Uncertainties Due to Baryons In Dark Matter Halos: A Brief Summary

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Outline

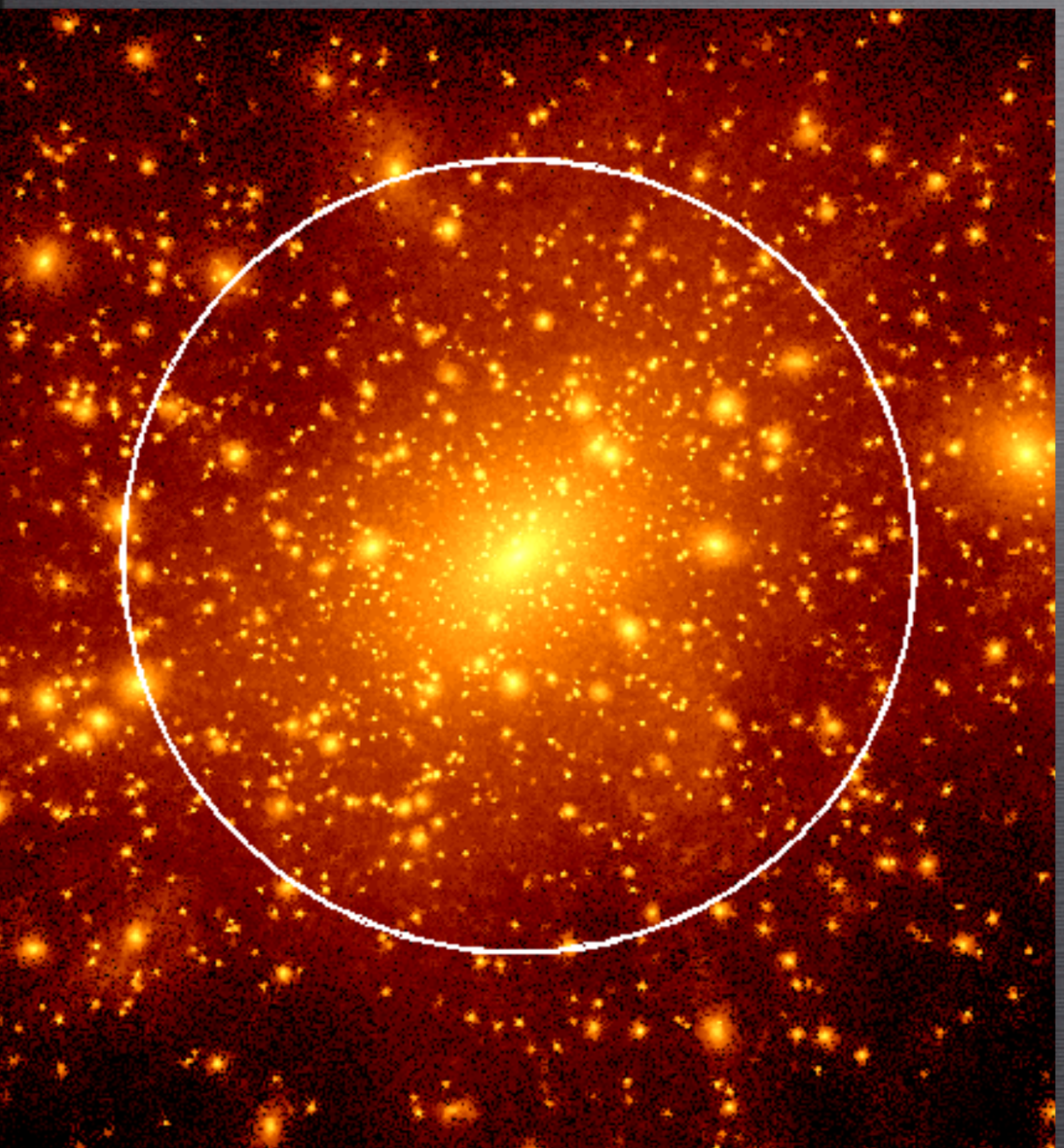
1. Overview of Structure Formation
   - 1.1. Dark Matter Halos and Halo Structure
   - 1.2. Galaxies and Galaxy Formation
2. Baryonic Influences on Dark Matter Halos
   - 2.1. Halo Contraction
   - 2.2. Halo Shapes
   - 2.3. Halo Substructure (Subhalos)
3. Summary

Why Care?

1. Baryons affect tests of dark matter on a variety of scales, using a variety of techniques
   - 1.1. Rotation Curve Measurements
   - 1.2. Gravitational Lensing Tests
   - 1.3. Direct DM Search Signal Predictions
   - 1.4. Abundance of Halo Substructure (subhalos)
   - 1.5. Halo Shape Tests for DM Self-Interactions
   - 1.6. DM Annihilation Luminosities & Morphologies

Halo Structure

Dark Matter Halos

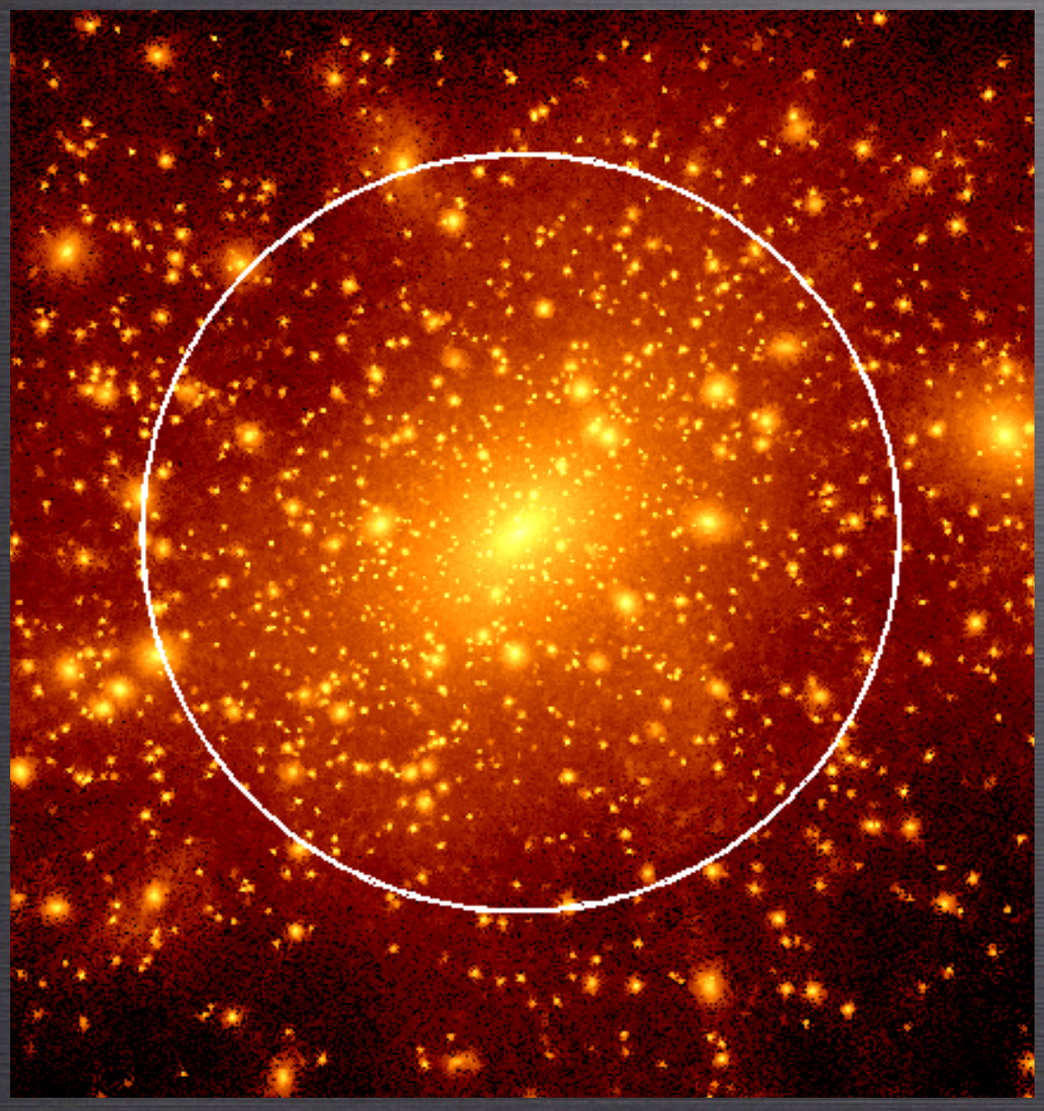


- Halos are "building blocks" of Nonlinear structure
- Virialized "Halos" have masses and radii...

$$\mathbf{M_{vir}} = \frac{4\pi}{3}\,\boldsymbol{\Delta}\langle\rho\rangle\,\mathbf{R_{vir}^3}$$

$$\boldsymbol{\Delta} \sim \mathbf{200}$$

Dark Matter Halos

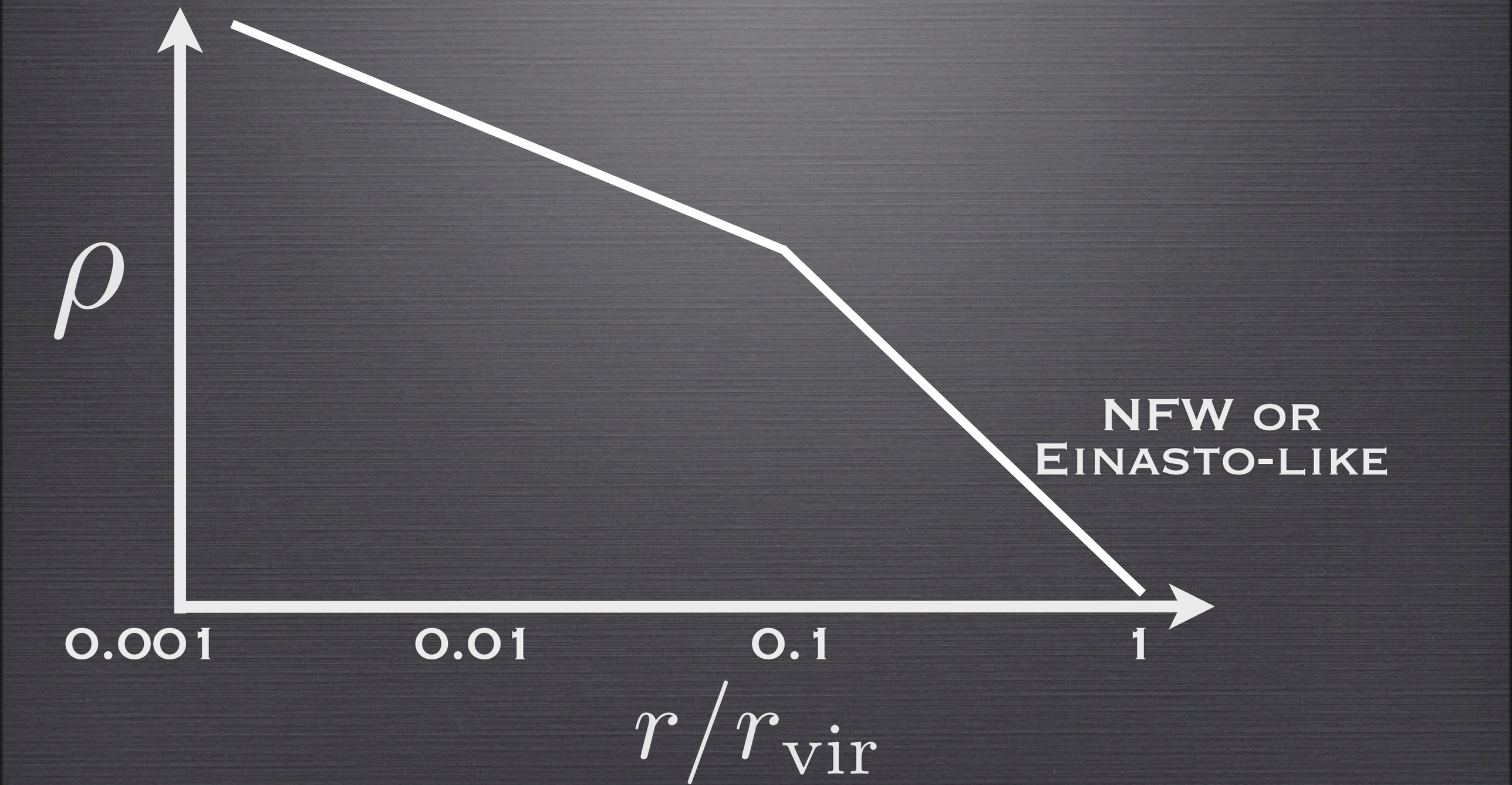


- Halos have spherically-averaged density structures...

$$\rho(\mathbf{r}) \propto \left(\mathbf{c}\frac{\mathbf{r}}{\mathbf{R_{vir}}}\right)^{-1}\left(1+\mathbf{c}\frac{\mathbf{r}}{\mathbf{R_{vir}}}\right)^{-2}$$

- The concentration parameter "c" specifies how centrally the dark matter is distributed.

What One May Really Care About?



