Inner Regions of Galaxies: The Effects of Baryons

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- gas cooling and star formation
- stellar or AGN feedback: gas blowout
- rounding of triaxial halo shapes
- test of triaxiality in the outer Galaxy

Dissipation of gas and star formation

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CONTRACTION OF DARK MATTER GALACTIC HALOS DUE TO BARYONIC INFALL[1]

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ABSTRACT

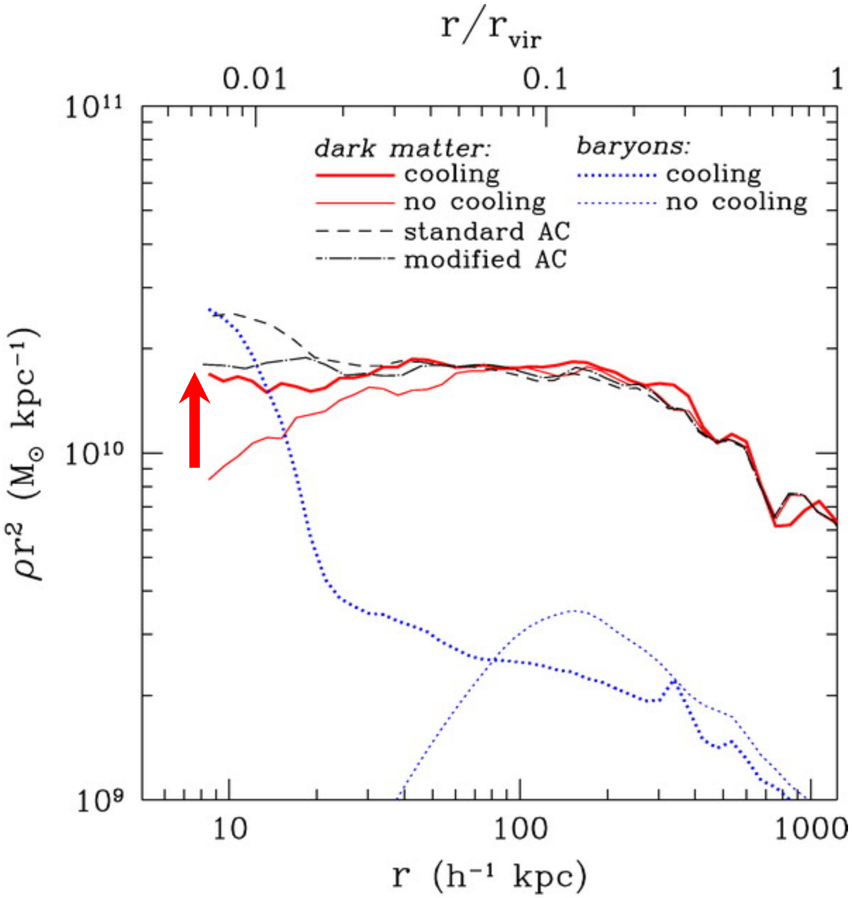
Varied evidence suggests that galaxies consist of roughly 10% baryonic matter by mass and that baryons sink dissipatively by about a factor of 10 in radius during galaxy formation. We show that such infall strongly perturbs the underlying dark matter distribution, pulling it inward and creating cores that are considerably smaller and denser than would have evolved without dissipation. Any discontinuity between the baryonic and dark matter mass distributions is smoothed out by the coupled motions of the two components. If dark halos have large core radii in the absence of dissipation, the above infall scenario yields rotation curves that are flat over large distances, in agreement with observations of spiral galaxies. Such large dissipationless cores may plausibly result from large internal kinetic energy in protogalaxies at maximum expansion, perhaps as a result of subclustering, tidal effects, or anisotropic collapse.

Subject headings: galaxies: evolution — galaxies: internal motions — galaxies: structure — interstellar: matter

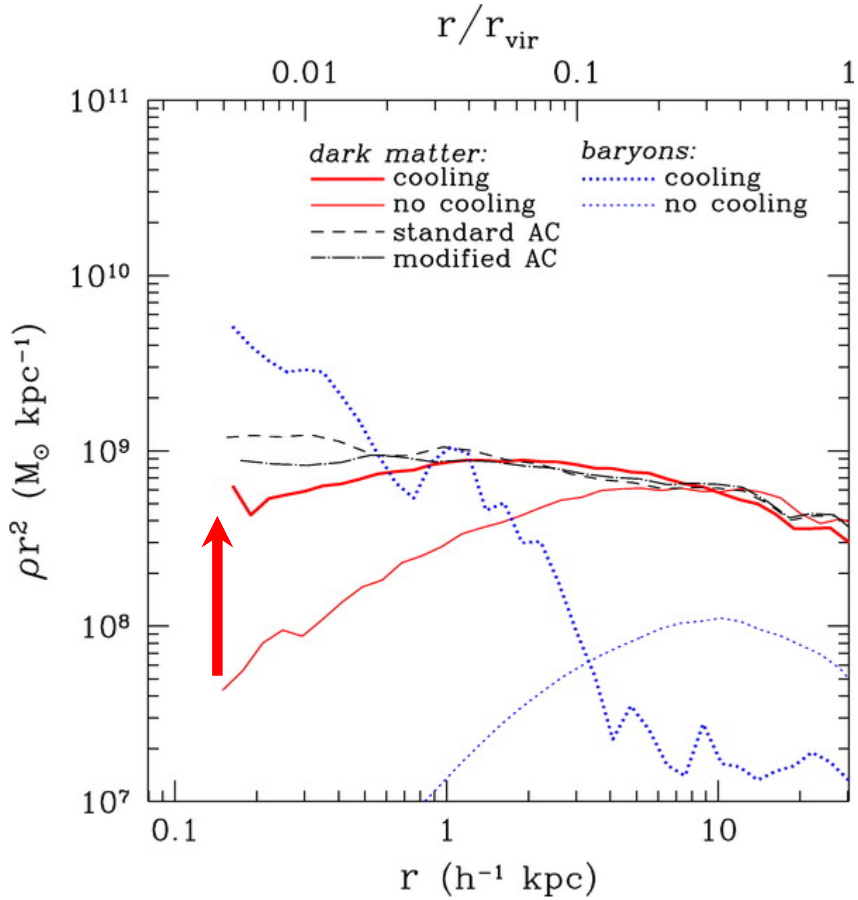
Zeldovich et al. (1980), Barnes & White (1984), Ryden & Gunn (1987), Flores et al. (1993), Dalcanton et al. (1997), Mo et al. (1998)

Gas cooling: hierarchical structure formation

cluster of galaxies



galaxy



Dark matter halos contract, but the standard model overestimates the effect (OG, Kravtsov, Klypin, Nagai 2004)

noticed previously by Barnes, Sellwood, and others (also Navarro/KITP)

Modified model of adiabatic contraction

Standard model is based on conservation of angular momentum for circular orbits *or* radial action for purely radial orbits.

