Title: Formation of CDM halos and mircohalos

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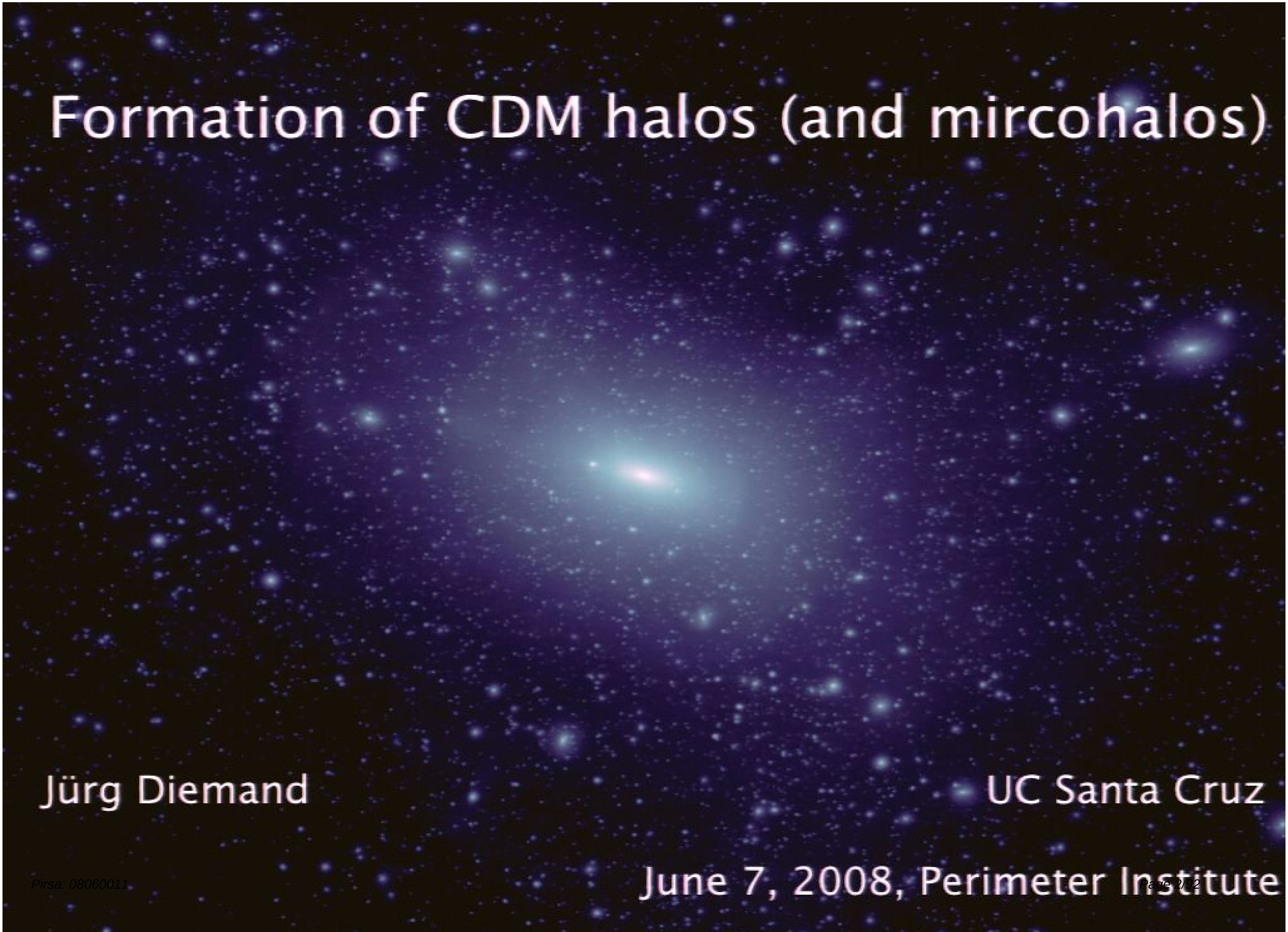
URL: http://pirsa.org/08060011

