Measurement of the Gas Mass Fraction via Sunyaev Zel'dovich Effect Observations of a Complete Sample of Galaxy Clusters

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Intro: What? Why?

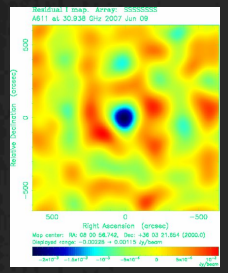
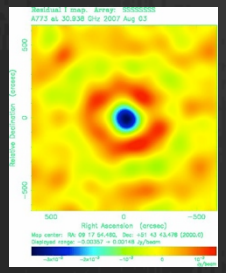
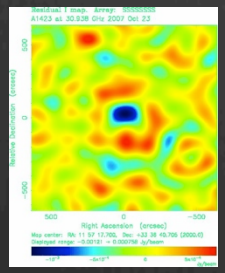
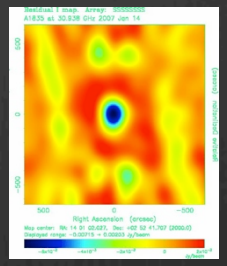
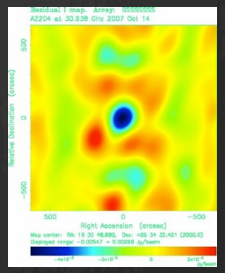
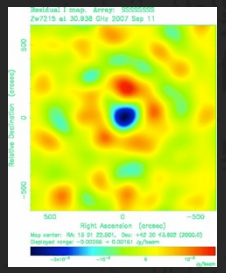
- Want to determine an accurate method for determining cluster masses using **only** SZ effect observations and an additional method for calculating f_{gas}
- Why SZ effect observations?
  - Cluster masses can be calculated using X-ray observations; however, these are severely limited with increasing redshift due to the nature of the cluster surface brightness equation

$$S_x = \frac{1}{4\pi(1+z)^3} \int n_e^2(r) \Lambda_{ee}(T_e) dl$$

  - The fluxes of SZ observations, are redshift **independent**, if spatially resolved
- Why masses of clusters?
  - Cluster Mass Function $\longrightarrow$ constraining cosmology

Intro: How?

- Analysis of a statistically complete cluster sample
  - Dahle (2006) sample of clusters from BCS
    - 35 of the most X-ray luminous massive clusters
    - Redshift range $0.15 < z < 0.3$
  - Reduction and analysis of cluster SZ data from SZA observations at CARMA
  - Calculate cluster masses
    - Used two independent cluster models defined by Arnaud et al. (2010) and Bulbul et al. (2010) and a method that makes use of the Virial Theorem

