Constraining σ_8 and Ω_m with the Velocity Distribution Function

Michelle Ntampaka

Image credit: nasa.gov

Image credit: Hubble Space Telescope

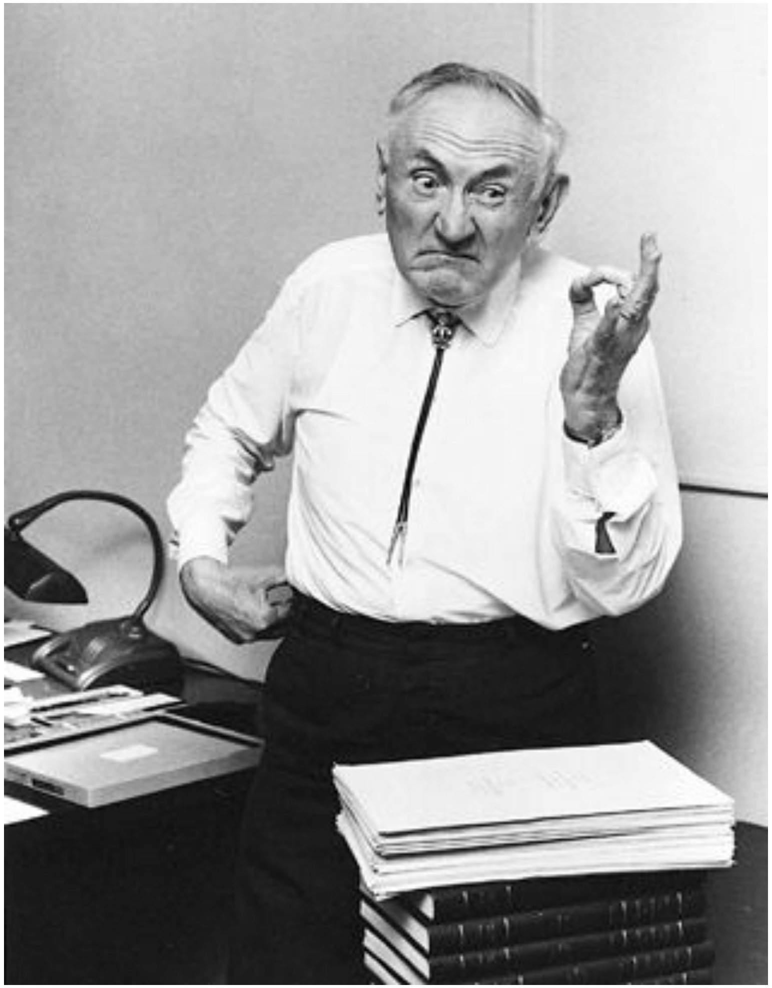
dunkle Materie

Scheinbare Geschwindigkeiten im Comahaufen.

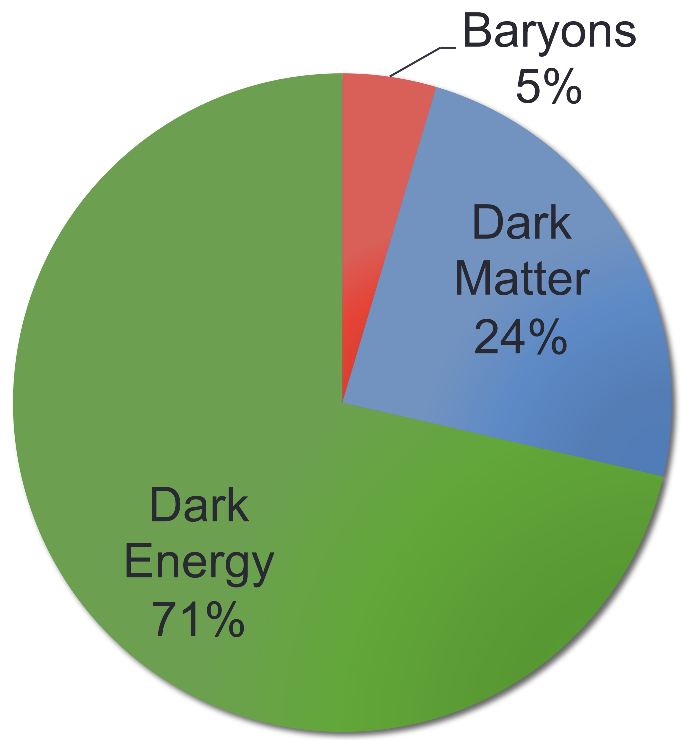
$v =$ 8500 km/sek	6900 km/sek
7900	6700
7600	6600
7000	5100 (?)

dunkle Materie

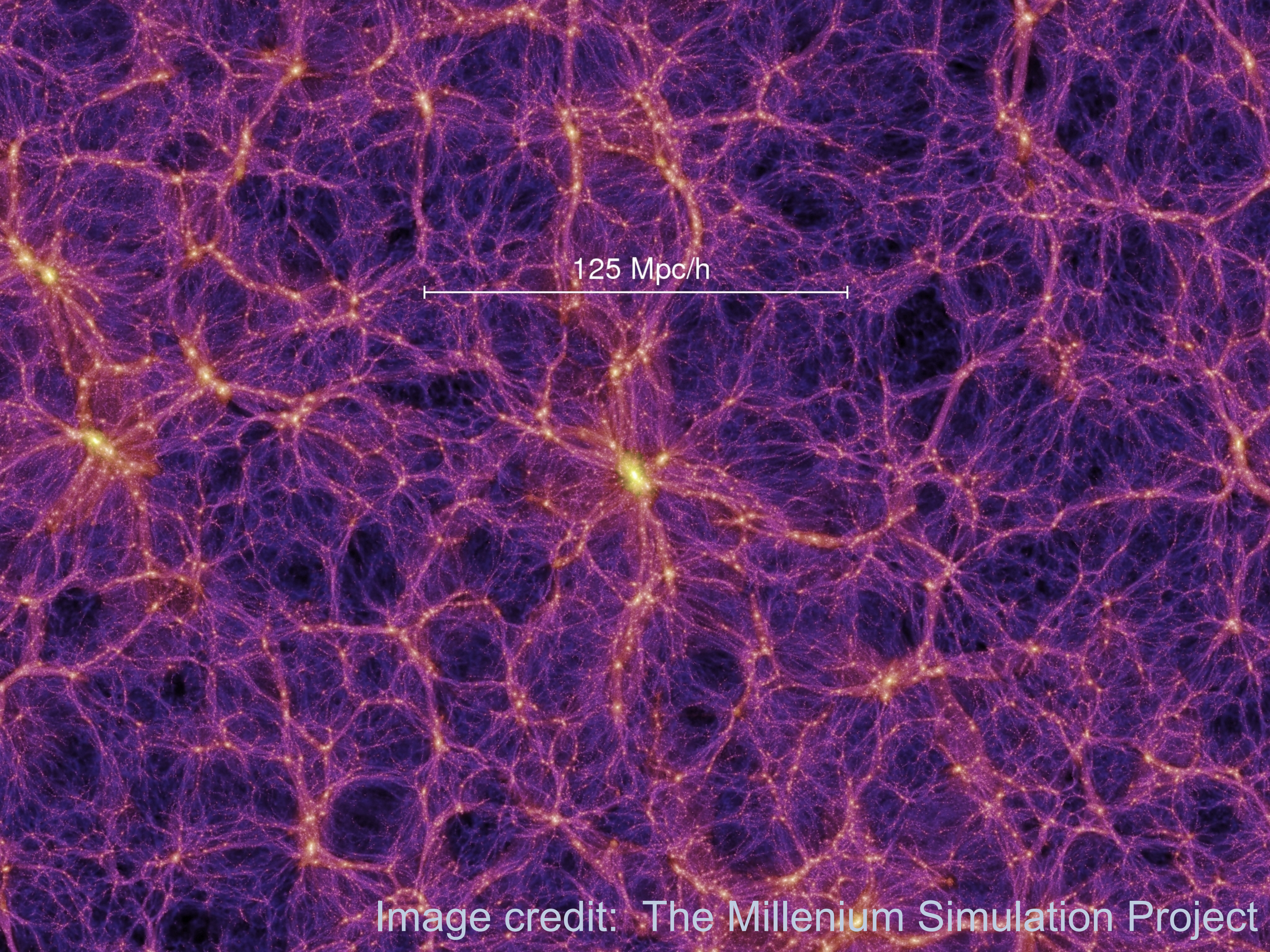
*In order to obtain the observed value of an average Doppler effect of 1000 km/s or more, the average density in the Coma system would have to be at least 400 times larger than that derived on the grounds of observations of luminous matter. If this would be confirmed we would get the surprising result that **dark matter** is present in much greater amount than luminous matter.*



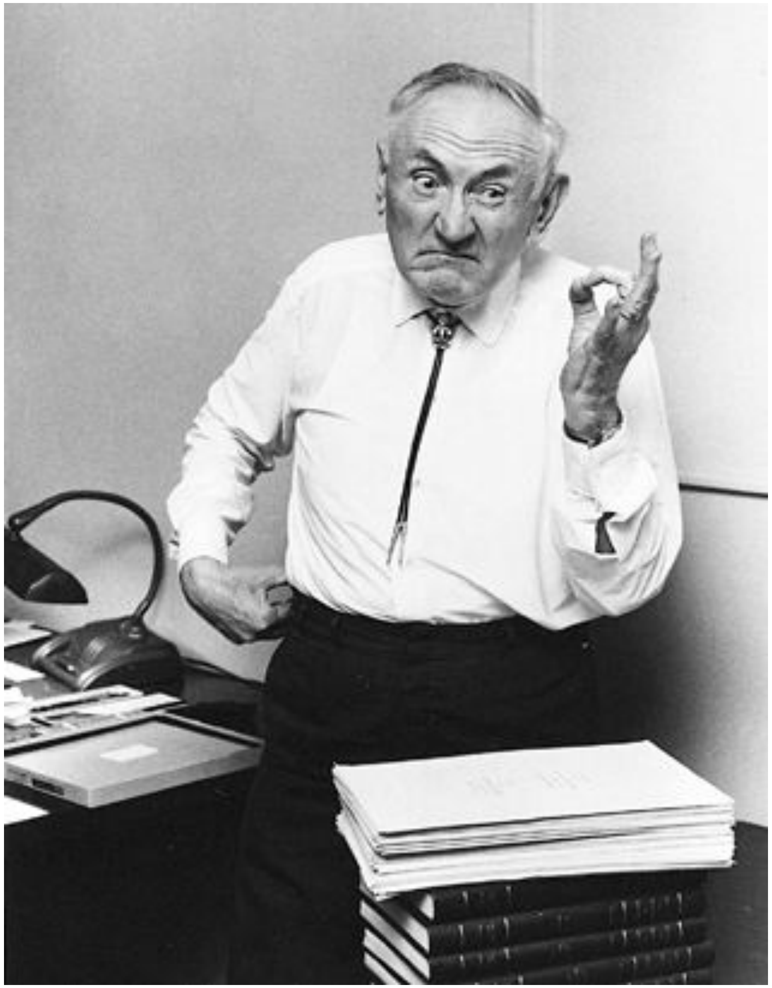
dunkle Materie



*the surprising result that **dark matter** is present in much greater amount than luminous matter.*


125 Mpc/h
Image credit: The Millenium Simulation Project

*In order to obtain the observed value of an average Doppler effect of 1000 km/s or more, the average density in the Coma system would have to be at least 400 times larger than that derived on the grounds of observations of luminous matter. If this would be confirmed we would get the surprising result that **dark matter** is present in much greater amount than luminous matter.*



In order to obtain the observed value of an average Doppler effect of 1000 km/s or more,

Virial Theorem

$$2K + U = 0$$

Virial Theorem

$$2K + U = 0$$

$$K = \sum_{i=1}^{N} \frac{1}{2} m_i \, v_i^2 \qquad U = -\sum_{i=1}^{N} \sum_{j<i} \frac{G \, m_i \, m_j}{r_{i,j}}$$