Orbits in real halos have a wide distribution of eccentricities.

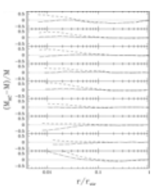
<u>Circular orbit</u>: $J^2 = J_{max}(E)^2 = GM(r)r$

<u>Radial orbit</u>, self-similar potential: $I_r^2 \propto M(r_a)r_a$

<u>General case</u>: $I_r^2 \propto M(\langle r \rangle)\langle r \rangle$ or $M(\langle r \rangle)r$

modified invariant = $M(\langle r \rangle)r$

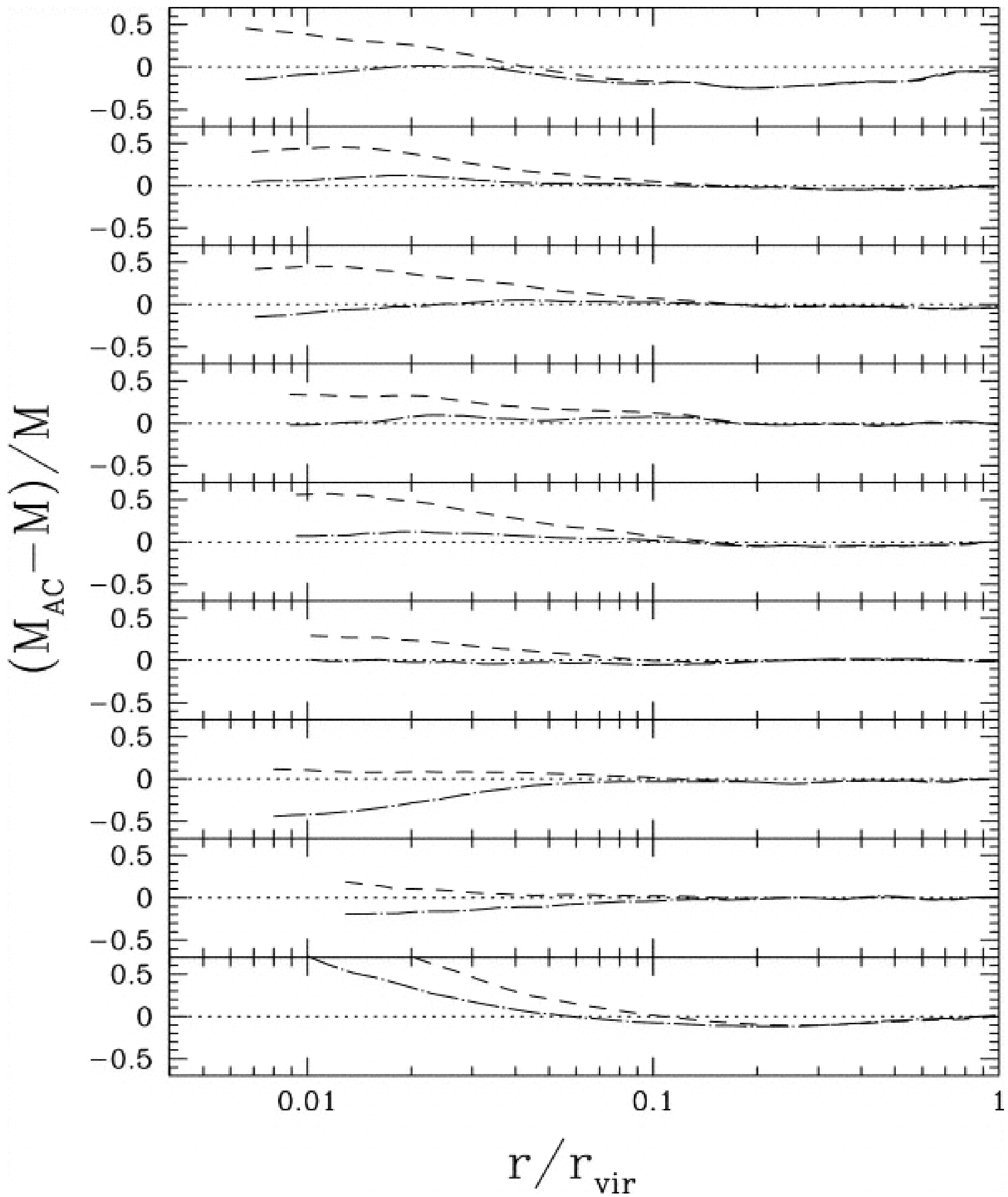
(*only approximately correct, but maintains the simplicity of the method – we need more simulations to calibrate this prescription)*



