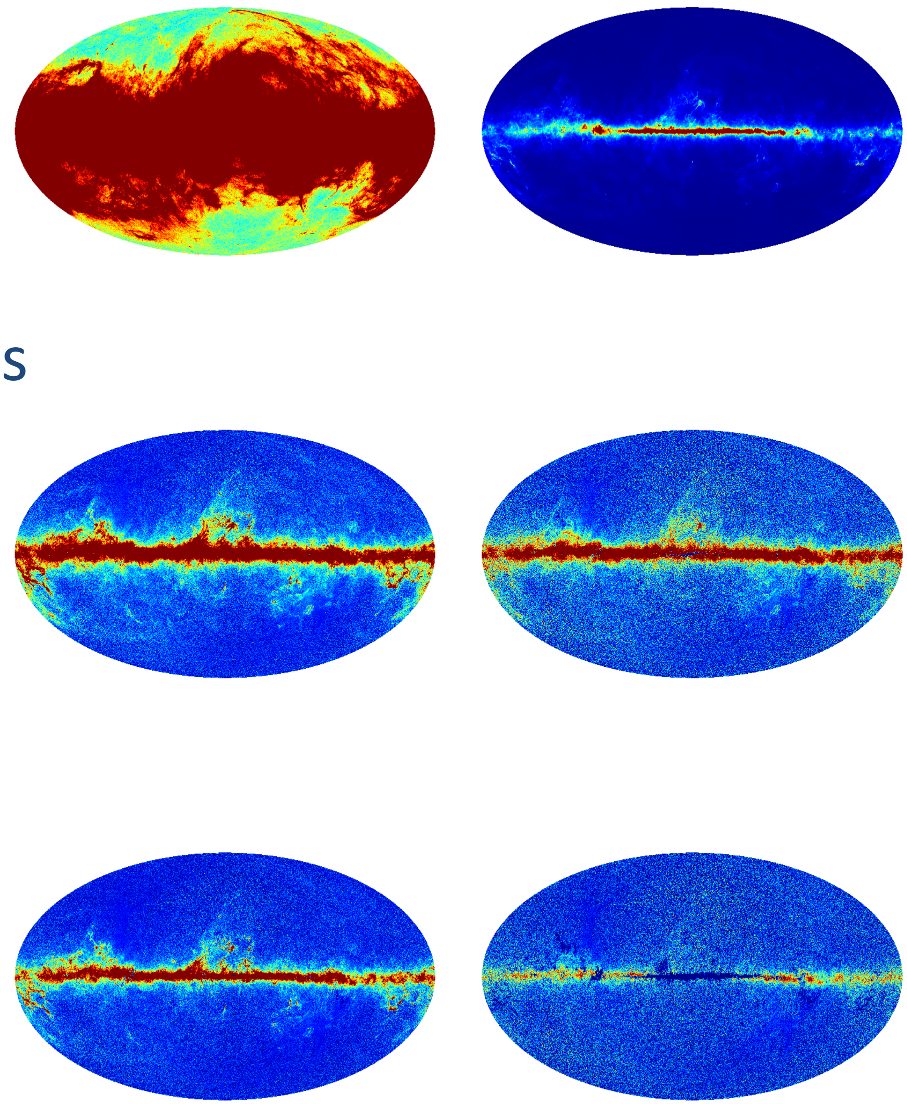
$$y(\boldsymbol{\theta}) = \int_0^{w_H} a \mathrm{d}w \; \frac{k_B \sigma_T}{m_e c^2} n_e T_e$$

Planck tSZ maps

- In Four bands :
  - 100, 143, 217 & 353 (GHz)
- Four linear combination of maps

$$y^i(p) = \sum_\nu b^i_\nu T_\nu(p)/T_0$$

- Remove :
  - Primary CMB
  - Radio emission ($\nu^{-2.15}$)
  - CO emission
  - Thermal emission (ν^{β})