Virial Theorem

$$2K + U = 0$$

$$K = \sum_{i=1}^{N} \frac{1}{2} m_i \, v_i^2 \qquad U = -\sum_{i=1}^{N} \sum_{j<i} \frac{G \, m_i \, m_j}{r_{i,j}}$$

$$\sigma_v^2 = \alpha_R \frac{GM}{R}$$

Virial Theorem

$$2K + U = 0$$

$$K = \sum_{i=1}^{N} \frac{1}{2} m_i \, v_i^2 \qquad U = -\sum_{i=1}^{N} \sum_{j<i} \frac{G \, m_i \, m_j}{r_{i,j}}$$

$$\sigma_v^2 = \alpha_R \frac{GM}{R}$$

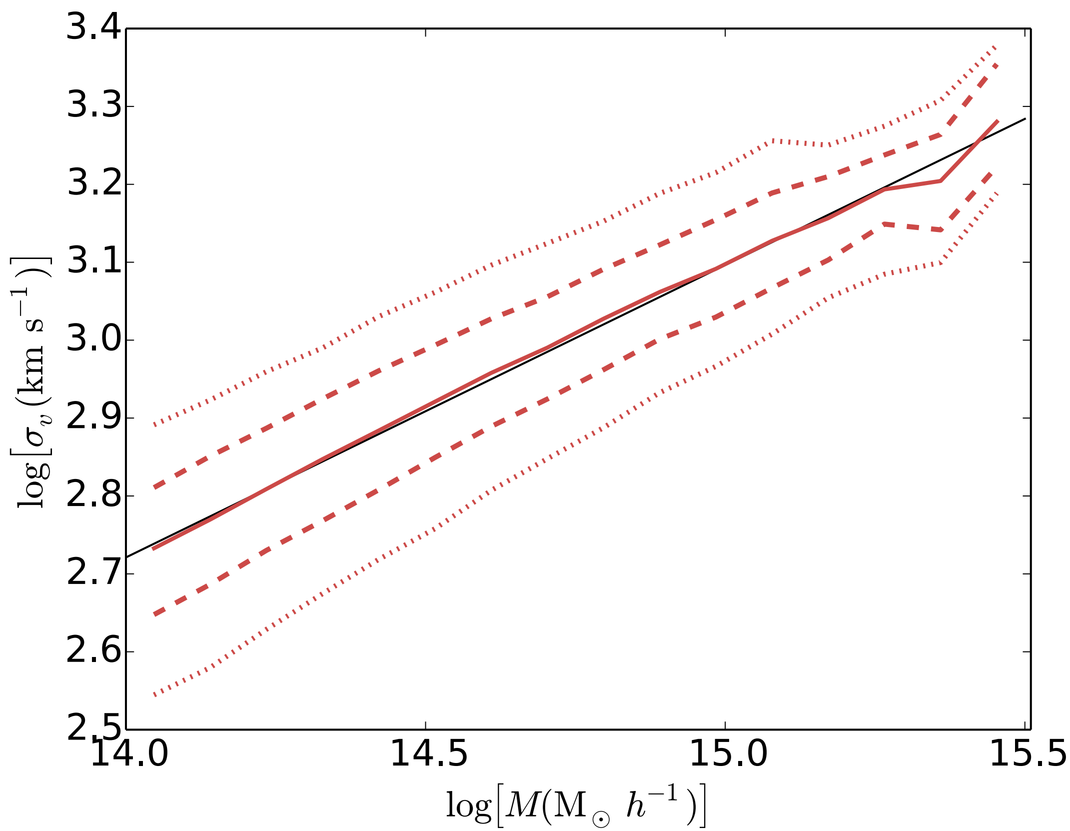
$$\sigma_v \propto M^{1/3}$$

M(σ) POWER LAW

M(σ) Power Law

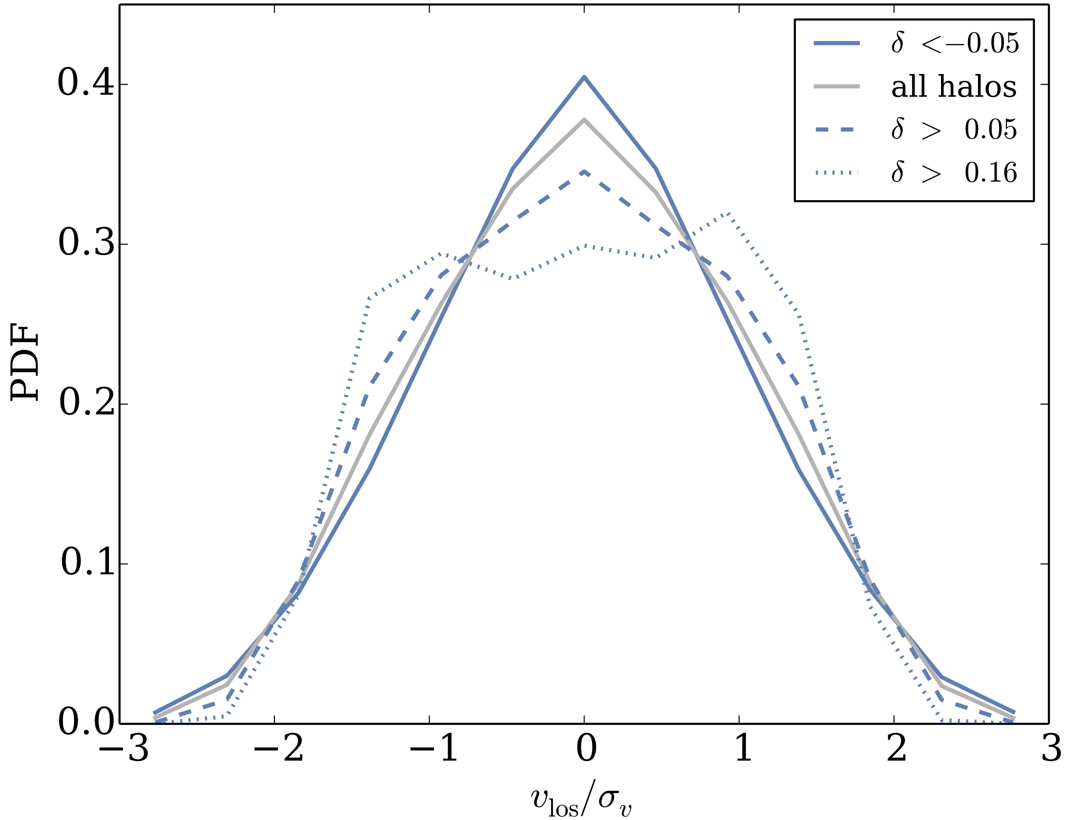
Reasons for scatter:

- triaxiality
- infalling matter or mergers
- galaxy selection
- bias between dark matter particle dispersion & galaxy dispersion