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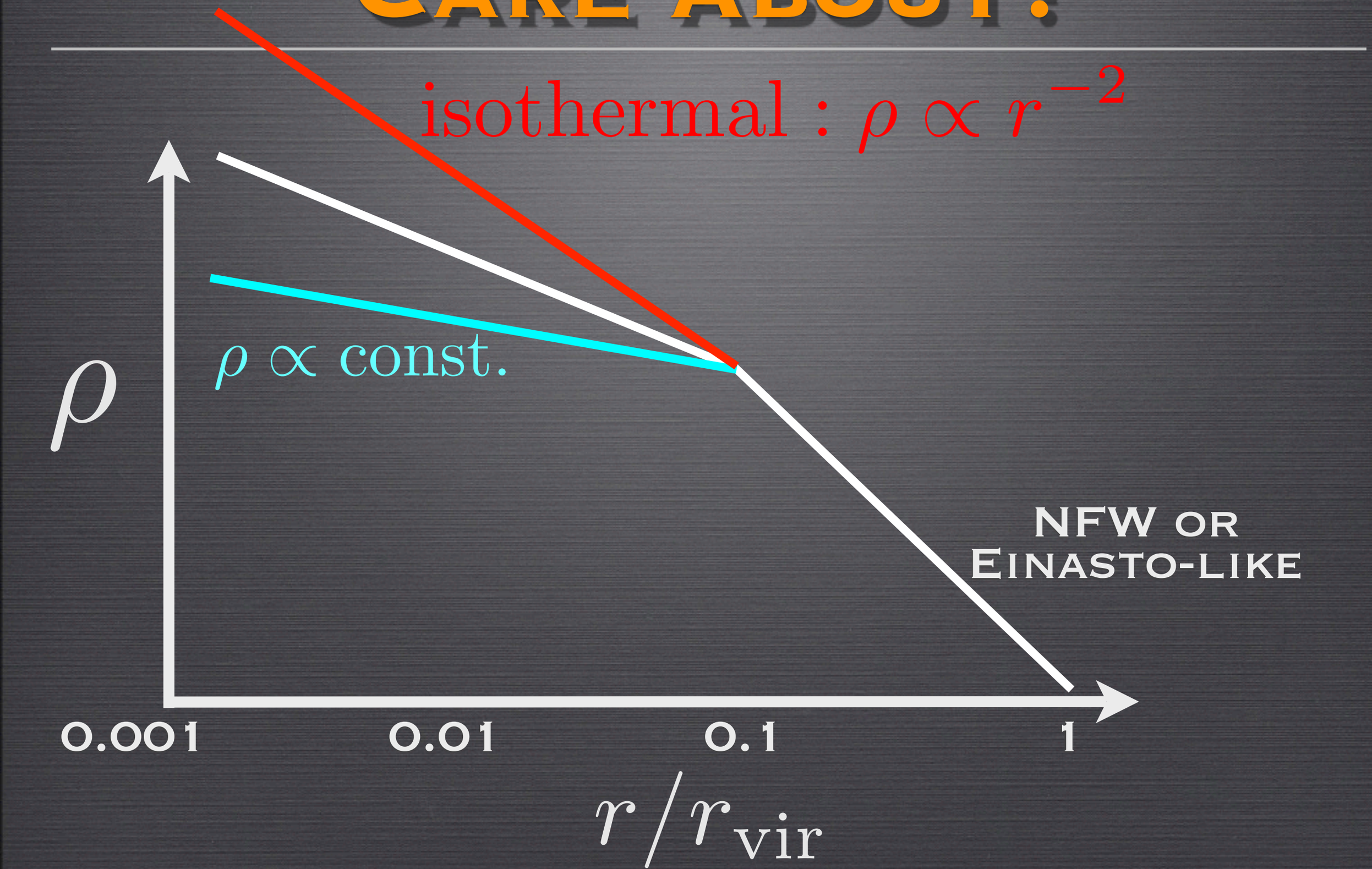
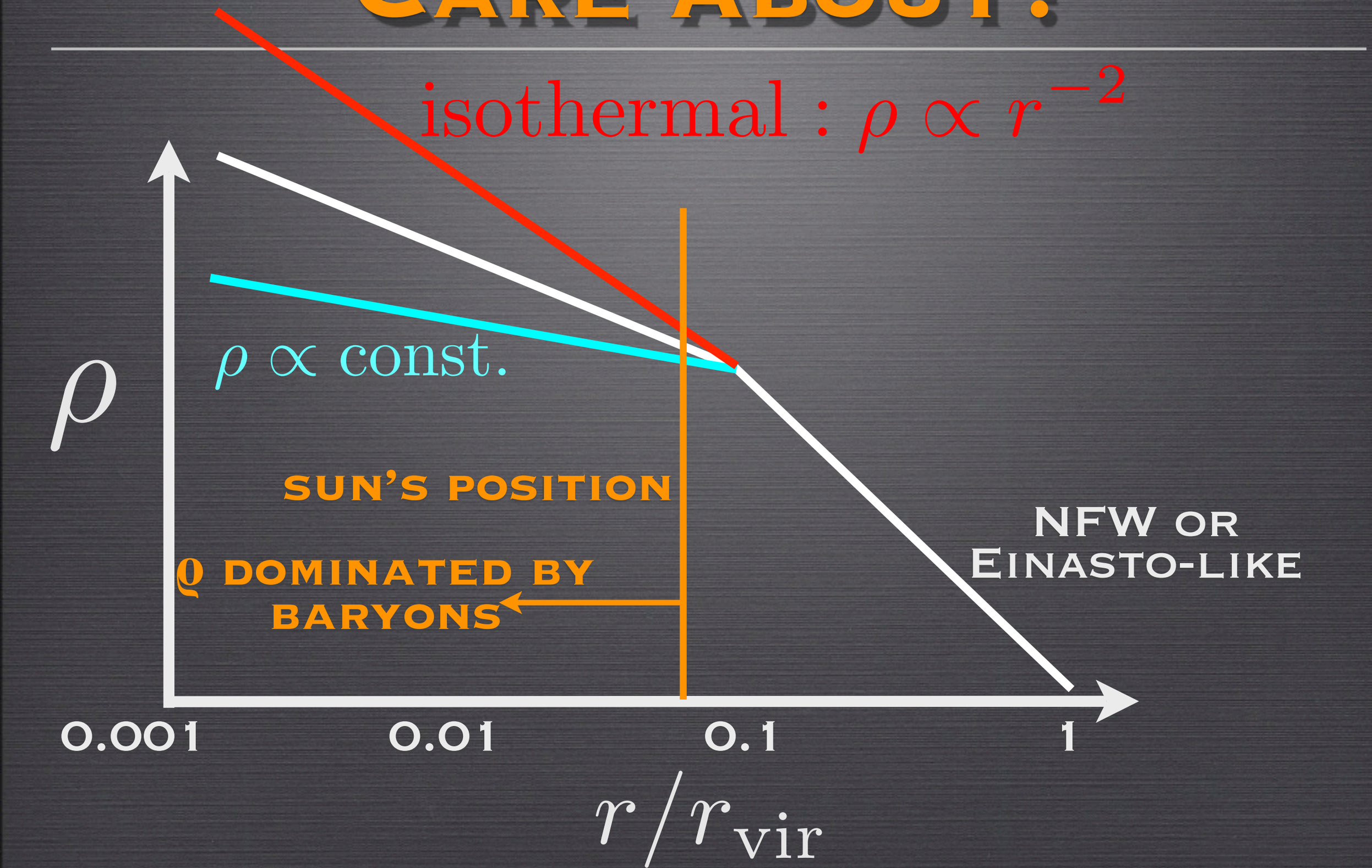
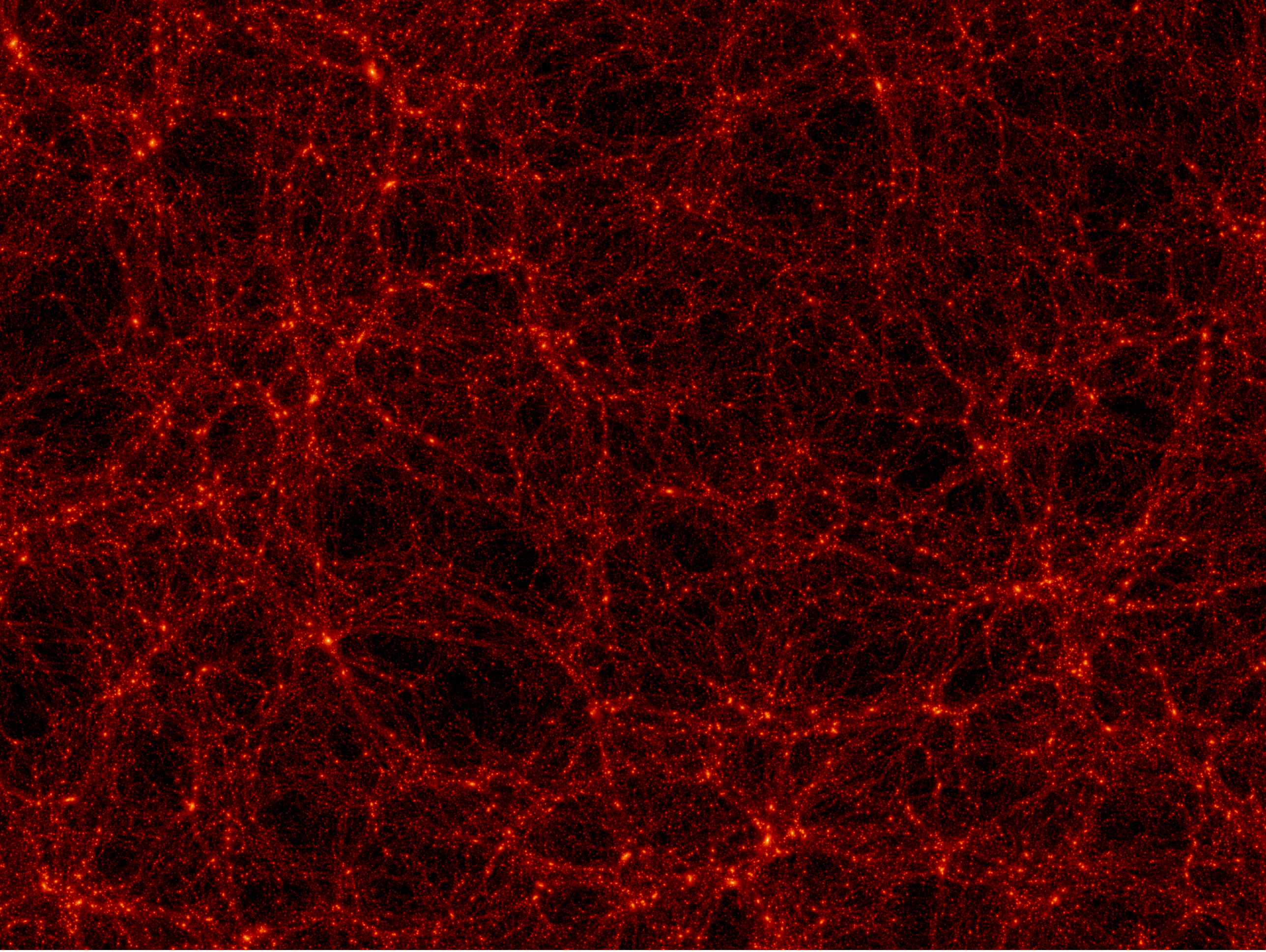
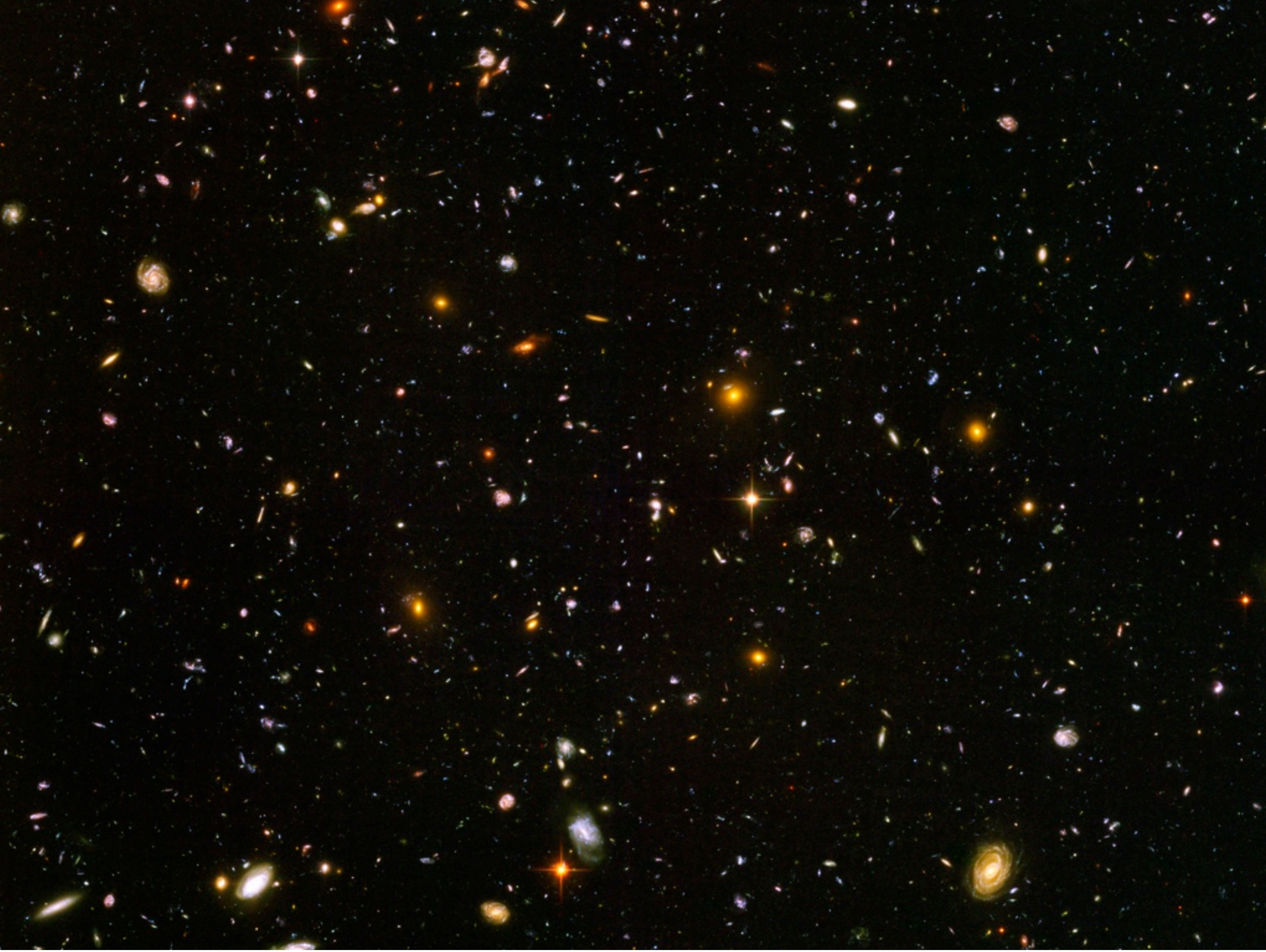


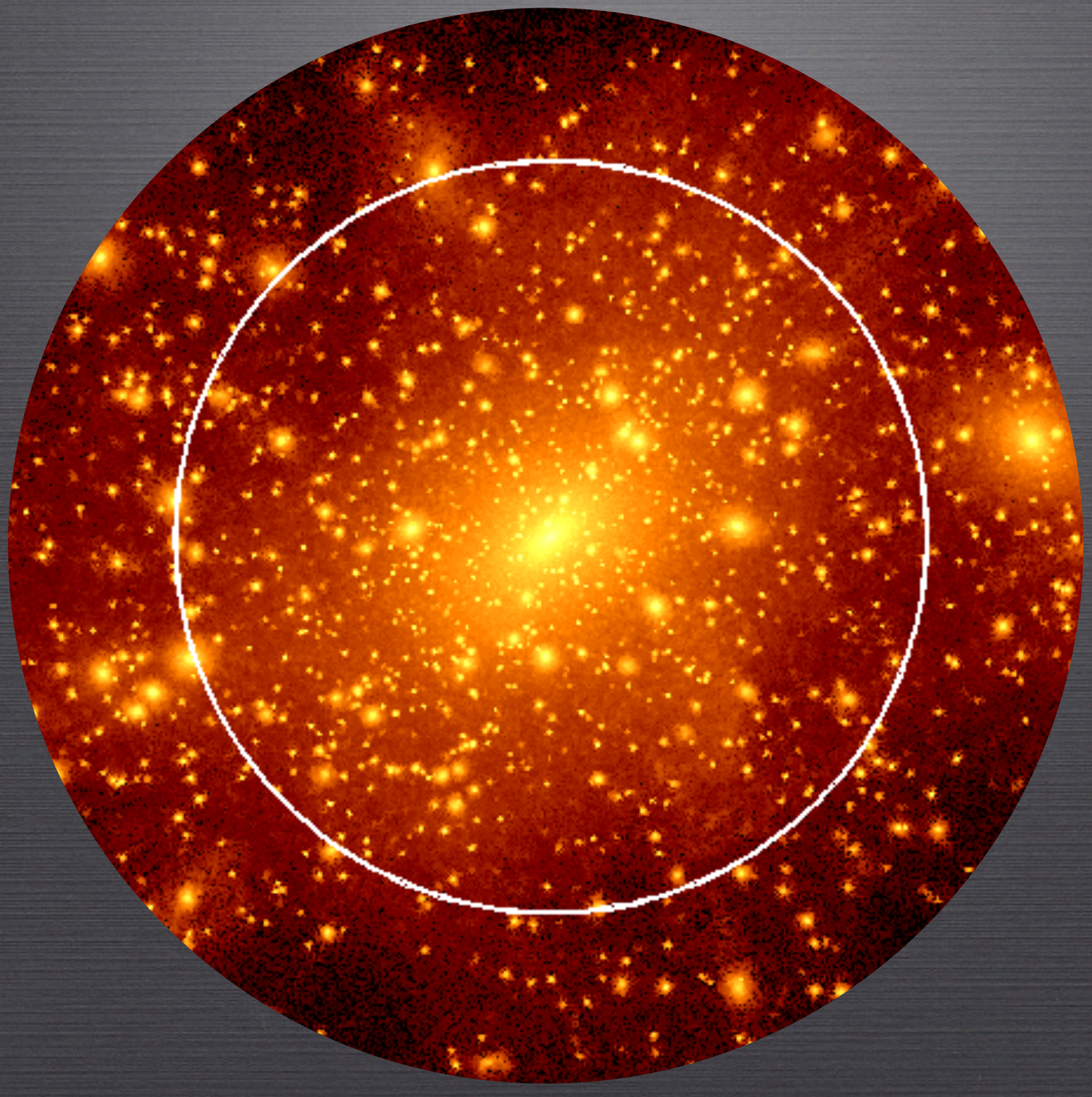
What One May Really Care About?