Virial Method for Calculating Cluster Masses

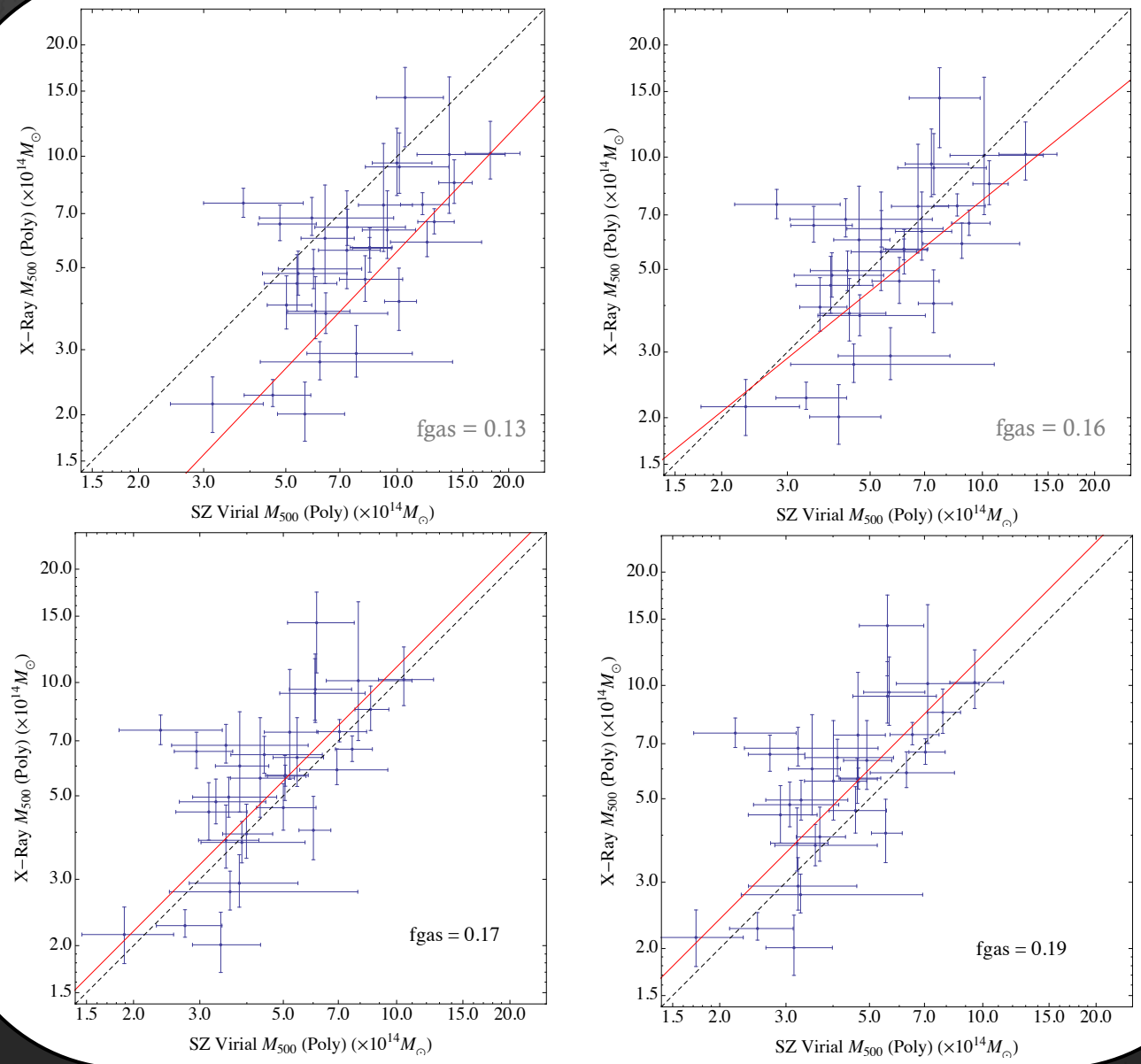
- Virial Theorem Method
  - Based on the assumption that clusters are virialized and therefore the SZE flux is proportional to its gravitational energy
  - The integrated SZE flux is also proportional to thermal energy of cluster