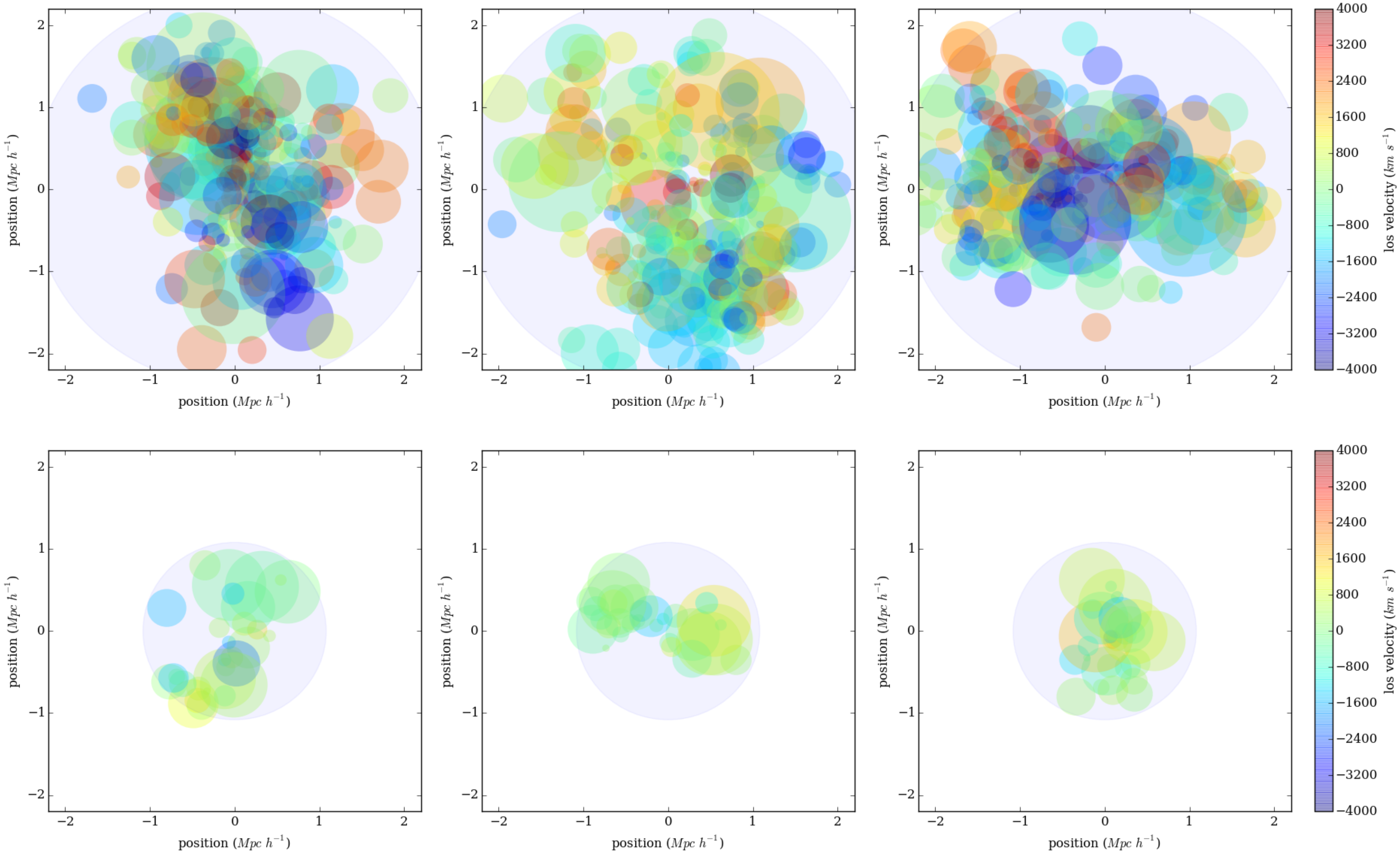
Signatures in the Velocity PDF

- Infalling matter & mergers lead to flatter velocity distributions

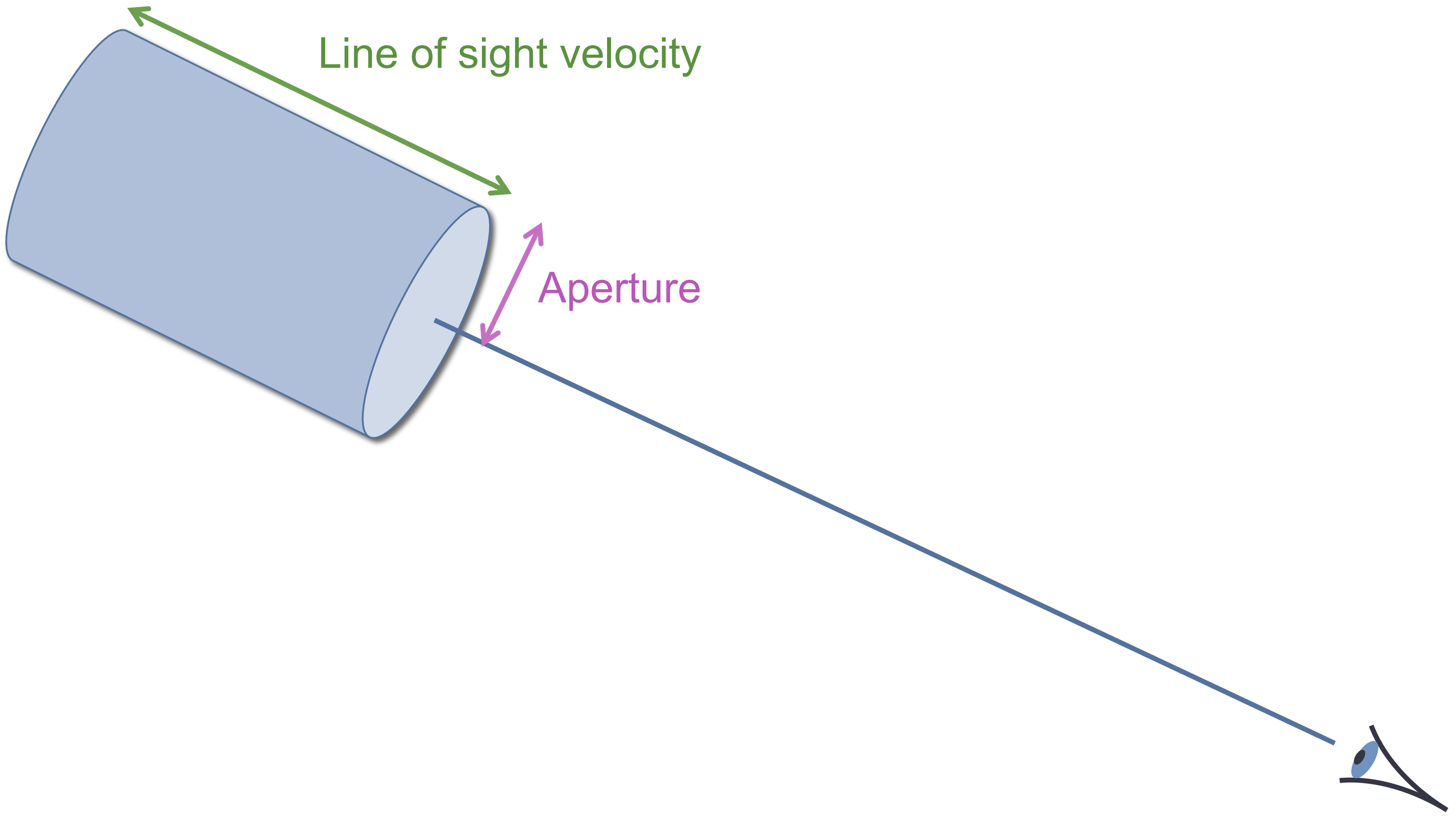


THE CLUSTER CATALOG

Ideal Cluster Catalog



Impure Cluster Catalog

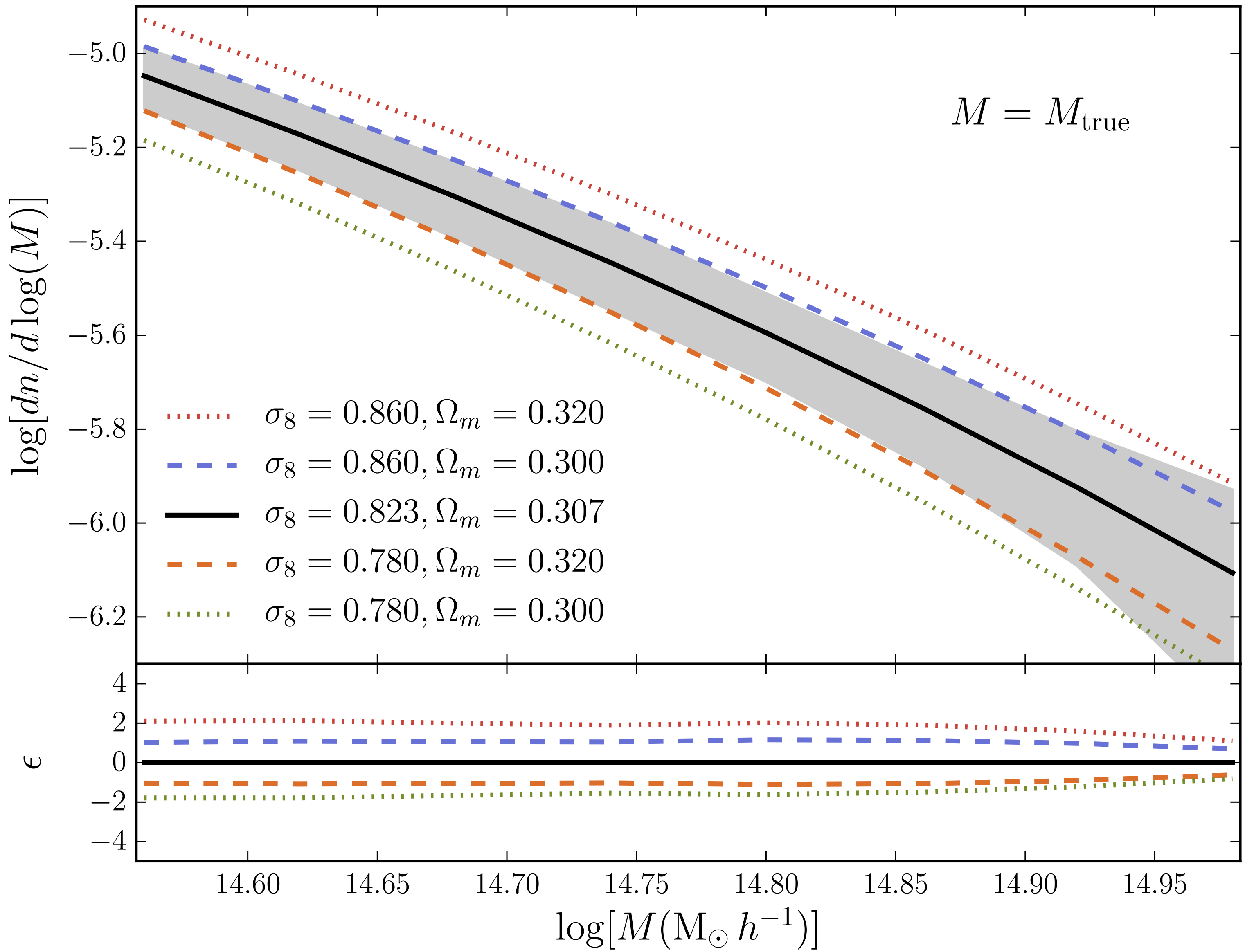


THE HALO MASS FUNCTION

THE HALO MASS FUNCTION

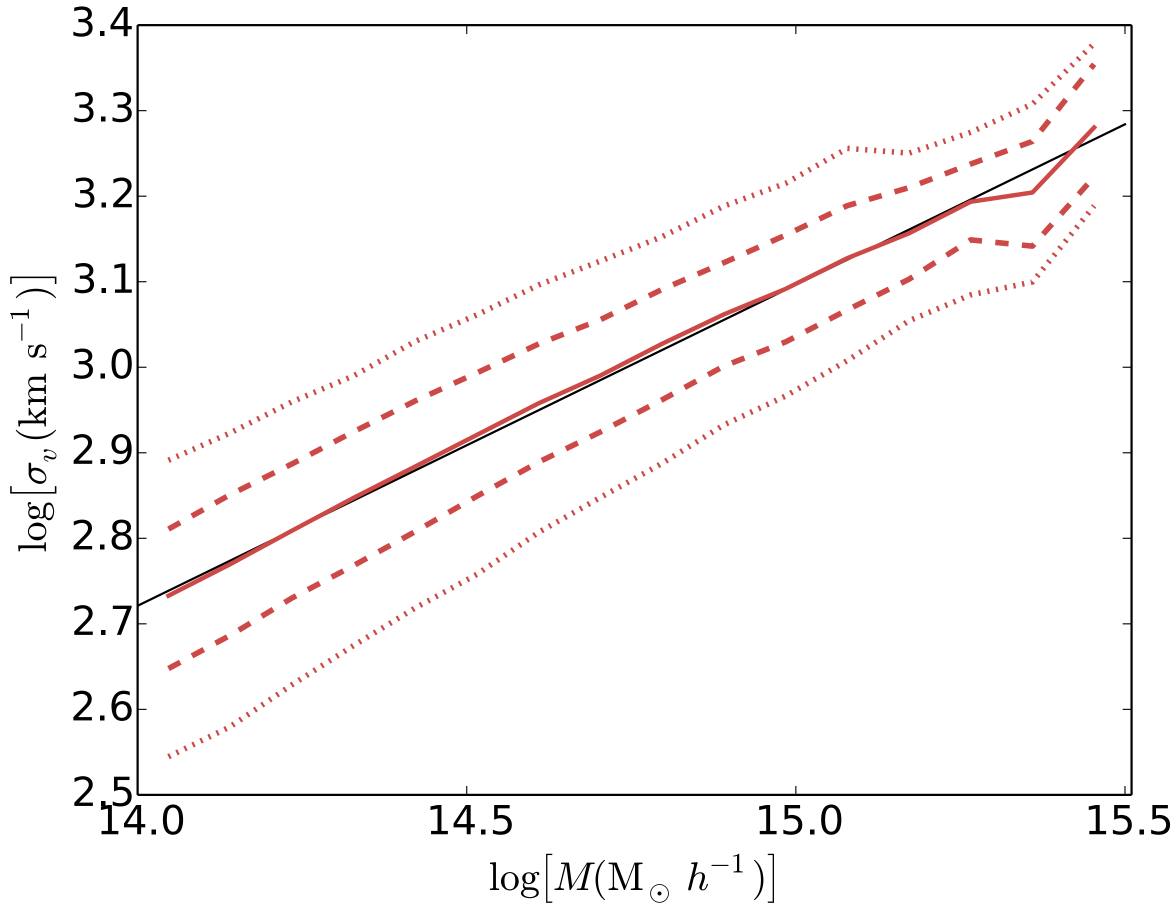
It's impolite to ask a galaxy cluster its mass.

Halo Mass Function



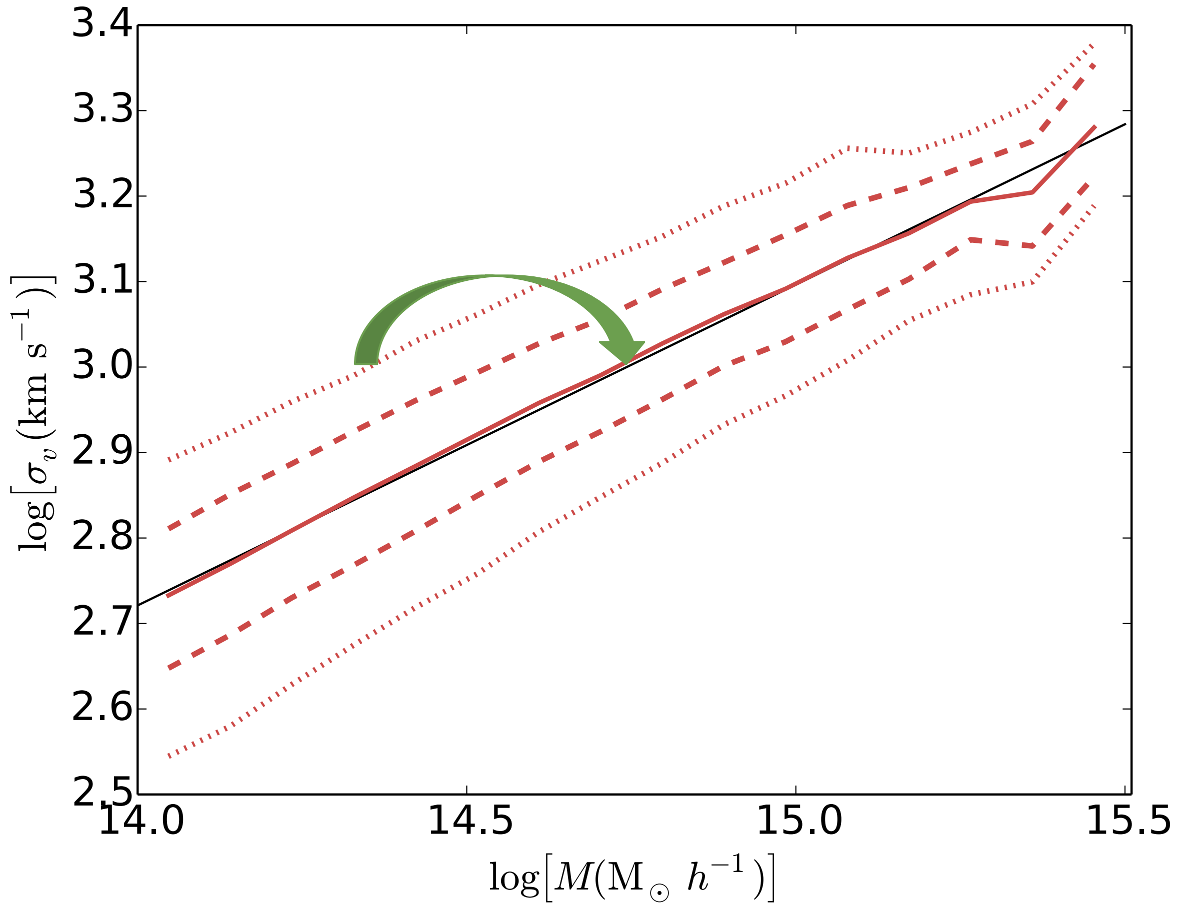
Eddington Bias in Dynamical Masses

Scatter in the M(σ) relationship, coupled with the steeply-declining HMF, alters the observed HMF.



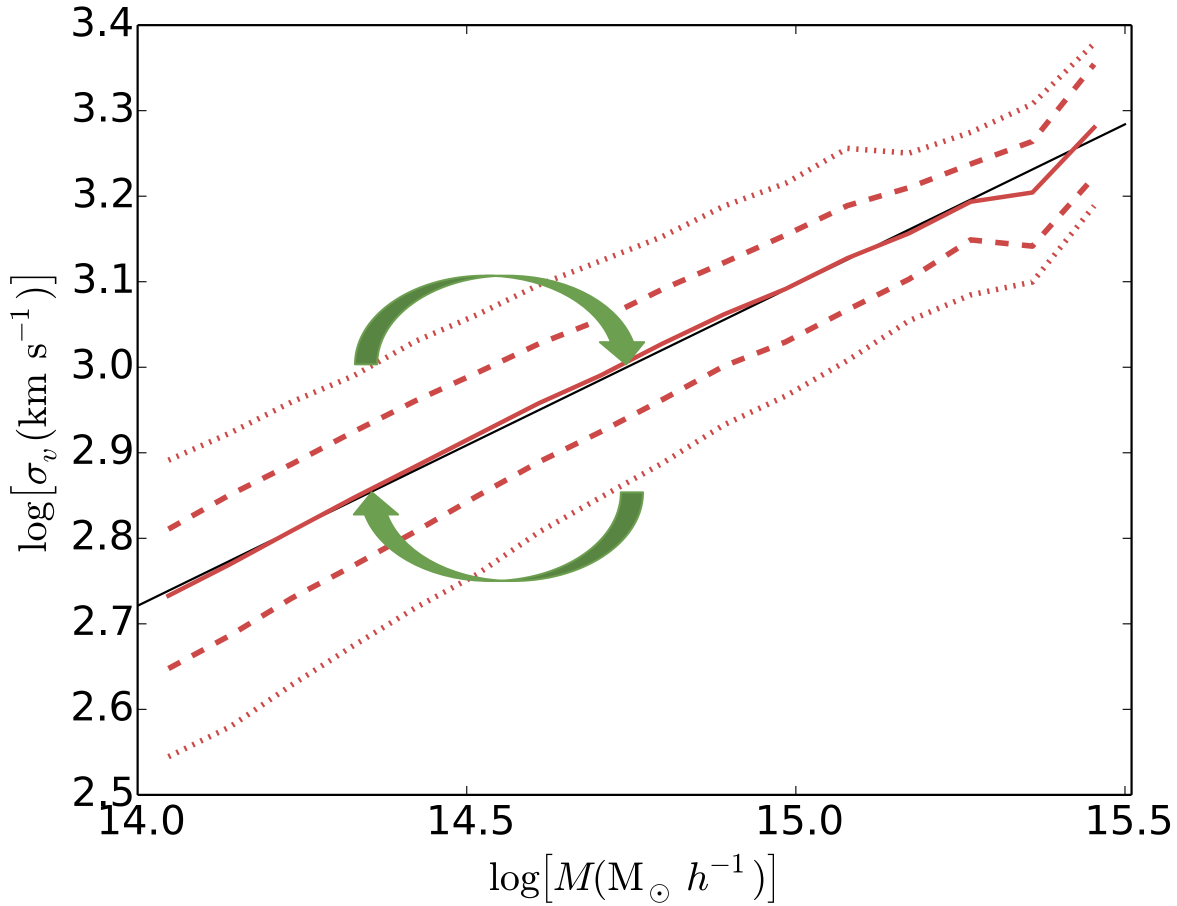
Eddington Bias in Dynamical Masses

Scatter in the M(σ) relationship, coupled with the steeply-declining HMF, alters the observed HMF.