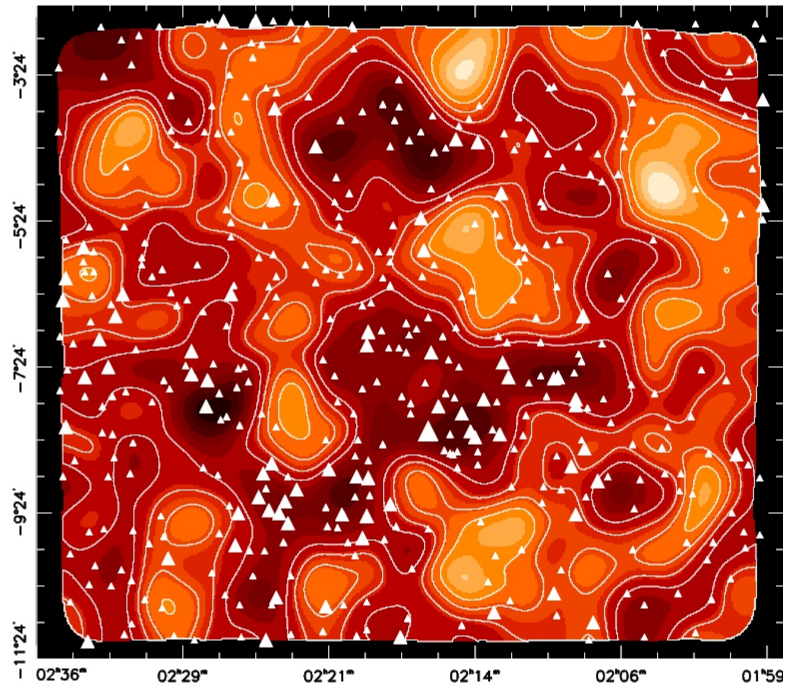
Van Waerbeke, Hinshaw & Murray PRD (2013)

CFHTLenS weak lensing maps

- Canada France Hawaii Telescope Lensing Survey

- 154 sq. deg. in Four patches

- Mass maps



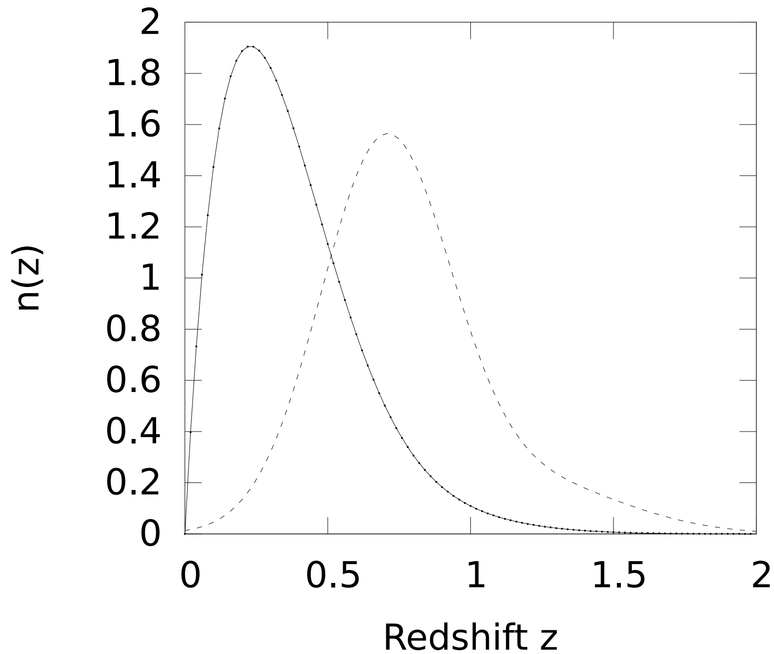
Van Waerbeke et al, MNRAS (2013)

$$\kappa(\boldsymbol{\theta}) = \int_0^{w_H} \mathrm{d}w W^{\kappa}(w) \delta_m(f_K(w)(\boldsymbol{\theta}), w)$$

CFHTLenS weak lensing maps

- Canada France Hawaii Telescope Lensing Survey

- 154 sq. deg. in Four patches



- Mass maps

Van Waerbeke, Hinshaw & Murray PRD (2013)

$$\kappa(\boldsymbol{\theta}) = \int_0^{w_H} \mathrm{d}w W^{\kappa}(w) \delta_m(f_K(w)(\boldsymbol{\theta}), w)$$

Lensing X tSZ

- Model :
  - Simple constant bias :

$$\delta_{\rm gas} = b_{\rm gas}(z)\delta_{\rm mm} \text{ with } b_{\rm gas}(z) \propto (1+z)^{-1}$$

