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# Clustering and Feedback in the Early Stages of Reionization

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# Feedback mechanisms

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Examples of localized feedback mechanisms:

1. First stars enrich the IGM with metals
2. Ionizing radiation promotes H<sub>2</sub> formation (or destruction)
3. **Ionized gas too hot to accreted into small halos**

(Oh & Haiman, 2003 MNRAS 346 456)

$$T_{\text{Vir,min}} = 10^2\text{K} \quad \text{in neutral regions}$$

$$T_{\text{Vir,min}} = 10^4\text{K} \quad \text{in ionized regions}$$

$$10^2\text{K} \leq T_{\text{Vir}} \leq 10^4\text{K} \quad \text{“minihalos”}$$

$$T_{\text{Vir}} \geq 10^4\text{K} \quad \text{“large halos”}$$

# Simple assumptions

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Furlanetto, Zaldarriaga, & Hernquist (2004 ApJ 613 1):

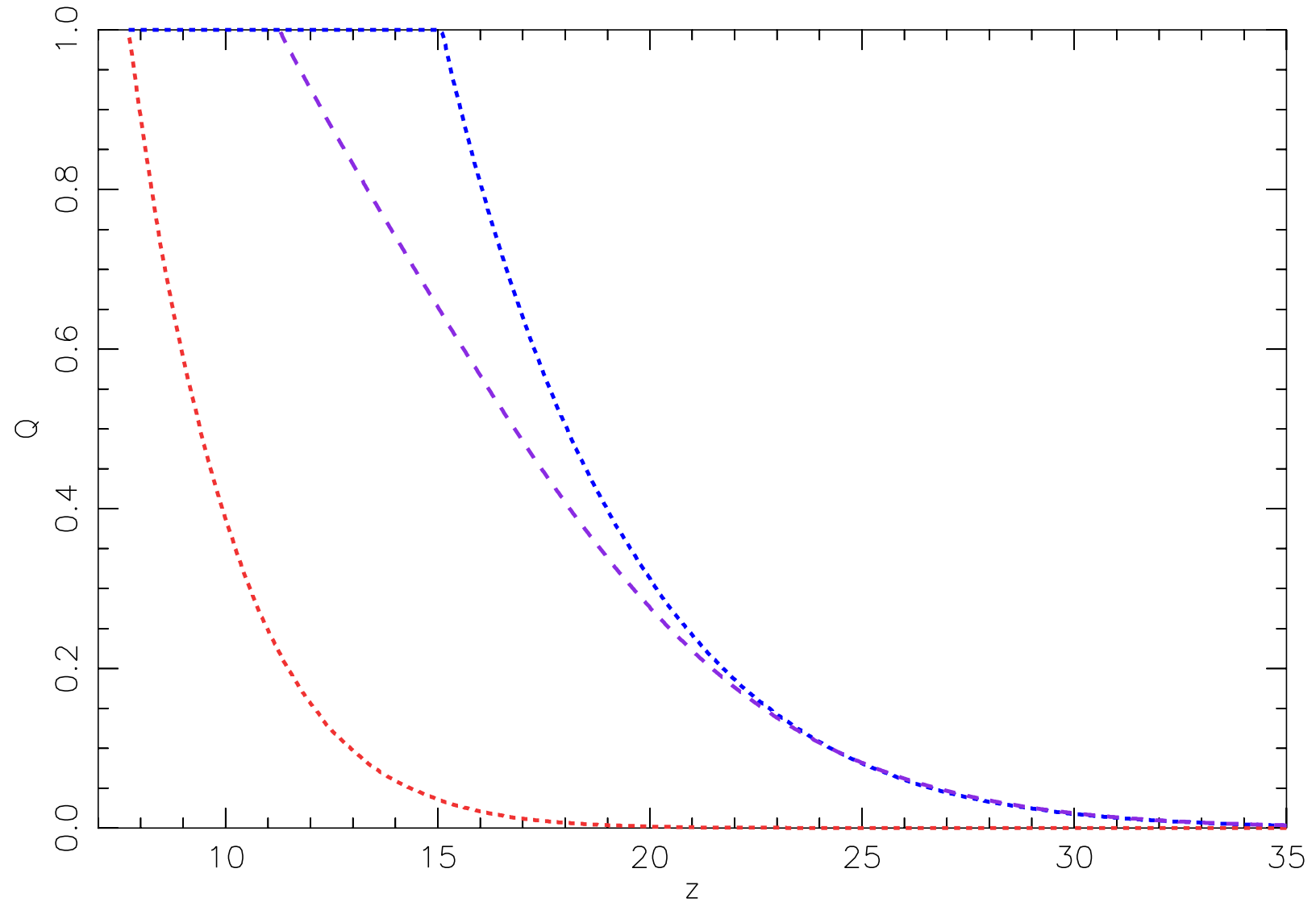
$$m_{\text{ion}} = \zeta m_{\text{halo}} \quad (1)$$