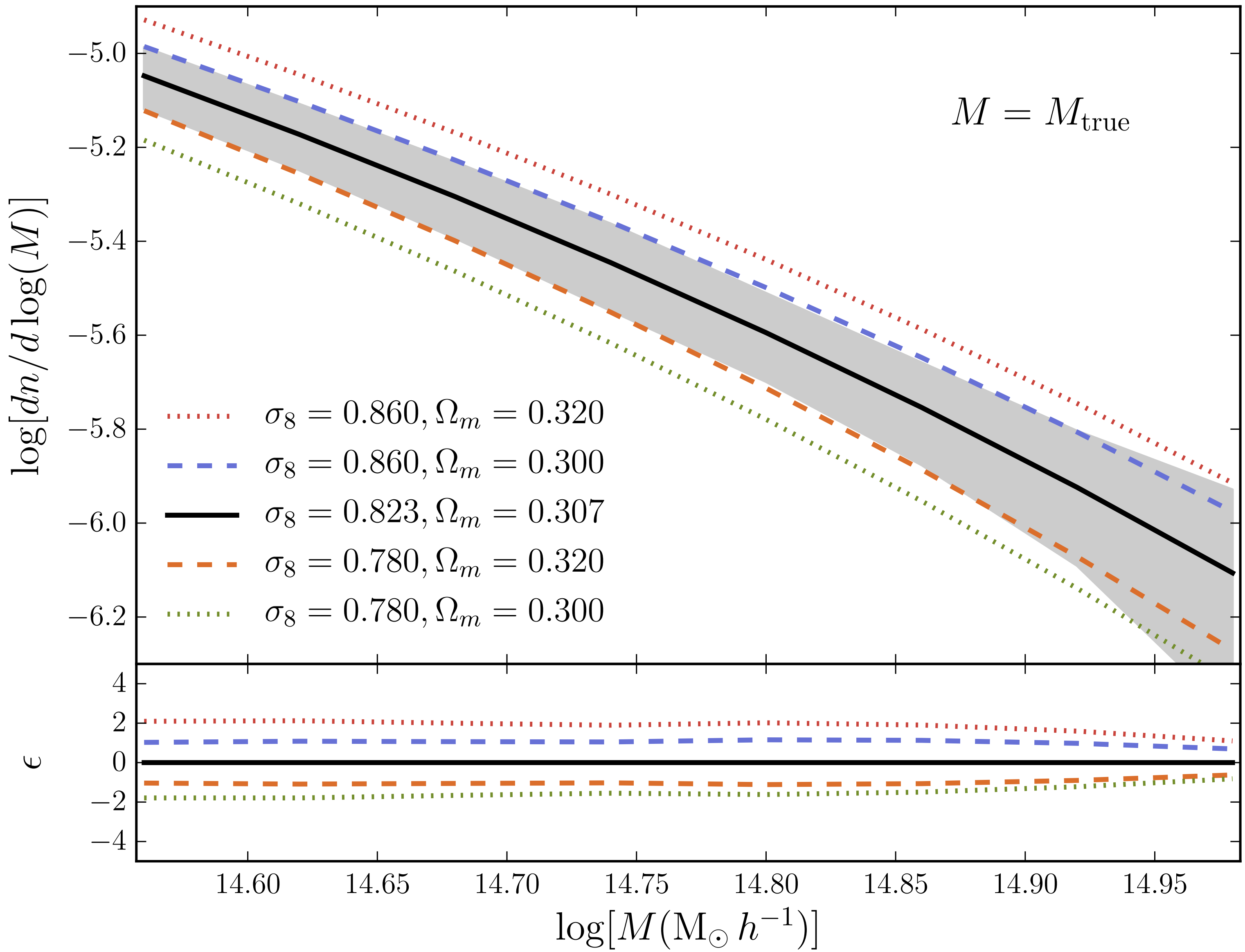


Eddington Bias in Dynamical Masses

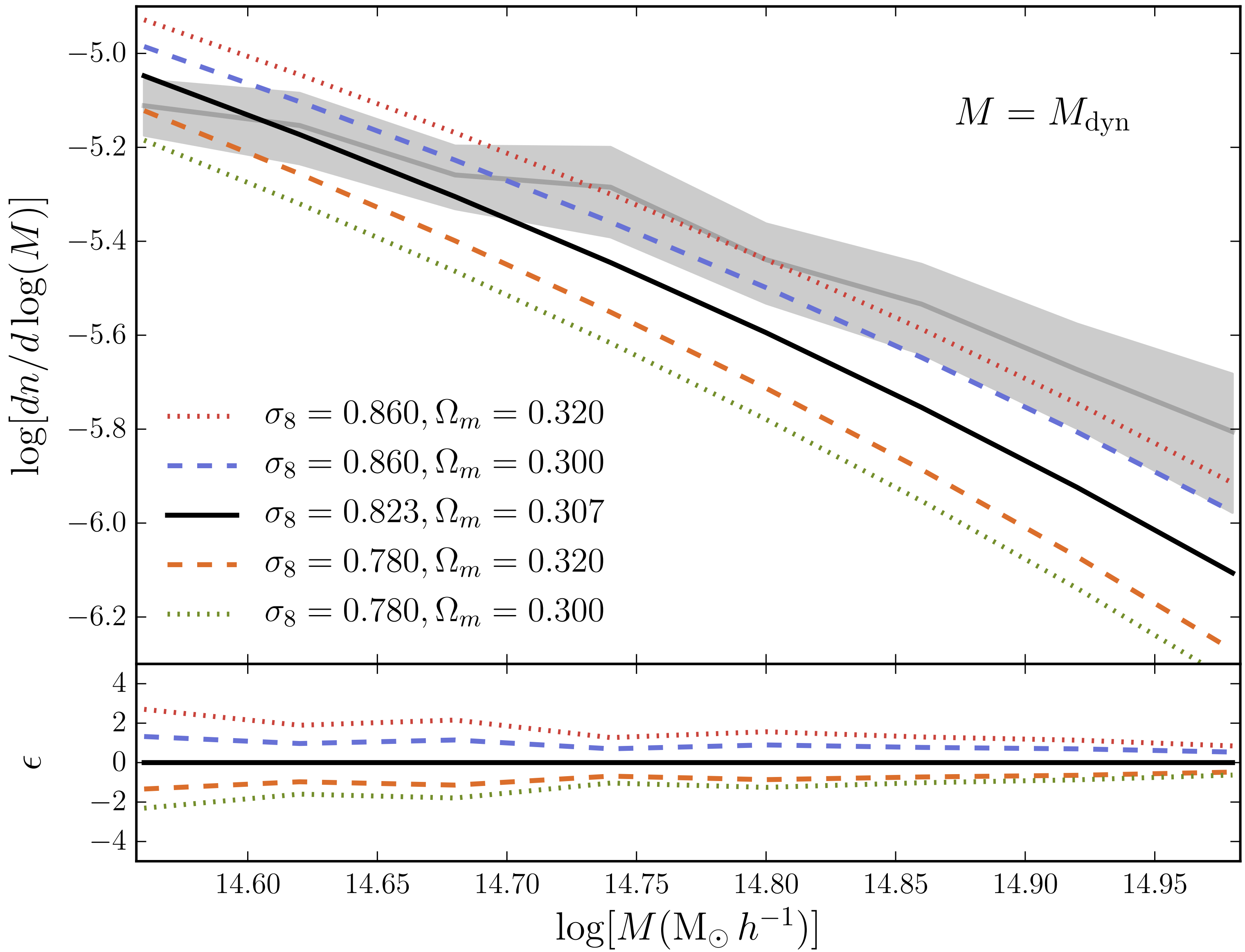
Scatter in the M(σ) relationship, coupled with the steeply-declining HMF, alters the observed HMF.



Halo Mass Function

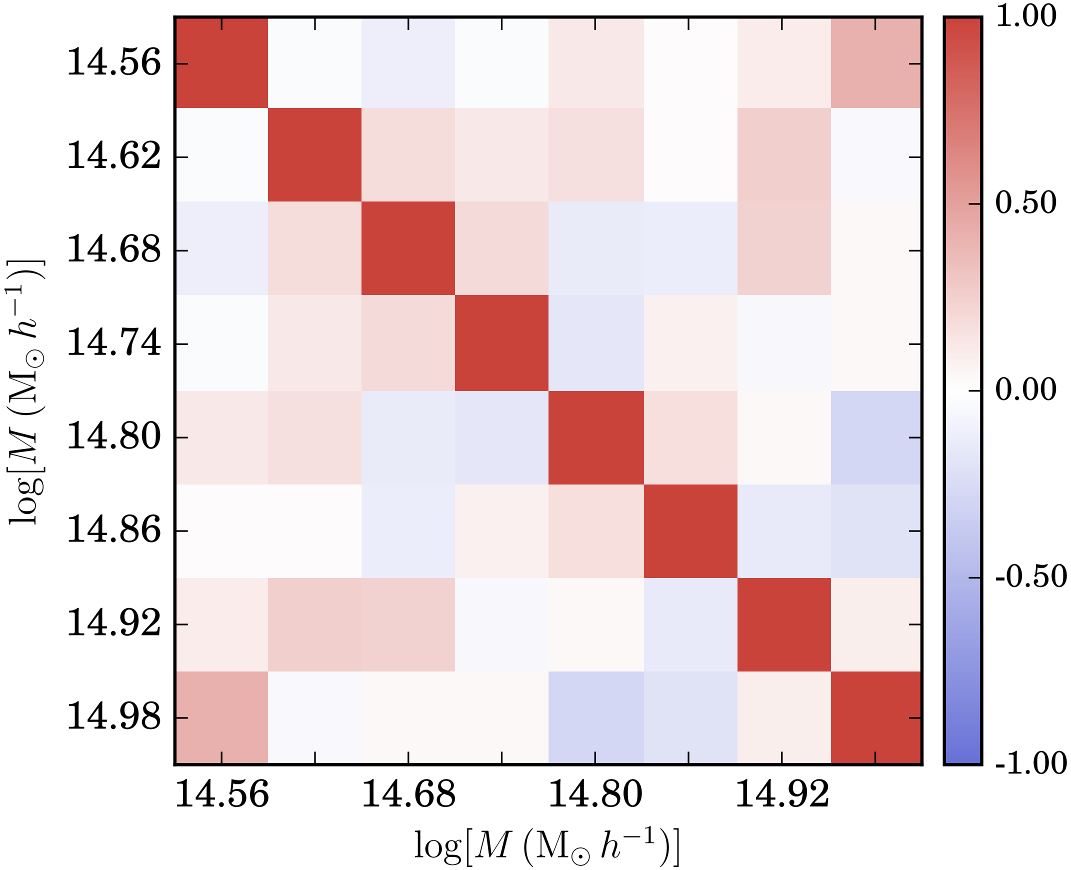


Halo Mass Function



χ^2 analysis for constraining σ_8 & Ω_m

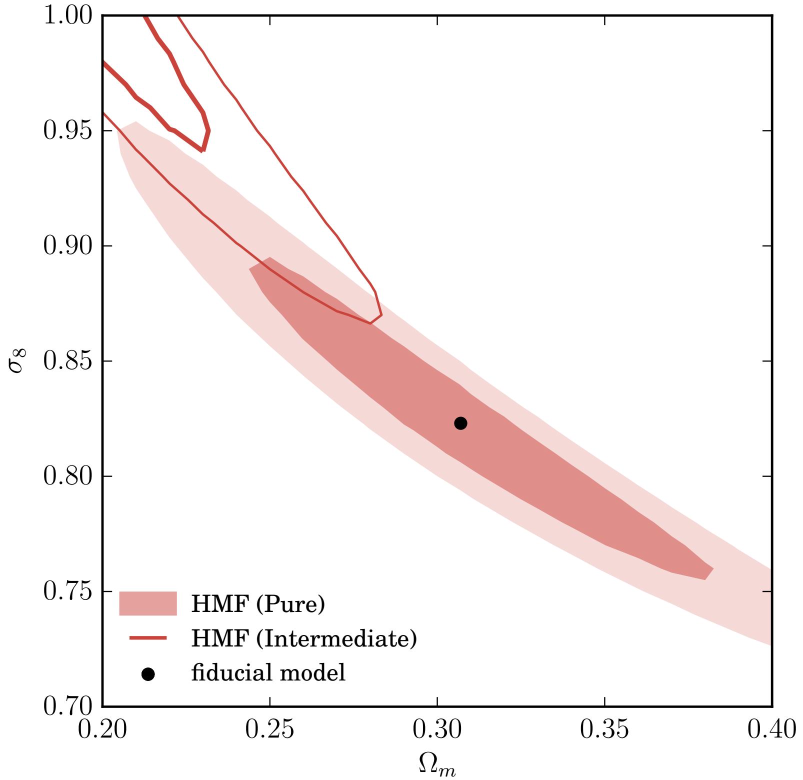
$$\chi^2(y|\sigma_8, \Omega_m) = (\bar{y} - y^\star)^T \, \hat{\Psi}^{-1} \, (\bar{y} - y^\star)$$