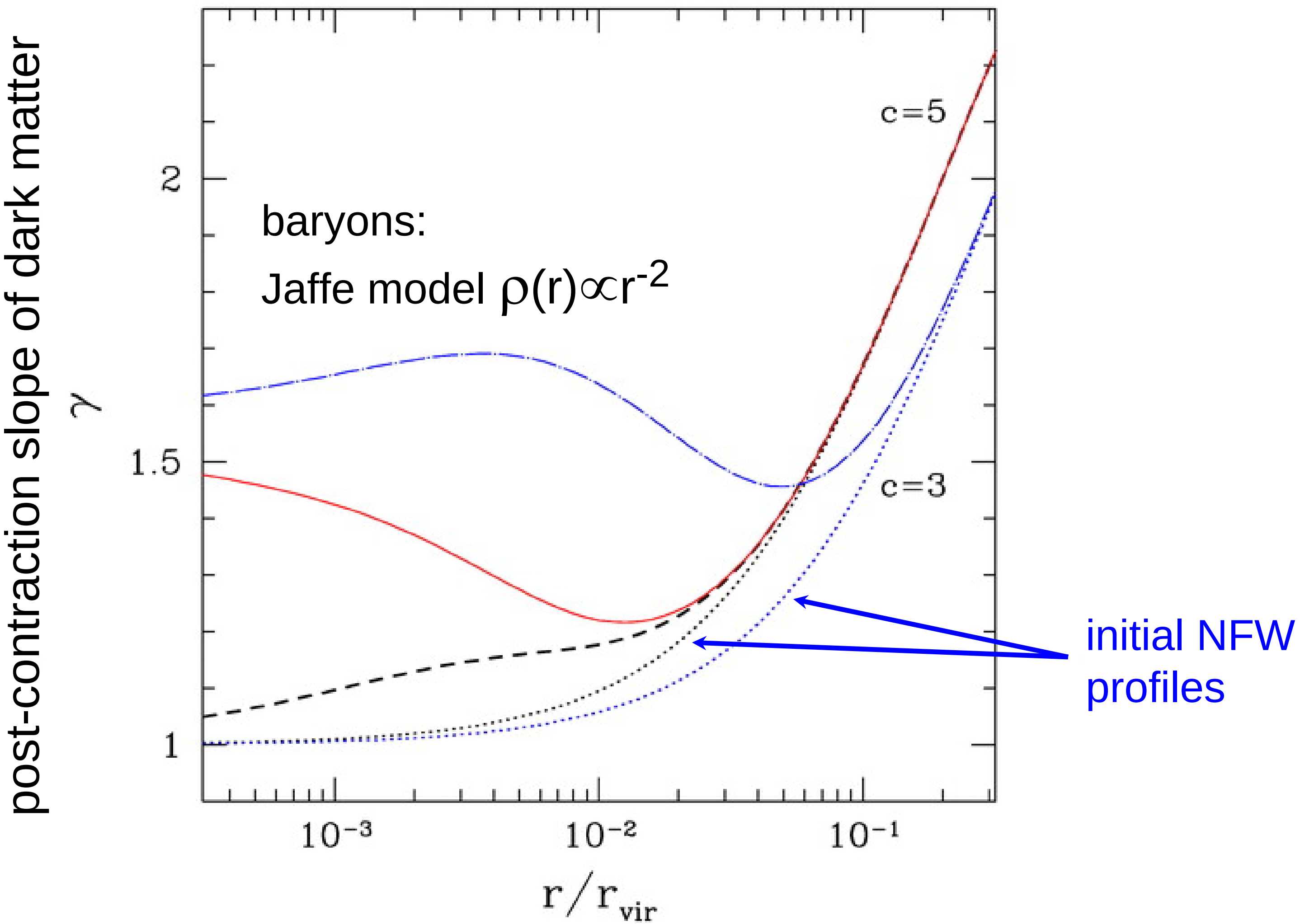
Contra: a new code for halo contraction

http://www.astro.lsa.umich.edu/~ognedin/contra/

Systematics



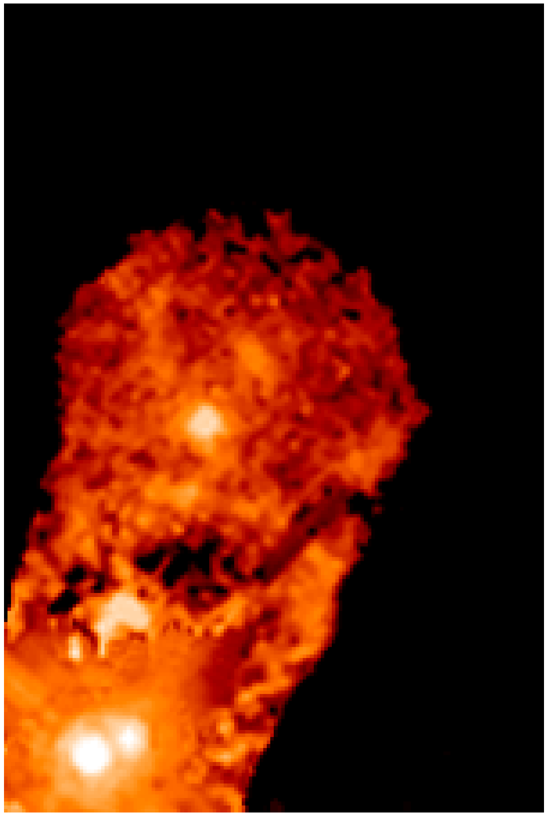
Lensing example: galaxy cluster MS 2137-23



baryon-dark matter decomposition: baryon mass can be over-subtracted and the concentration of dark matter under-estimated

Baryon blowout : Stellar or AGN feedback

Maximum expansion of a dark matter halo is achieved when: feedback is very efficient + mass of young stars is negligible + gas removal timescale is shorter than the dynamical time