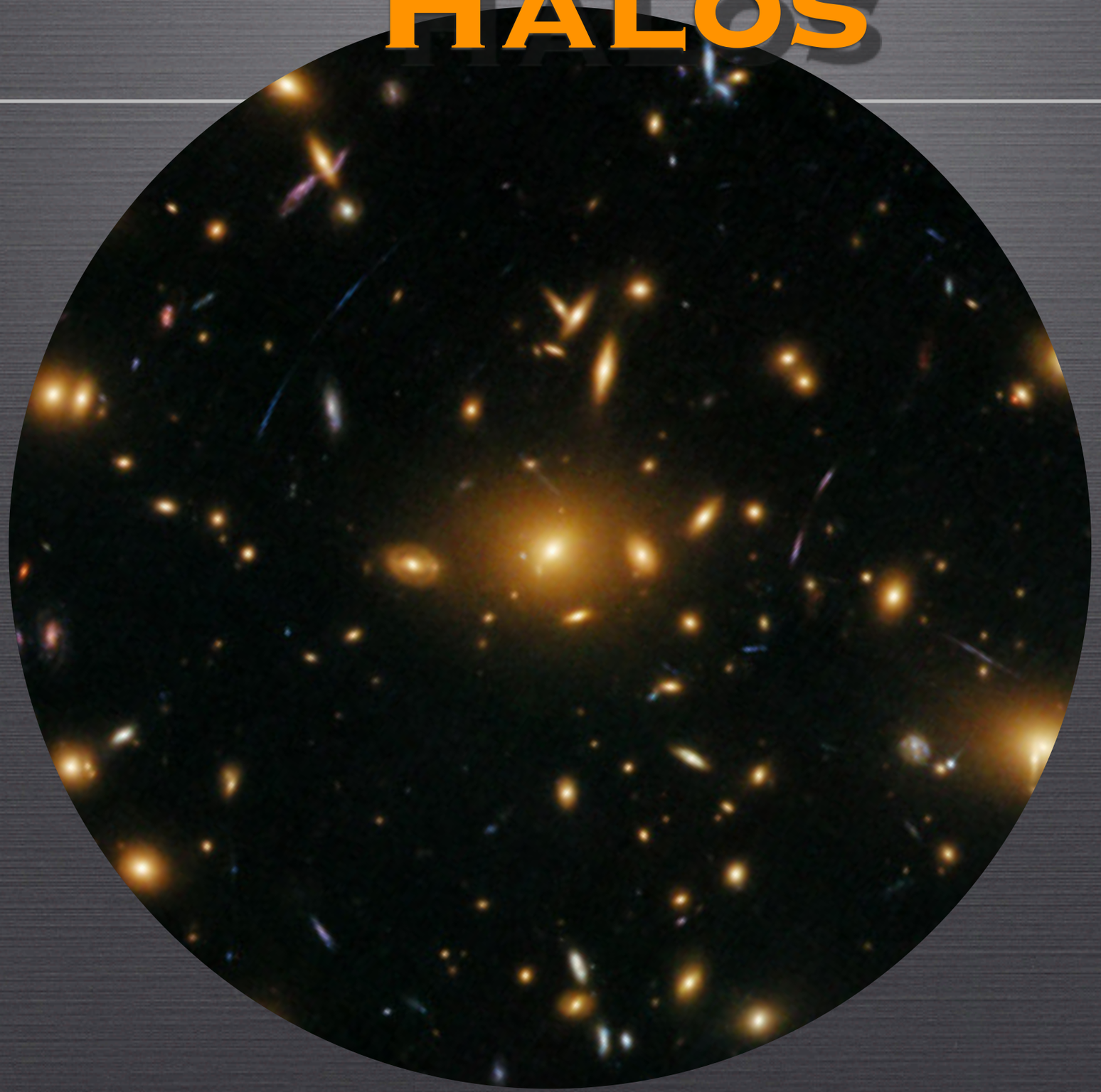




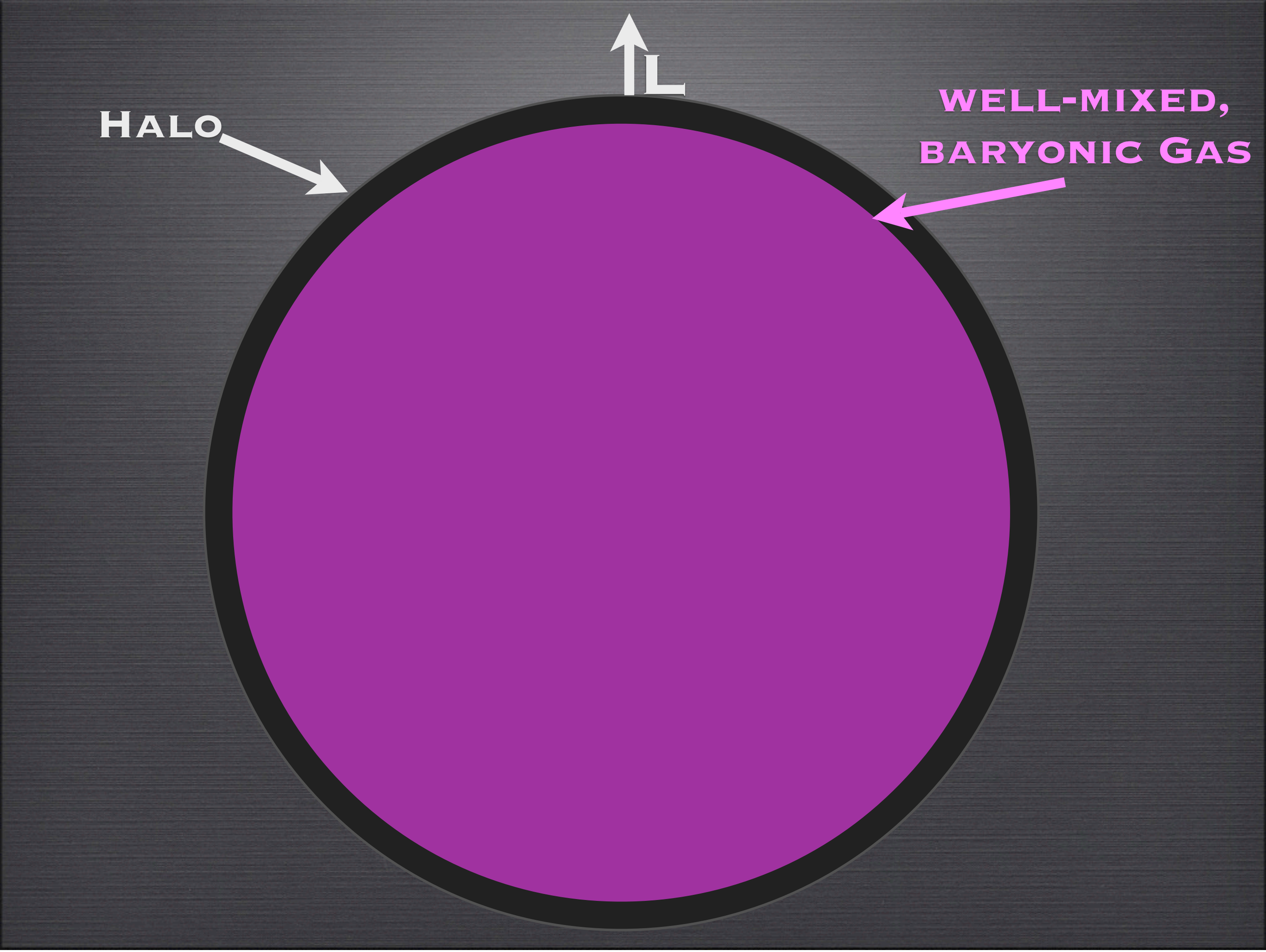
Dark Matter Halos

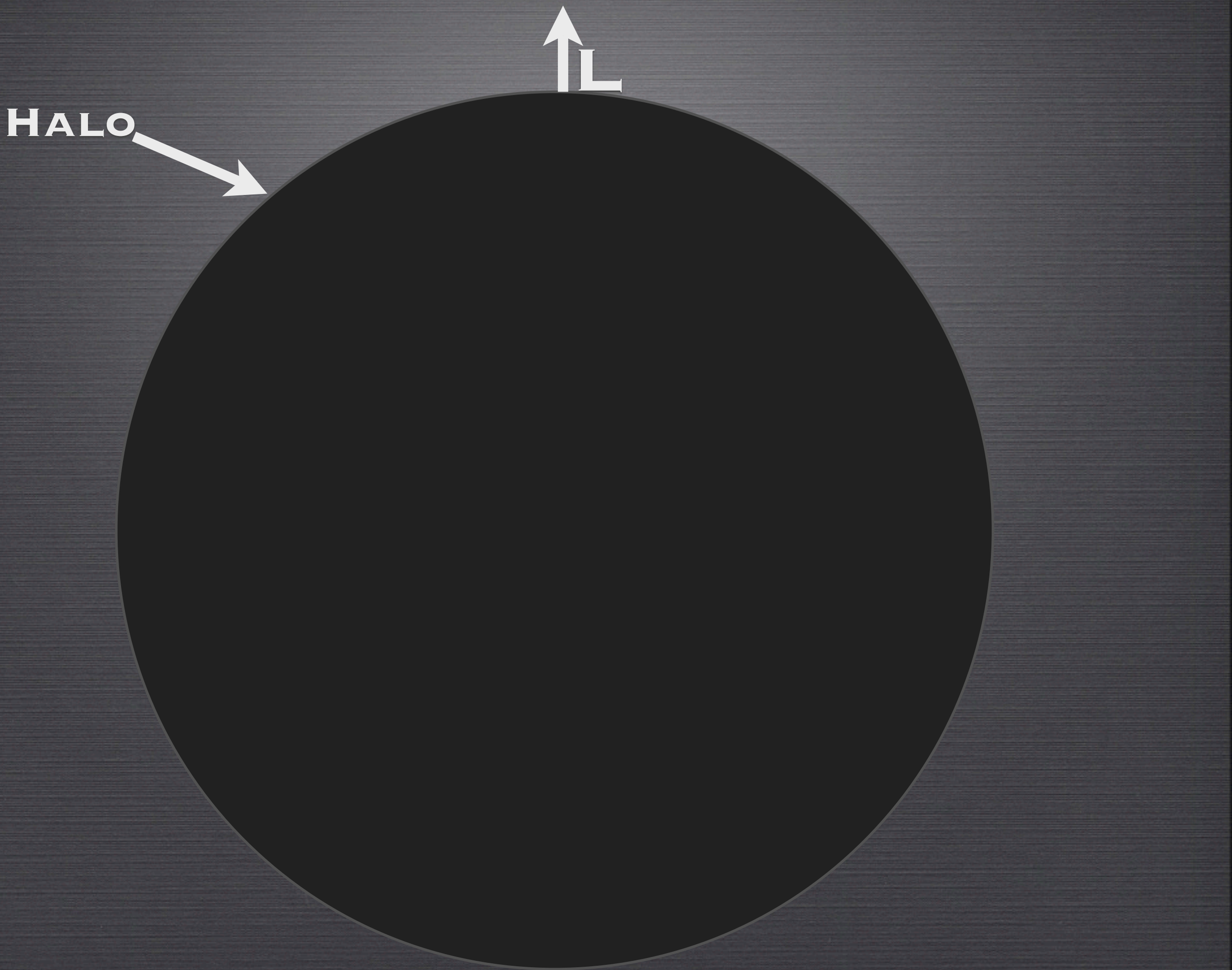


Galaxies Form in Halos



Galaxy Formation & Halo Contraction

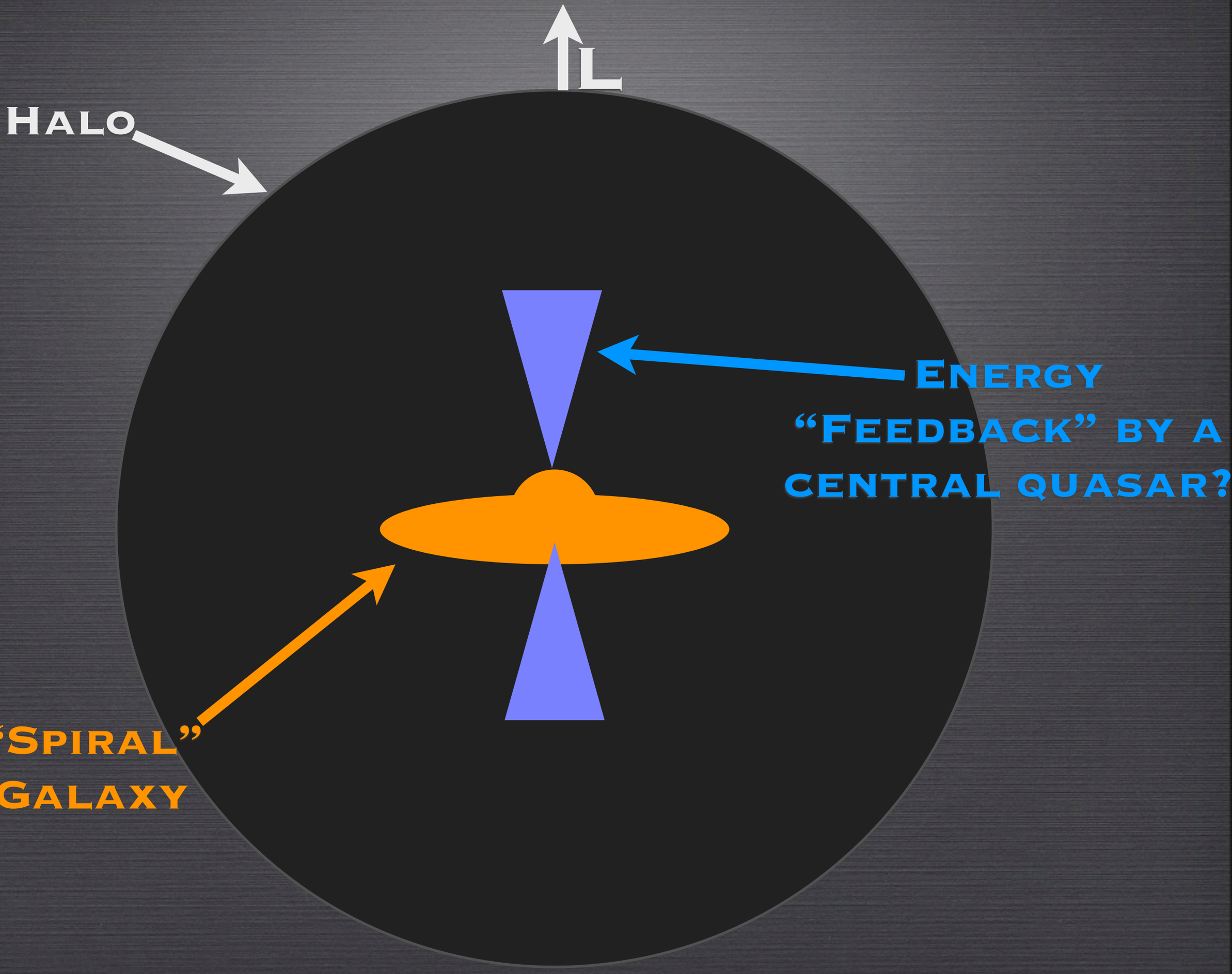

L
Halo
well-mixed,
baryonic Gas


L
Halo

L

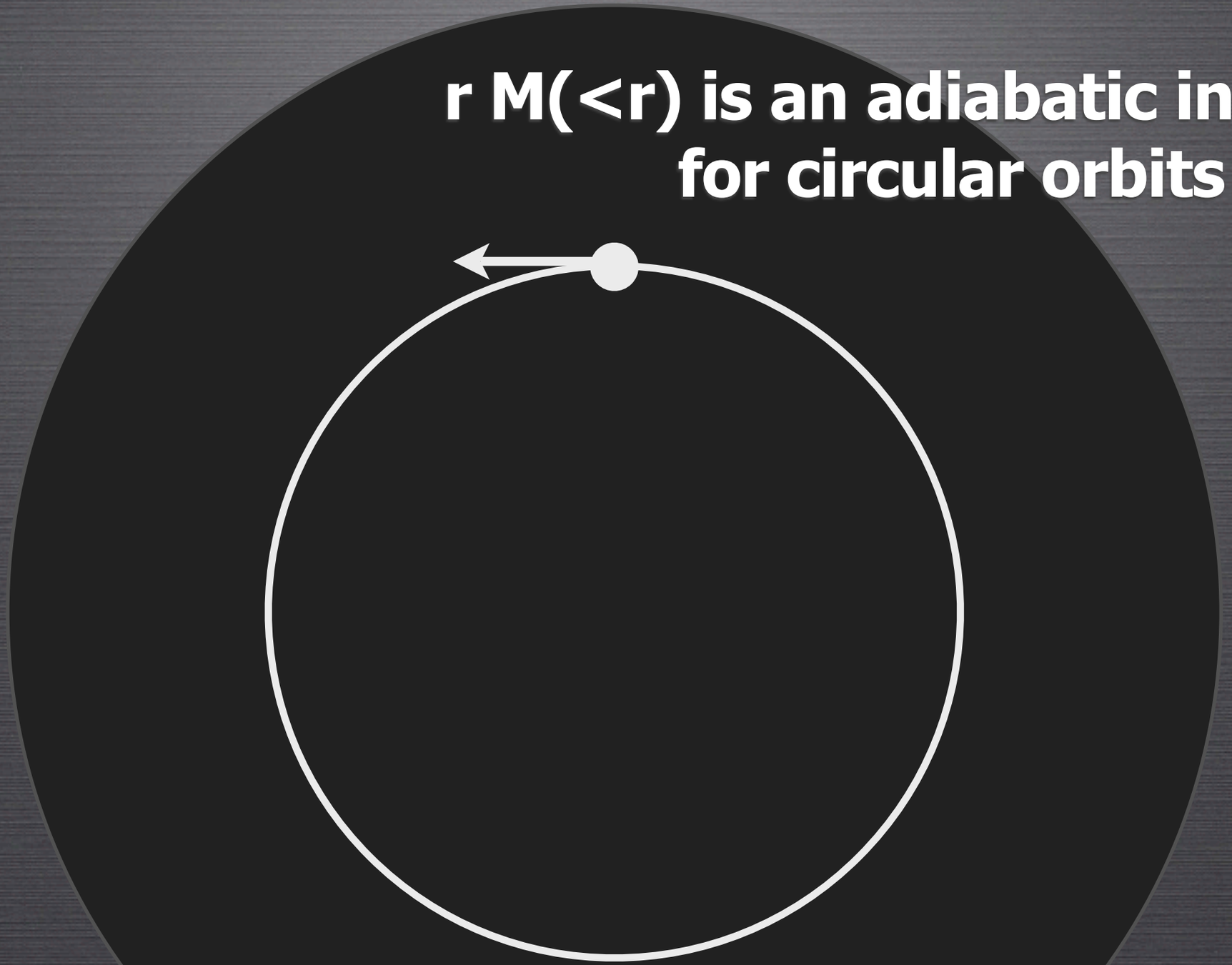
Halo

"Spiral"
Galaxy


L
Halo
Energy
"Feedback" by a
central quasar?
"Spiral"
Galaxy

Adiabatic Contraction

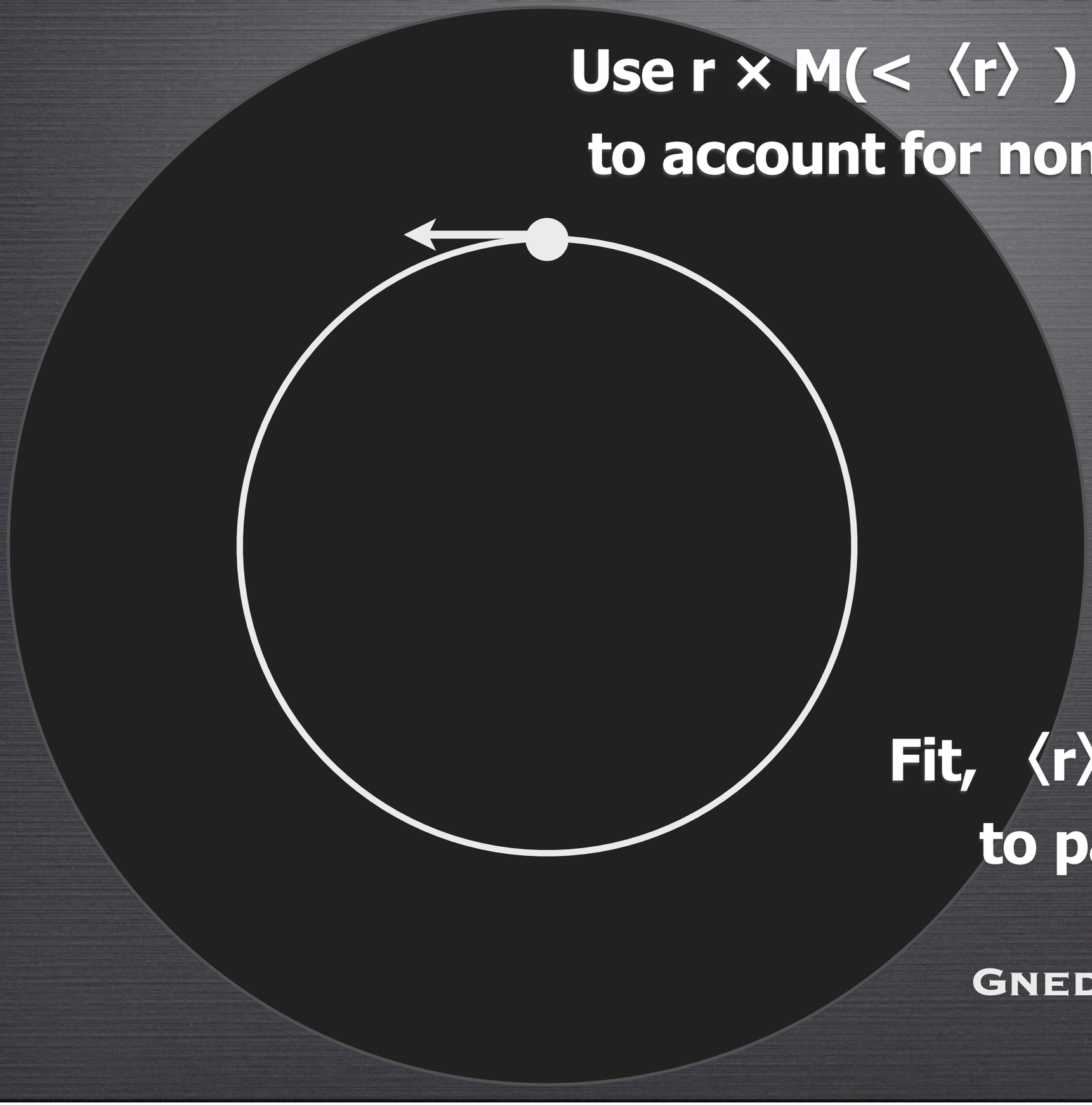
r M(<r) is an adiabatic invariant for circular orbits