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

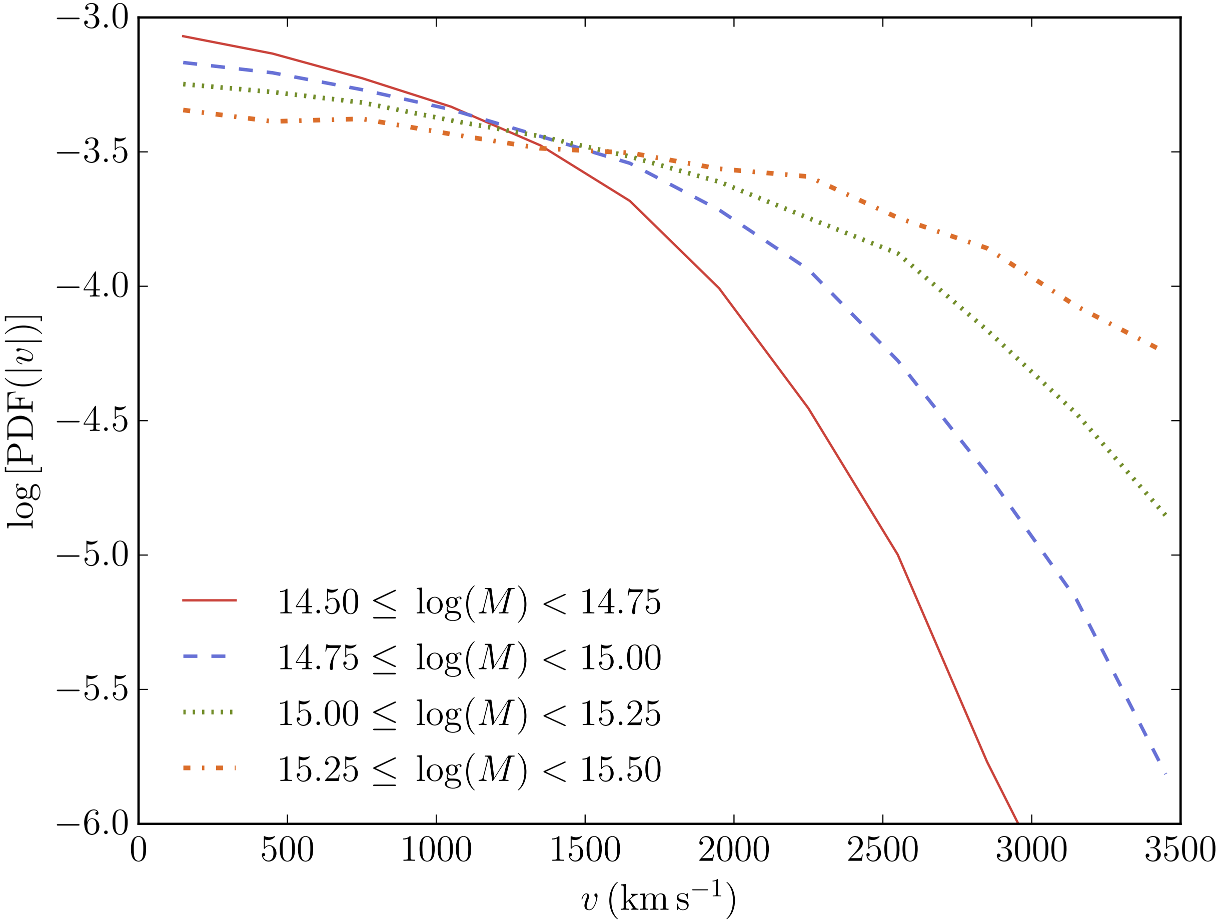
Constraining Cosmological Models

- Measurement error biases to low Ω_m and high σ_8.
- Fiducial model lies outside of the 99% likelihood contour.



A FORWARD MODELING APPROACH:
The Velocity Distribution Function (Mocks)

Velocity PDF

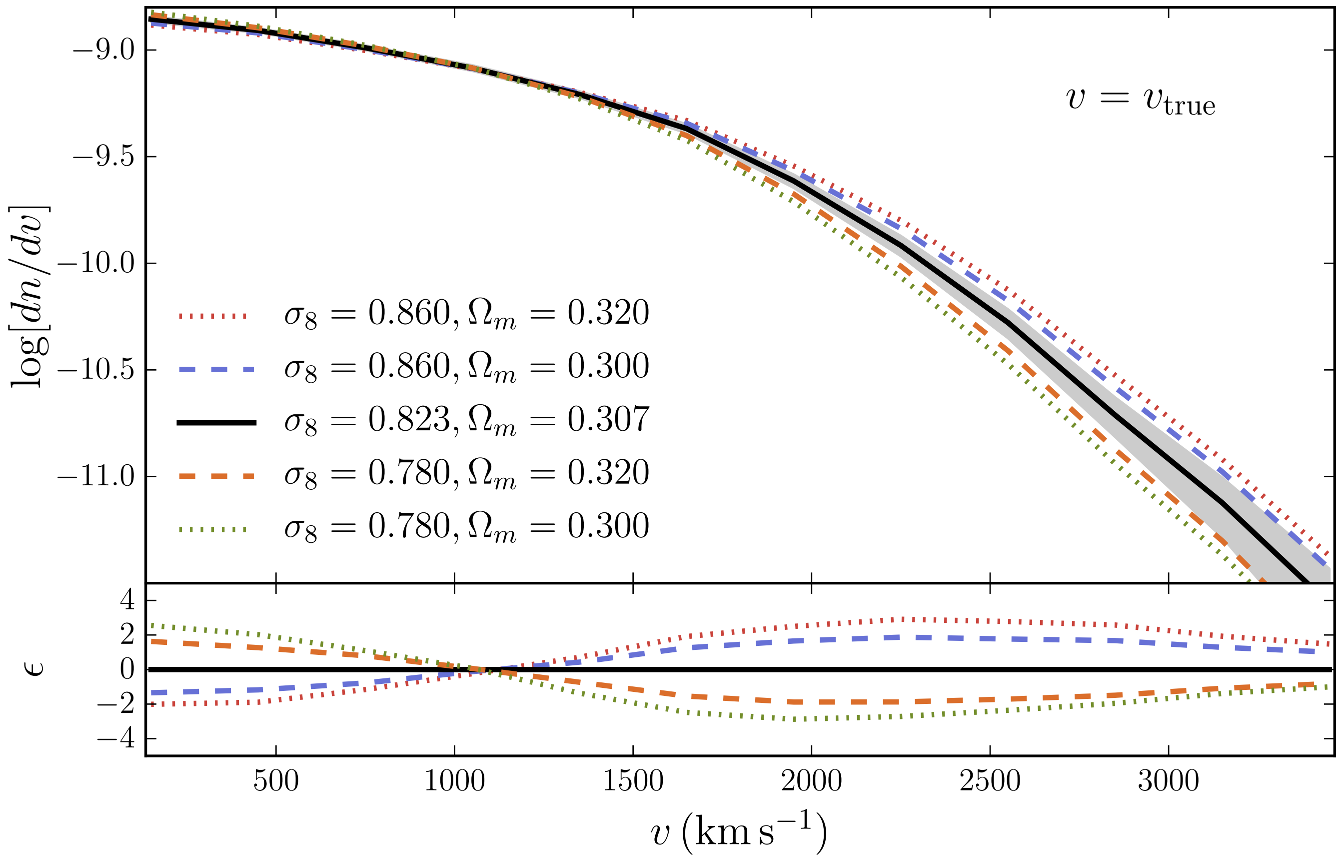


Velocity Distribution Function

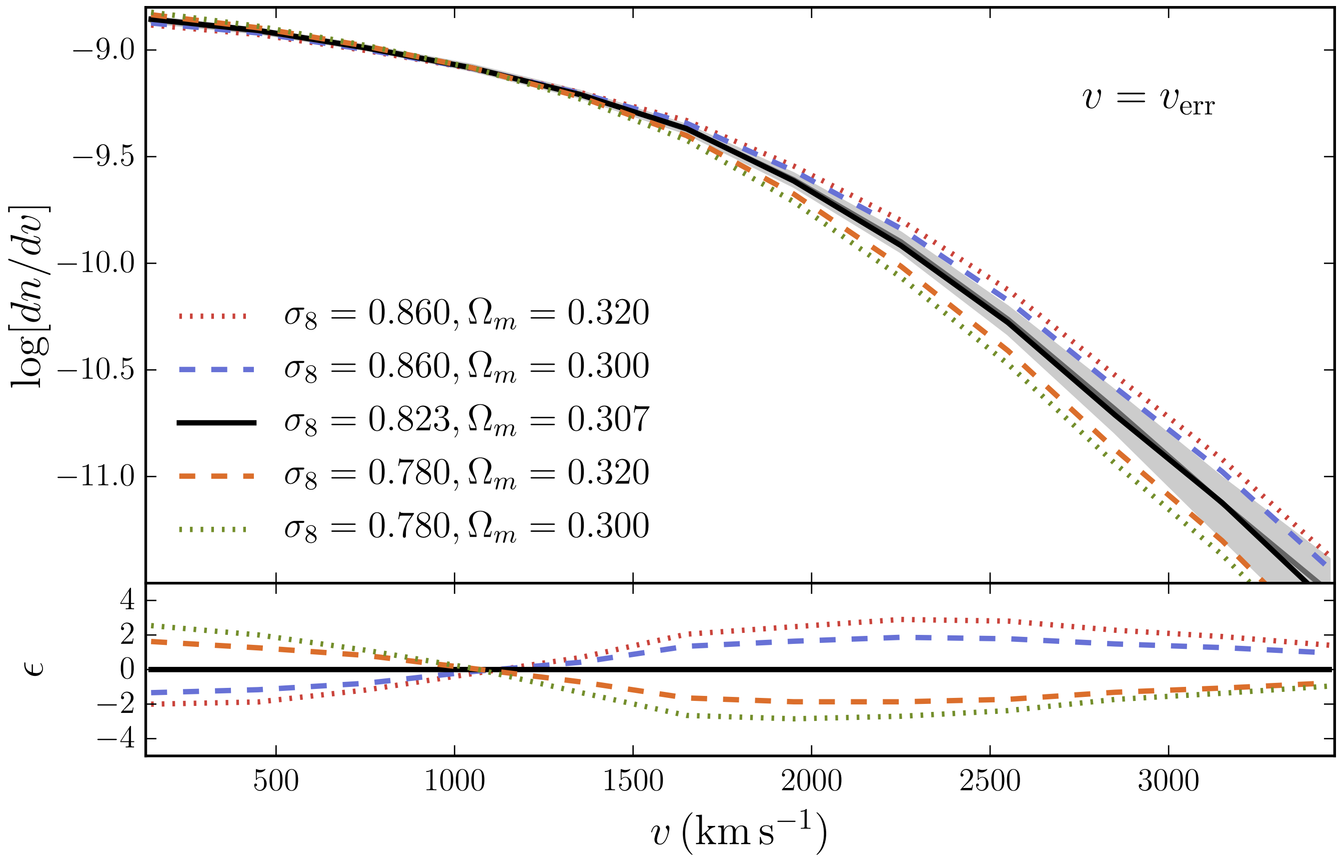
$$\frac{dn}{dv}(v) \equiv \frac{1}{V} \sum_{i=1}^{N} [\mathrm{PDF}(|v|)]_i$$

- Sum the most massive or the richest - or simply the observed - clusters in a volume