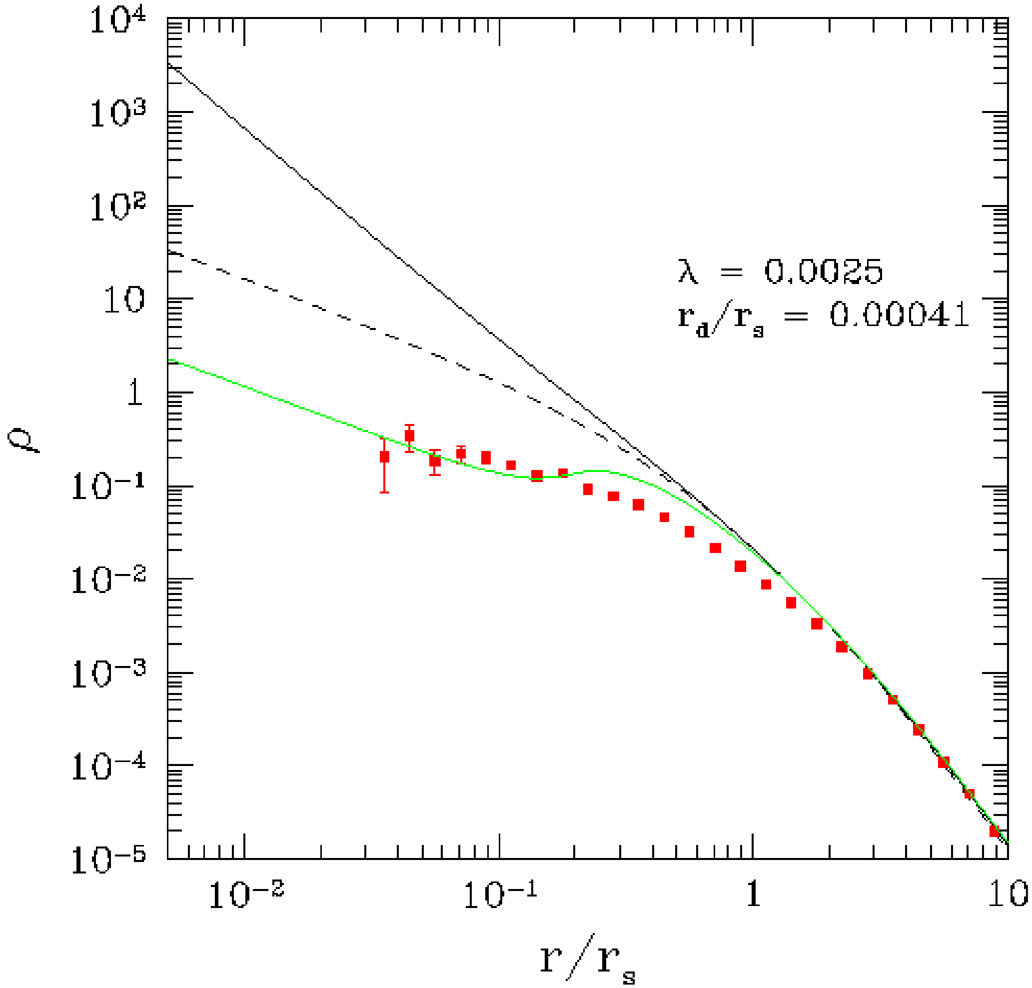
Can gas cooling and subsequent removal affect dark matter cusps?

Expect a difference from the collisionless profile: *only if gas removal is maximally efficient and takes place on a shorter timescale than gas cooling*

(Navarro et al. 1996, Lia et al. 2000, OG & Zhao 2002)

Maximum blowout cannot turn cusps into cores

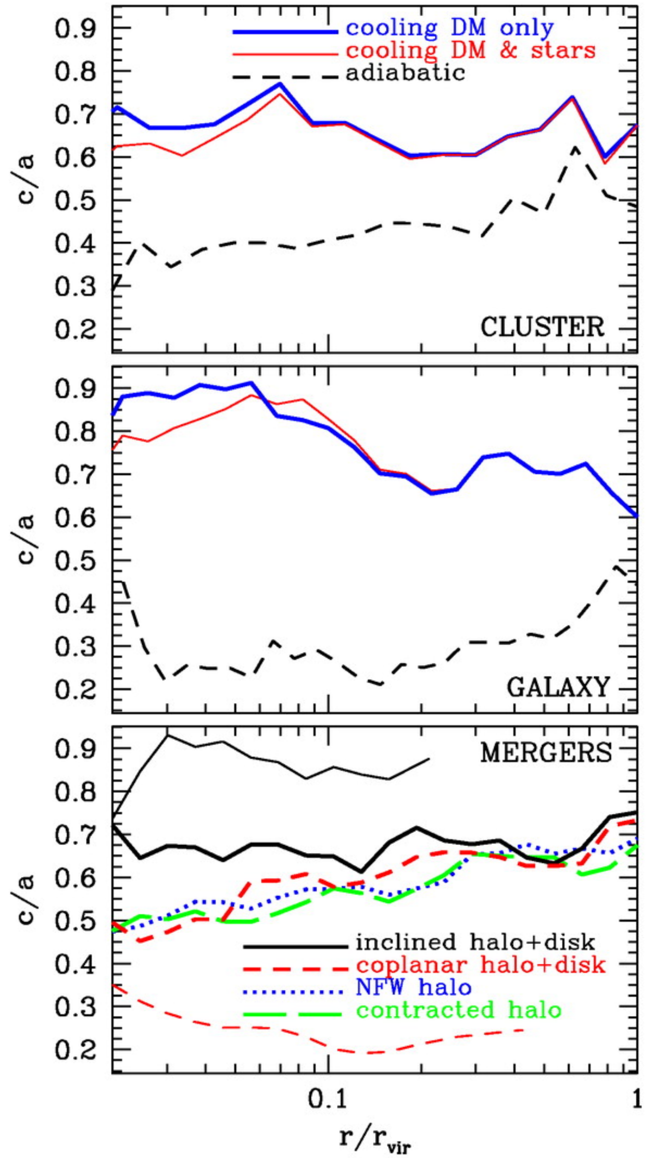
OG & Zhao (2002)