Steigman et al. 1978;
Zel'Dovich et al. 1980;
Blumenthal et al. 1986

Adiabatic Contraction

Use $r \times M(< \langle r \rangle)$ as an invariant to account for noncircular orbits

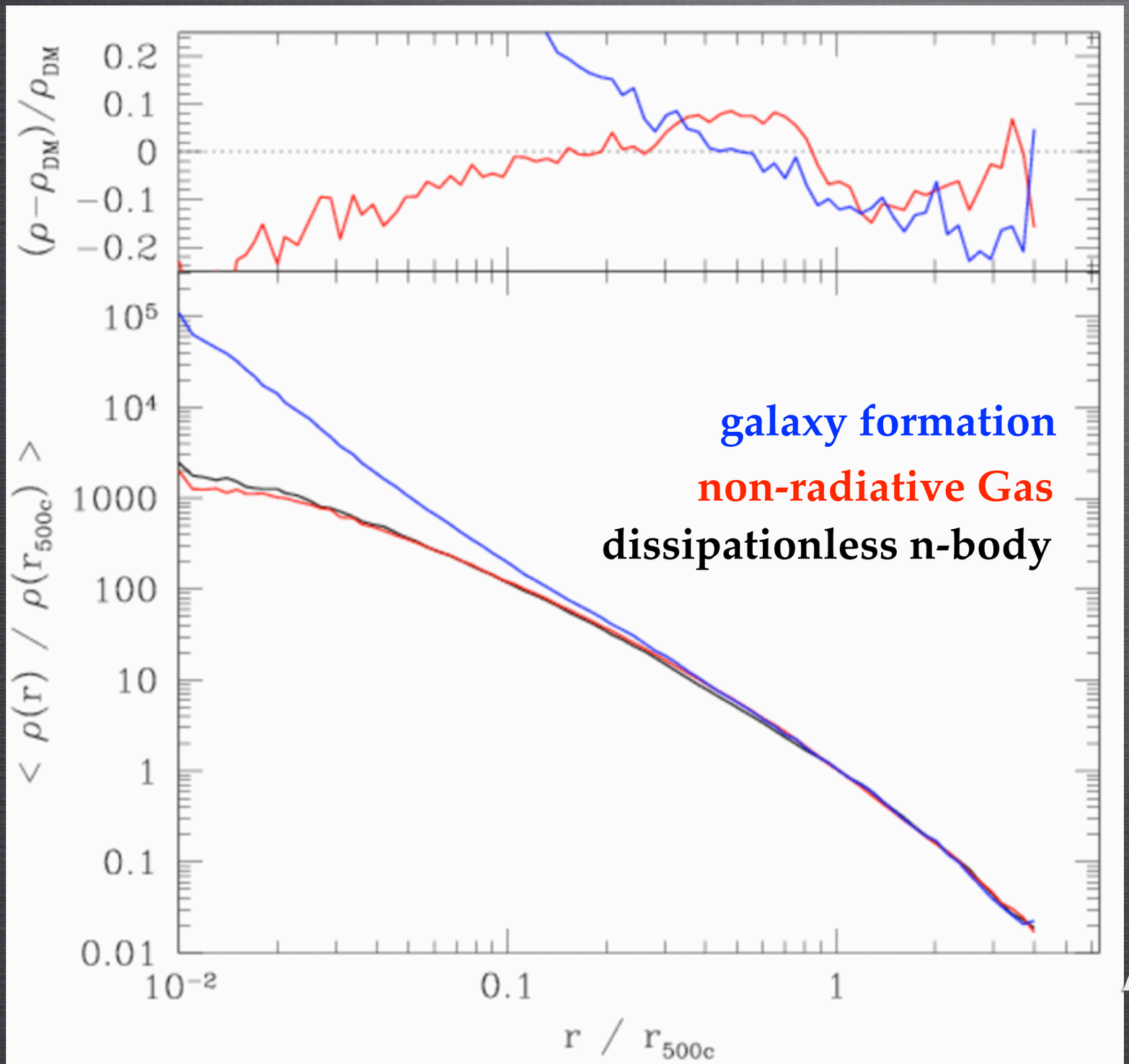


Fit, $\langle r \rangle = A r_{vir} (r/r_{vir})^w$ to particle orbits

Gnedin et al. 2005

Halos with Galaxies

Rudd et al. 2008

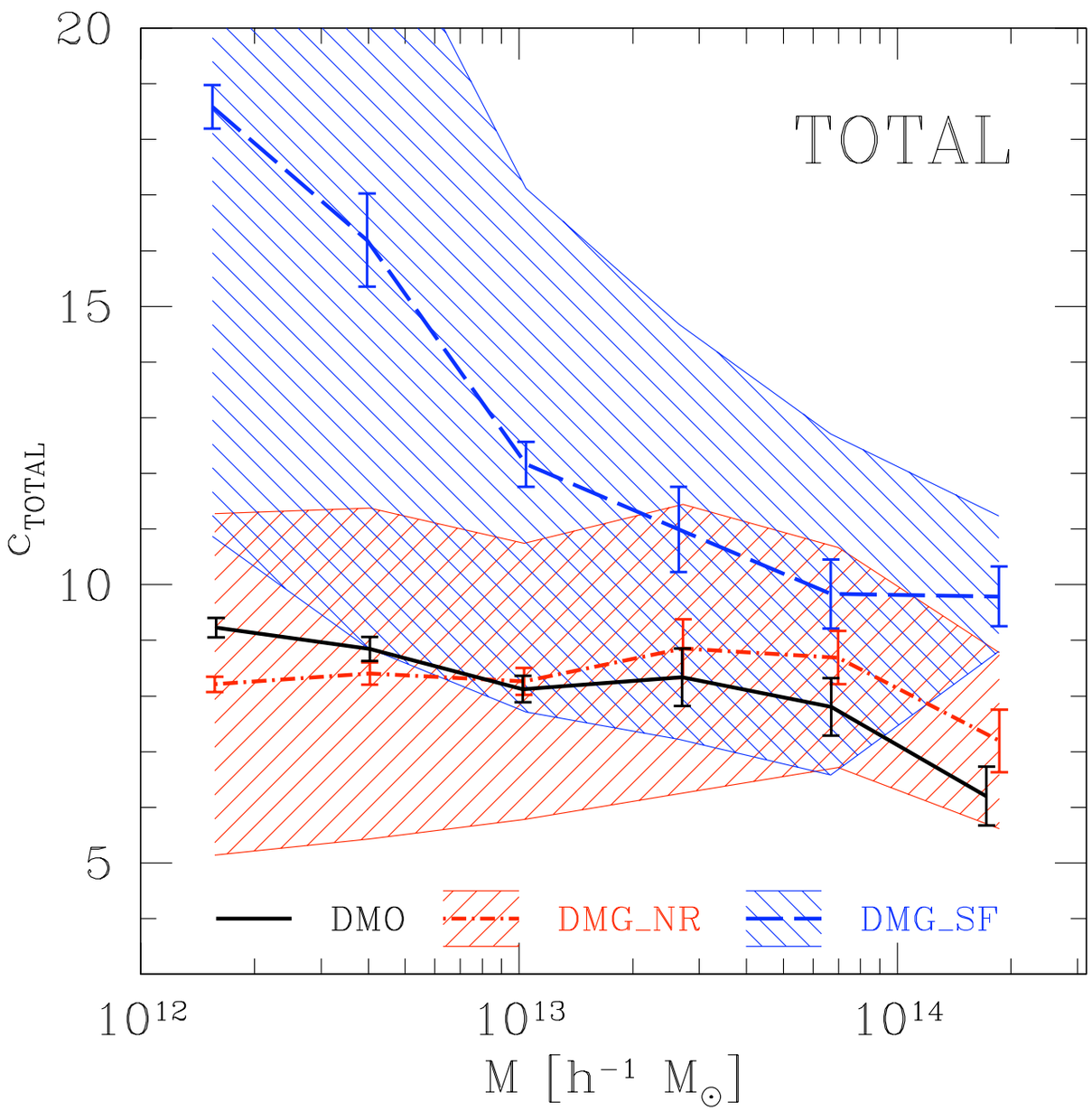


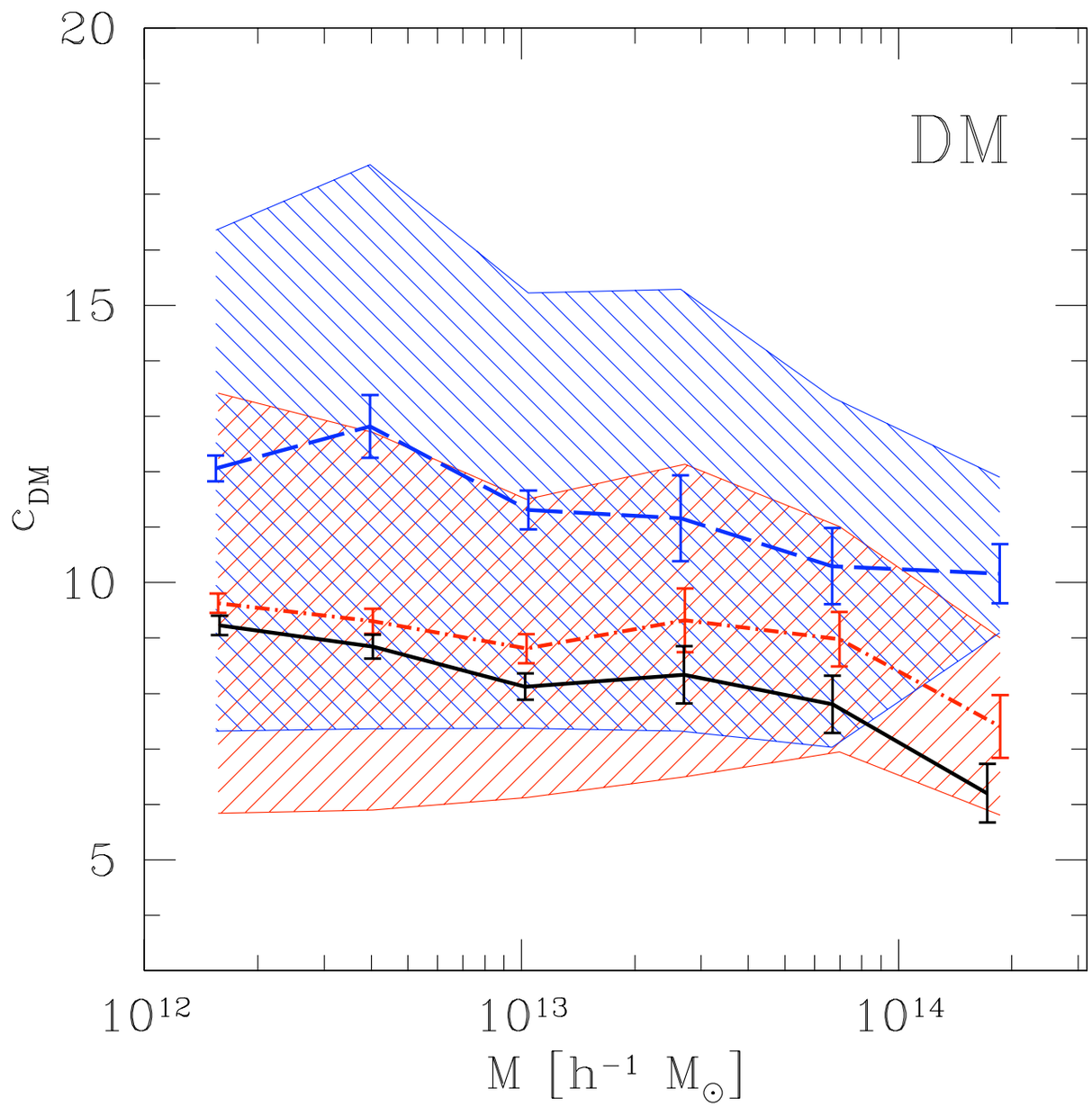
Halos in galaxy forming simulations look have steeper profiles

Also: Rasia et al. 2008; Guillet et al. 2009; Casarini et al. 2010

Halos with Galaxies

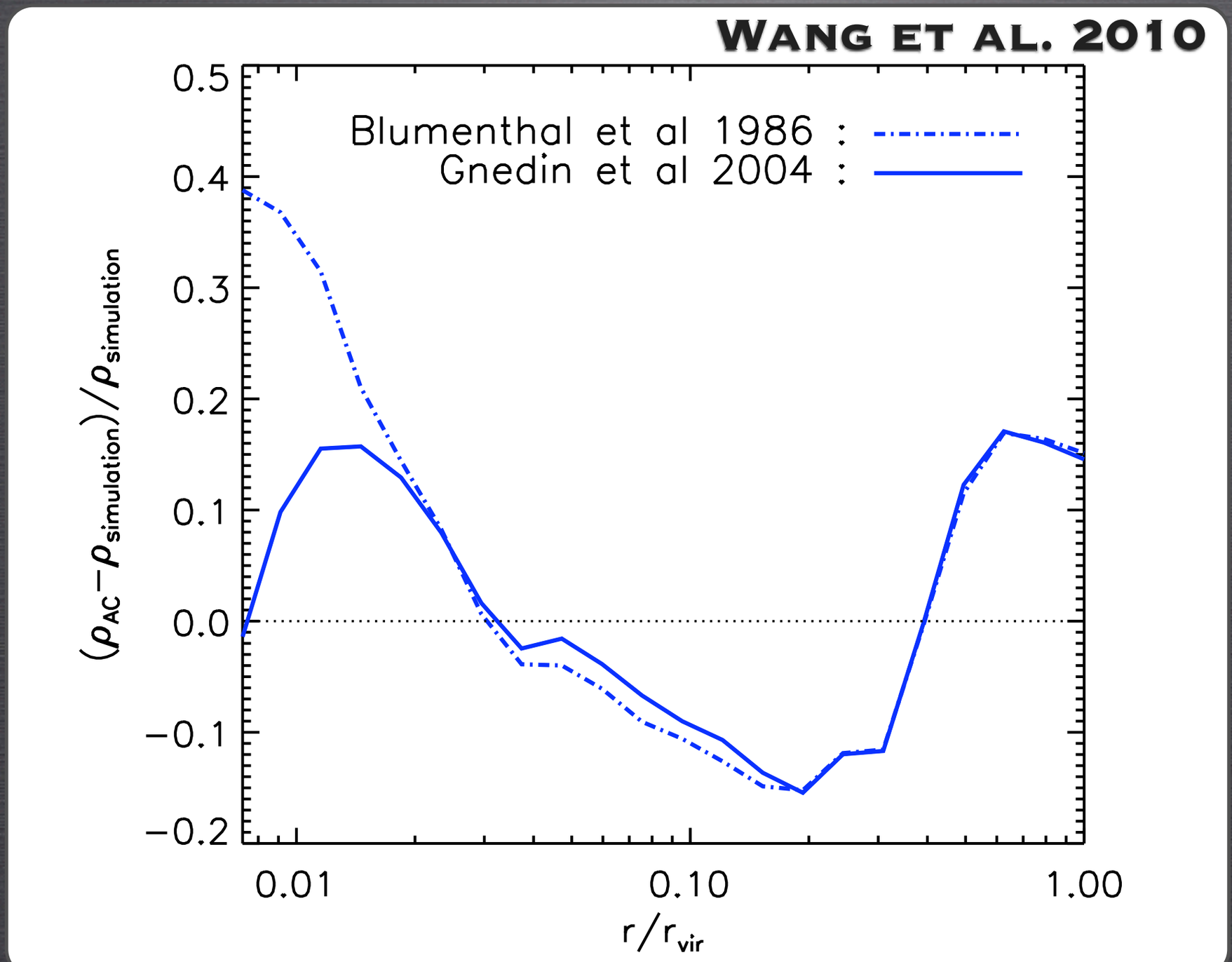
Rudd et al. 2008





- **Modified Halo Concentration Relation Relative to the Standard N-Body Result**