Velocity Distribution Function

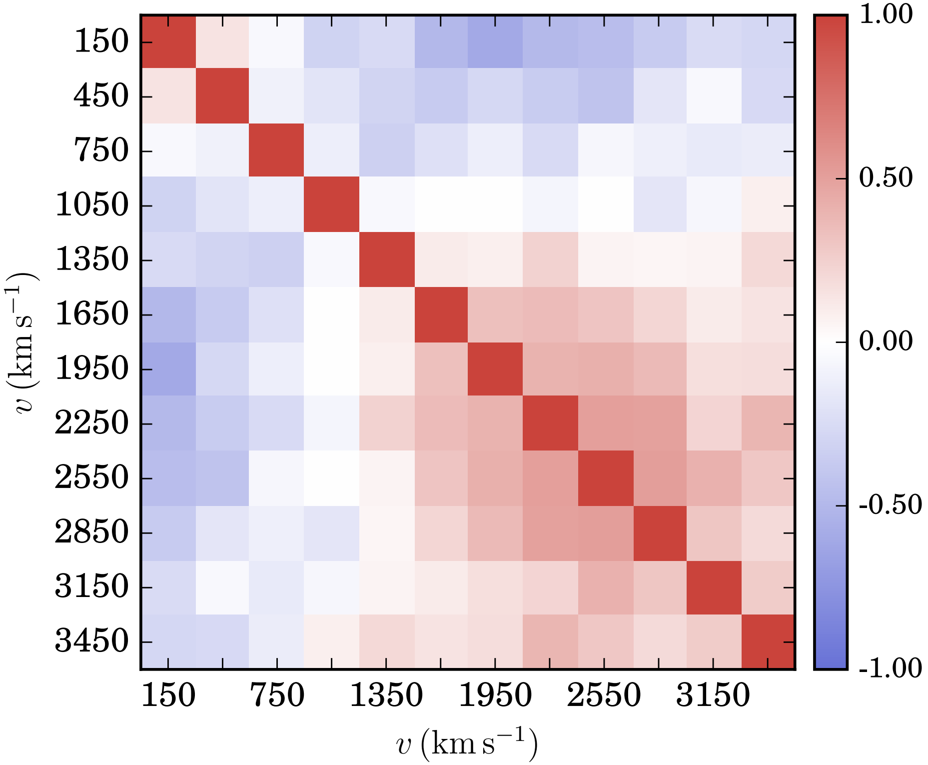


Velocity Distribution Function with velocity error



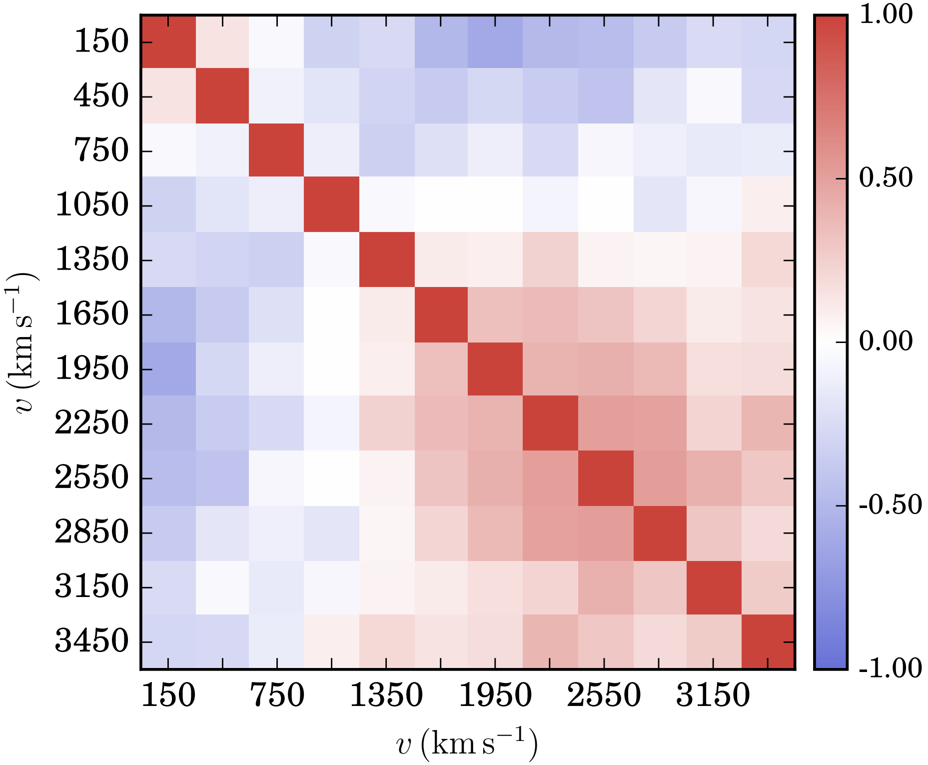
χ^2 analysis for constraining σ_8 & Ω_m

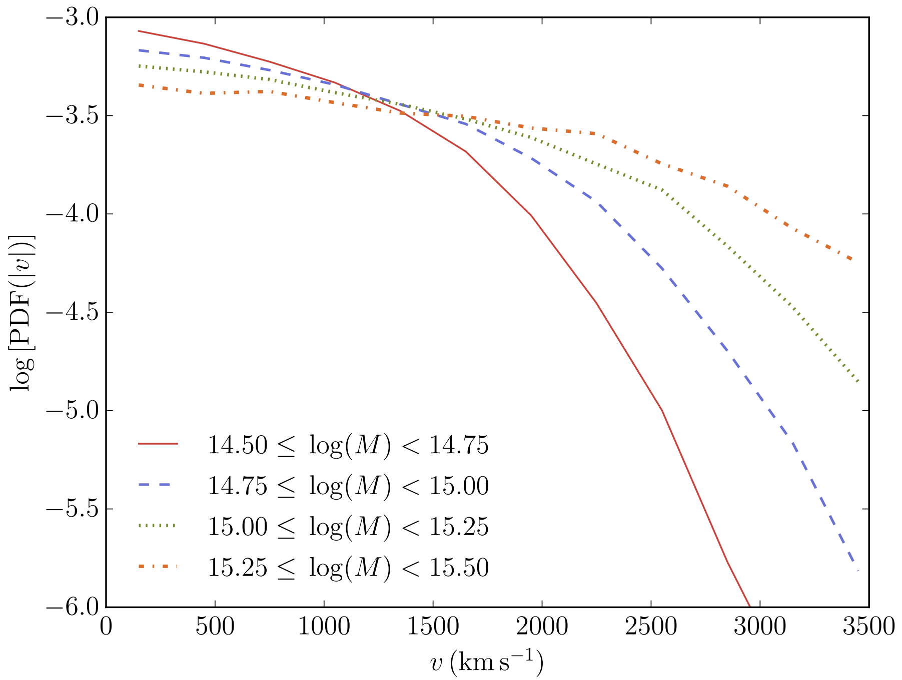
$$\chi^2(y|\sigma_8,\,\Omega_m) = (\bar{y} - y^\star)^T\,\hat{\Psi}^{-1}\,(\bar{y} - y^\star)$$



χ^2 analysis for constraining σ_8 & Ω_m

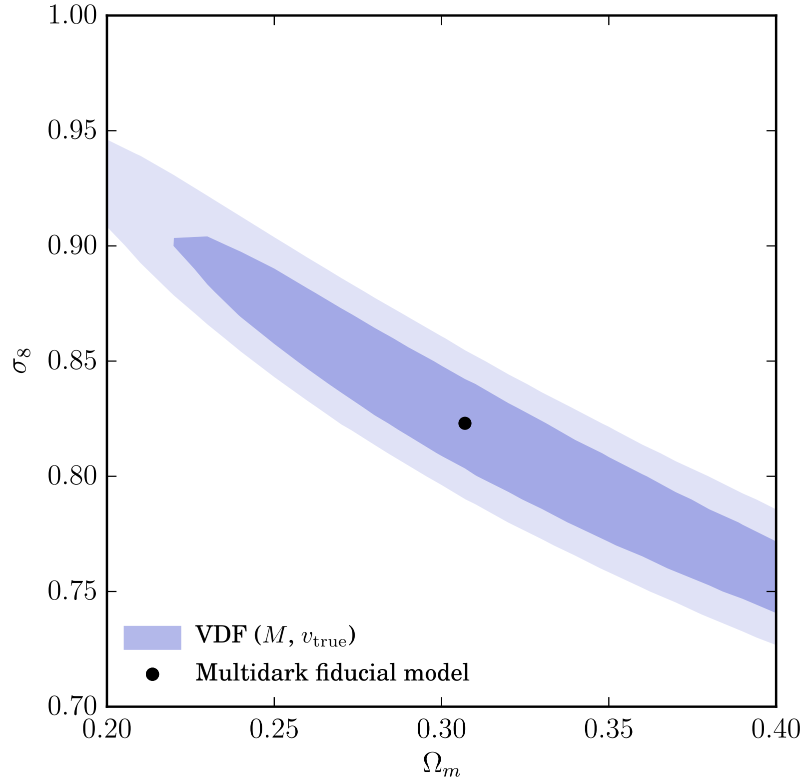
$$\chi^2(y|\sigma_8,\, \Omega_m) = (\bar{y} - y^\star)^T\, \hat{\Psi}^{-1}\, (\bar{y} - y^\star)$$





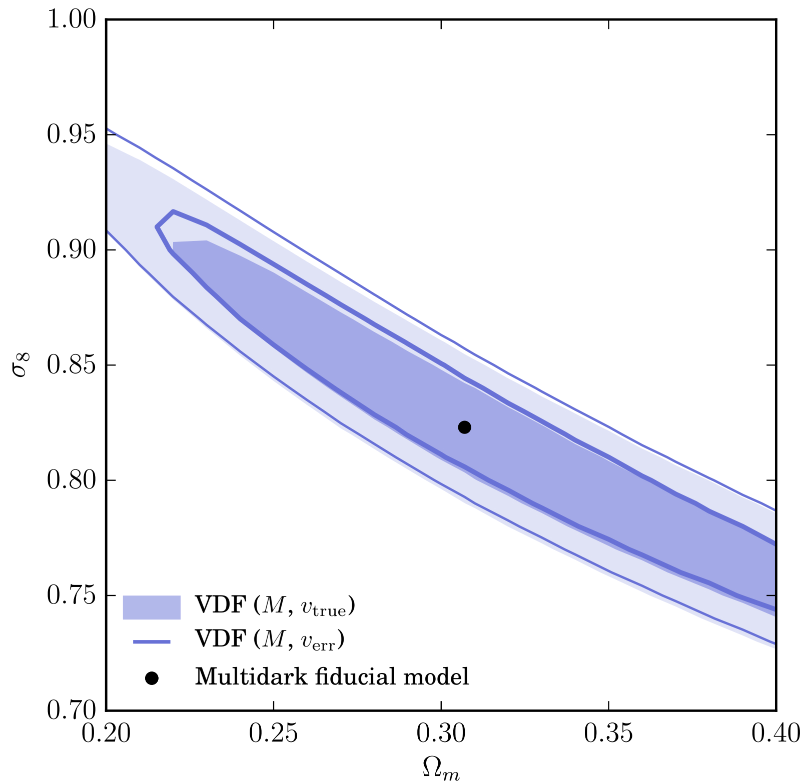
Constraining Cosmological Models with the VDF

- Constraints can be approximated as a band in the Ω_m-σ_8 plane.



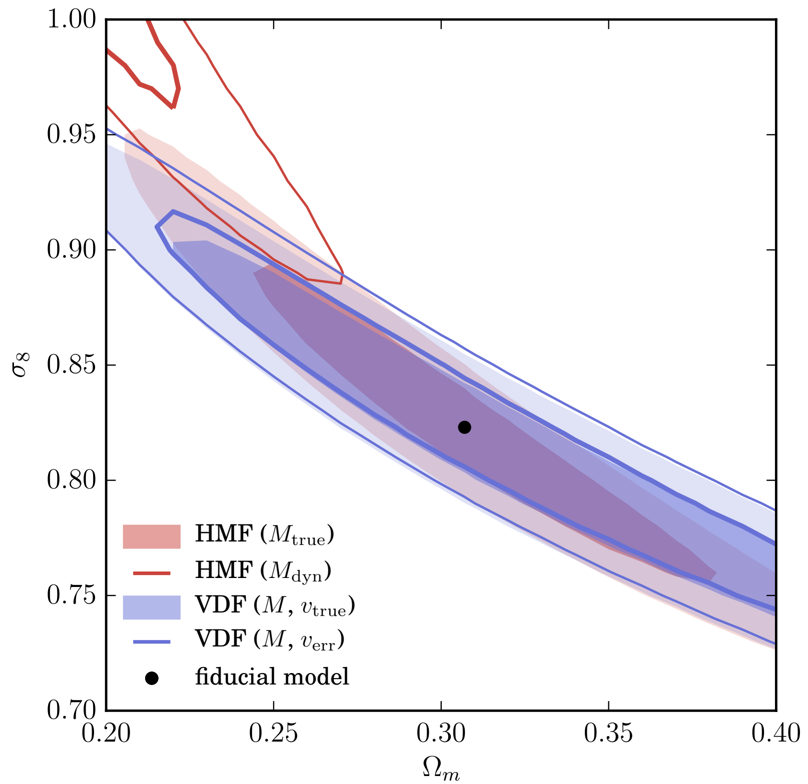
Constraining Cosmological Models with the VDF

- 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.



PRELIMINARY COSMOLOGICAL CONSTRAINTS WITH THE VDF APPLIED TO HECS-SZ CLUSTERS

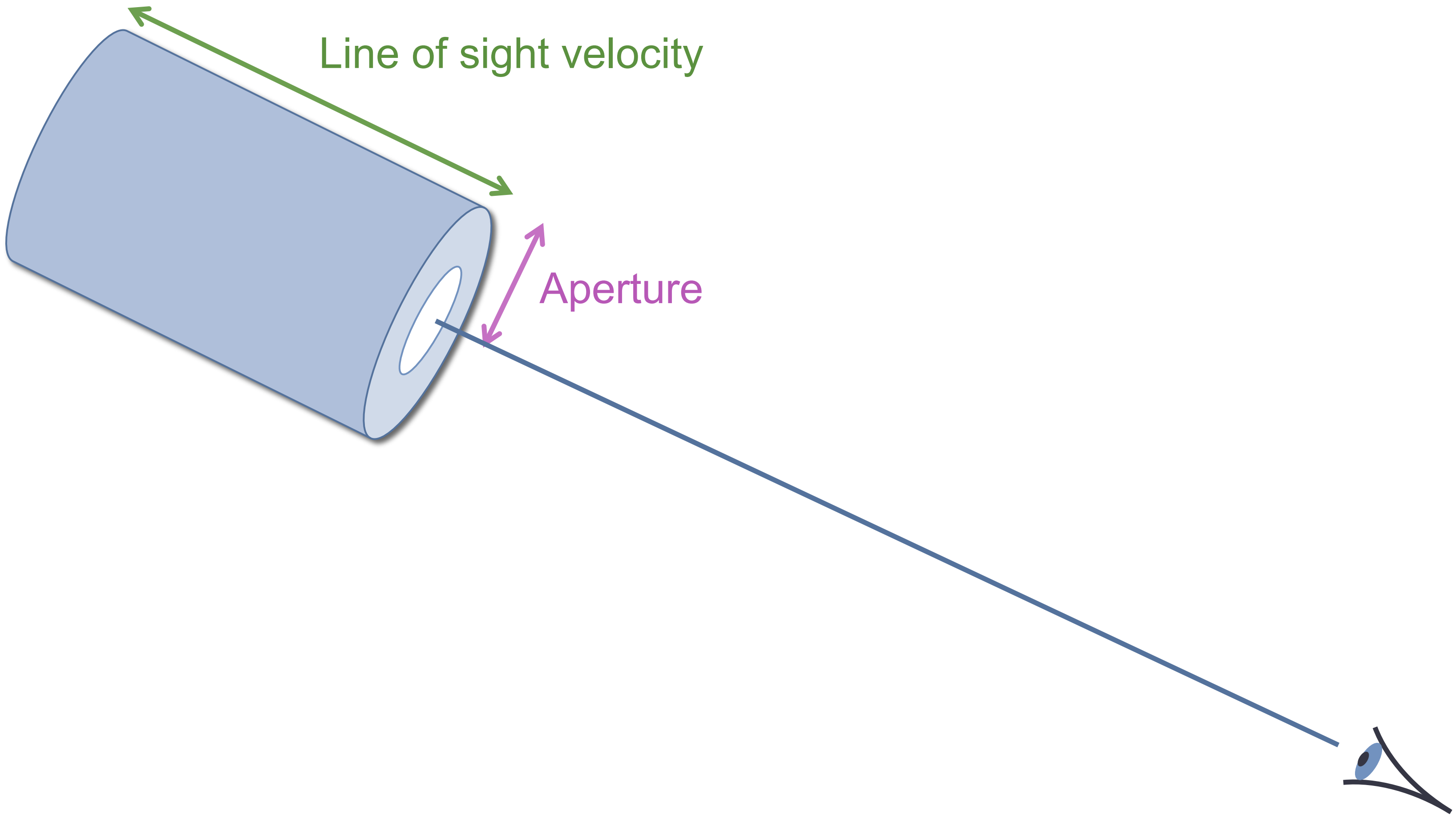
HeCS-SZ Clusters

- Spectroscopic follow up of an SZ-complete survey of 83 clusters
- Selected from SDSS DR6 and DR10
- z<0.3 with a footprint of 20%-28% of the full sky