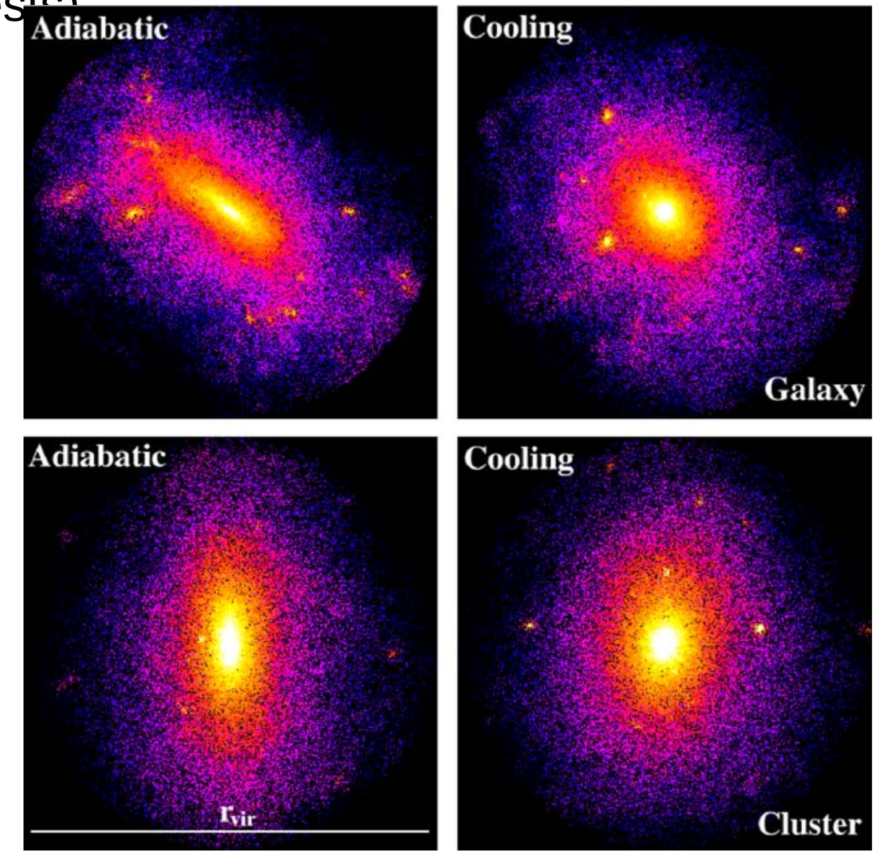
if $r_d \leq r_s$: heating proportional to binding energy M_d/r_d

if $r_d << r_s$: energy input proportional to disk mass M_d

Baryons make triaxial halos rounder



In the inner regions where baryon mass dominates, halo shape becomes rounder (Kazantzidis et al. 2004, also Navarro/KITP; Bullock/KITP – observational tests)



HyperVelocity Stars: New Probes of Galaxy's Halo

likely ejected from the Galactic Center with 600-1000 km/s *(three-body interaction with the supermassive black hole)* first discovered in 2005, probe halo potential to 100 kpc