$$q = \zeta f_{\text{coll}}(m, \delta, z, T_{\text{Vir, min}}) \quad (2)$$

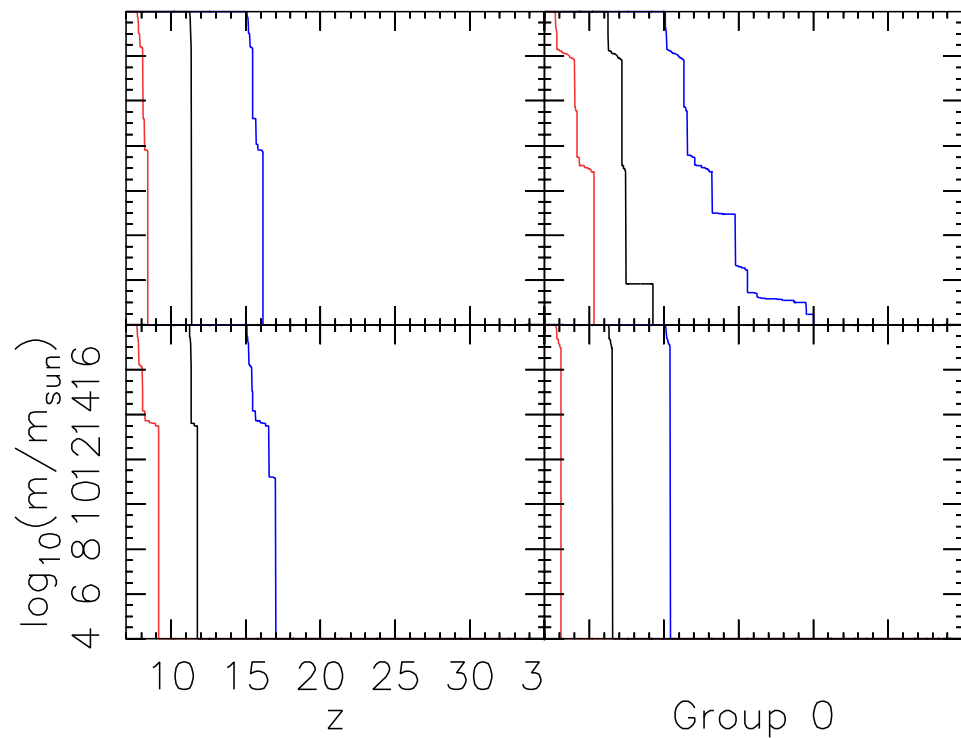
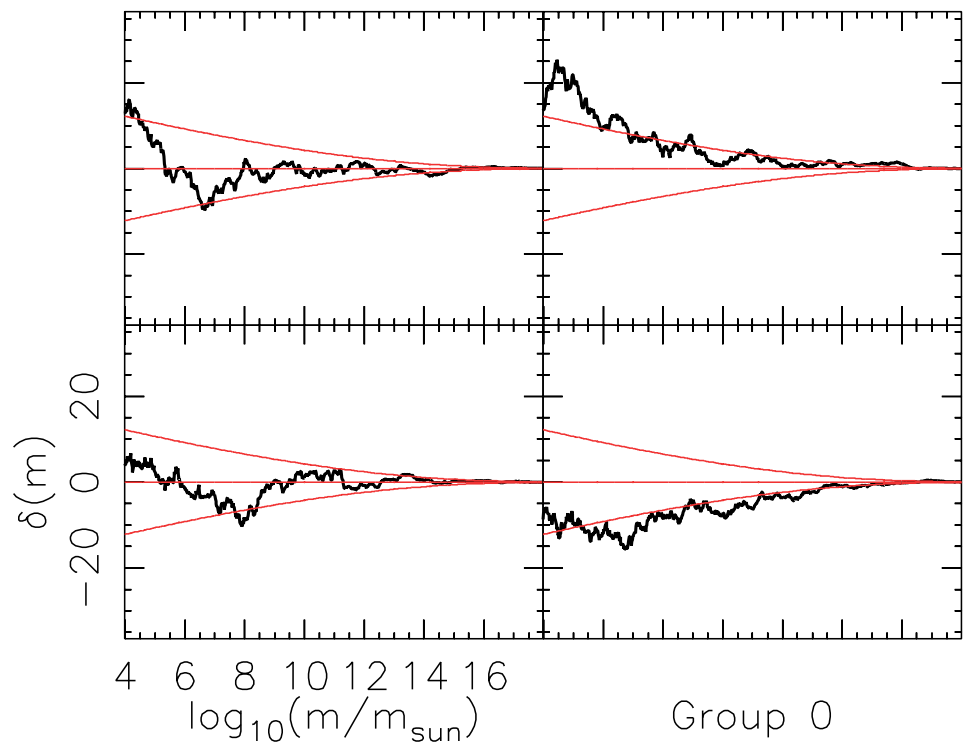
Add feedback:

$$\frac{dq}{dz} = \frac{dq_{\text{large}}}{dz} + (1 - q) \frac{dq_{\text{mini}}}{dz} \quad (3)$$

# Universal ionization fraction (with unbiased feedback)

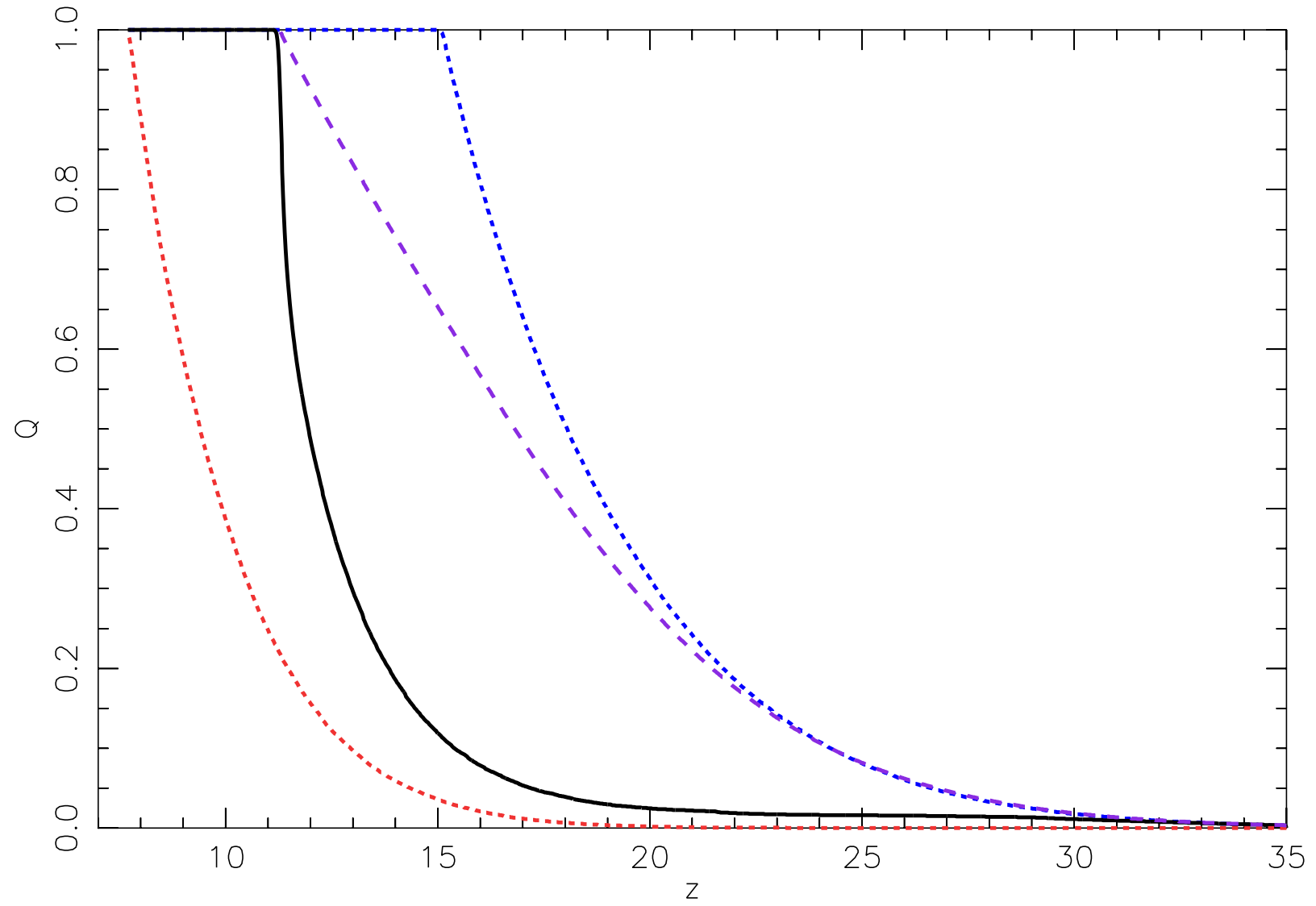


# Density profiles and ionized region mass histories

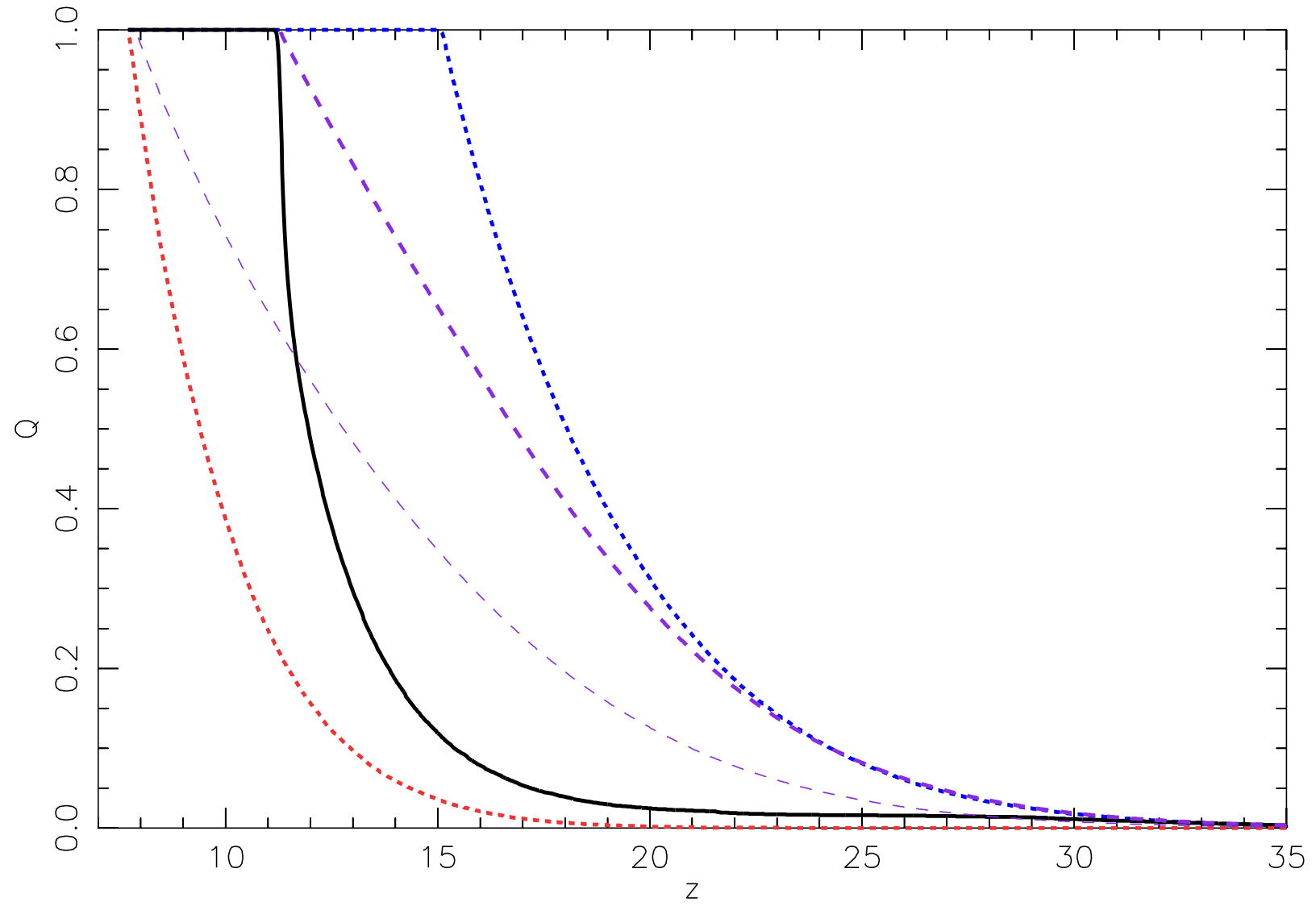


$$m_{\text{ion}}(m) = \sum_{m' < m} m_{\text{ion,shell}}(m')$$