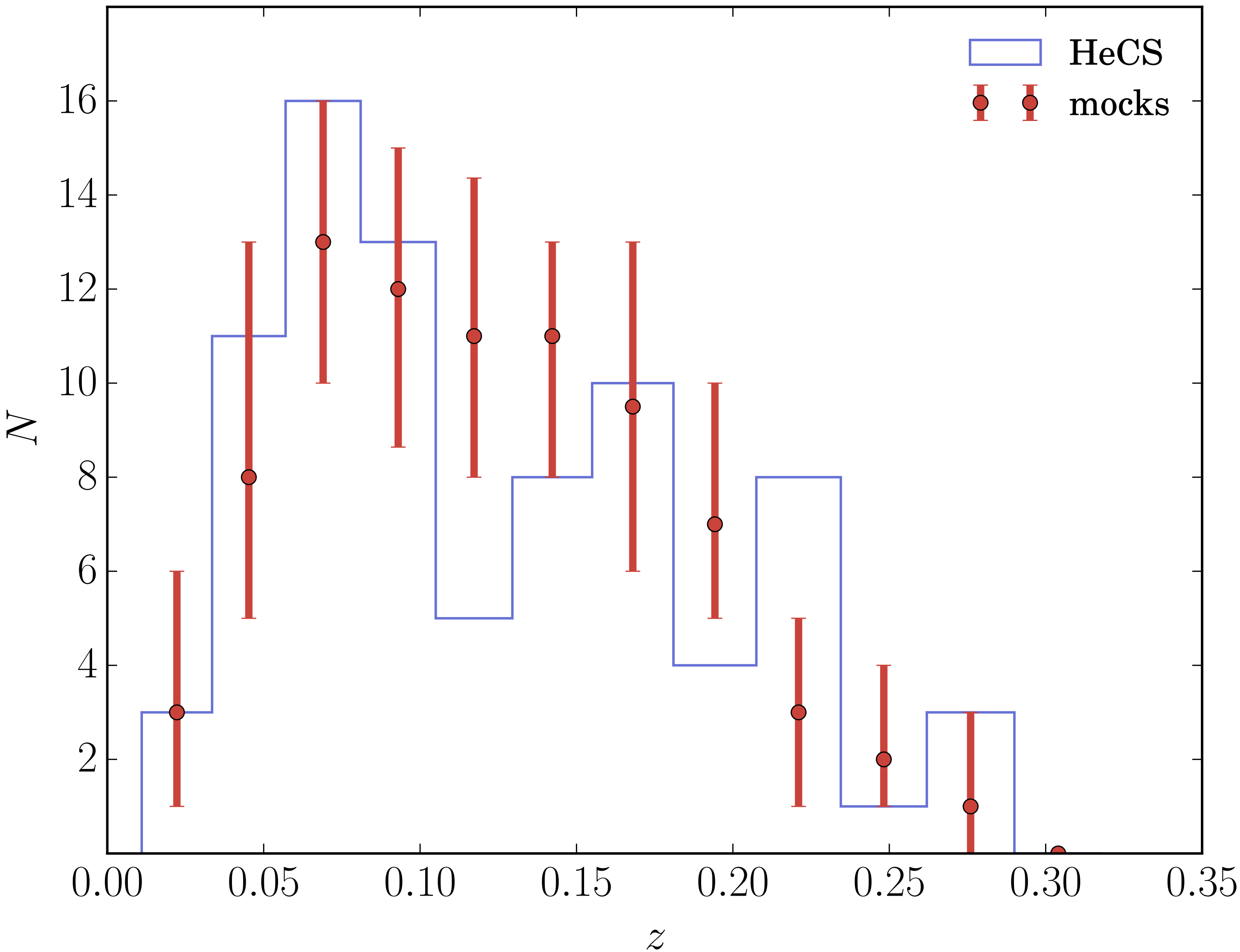
HeCS-SZ: the Hectospec Survey of Sunyaev-Zeldovich-Selected Clusters.
Kenneth J. Rines, Margaret J. Geller, Antonaldo Diaferio, and Ho Seong Hwang

