An Analytic Model for Galaxy Cluster Shocks

Sam Charney[1], Dhayaa Anbajagane[2], Bhuvnesh Jain[1]

[1]University of Pennsylvania, [2]University of Chicago

Background

- Galaxy clusters are very large groups of galaxies bound together by gravity.
  - They are important in understanding the structure, formation, and development of the universe.
- A shock forms when cold, high-velocity gas falls into a galaxy cluster and exceeds the local sound speed.
- Shocks can be observed in pressure profiles of clusters, which are useful probes of internal thermodynamic conditions.
  - Pressure profiles are measured via the Sunyaev-Zeldovich effect (spectral distortion of CMB photons by high-energy cluster electrons).
- We use data from two different sources: the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT).

Methods

- Stack pressure profiles of individual clusters (weighted by SNR) to give a combined pressure profile for each survey.
  - Stacking gives an idea of overall trends. Previously, shocks had only been seen in individual clusters.
- Generate a prediction for profiles by summing a "one-halo" model and a "two-halo" model, dubbed "total halo model."
- Multiply total halo model by a negative, normalized Gaussian to account for shock feature between 1 and 2 R/R_{200}
- Use a Markov Chain Monte Carlo (MCMC) algorithm to find the best parameters for the Gaussian that optimally fit the pressure deficit.
  - We use the Emcee package (Foreman-Mackey, 2013).

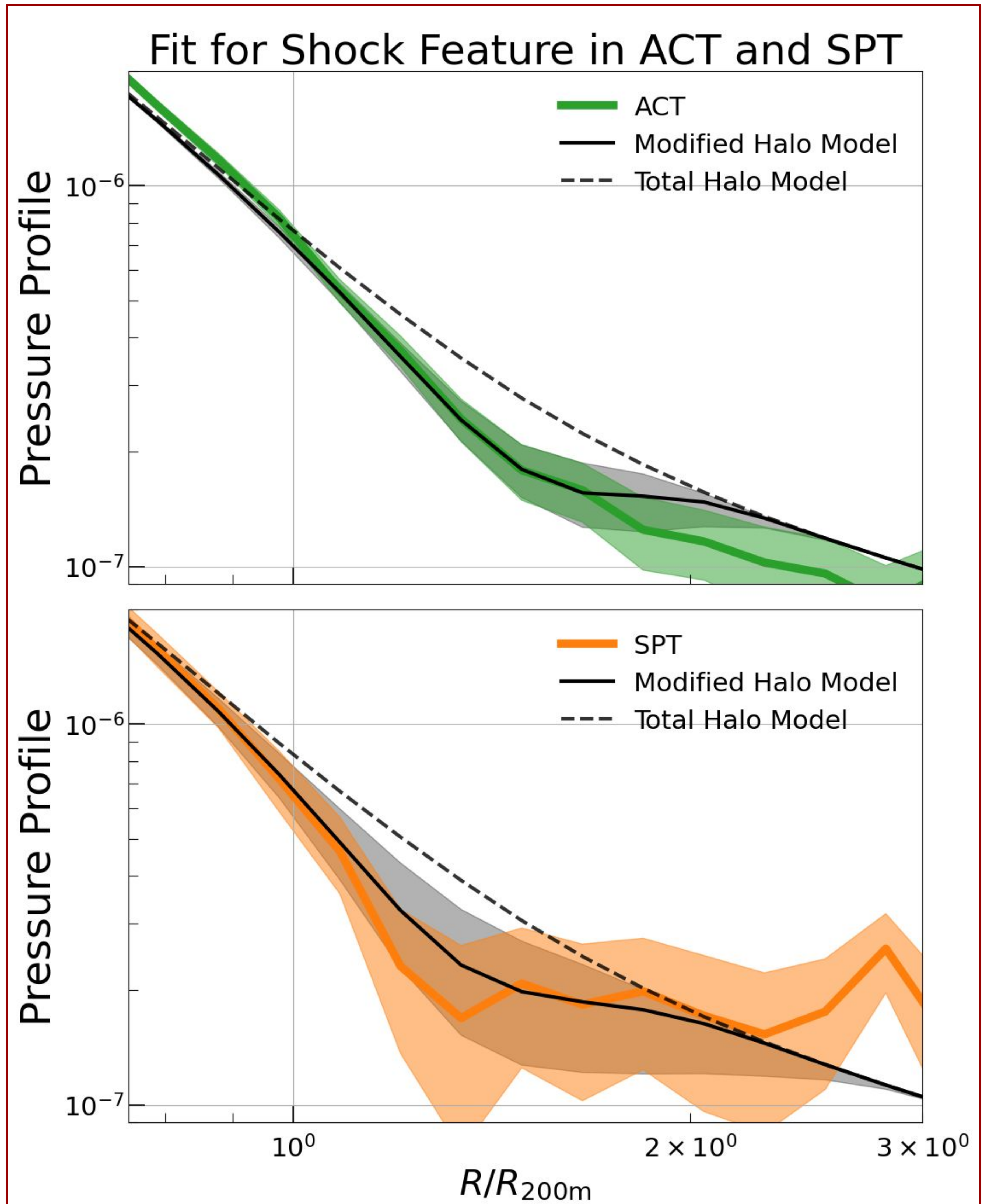

Figure 1: *Plots showing the aggregated pressure profiles from two surveys: ACT (top) and SPT (bottom) in the solid color, with observation error as the shaded area surrounding. The dashed black line is the total halo model: the sum of the one- and two- halo models with no other modifications. The solid black line is the total halo model with the Gaussian modification, fitted by MCMC, with the shaded black region being the 1σ bounds on the posterior distribution. In both cases, the modified halo model fits the pressure profiles better than the unmodified version.*