$$2E_{th} - 3P(r)V = -U_g$$

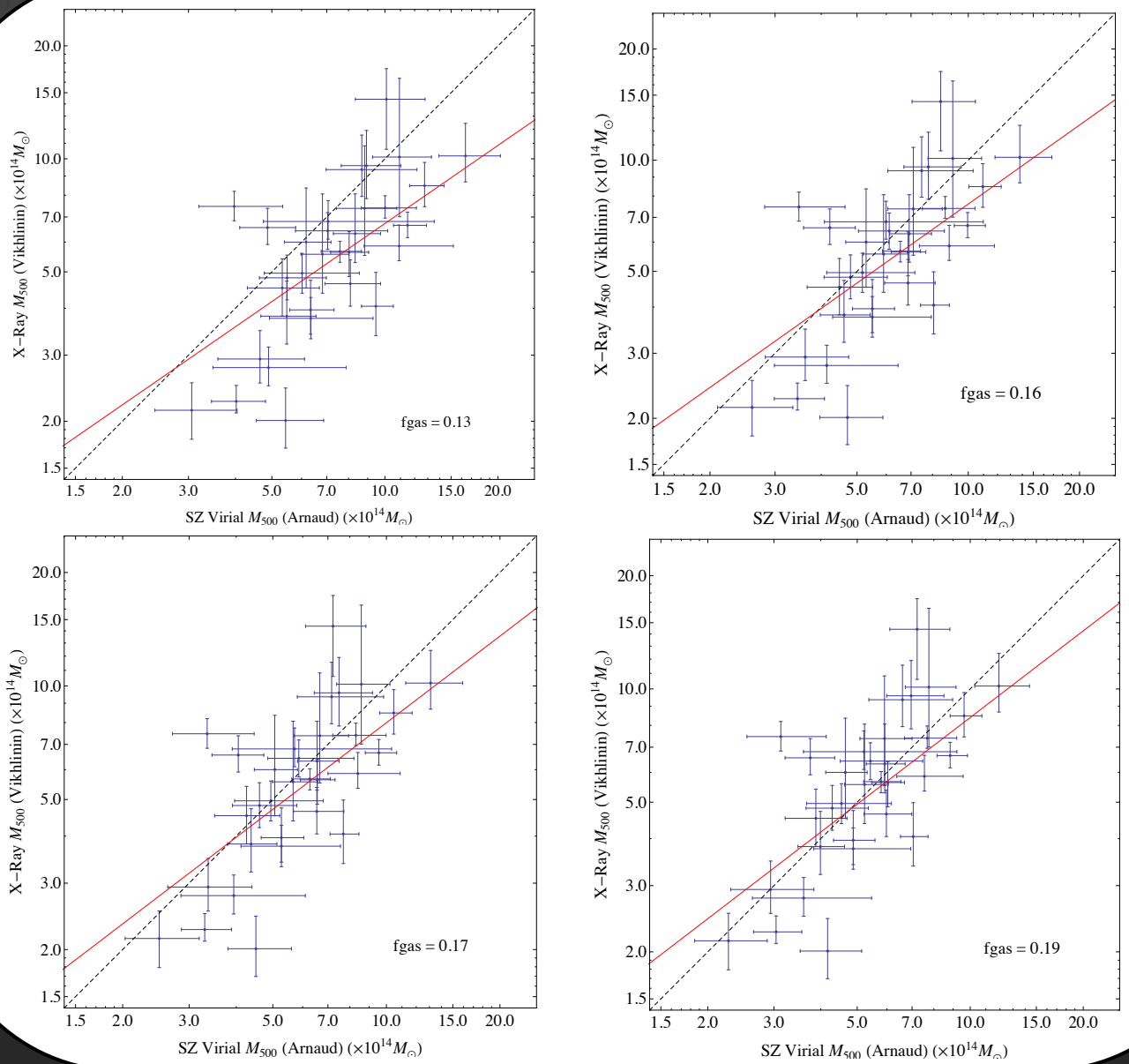
$$\Rightarrow 0 = 3 * 4\pi\left(1 + 1/\mu_e\right)P_{e_0}\int_0^{r_{500}}\left(\frac{\ln\left(1 + r/r_s\right)}{r/r_s}\right)^{n+1} r^2 dr - \left(4\pi\rho_0 r_s^2\right)^2 G * f_{gas}\int_0^{r_{500}}\left[\frac{1}{\left(1 + r/r_s\right)^3} + \frac{\ln\left(1 + r/r_s\right)}{\left(1 + r/r_s\right)^2}\right] dr$$

  - Solve numerically using the Newton-Raphson method for finding roots to determine the value of r_{500} that allows the Virial relation to hold true
    - $\mu_e = 1.17$ and $f_{gas} = \{0.13, 0.16, 0.17, 0.19\}$; P_{e0} and r_s determined by fitting CARMA data to cluster models