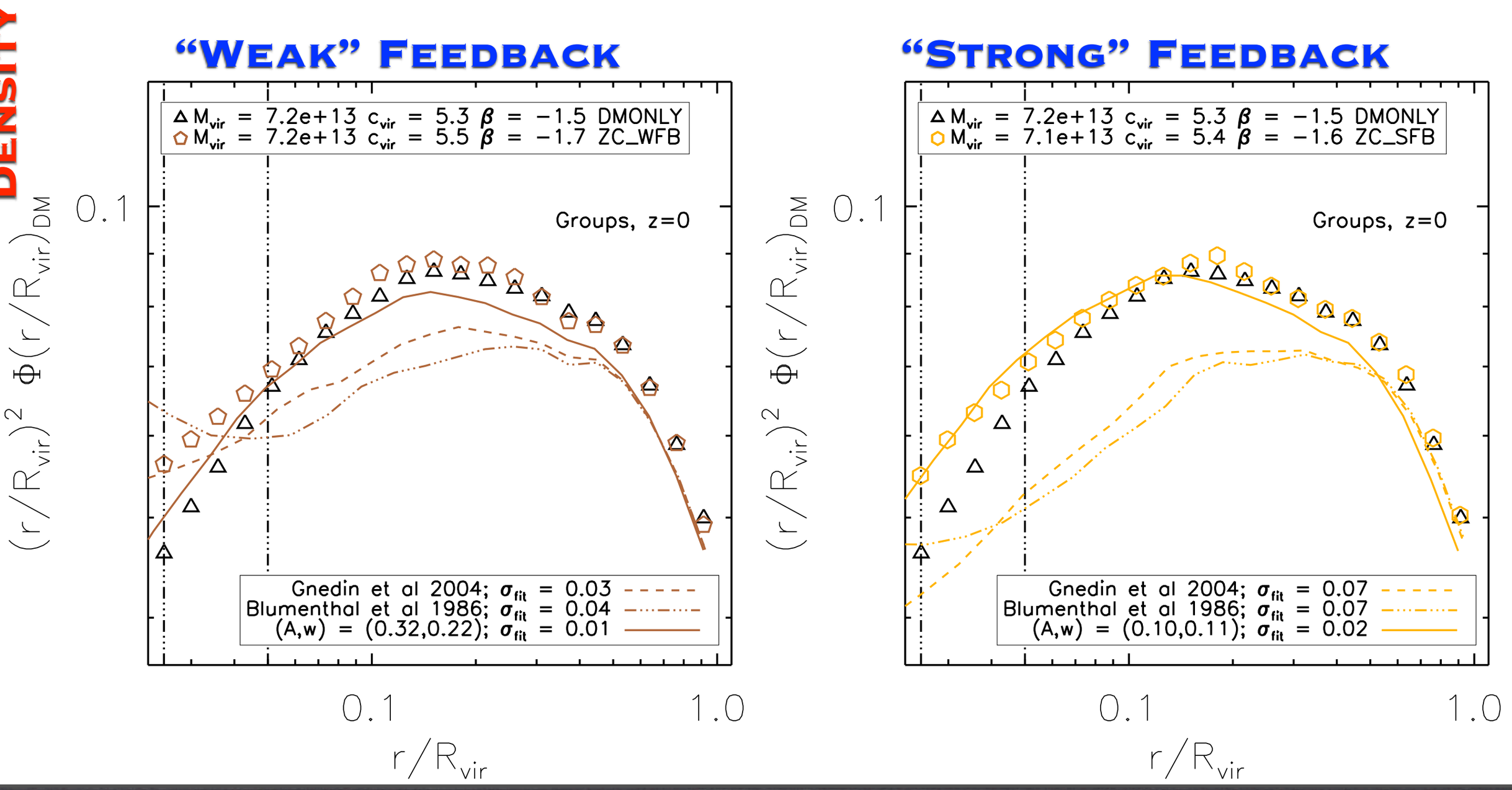
Contraction Model Residuals



Similar: Gustafsson+06; Pedrosa+09; Tissera+10; Duffy+10

Example Contraction

Duffy et al. 2010

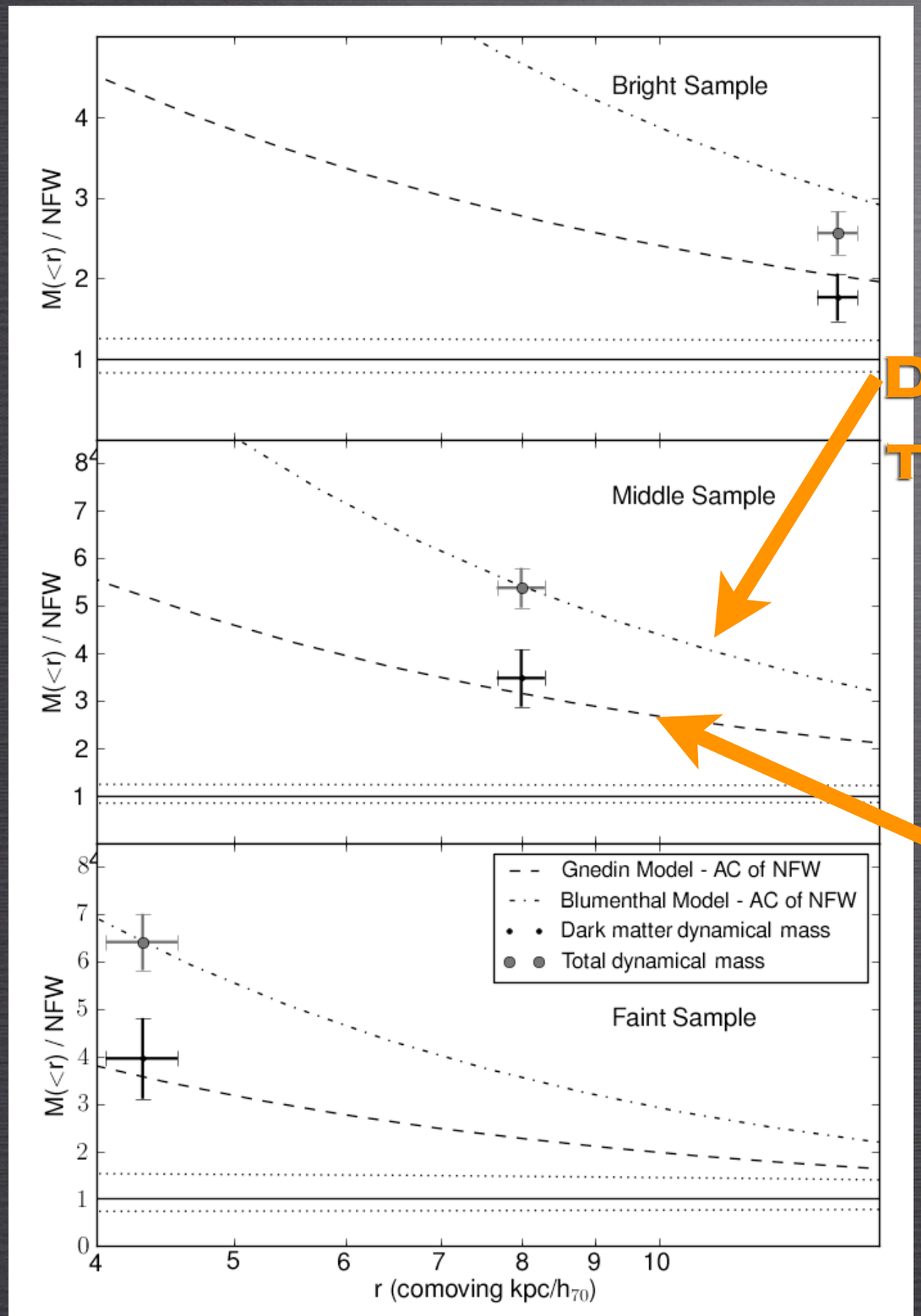


See also: Gnedin+04; Gustafsson+06; Romano-Diaz+08; Kazantzidis+08; Pedrosa+09; Tissera+10; Wang+10

Is there evidence for contraction?

Yes?

Schulz et al. 2010

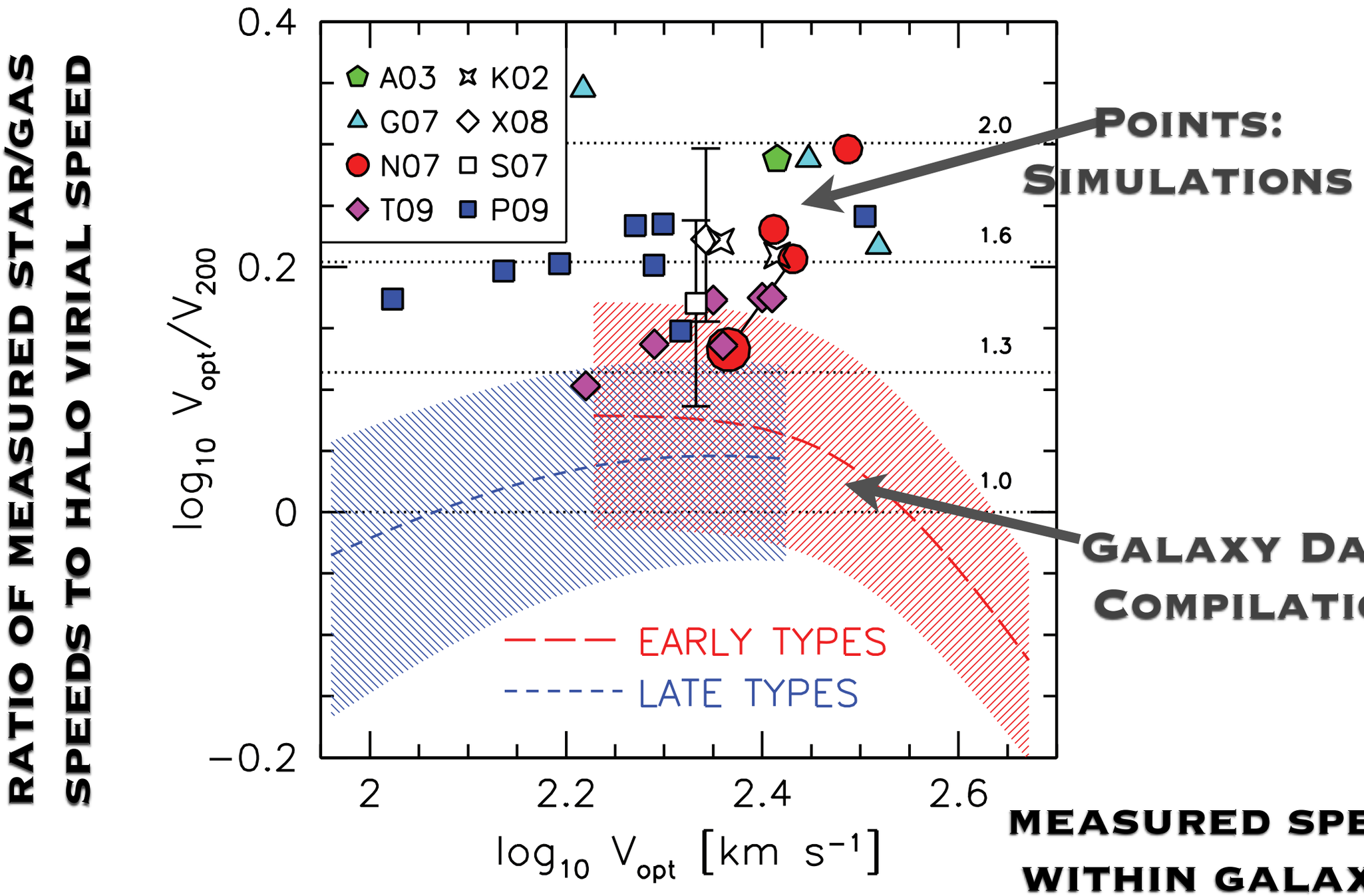


Dark matter contribution to mass based on velocity dispersions & stellar population modeling

Mass implied by weak lensing on large scales & NFW assumption for halo

No?

Dutton et al. 2010

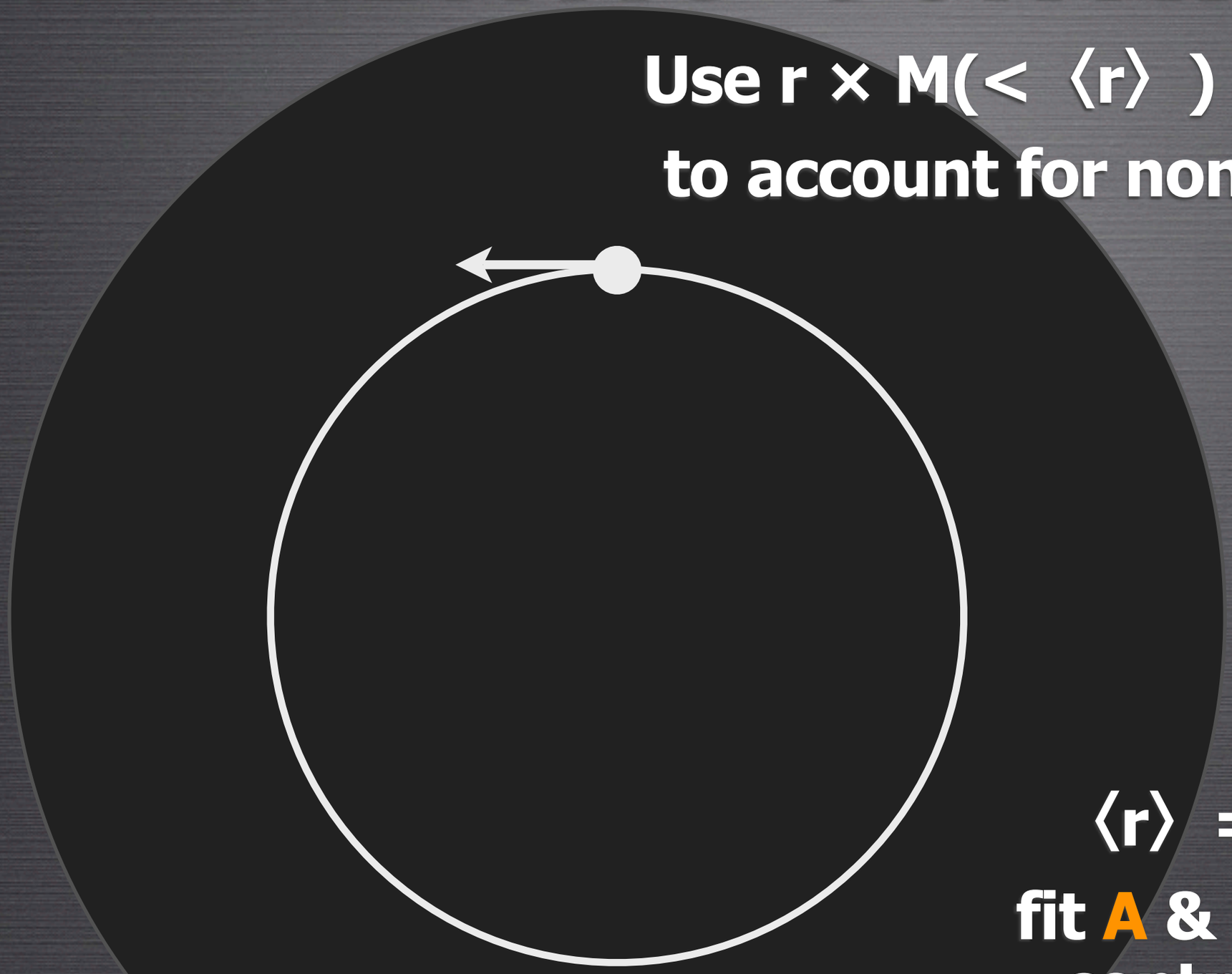


Also: Gnedin et al. 2006; Sand et al. 2008; Simon et al. 2008; Trachternach et al. 2008; de Blok et al. 2010...

Can the simple model be "Corrected"?

Adiabatic Contraction

Use $r \times M(< \langle r \rangle)$ as an invariant to account for noncircular orbits



$$\langle r \rangle = A r_{vir} (r/r_{vir})^{w}$$

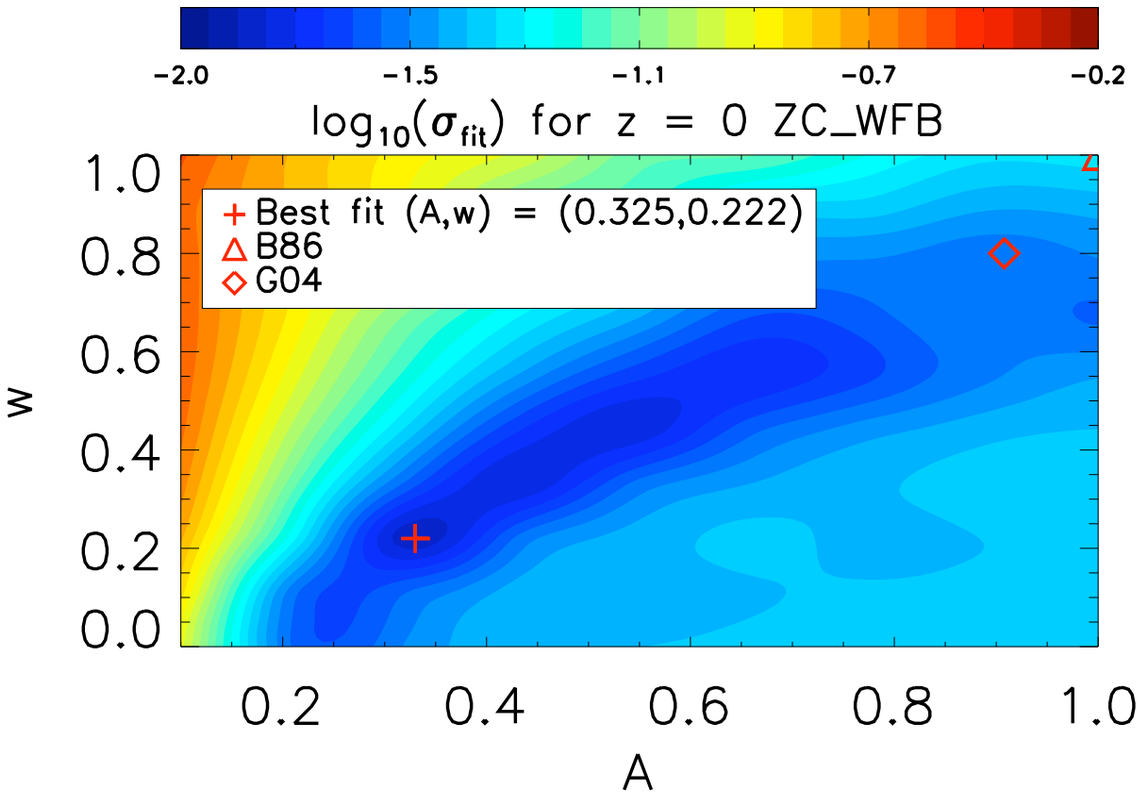
fit A & w to get better contraction model!