Equation for the Modified Halo Model: $THM * \left(1 + A\frac{\mathcal{N}(r,\mu,\sigma)}{\mathcal{N}(\mu,\mu,\sigma)}\right)$

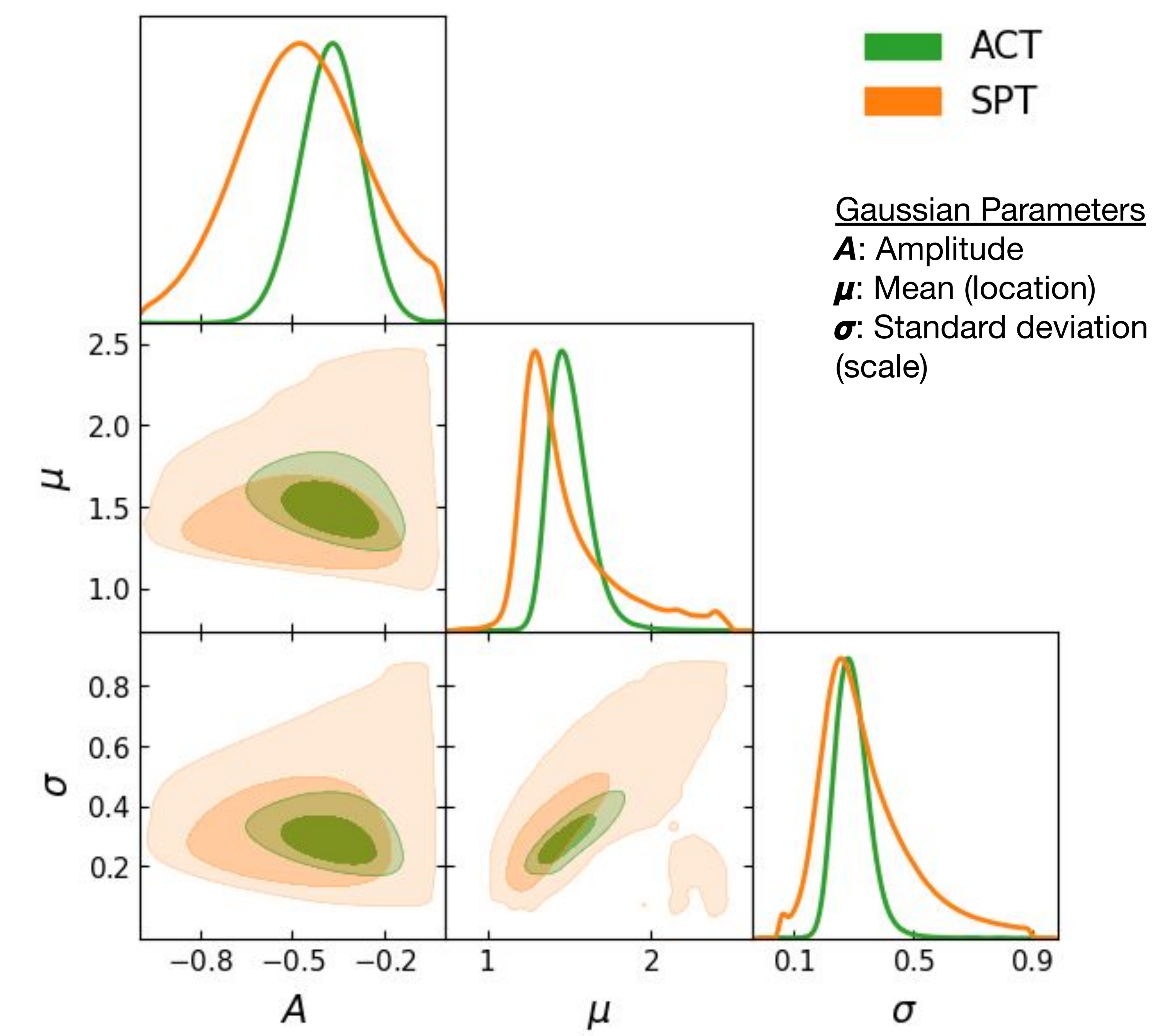

Figure 2: *A corner plot showing the posterior distribution of the three parameters of the Gaussian function in the Modified Halo Model. SPT has more error on the posterior than ACT does, but SPT and ACT have parameter constraints that agree within 0.5σ, which lends credence to the shock feature being universal.*

Results

- Shock features can be fit using a simple Gaussian and MCMC to determine the best parameters.
- The amplitude of the Gaussian can be used as an estimator of the significance of the shock feature and the mean can be used as an estimator for the location.
  - These observational models of shocks help test theories and probe the physics of the universe.
- This method is not perfect: it requires some hand-tuning of priors and at times only fits small fluctuations instead.
  - However, it does fit well after minor user intervention, serving as an effective proof of concept.