# Universal ionization fraction (with biased feedback)



# Universal ionization fraction (bounds on comparison)



# Optical depths

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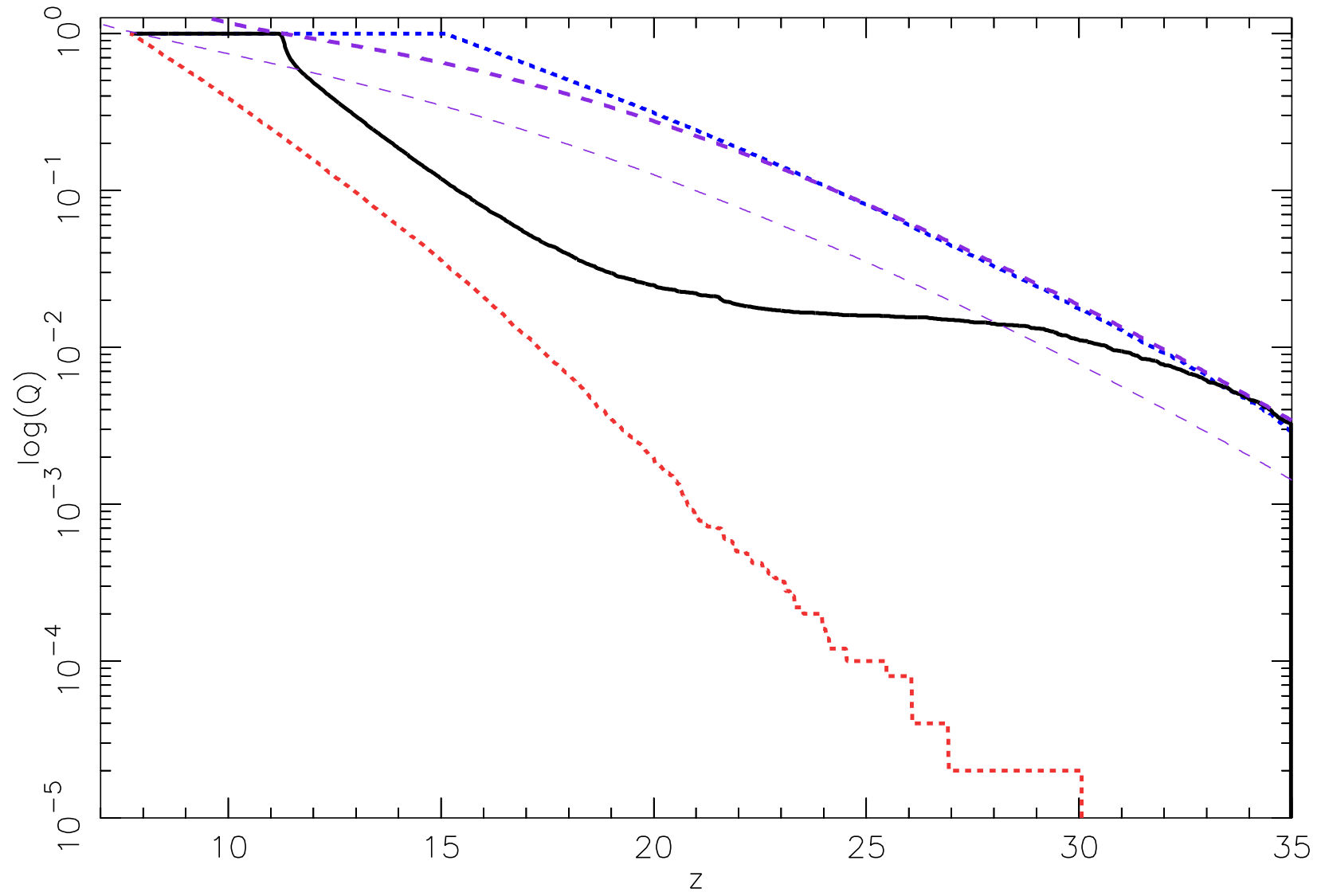
$\tau = 0.21$	all halos
$\tau = 0.20$	unbiased feedback
$\tau = 0.14$	unbiased feedback (low $\zeta$ )
$\tau = 0.12$	clustered feedback
$\tau = 0.08$	large halos only

# Conclusions

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1. Minihalo suppression can be enhanced by clustering at high redshift.
2. Such enhanced suppression can produce substantial changes in the high- $z$  tail of the ionization fraction,
3. and can reduce  $\tau$  for fixed  $\zeta$  or  $z_{\text{EOR}}$ .
4. Clustering may be important for a variety of feedback effects.

# Universal ionization fraction (log plot)



# Ionized bubble size