Gustafsson+06; Wang+10; Duffy+10

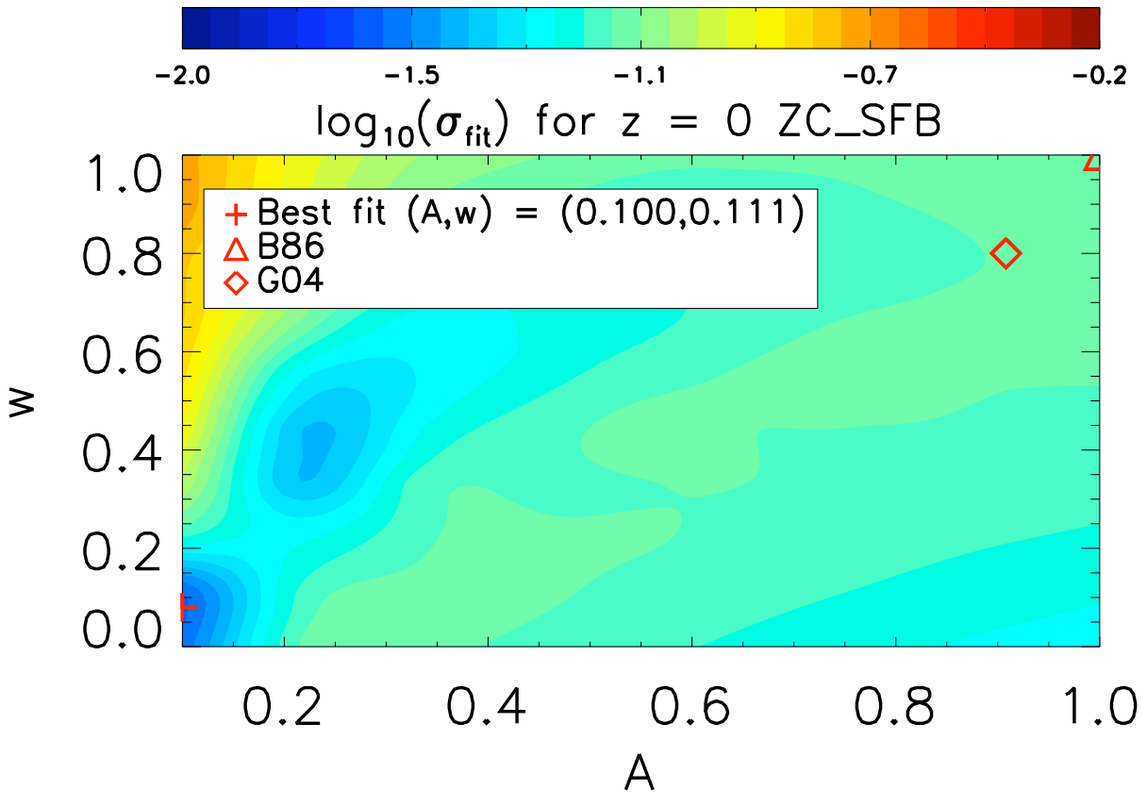
Orbit Correction?

Duffy et al. 2010

"Weak" Feedback



"Strong" Feedback

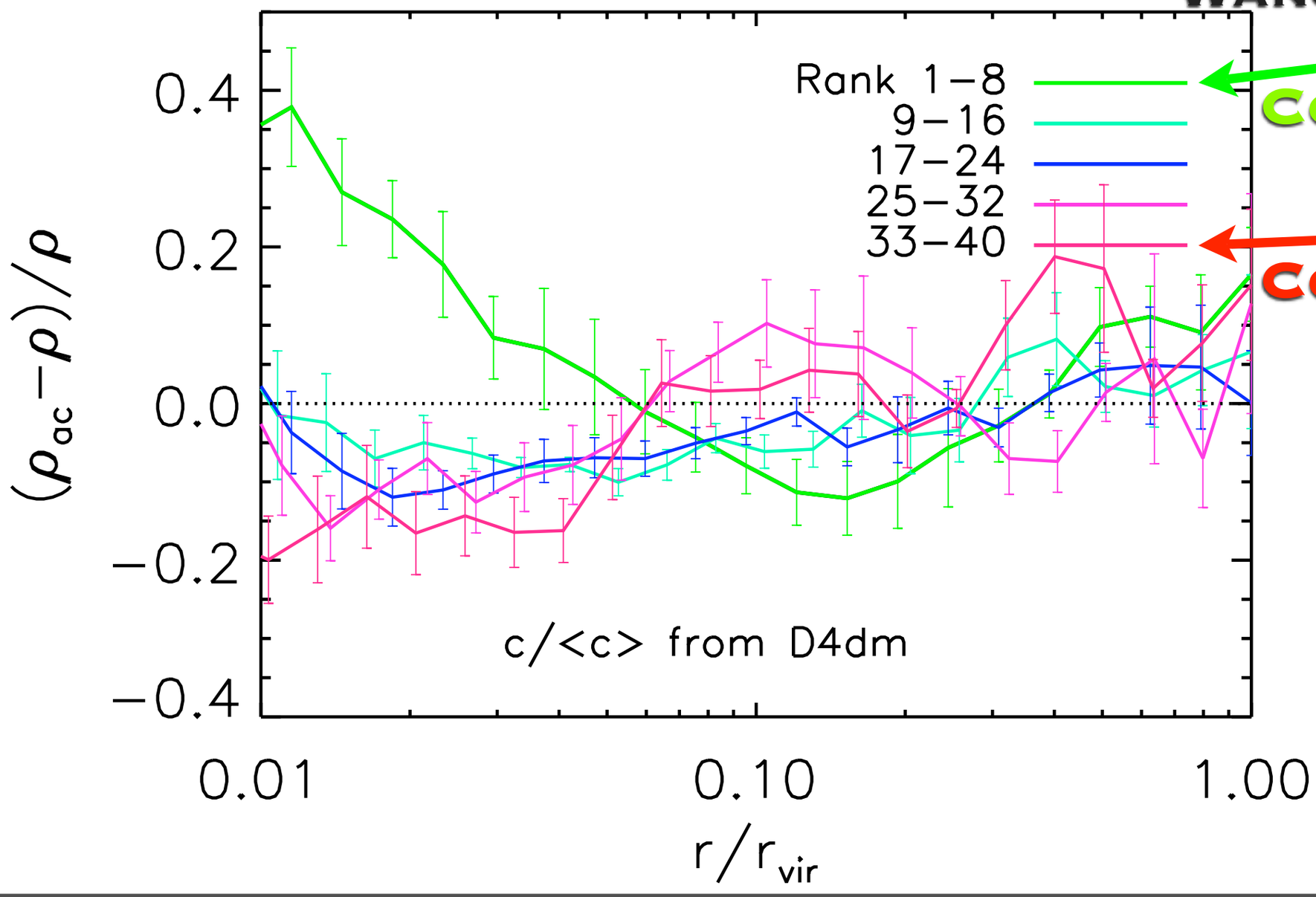


1. "Best" model does not reflect particle orbits!
2. "Best" model depends upon baryonic feedback and assembly history: complicated!

Similar: Gustafsson+06; Wang+10

Halo Dependence?

Wang et al. 2010



High Concentration

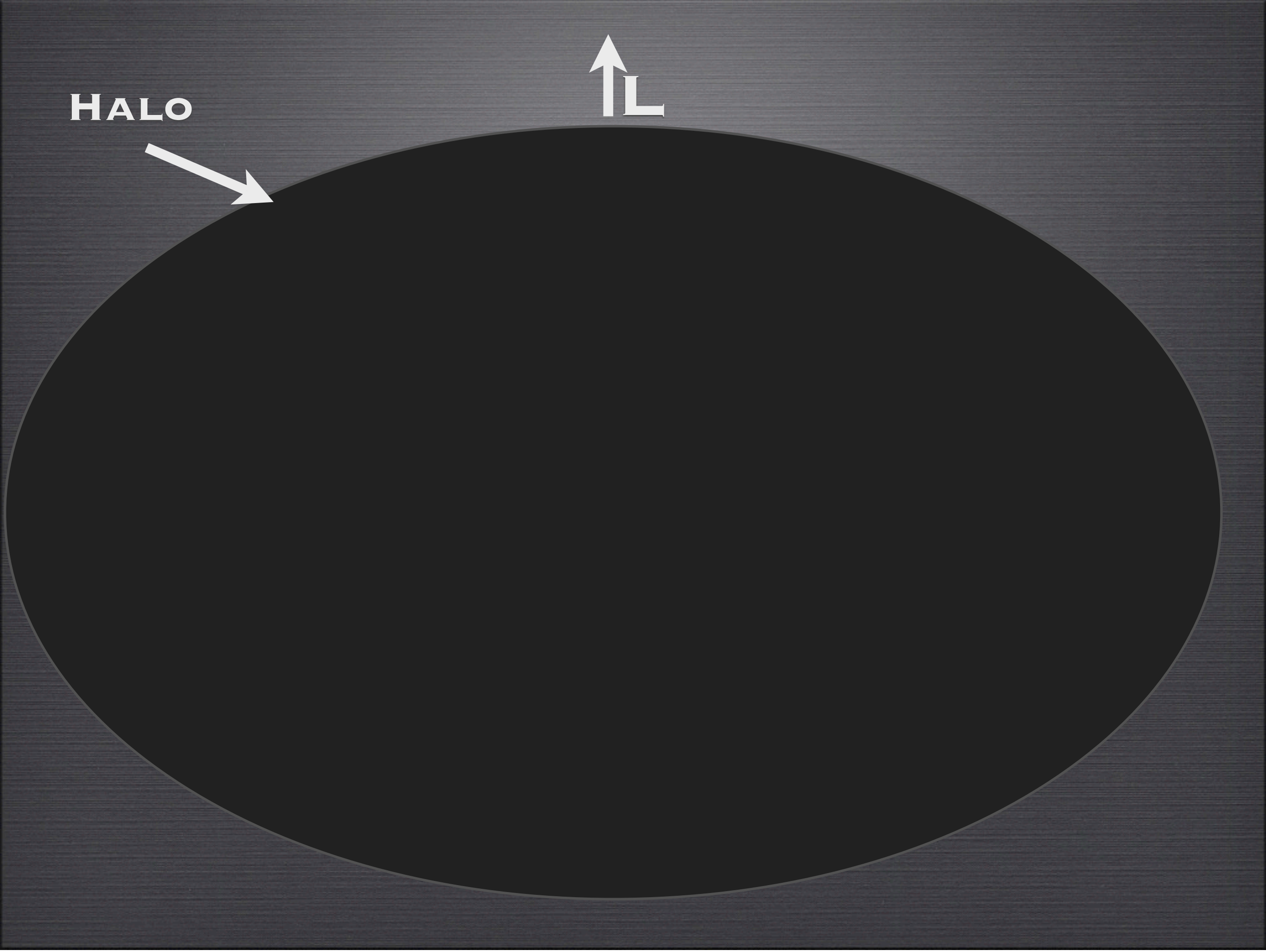
Low Concentration

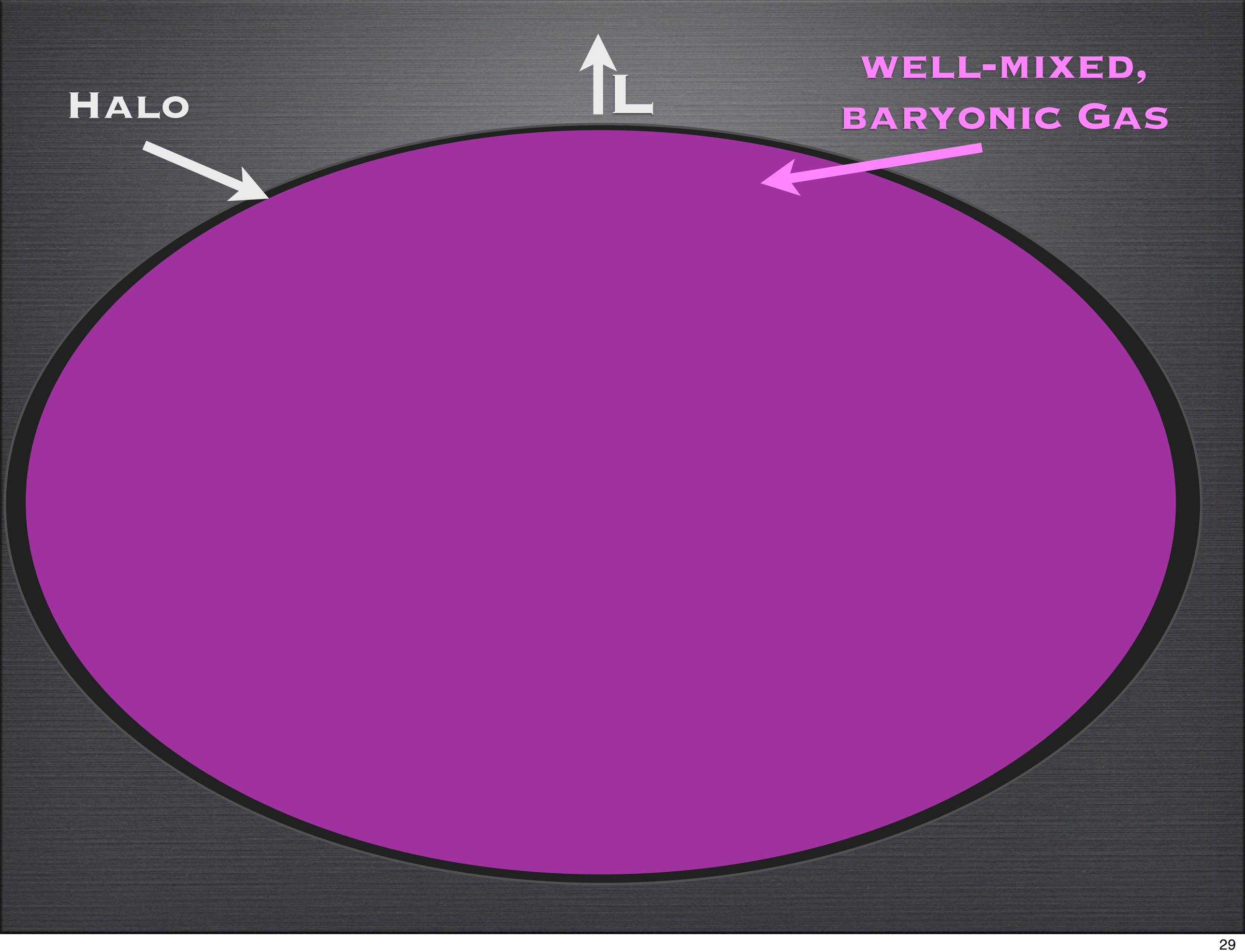
1. Residuals depend upon dark matter halo properties

Status

1. The degree of halo contraction depends not only upon the "final state" of the halo, but on its assembly history.
2. The degree of contraction depends upon the manner in which the stars were assembled from the early inter-galactic gas.
3. These facts are making definitive predictions difficult because galaxy formation is not understood in detail.

Halo Shapes


Halo
L


Halo
L
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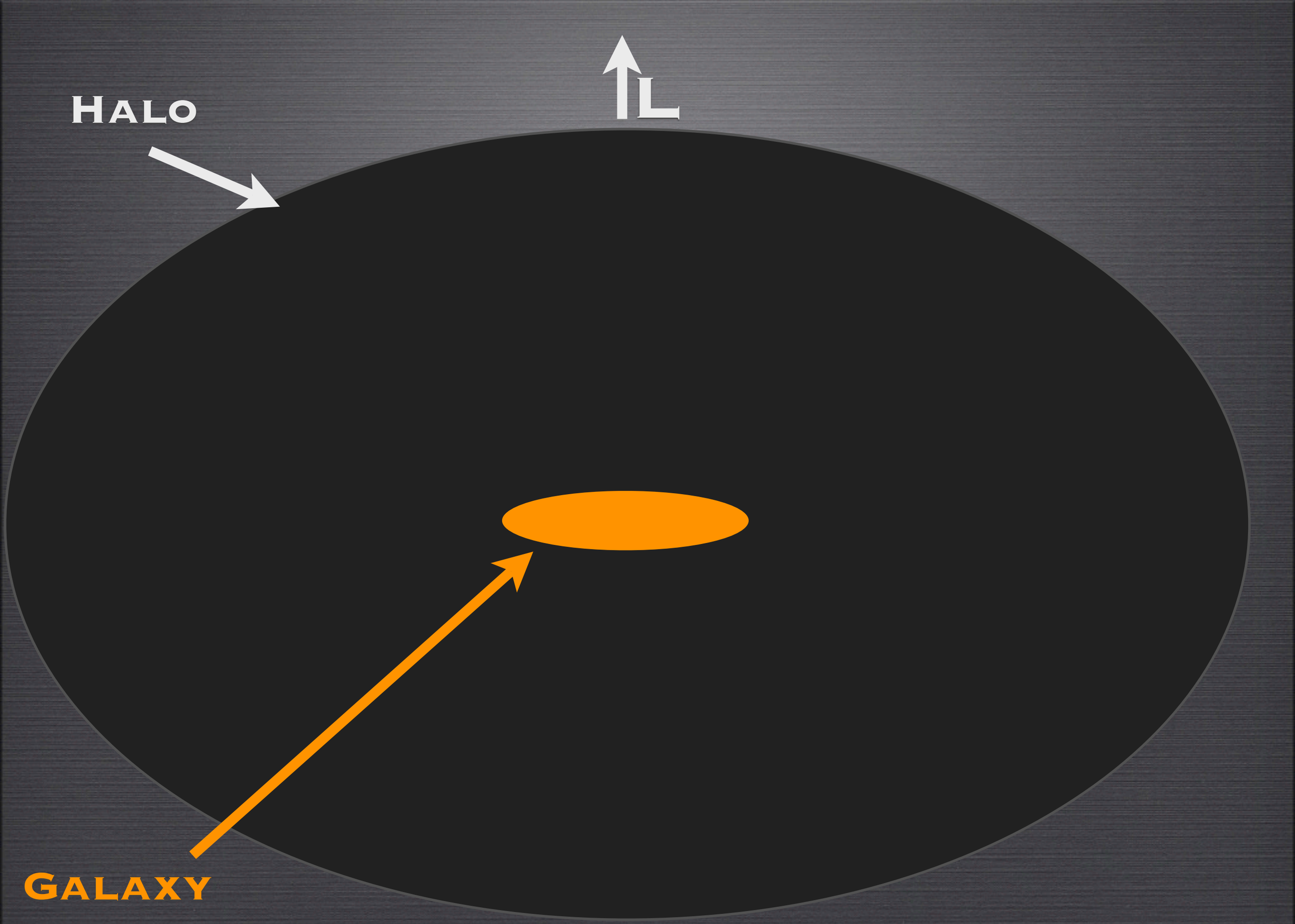
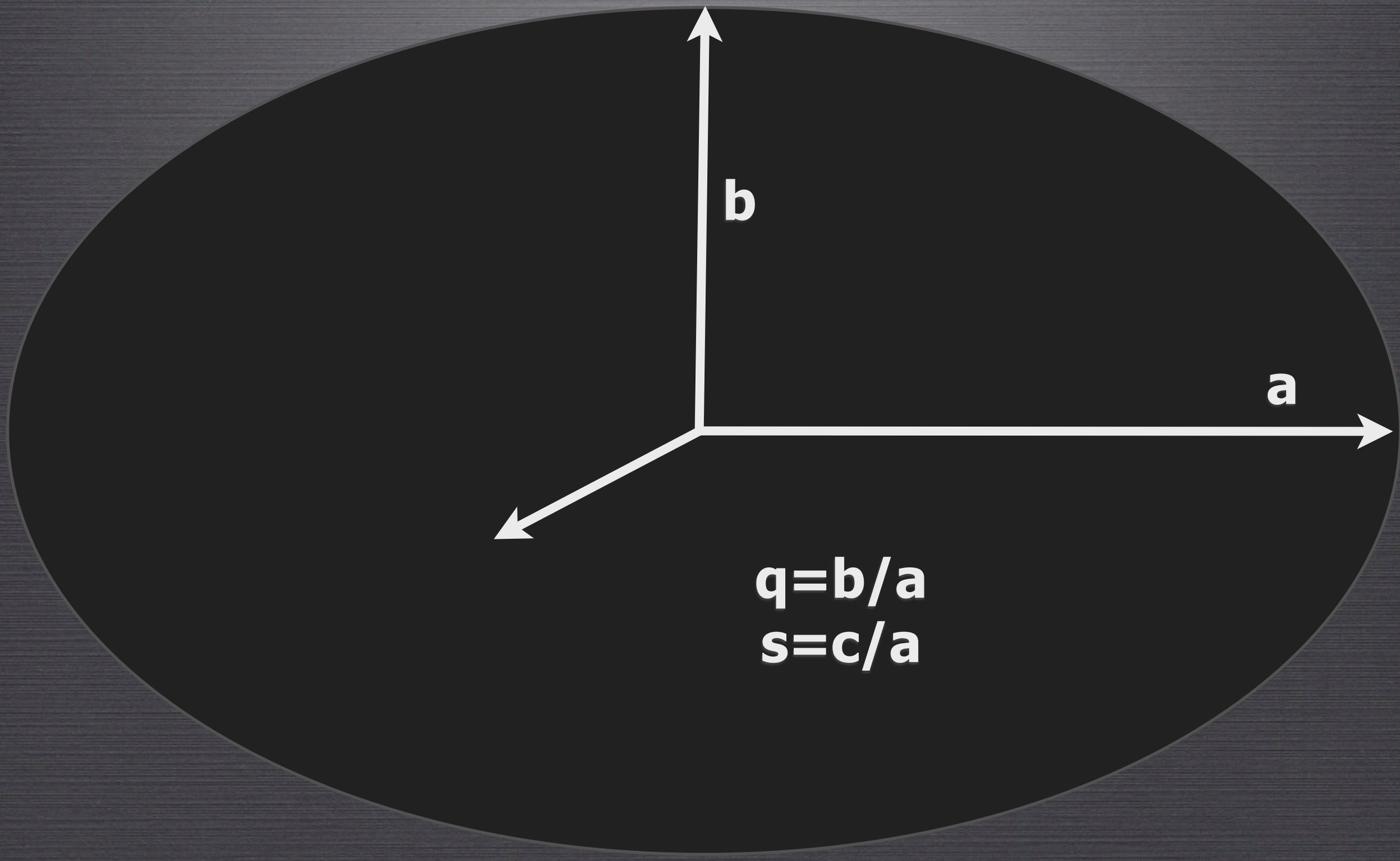