Results: Bulbul Model

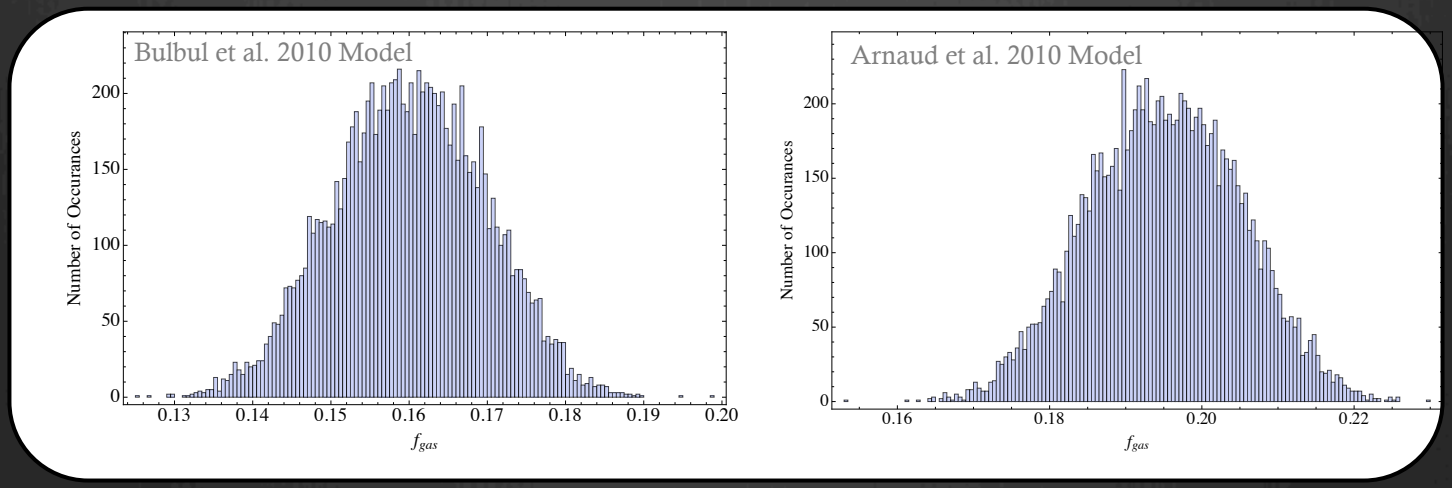


Results: Arnaud Model



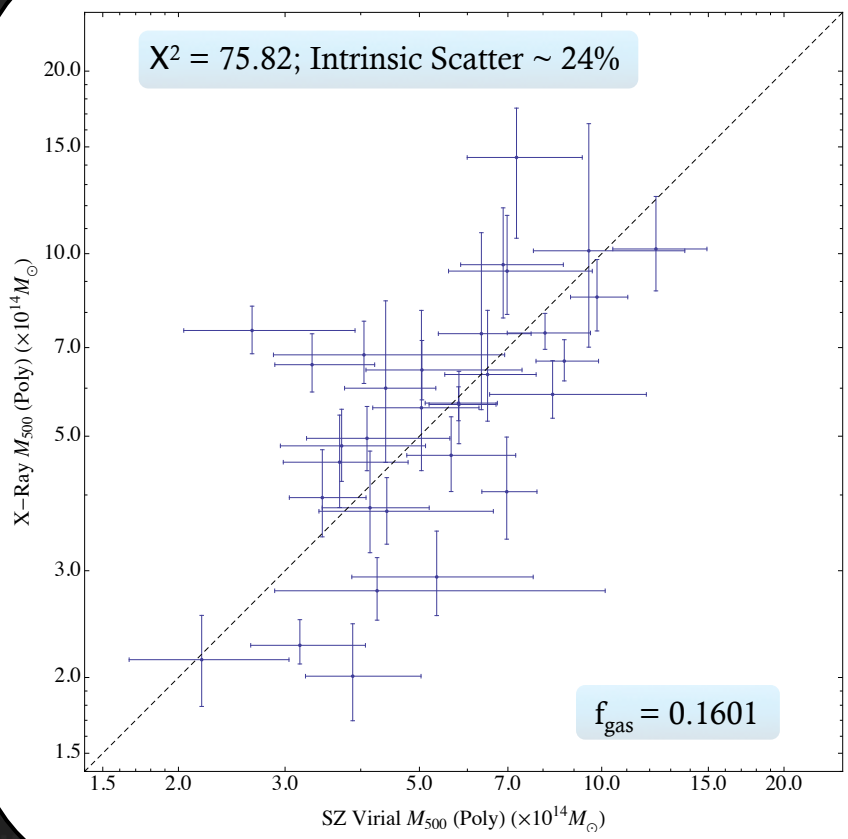
Measuring the Gas Mass Fraction

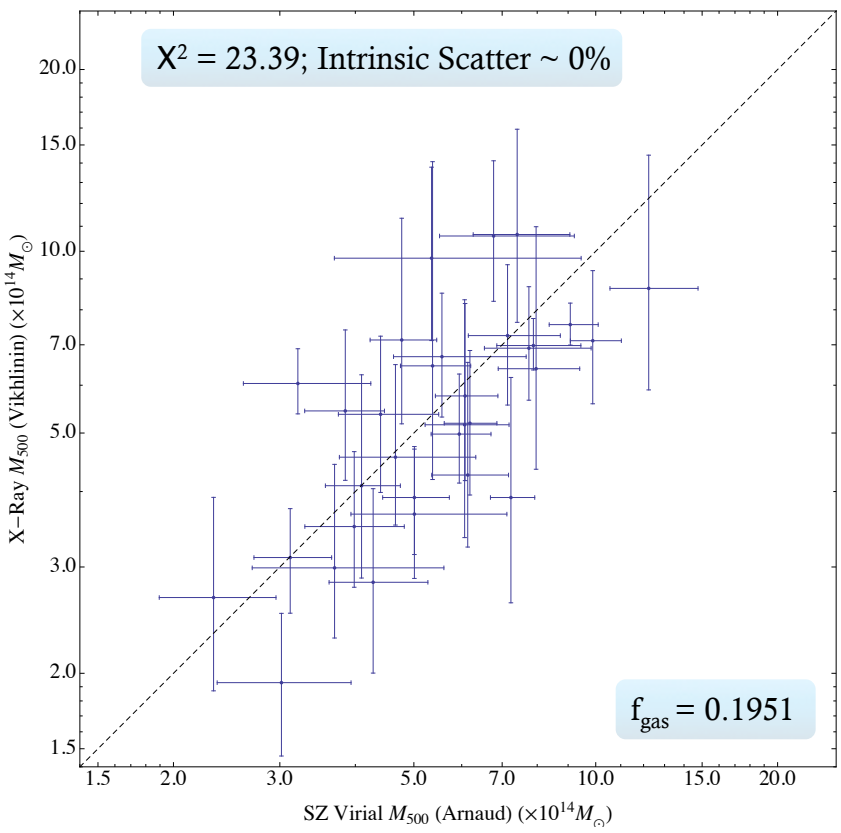
- Desire CARMA derived masses to equal X-ray masses
  - Set the best fit line to x=y and allow f_{gas} to be a free parameter
  - Iterate through a Monte Carlo Markov Chain to determine most probable corresponding fgas value



Model	f_{gas} (r_{500})
Bulbul	$0.1601^{+0.0099}_{-0.0101}$
Arnaud	$0.1951^{+0.0103}_{-0.0104}$

Results: f_{gas}





Conclusion

- Ultimate Goal: <u>measure cluster masses using SZ observations only and independently calculate the gas mass fraction</u>
- SZ observations are appropriate for measuring distant cluster masses since SZE flux is redshift independent
- Determining masses over a large range of redshifts could lead to further defining constraints on cosmology
- Presented mass and f_{gas} results from the analysis of SZE data for 32 clusters
  - Expect to begin to draw conclusions on the implications of these results including the concern about potential systematic errors in X-ray mass calculations such as clumping