Measurement of the Gas Mass Fraction via Sunyaev Zel’doovich 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 $f_{\text{gas}}$

✧ 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

\[ S_x = \frac{1}{4\pi(1+z)^3} \int n_e^2(r)\Lambda_e(T_e)\,dl \]

✧ The fluxes of SZ observations, are redshift independent, if spatially resolved

✧ Why masses of clusters?
  ✧ Cluster Mass Function \(\rightarrow\) 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

\[ 2E_{th} - 3P(r)V = -U_g \]

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

- 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 \( f_{gas} = \{0.13, 0.16, 0.17, 0.19\} \); \( P_{e_0} \) and \( r_s \) determined by fitting CARMA data to cluster models
Results: Bulbul Model

\[ \text{fgas} = 0.13 \]

\[ \text{fgas} = 0.16 \]

\[ \text{fgas} = 0.17 \]

\[ \text{fgas} = 0.19 \]
Results: Arnaud Model

\[ f_{\text{gas}} = 0.13 \]

\[ f_{\text{gas}} = 0.16 \]

\[ f_{\text{gas}} = 0.17 \]

\[ f_{\text{gas}} = 0.19 \]
Measuring the Gas Mass Fraction

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

<table>
<thead>
<tr>
<th>Model</th>
<th>$f_{\text{gas}} (r_{500})$</th>
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<tbody>
<tr>
<td>Bulbul</td>
<td>0.1601$^{+0.0099}_{-0.0101}$</td>
</tr>
<tr>
<td>Arnaud</td>
<td>0.1951$^{+0.0103}_{-0.0104}$</td>
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Results: $f_{gas}$

$\chi^2 = 75.82$; Intrinsic Scatter ~ 24%

\[ f_{gas} = 0.1601 \]

$\chi^2 = 23.39$; Intrinsic Scatter ~ 0%

\[ f_{gas} = 0.1951 \]
Conclusion

✧ Ultimate Goal: measure cluster masses using SZ observations only and independently calculate the gas mass fraction

✧ 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 $f_{\text{gas}}$ 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