The Velocity Distribution Function of Galaxy Clusters as a Cosmological Probe

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Scheinbare Geschwindigkeiten im Comahaufen.

\[
v = 8500 \text{ km/sek} \quad 6900 \text{ km/sek}
\]
\[
7900 \quad 6700
\]
\[
7600 \quad 6600
\]
\[
7000 \quad 5100 (?)
\]
Sources of Scatter in Dynamical Mass Estimates

From the virial theorem, $\sigma_v \propto M^{1/3}$

Sources of scatter:
- Mergers
- Infalling matter
- Halo triaxiality
- Observational effects
Multidark Simulation

Image credit: cosmosim.org
HALO MASS FUNCTION

It’s impolite to ask a galaxy cluster its mass
Halo Mass Function

$M = M_{\text{true}}$

$\log\left[\frac{dn}{d\log(M)}\right]$

$\log[M(M_\odot h^{-1})]$
Eddington Bias in Dynamical Masses

Scatter in the $M(\sigma)$ relationship, coupled with the steeply-declining HMF, alters the observed HMF.
Halo Mass Function
Halo Mass Function with Measurement Error

- True mass function can be recovered if the scatter is well-understood.
$\chi^2$ analysis for constraining $\sigma_8$ & $\Omega_m$

$$\chi^2(y|\sigma_8, \Omega_m) = (\bar{y} - y^*)^T \hat{\Psi}^{-1} (\bar{y} - y^*)$$

- Compare the mock observed HMF to that predicted by an analytic HMF.
Constraining Cosmological Models

• When cluster masses are perfectly known, the parameter constraints contain the fiducial model.
Constraining Cosmological Models

- Measurement error biases to low $\Omega_m$ and high $\sigma_8$.
- Fiducial model lies outside of the 99% likelihood contour.
THE VELOCITY DISTRIBUTION FUNCTION
Velocity PDF

\[ \log[\text{PDF}(v)] \quad \text{for} \quad 14.50 \leq \log(M) < 15.00 \]

\[ \log(M) < 15.00 \quad \text{for} \quad 15.00 \leq \log(M) < 15.25 \]

\[ \log(M) < 15.25 \quad \text{for} \quad 15.25 \leq \log(M) < 15.50 \]
Velocity Distribution Function

\[ \log[dn/dv] = \log[v_{\text{true}}/\sigma_8] \]

- \( \sigma_8 = 0.860, \Omega_m = 0.320 \)
- \( \sigma_8 = 0.860, \Omega_m = 0.300 \)
- \( \sigma_8 = 0.823, \Omega_m = 0.307 \)
- \( \sigma_8 = 0.780, \Omega_m = 0.320 \)
- \( \sigma_8 = 0.780, \Omega_m = 0.300 \)
Velocity Distribution Function
with velocity error

\[ \log[dn/dv] = v_{\text{err}} \]

\( v = v_{\text{err}} \)
\( \chi^2 \) analysis for constraining \( \sigma_8 \) & \( \Omega_m \)

\[
\chi^2(y|\sigma_8, \Omega_m) = (\bar{y} - y^*)^T \hat{\Psi}^{-1} (\bar{y} - y^*)
\]
Constraining Cosmological Models with the VDF

- Constraints can be approximated as a band in the $\Omega_m$-$\sigma_8$ plane.
Constraining Cosmological Models with the VDF

- Measurement error introduces a nearly-negligible bias.
Constraining Cosmological Models with the VDF

- HMF and VDF give similar constraints when true cluster properties are known.
- VDF is less sensitive to measurement error than the HMF.
• Can be robustly predicted from $N$-body simulations that capture dynamics of substructure in clusters.
• Applying the VDF requires a large spectroscopic data set of cluster members.
• Applying the VDF to smaller observations ($N<200$) retains the insensitivity to measurement error, though with broader constraints.
The Velocity Distribution Function of Galaxy Clusters

- A new way to quantify the abundance of galaxy clusters using dynamic measurements (arxiv: 1602.01837).
- Less sensitive to systematics than a more traditional halo mass function approach where scatter in mass estimate introduces bias.