2016 Astrophysical Journal, 819, 1.

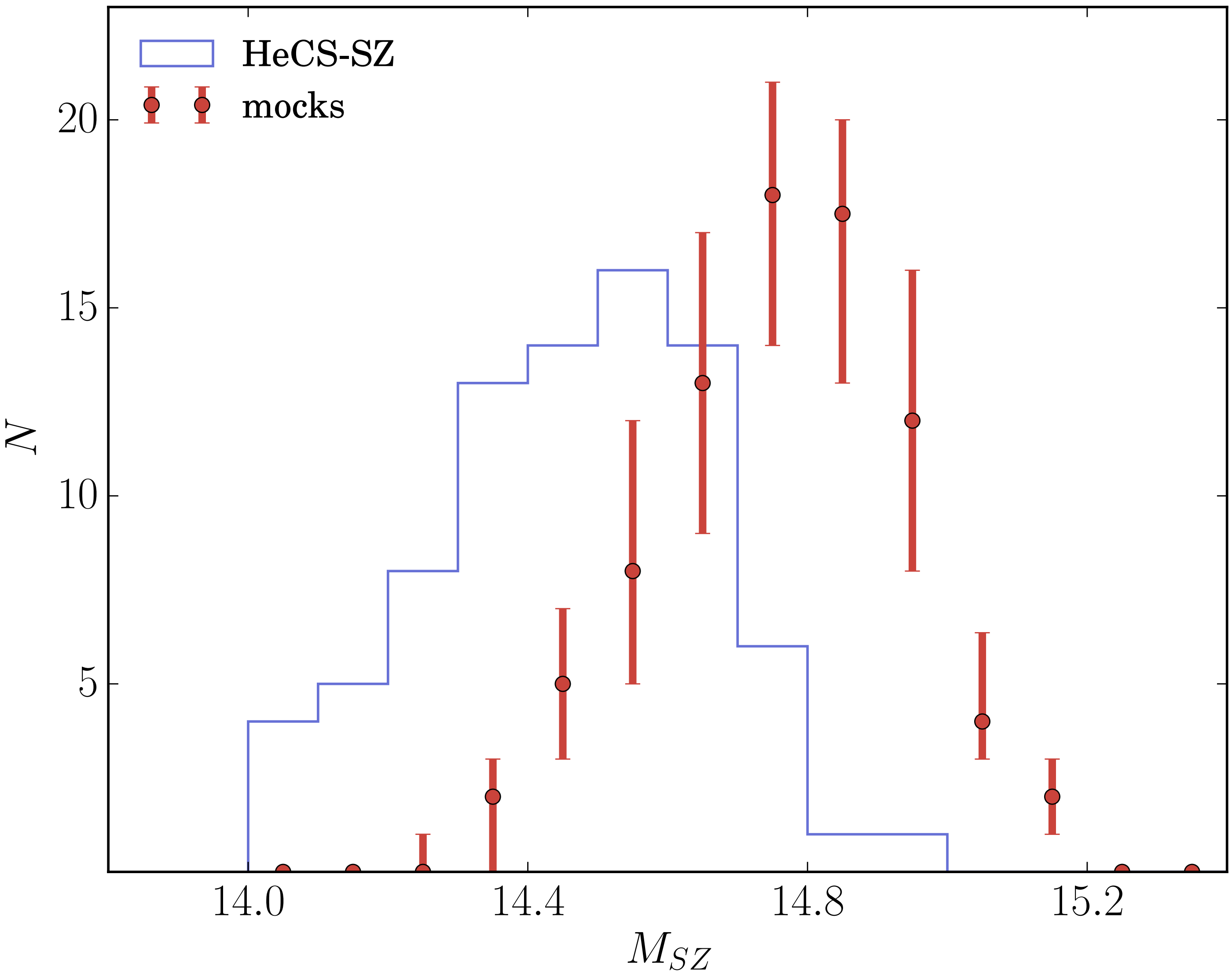
Interlopers



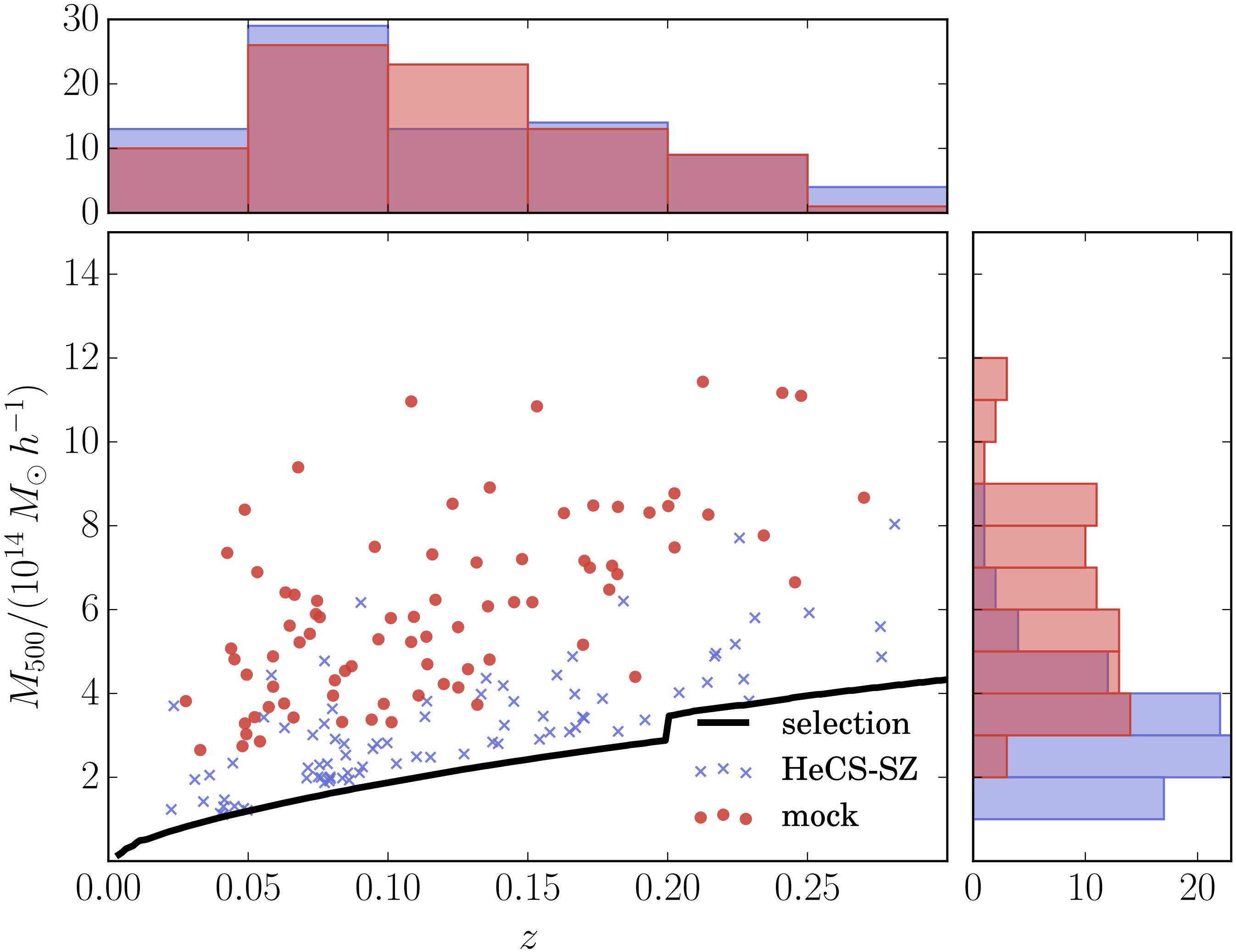
HeCS-SZ Clusters



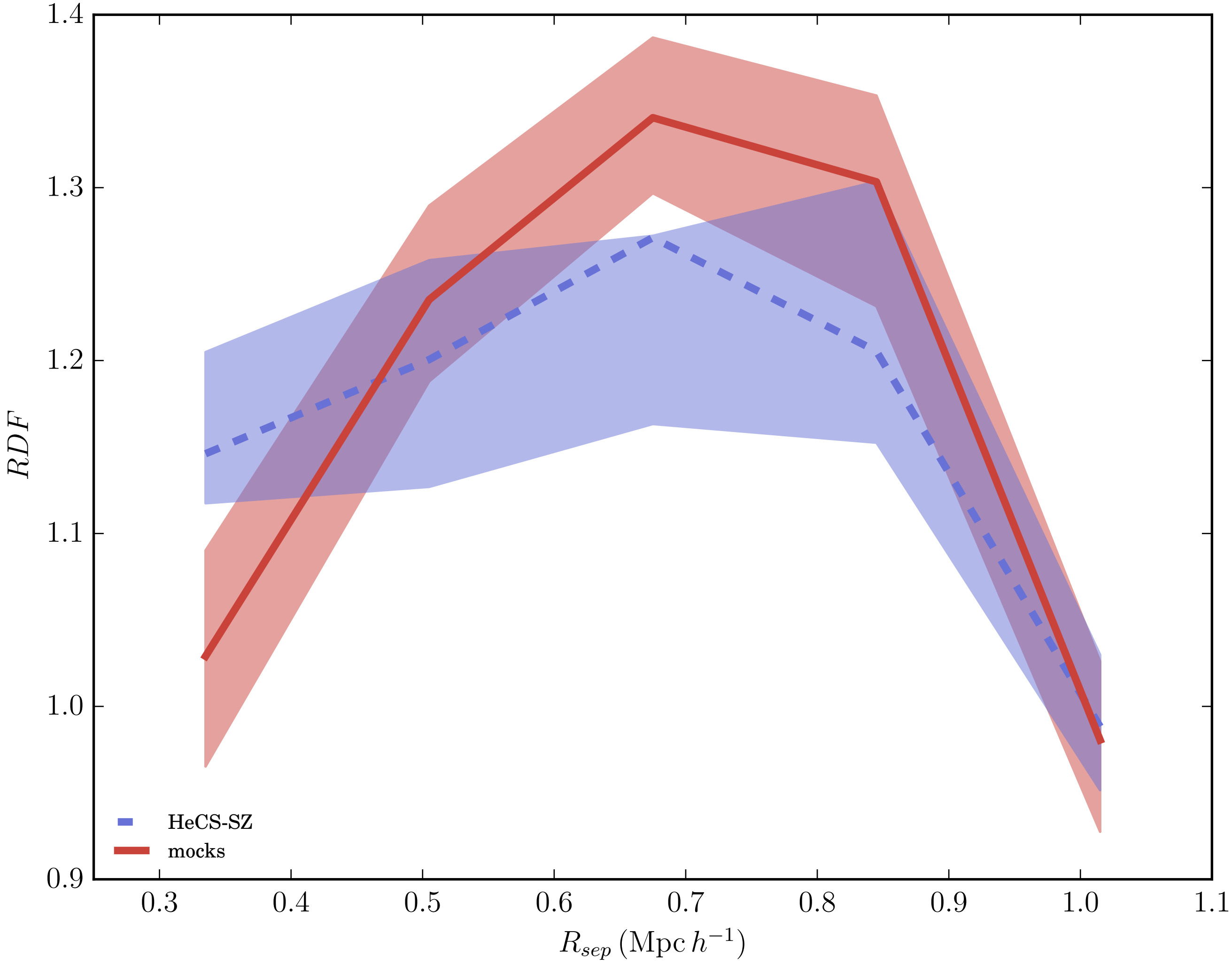
HeCS-SZ Clusters



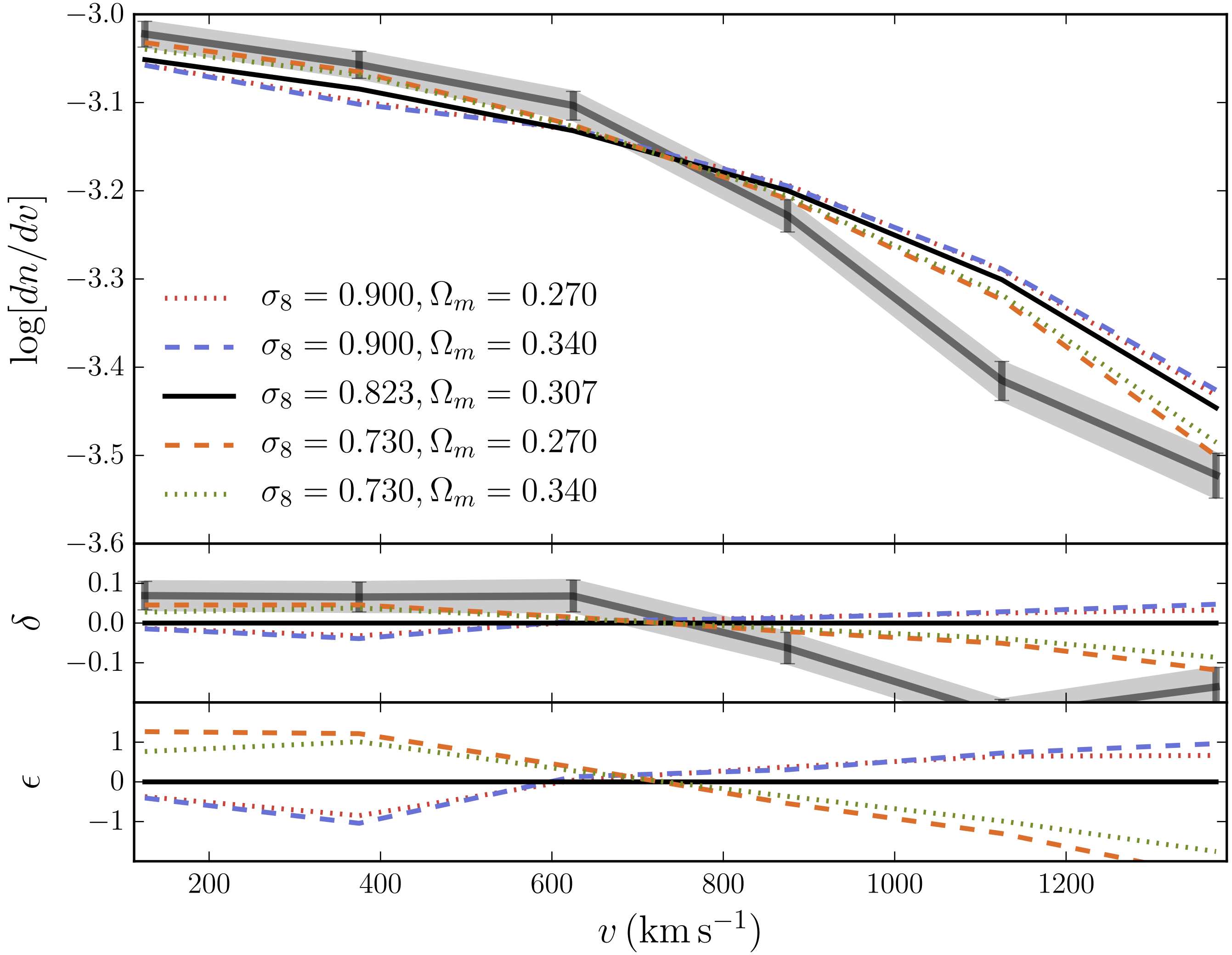
HeCS-SZ Clusters



Radial Distribution of Galaxies

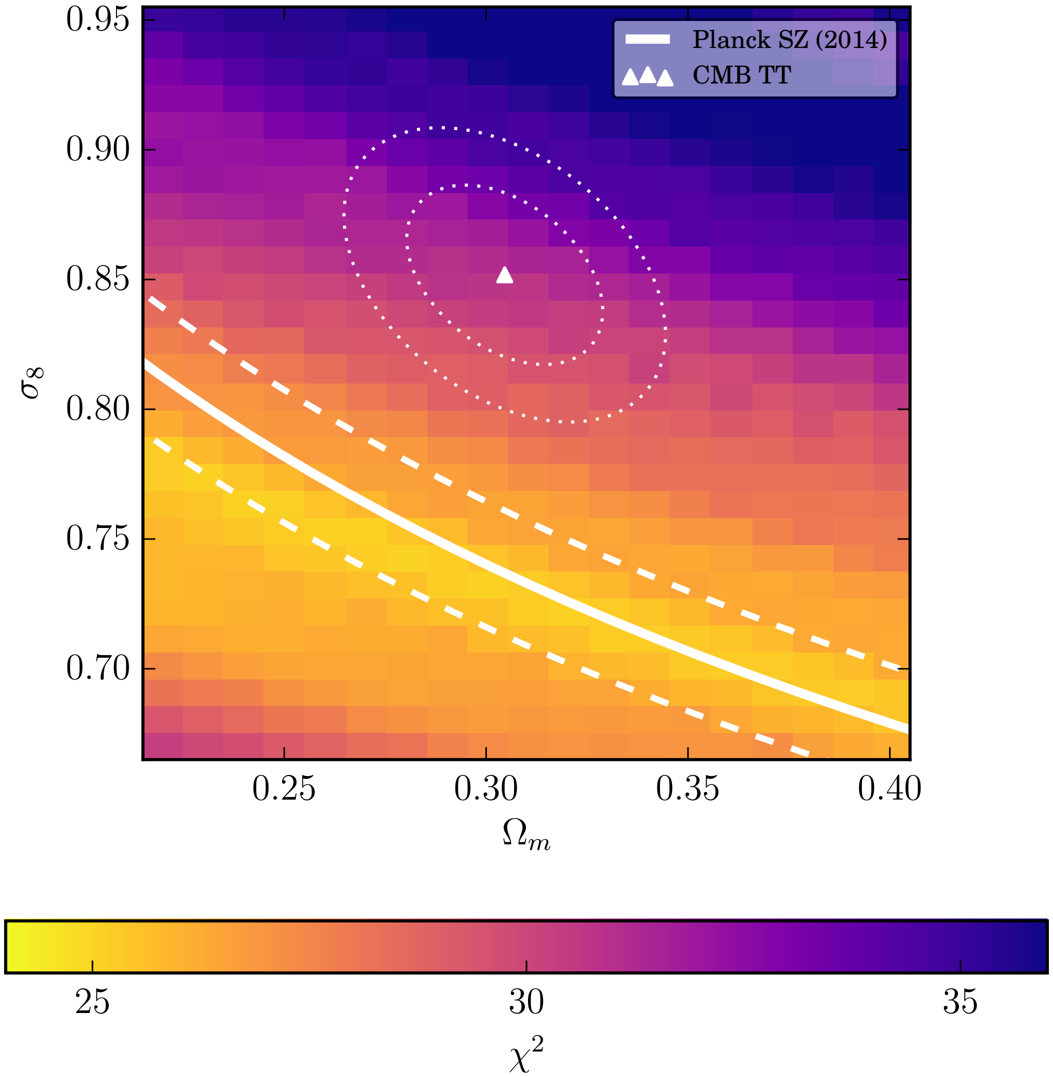


VDF



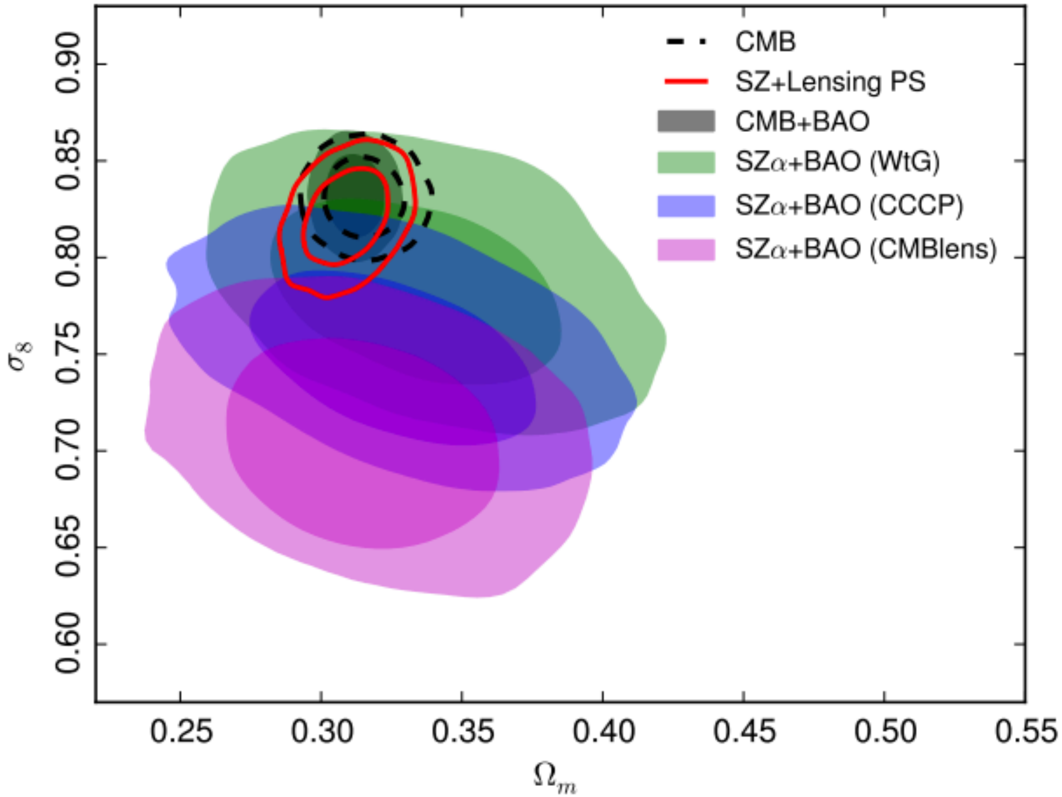
$\sigma_8 = 0.900, \Omega_m = 0.270$
$\sigma_8 = 0.900, \Omega_m = 0.340$
$\sigma_8 = 0.823, \Omega_m = 0.307$
$\sigma_8 = 0.730, \Omega_m = 0.270$
$\sigma_8 = 0.730, \Omega_m = 0.340$
$\log[dn/dv]$
δ
ϵ
$v\,(\mathrm{km\,s^{-1}})$
−3.0
−3.1
−3.2
−3.3
−3.4
−3.5
−3.6
0.1
0.0
−0.1
1
0
−1
200
400
600
800
1000
1200

VDF



Planck SZ (2014)
CMB TT
0.95
0.90
0.85
0.80
0.75
0.70
σ_8
0.25
0.30
0.35
0.40
Ω_m
25
30
35
χ^2

Planck 2016 CMB & SZ Cluster Constraints



Highlights

- Forward modeling with the Velocity Distribution Function reduces bias in cosmological constraints caused by measurement error.
- Preliminary analysis of the HeCS-SZ clusters shows a tension with the CMB TT constraints (but in agreement with other LSS probes).