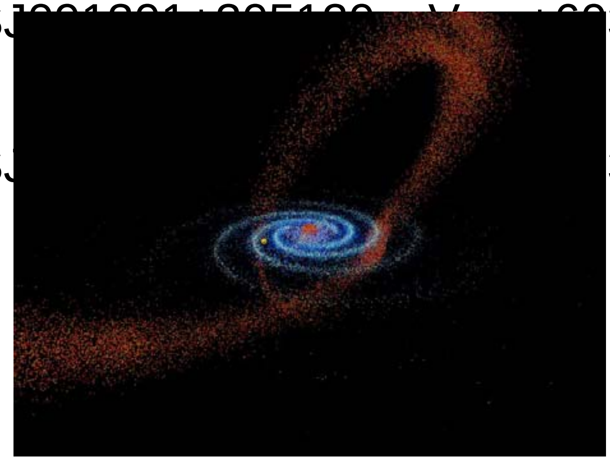
SDSSJ090745+024507: V_r = +853 km/s

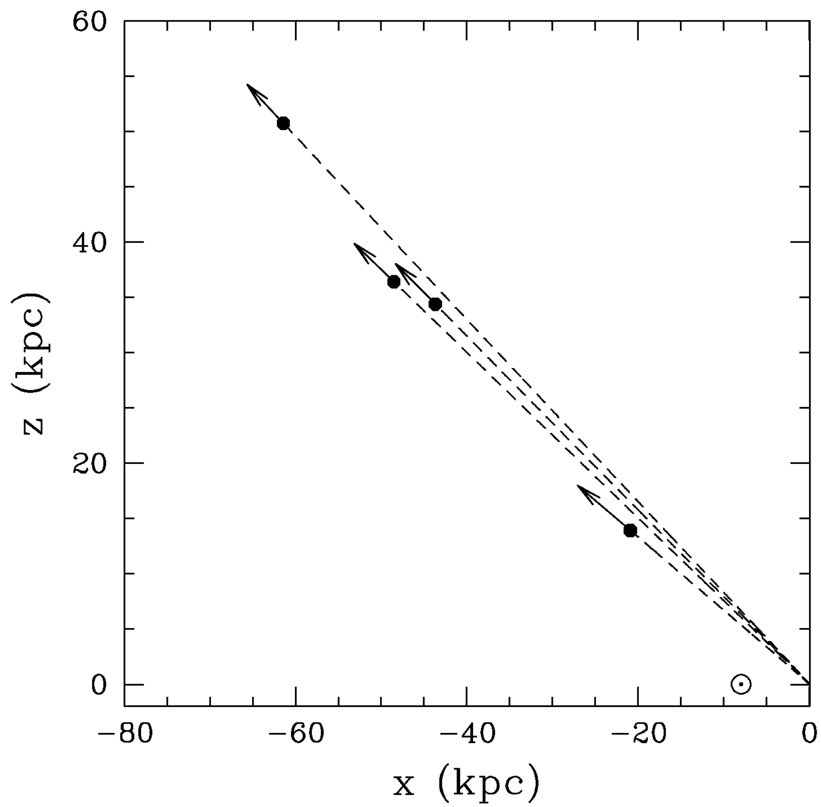
SDSSJ093321+441705: V_r = +708 km/s

HE0437-5439: V_r = +723 km/s

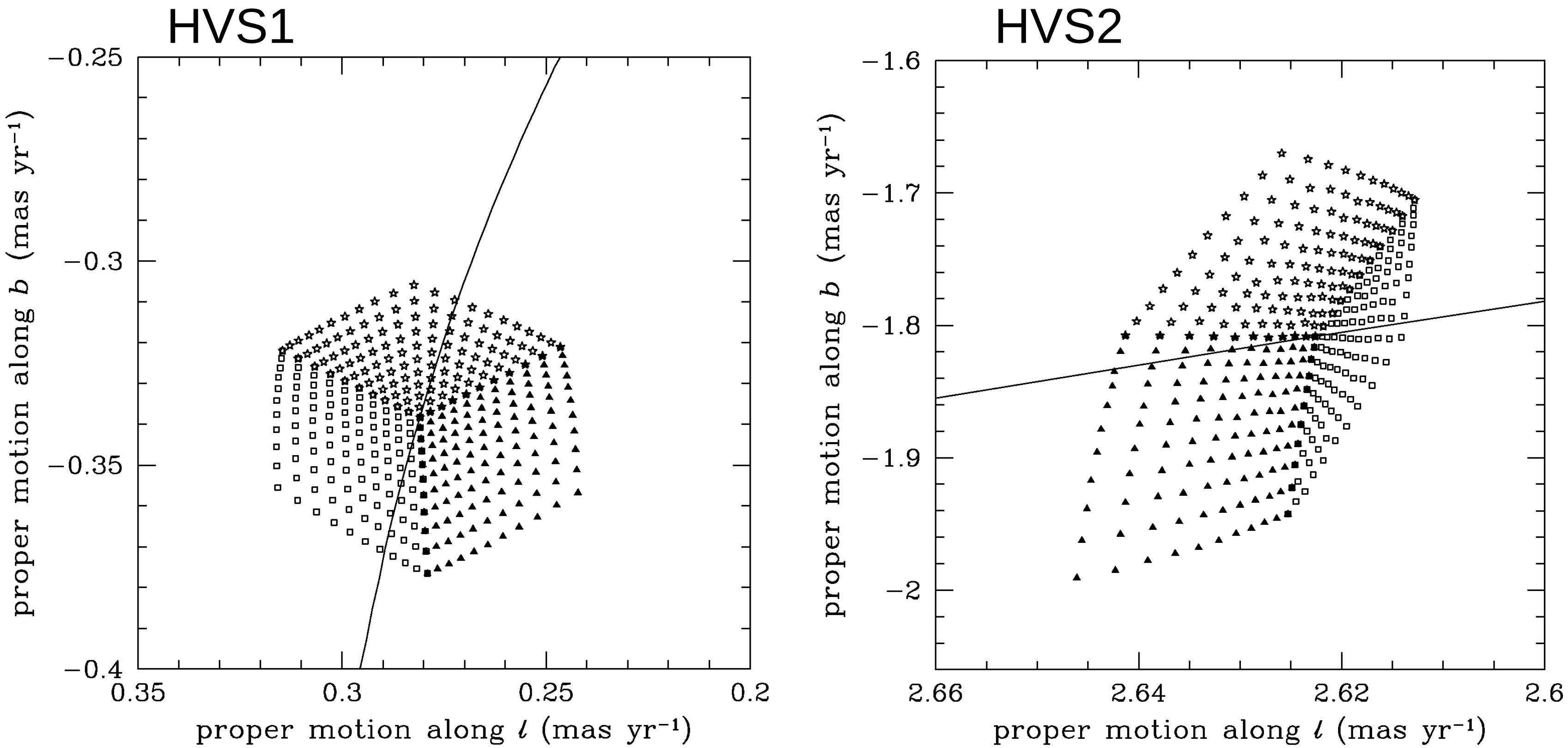
SDSSJ ... 3 km/s

SDSSJ ... 3 km/s





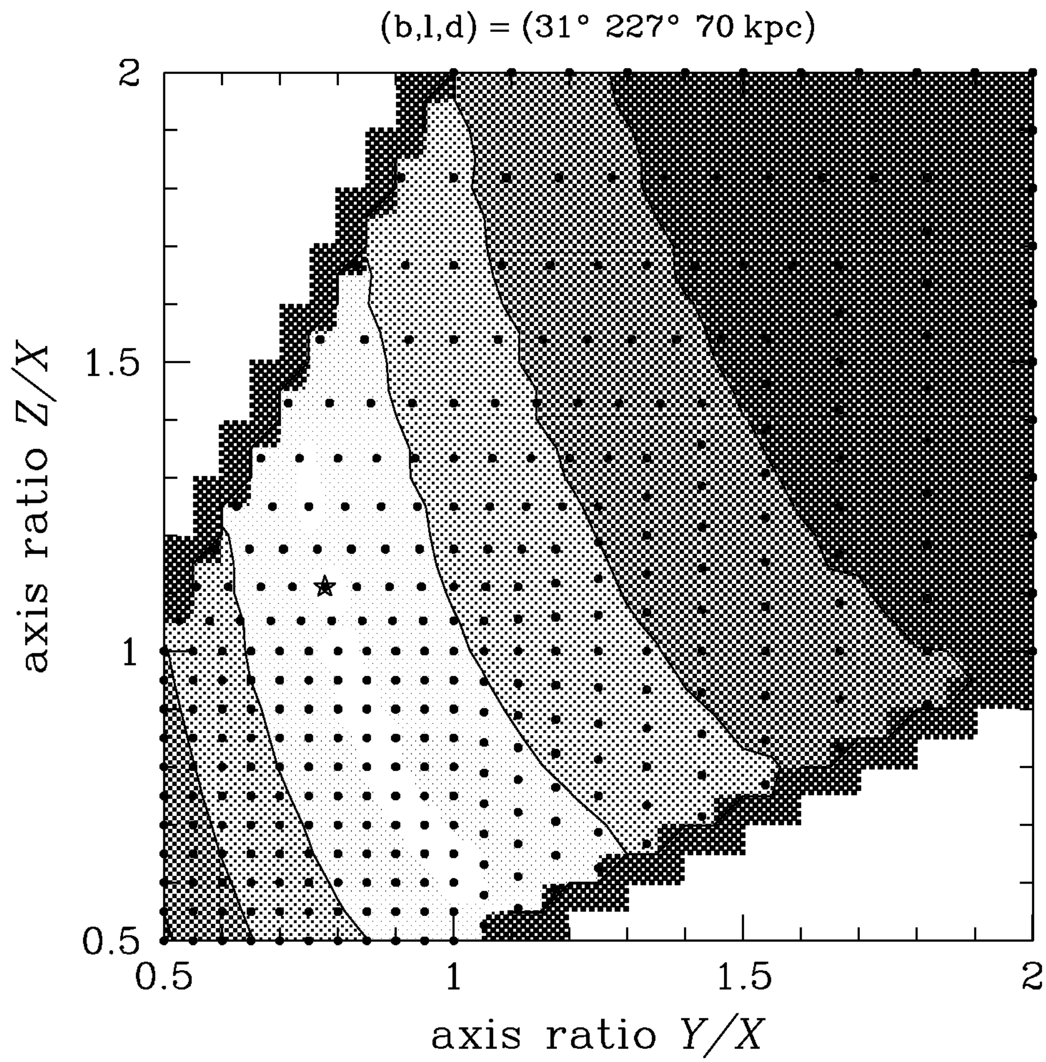
Measuring proper motions of HVS can determine the shape and orientation of the dark matter halo: **direct test of CDM**