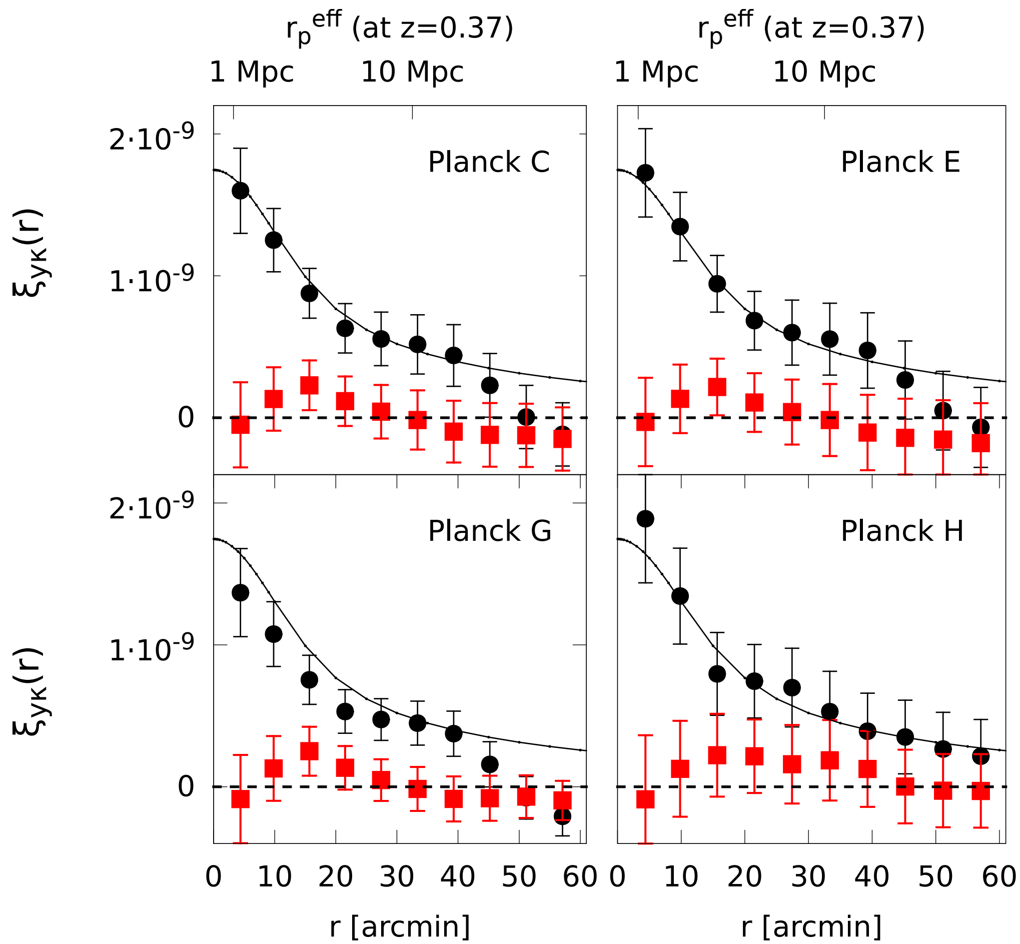
  - Power spectra :

$$\begin{aligned} P_{\pi\pi}(k) &= b_\pi^2 P_{mm}(k) \\ P_{\pi m}(k) &= b_\pi P_{mm}(k) \end{aligned}$$

  - tSZ window function :

$$W^{\rm SZ} = \bar{n}_e \sigma_T \frac{k_B T_e(0)}{m_e c^2} b_{\rm gas}(0)$$

Results



Van Waerbeke, Hinshaw & Murray PRD (2013)

$$\left(\frac{b_{\rm gas}}{1}\right)\left(\frac{T_e(0)}{0.1\ {\rm keV}}\right)\left(\frac{\bar{n}_e}{1\ {\rm m}^{-3}}\right) = 2.01 \pm 0.31$$

Implications

- Robust w.r.t. different cleaning models (maps)

- Rough calculation :

$$b_{\rm gas} = 6 \text{ and } \bar{n}_e = 0.25\,{\rm m}^{-3}$$

$$T_e \sim 0.13 \text{ keV} \sim 10^6 \text{ K}$$

- Indication of baryons in warm plasma ?

$$T_e \sim 10^5 - 10^7 \text{ K}$$

- Requires better modeling !