Halo
L
Galaxy

Halo

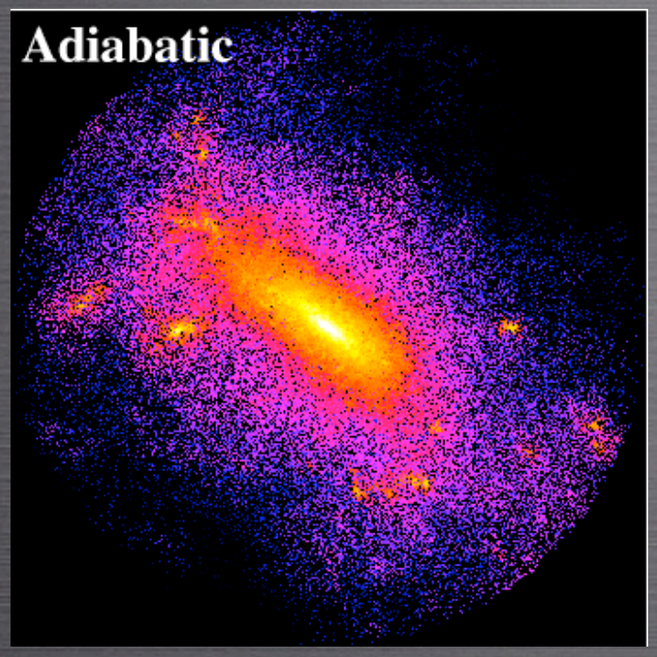
L

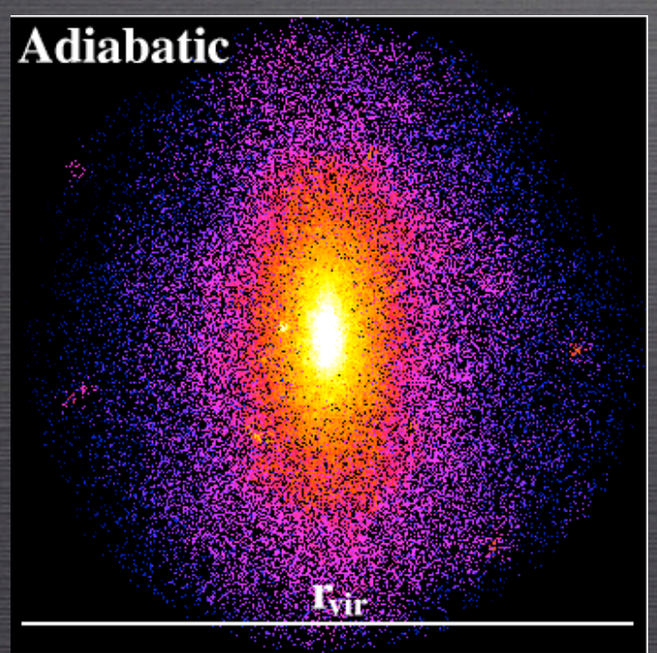
Galaxy


b
a
q=b/a
s=c/a

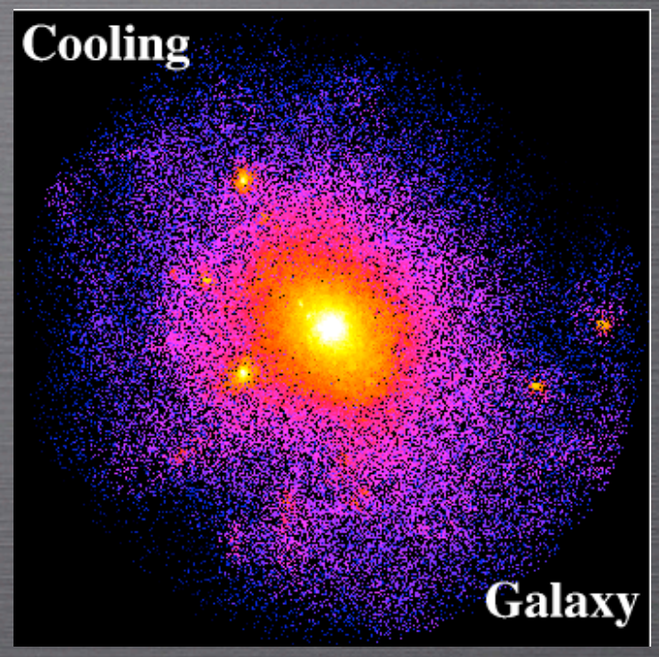
With Baryons

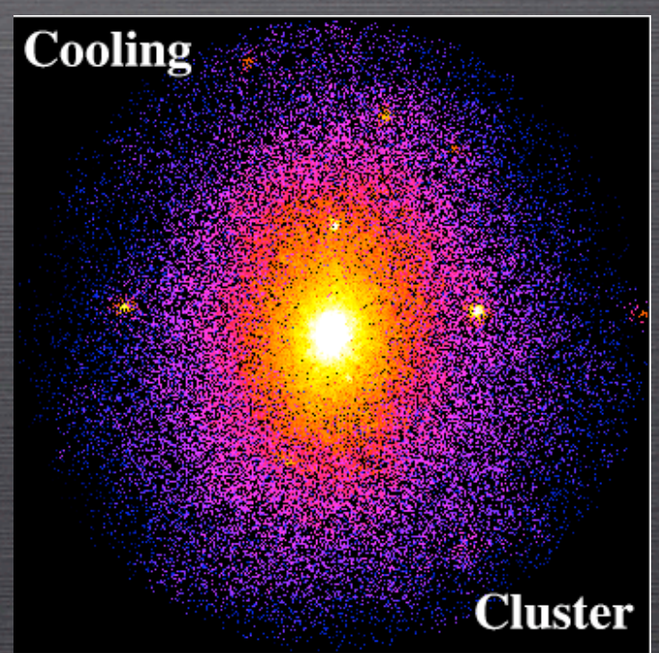
No Baryon cooling





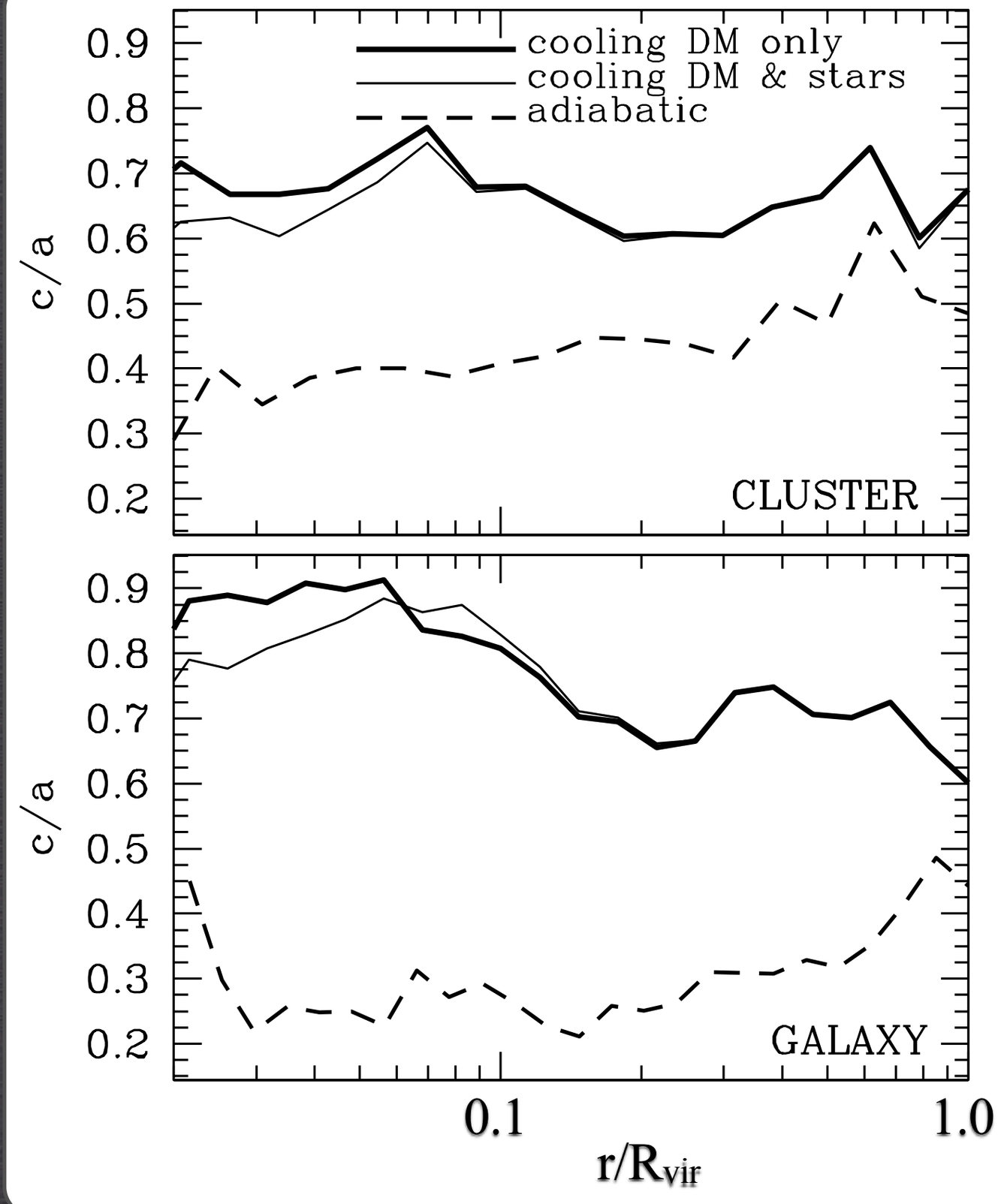
With Baryon cooling





Halos become significantly more spherical when baryons cool and form galaxies

With Baryons

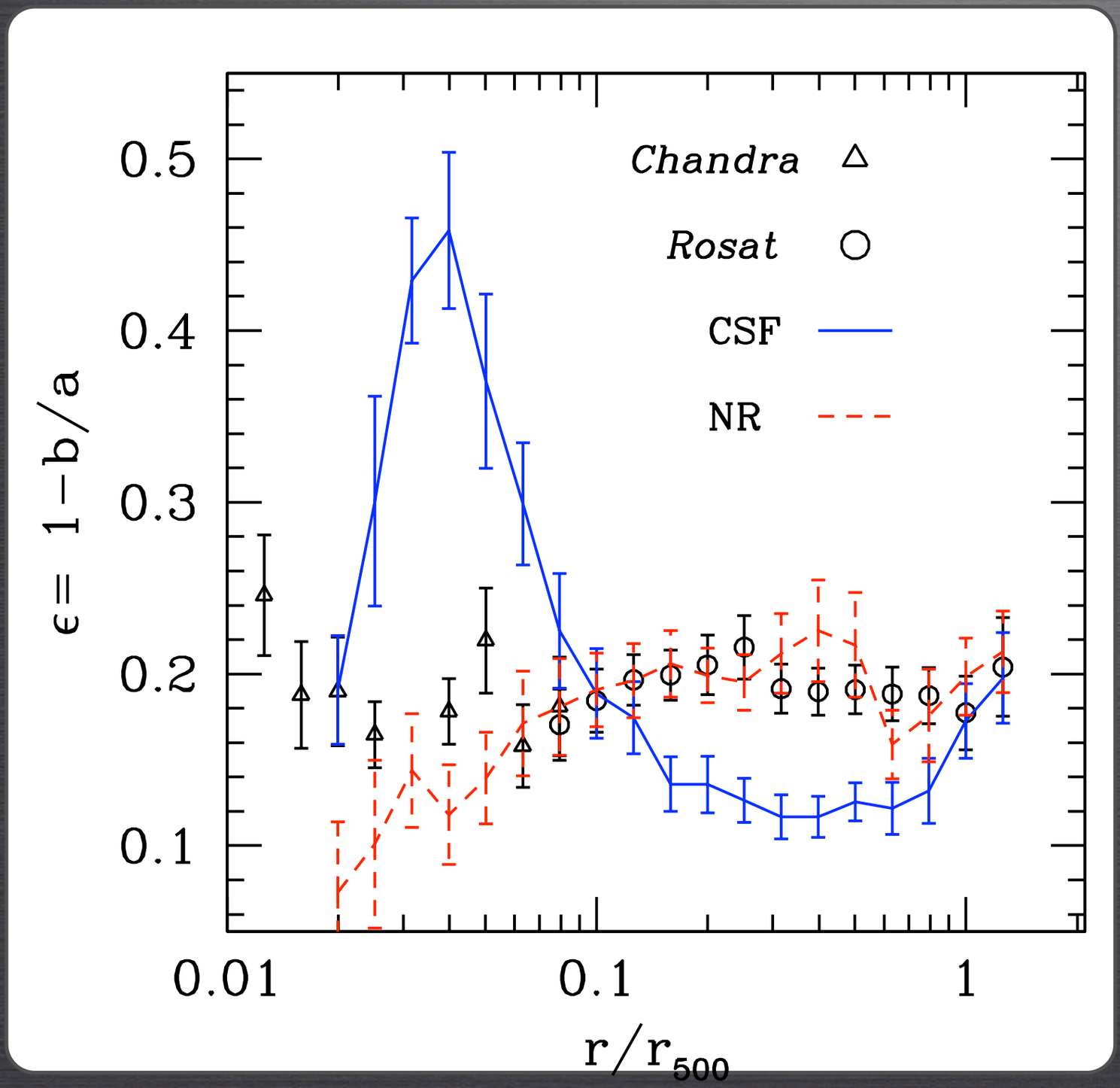


Kazantzidis et al. 2005

- Baryonic cooling in simulations gives dramatic changes in halo shape (but not velocity anisotropy; Tissera+2010)
- Changes as large as $\Delta(c/a) \approx 0.2$ are typical

Testing This

- Mock X-ray maps of simulated clusters compared to data...