OG, Gould, Miralda-Escude, Zentner 2005

Constraints on the halo axis ratios

From two HVS: strong constraints and distance determination



Summary

Gas cooling and star formation lead to the contraction of dark matter halos (compared to the collisionless case)

It can significantly increase central concentration of dark matter in galaxies and clusters of galaxies

Important for the interpretation of observed rotation curves, evolution of bars, and mass reconstruction from strong lensing

Even maximum baryon blowout cannot turns cusps into cores

In realistic situations halo contraction cannot be reversed

Baryon concentration makes inner regions of halos rounder

Hypervelocity stars probe triaxiality of dark halos in the outer Galaxy and directly test CDM predictions: first results in 2008

The Astrophysical Journal, 616:16–26, 2004 November 20

RESPONSE OF DARK MATTER HALOS TO CONDENSATION OF BARYONS: COSMOLOGICAL SIMULATIONS AND IMPROVED ADIABATIC CONTRACTION MODEL

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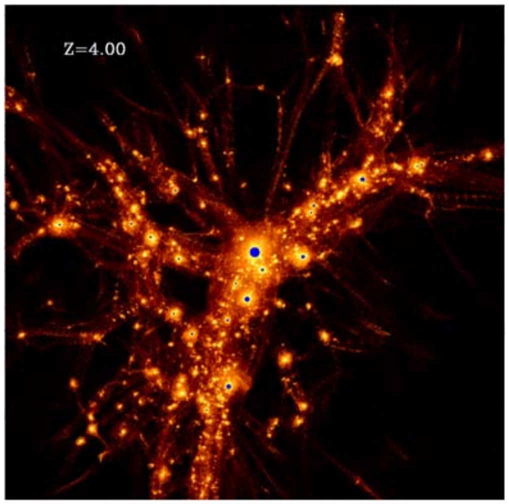
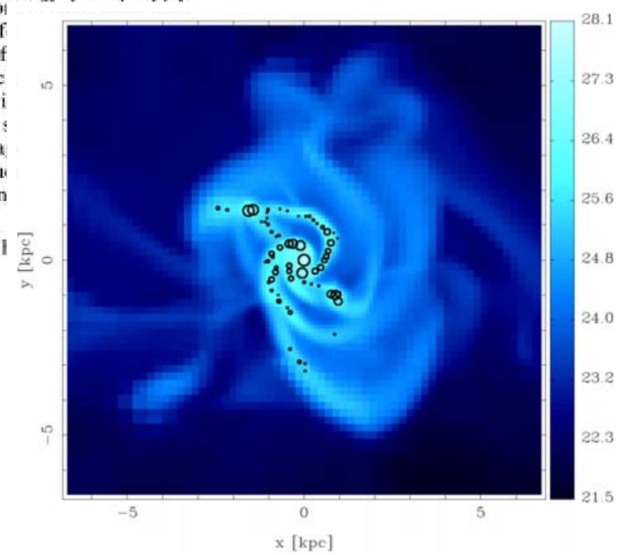
ABSTRACT

The cooling of gas in the centers of dark matter halos is expected to lead to a more concentrated dark matter distribution. The response of dark matter to the condensation of baryons is usually calculated using the model of adiabatic contraction, which assumes spherical symmetry and circular orbits. In contrast, halos in the hierarchical structure formation scenarios grow via multiple violent mergers and accretion along filaments, and particle orbits
ccentric. We study the effects of the cooling of gas in the inner regio
l simulations that include gas dynamics, radiative cooling, and star f
ideed increases the density of dark matter and steepens its radial prof
the case without cooling. For the first time, we test the adiabatic
ns and find that the standard model systematically overpredicts the i
of the virial radius. We show that the model can be improved by a
from $M(r)r$ to $M(\bar{r})r$, where r and $\bar{r}$ are the current and orbit-avera
oximately accounts for orbital eccentricities of particles and reprodu
'e present analytical fitting functions that accurately describe the tran
odified model and can be used for interpretation of observations.