Halo model description

Y.Z. Ma et al arxiv 1404.xxxx

- Model :

$$C_\ell^{\kappa y} = C_\ell^{\kappa y,1\mathrm{h}} + C_\ell^{\kappa y,2\mathrm{h}}$$

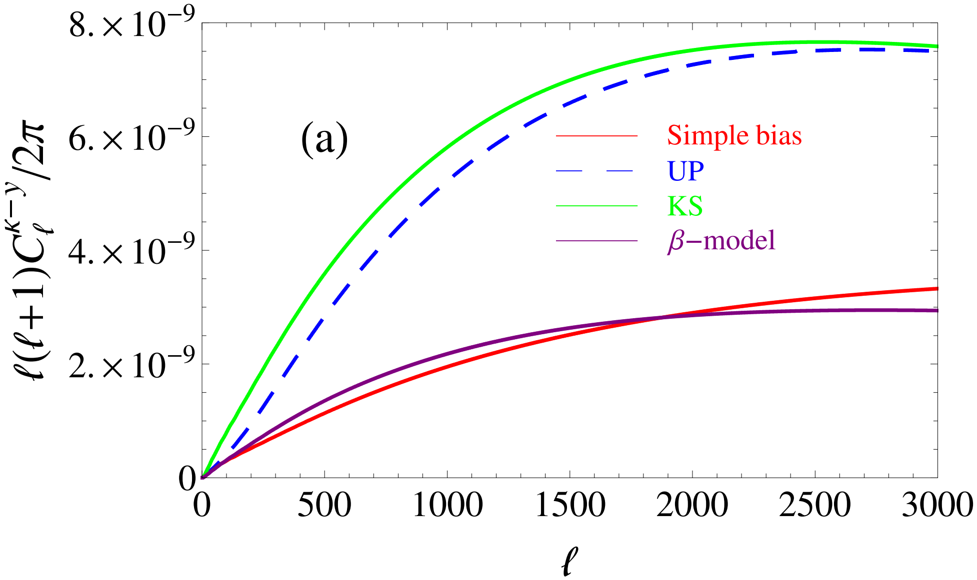
- Gas pressure profile :

$$y_\ell = \frac{4\pi r_\mathrm{s}}{\ell_\mathrm{s}} \left(\frac{\sigma_\mathrm{T}}{m_\mathrm{e}c^2}\right) \int \mathrm{d}x\, x^2 \left(\frac{\sin(\ell x/\ell_s)}{\ell x/\ell_s}\right) P_\mathrm{e}(x; M, z)$$

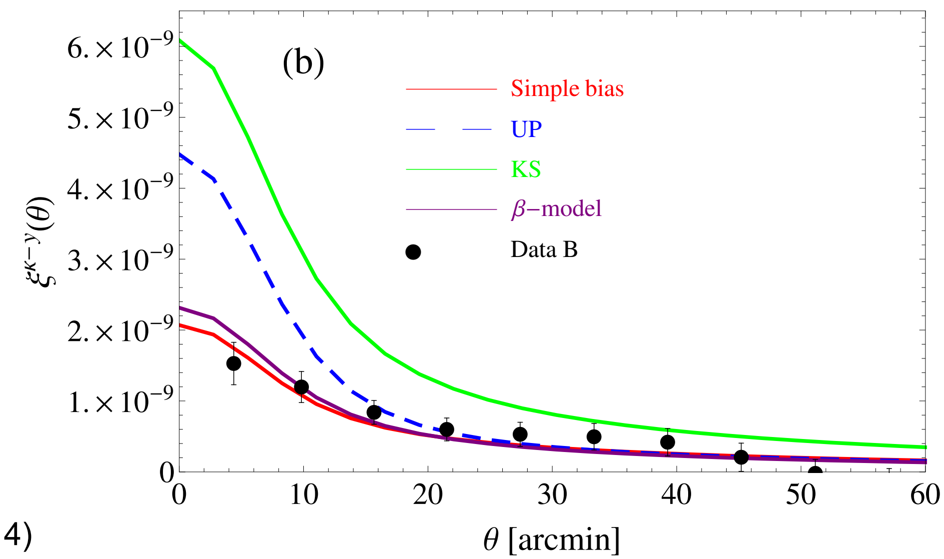
- Three different gas models :
  - Komatsu–Seljak (KS)
  - Universal Pressure (UP)
  - β-model

Halo model description, Results

- Power spectrum:



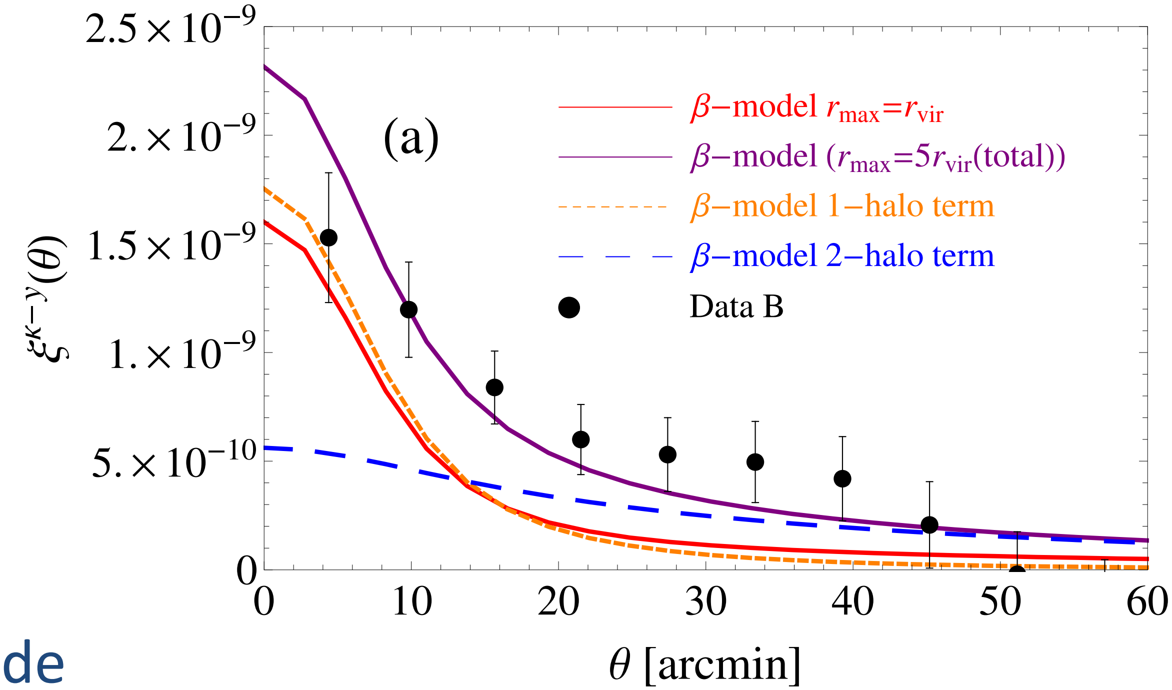
- Correlation function:



Y.Z. Ma et al (2014)

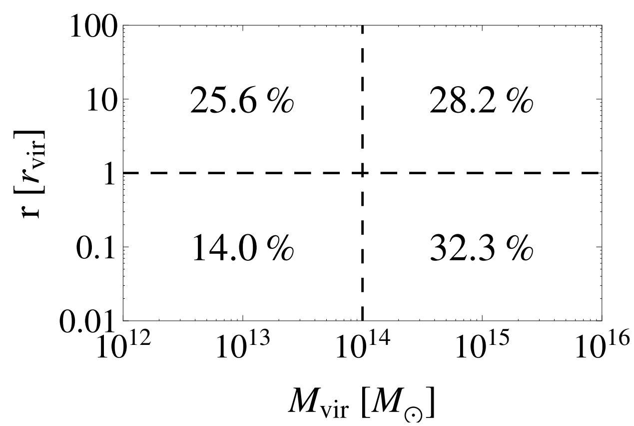
1- halo & 2-halo contributions

- β-model



- Half of the signal outside Virial radius

$$T_e \sim 10^5 - 10^7 \ \mathrm{K}$$



Y.Z. Ma et al (2014)

Summary

- First detection of lensing-tSZ correlation at 6 σ
  (Van Waerbeke, Hinshaw & Murray, PRD 2013)

- Halo-model description (Ma et al) :
  - Contribution from 1-halo (4σ) and 2-halo (4σ) terms
  - Significant contribution from outside Virial Radius (~ 50 %)
  - Significant contribution from low-mass halos (~40%)
  - Gas outside Virial radius : $T_e \sim 10^5 - 10^7 \text{ K}$

Consistent with missing baryons !