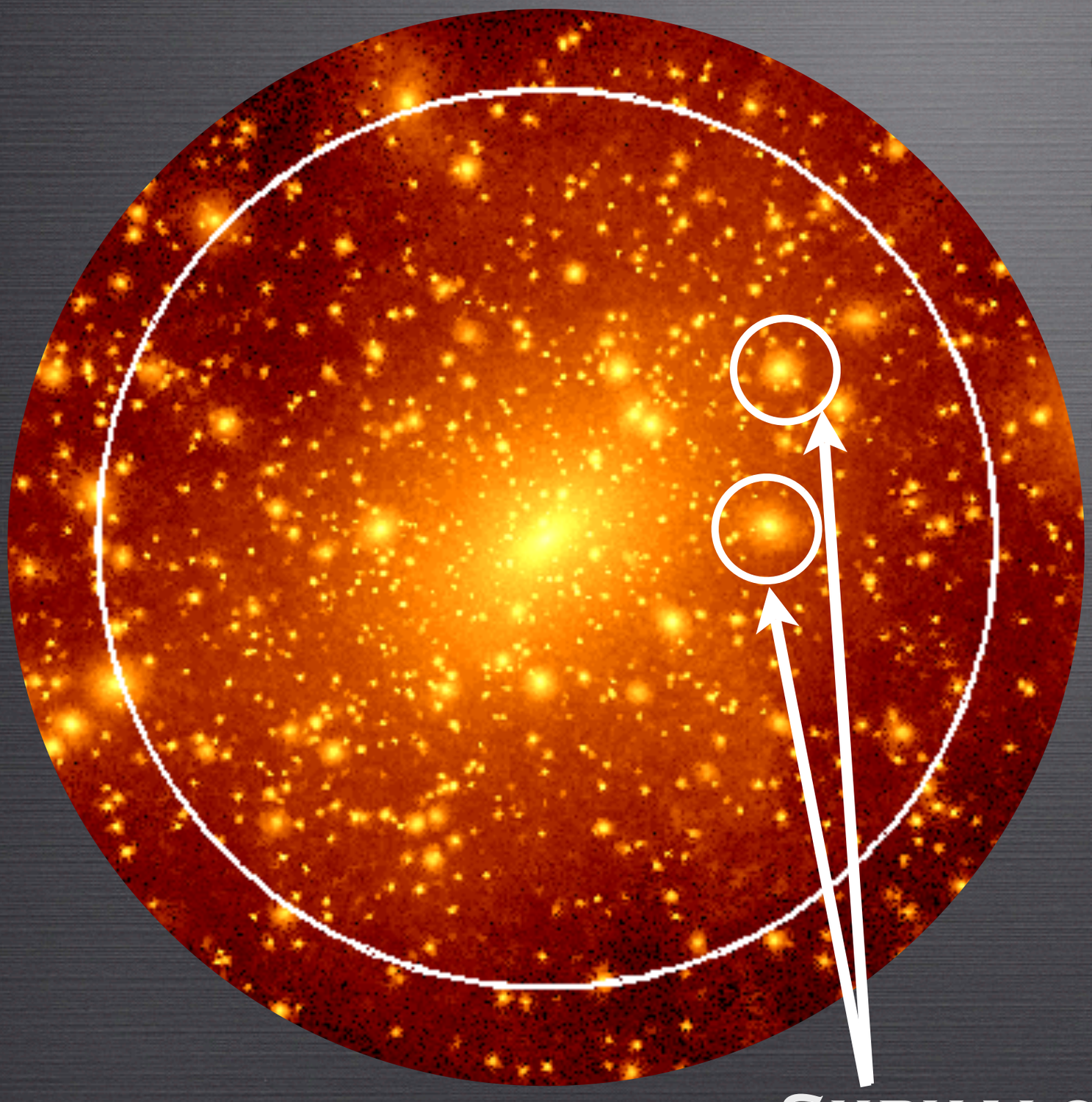


- Elliptical shapes of cluster suggest minimal shape transformation (and minimal cooling?)

Lau et al. 2011

Halo Substructure with Baryons

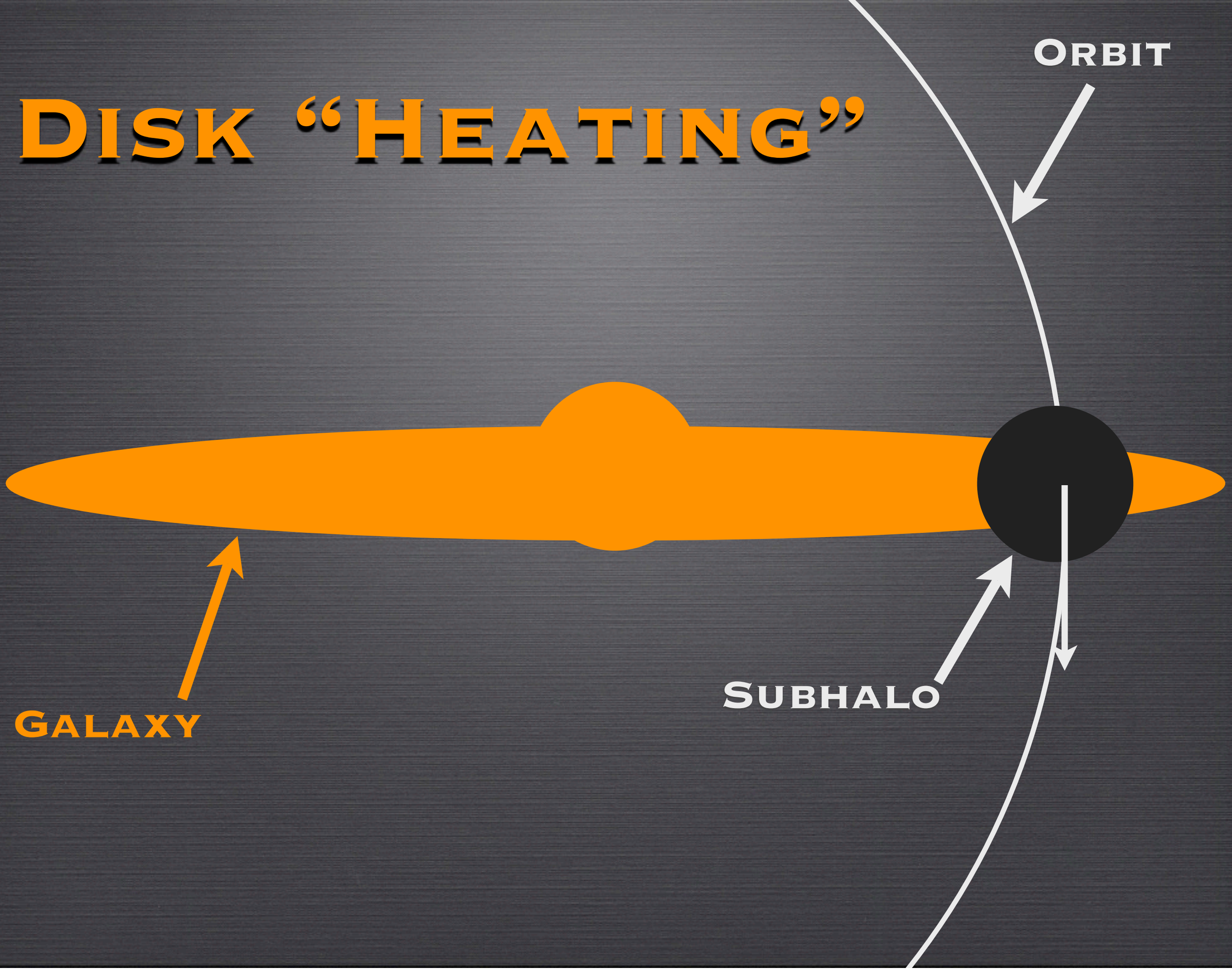
Subhalos



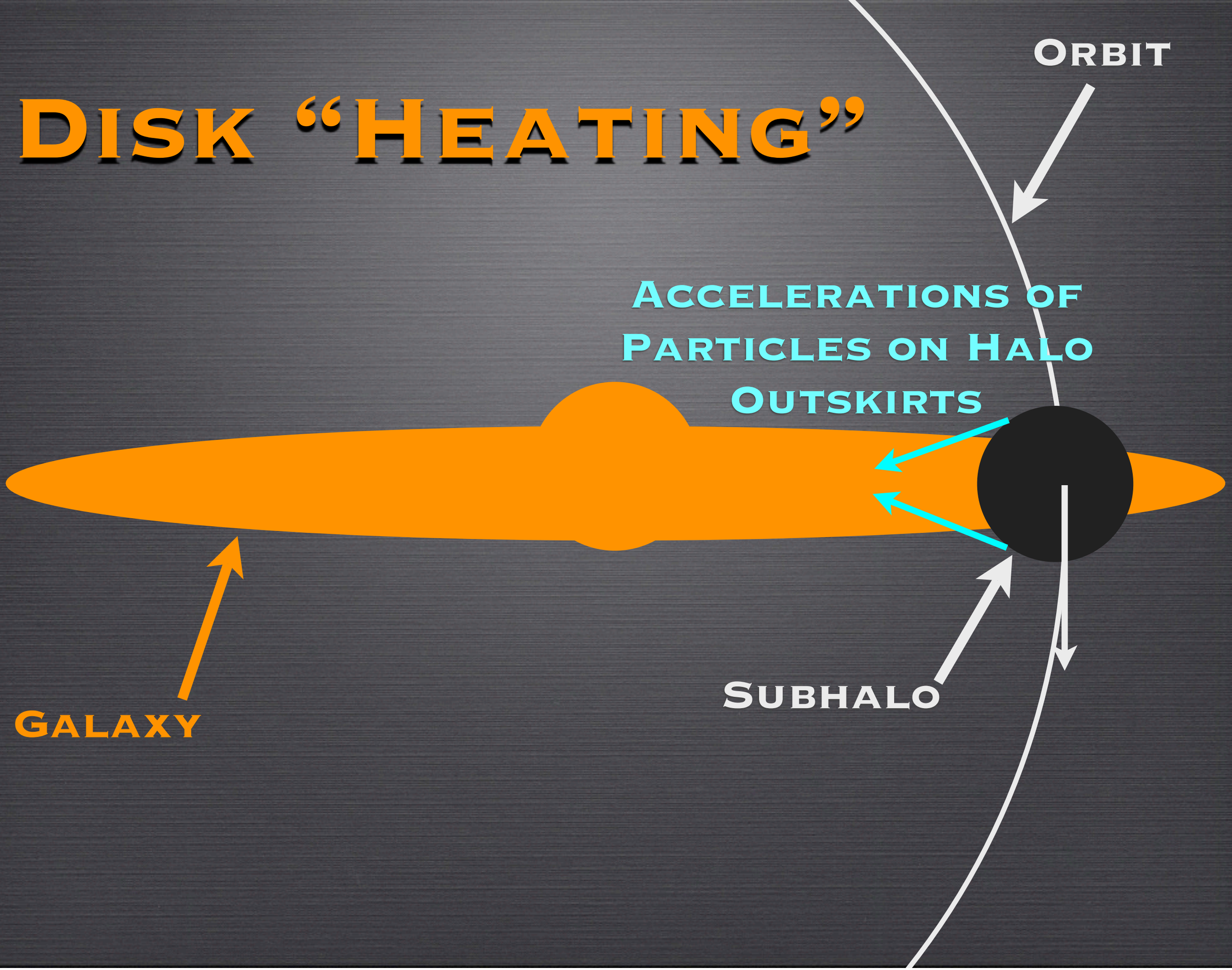
- "Subhalos" are the self-bound, smaller clumps the Lie within the "Virialized" regions of larger "Halos"

- Subhalos are, to rough approximation, much like smaller, denser halos

Disk "Heating"

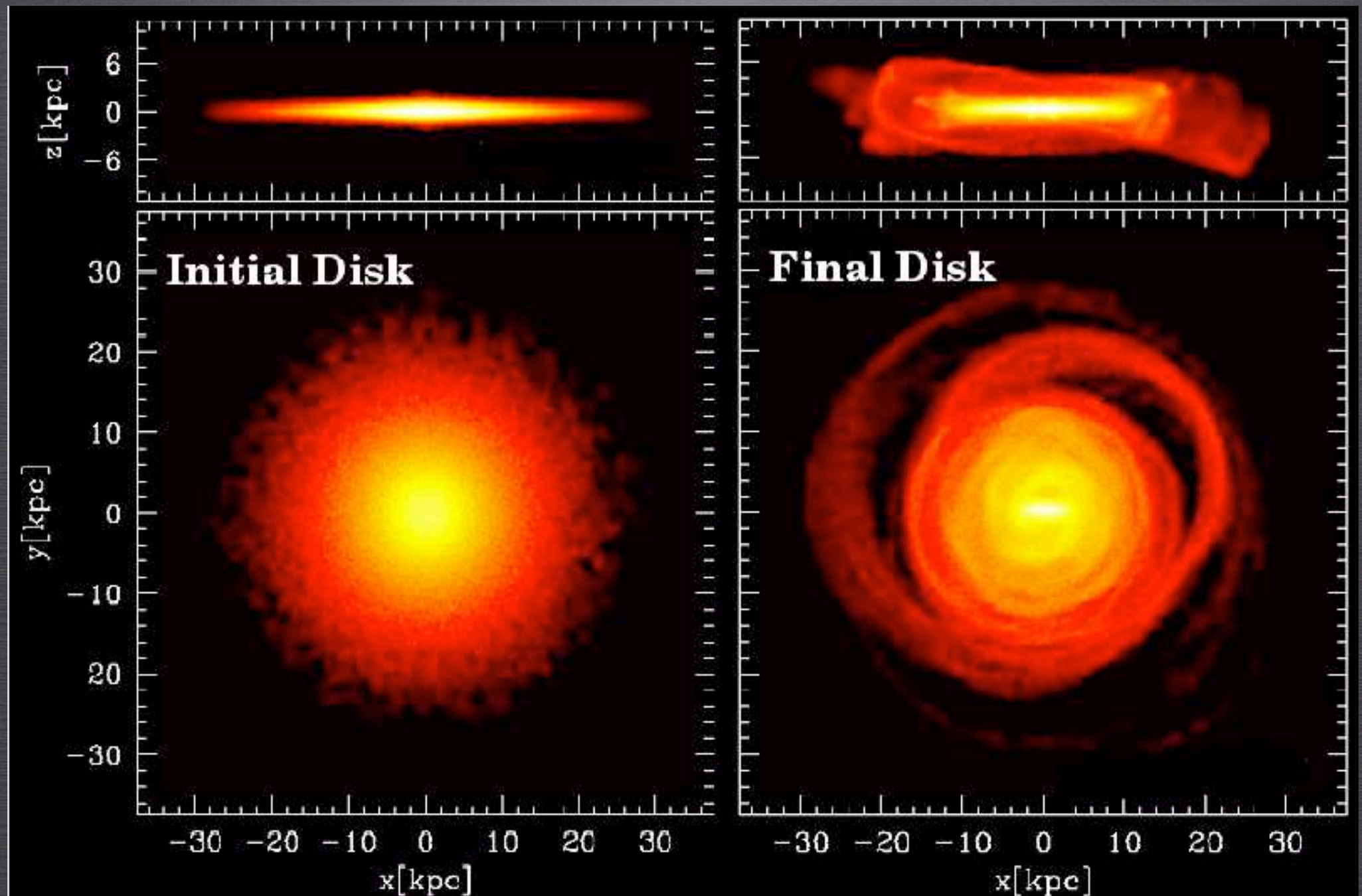


Disk "Heating"



Disk Consequences

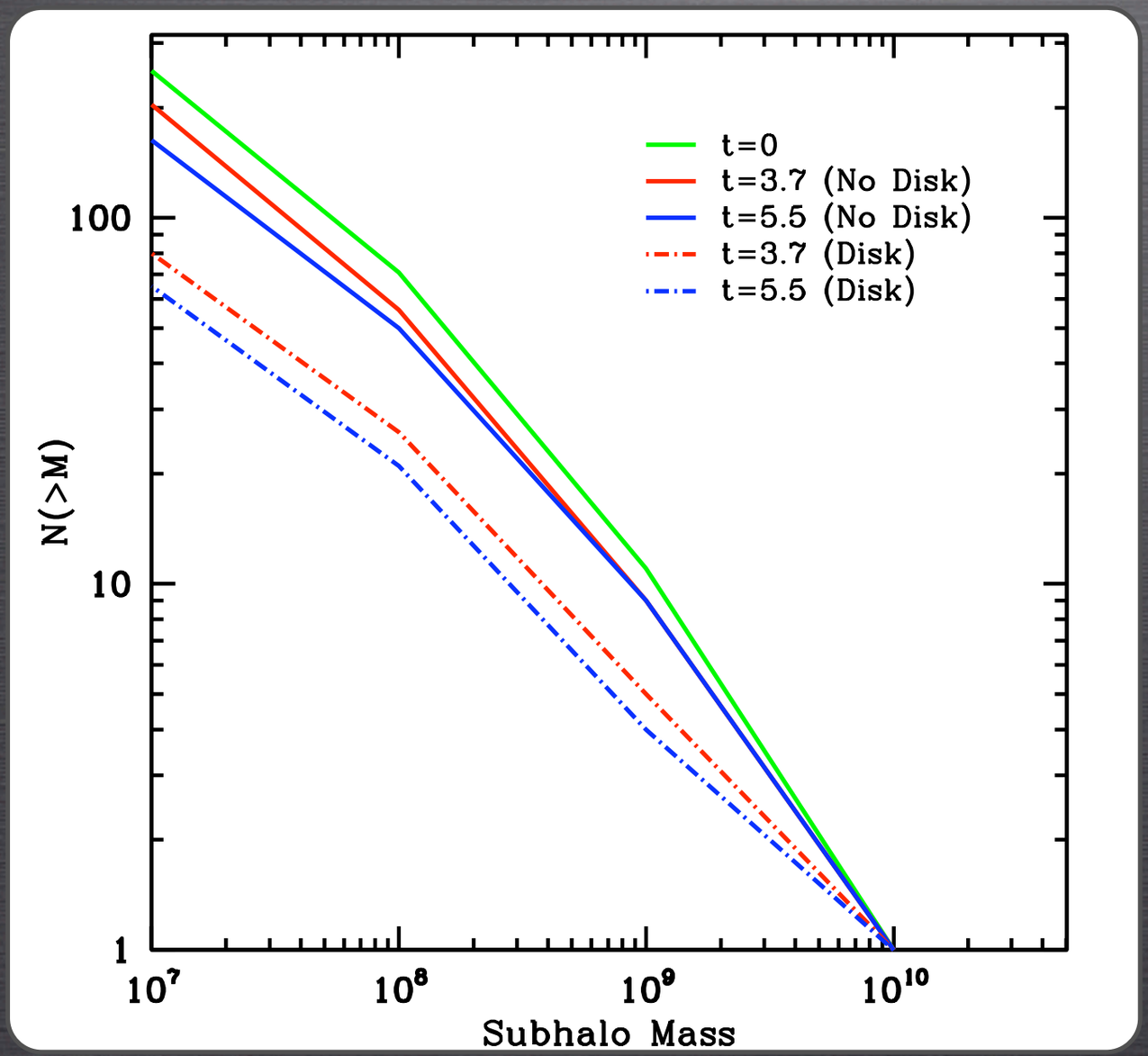
- The disk is heated and disk "features" are generated...



Kazantzidis et al. 2010

Subhalo Consequences

- The disk "heats" substructure and serves to destroy them more efficiently than N-body only simulations



D'Onghia et al. 2010

Also: Kazantzidis et al. 2009; Romano-Diaz et al. 2010

"Conclusions"

1. Some Halo Contraction Likely Happens, but it is hard to assess the degree and it depends upon messy details of galaxy formation
2. Baryonic Contraction likely makes halos rounder (altering, in principle, constraints on SIDM), but the degree is again hard to assess
3. The presence of galaxies should reduce the prevalence of substructure, but the degree is hard to assess