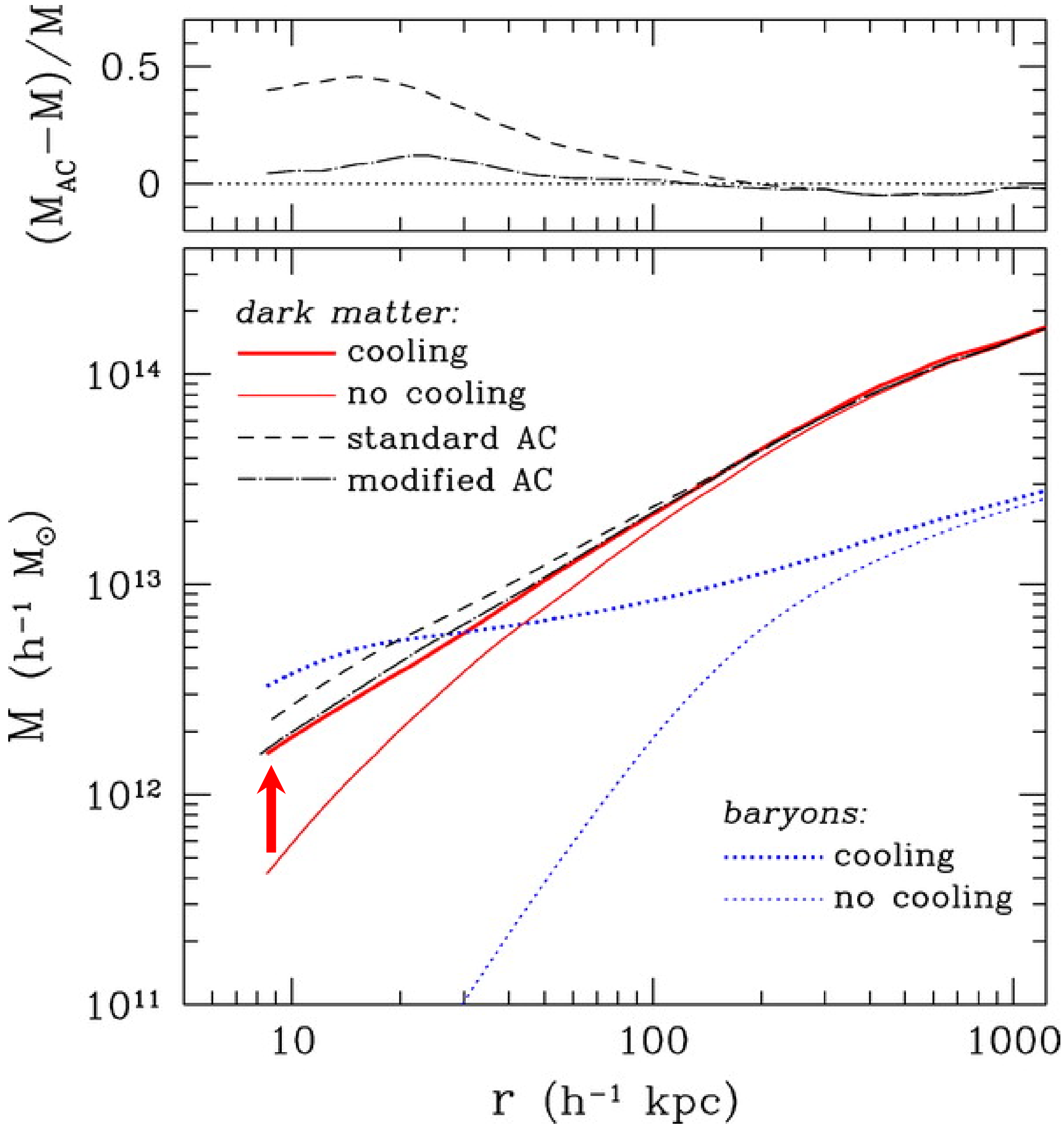
iology: theory — dark matter — galaxies: formation — galaxies:
iods: numerical





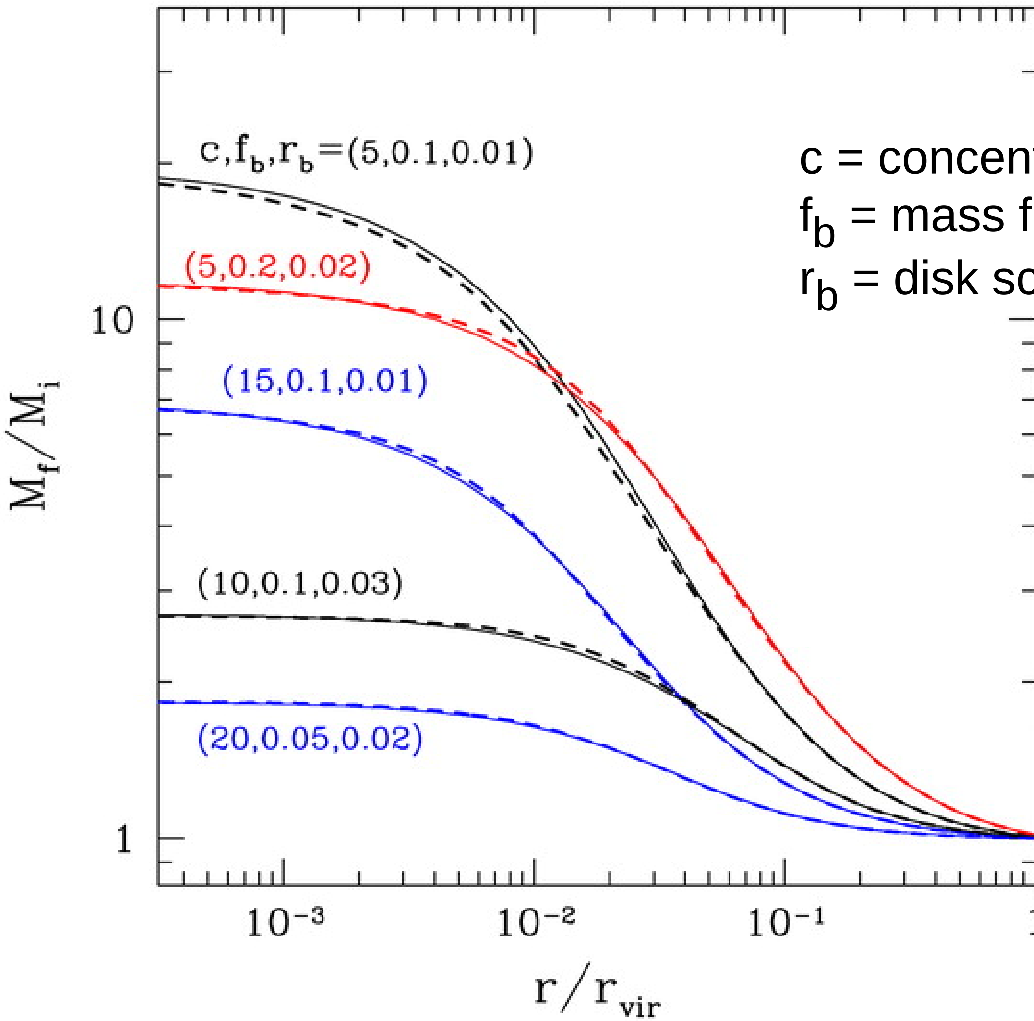
Gasdynamics cosmological simulations of 8 galaxy clusters at z=0 and one galaxy at z=4 with *adaptive mesh refinement* code ART

Compare runs *with* and *without* gas cooling, for the same initial conditions (OG, Kravtsov, Klypin & Nagai 2004, ApJ 616, 16)



$(M_{AC}-M)/M$
0.5
0
dark matter:
cooling
no cooling
standard AC
modified AC
baryons:
cooling
no cooling
$M\ (h^{-1}\ M_\odot)$
10^{14}
10^{13}
10^{12}
10^{11}
10
100
1000
$r\ (h^{-1}\ kpc)$

Increase of the dark matter mass in the modified model



c = concentration of NFW halo

f_b = mass fraction of exp. disk

r_b = disk scale length / r_{vir}