Abstract:

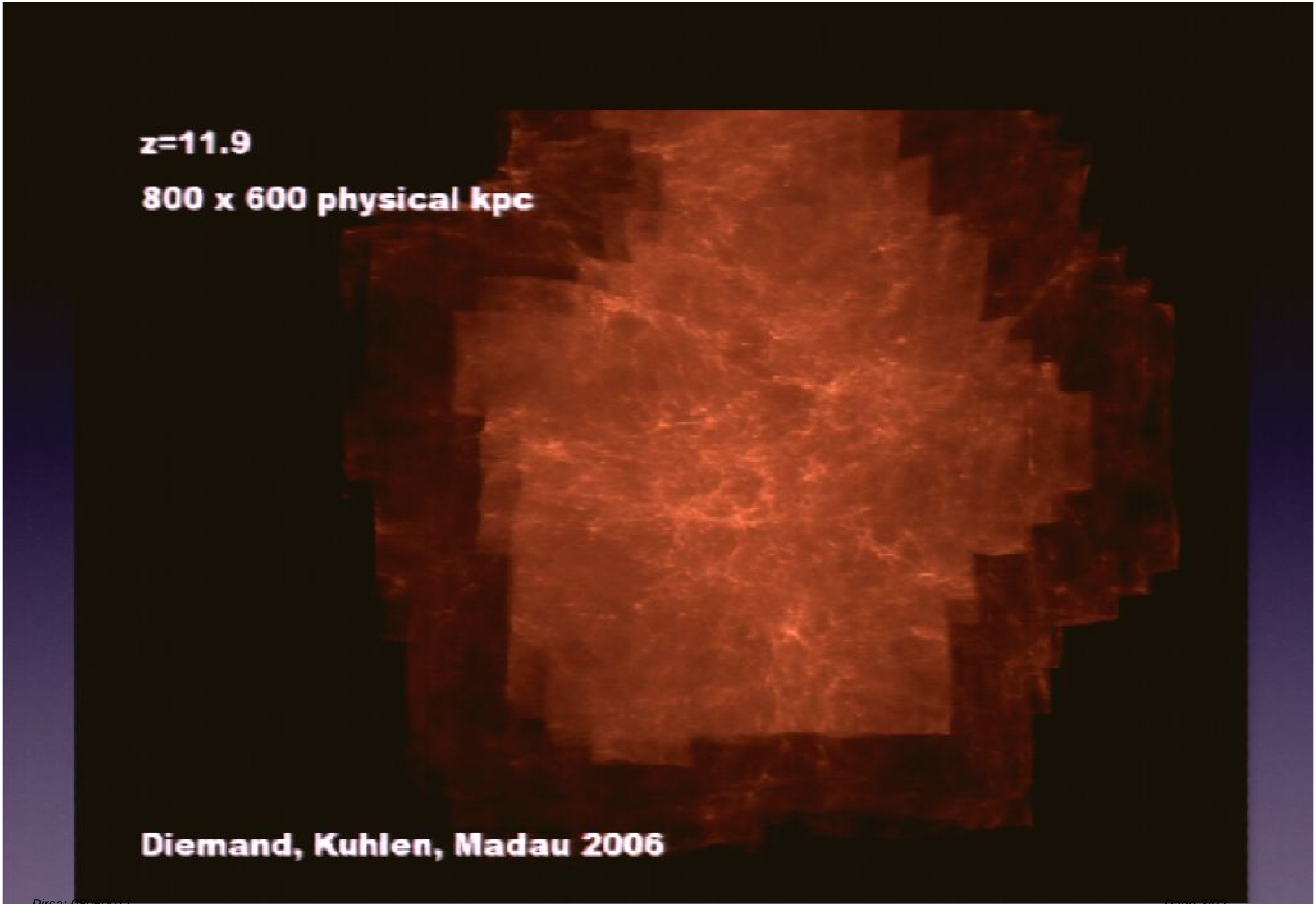


Formation of CDM halos (and mircohalos)

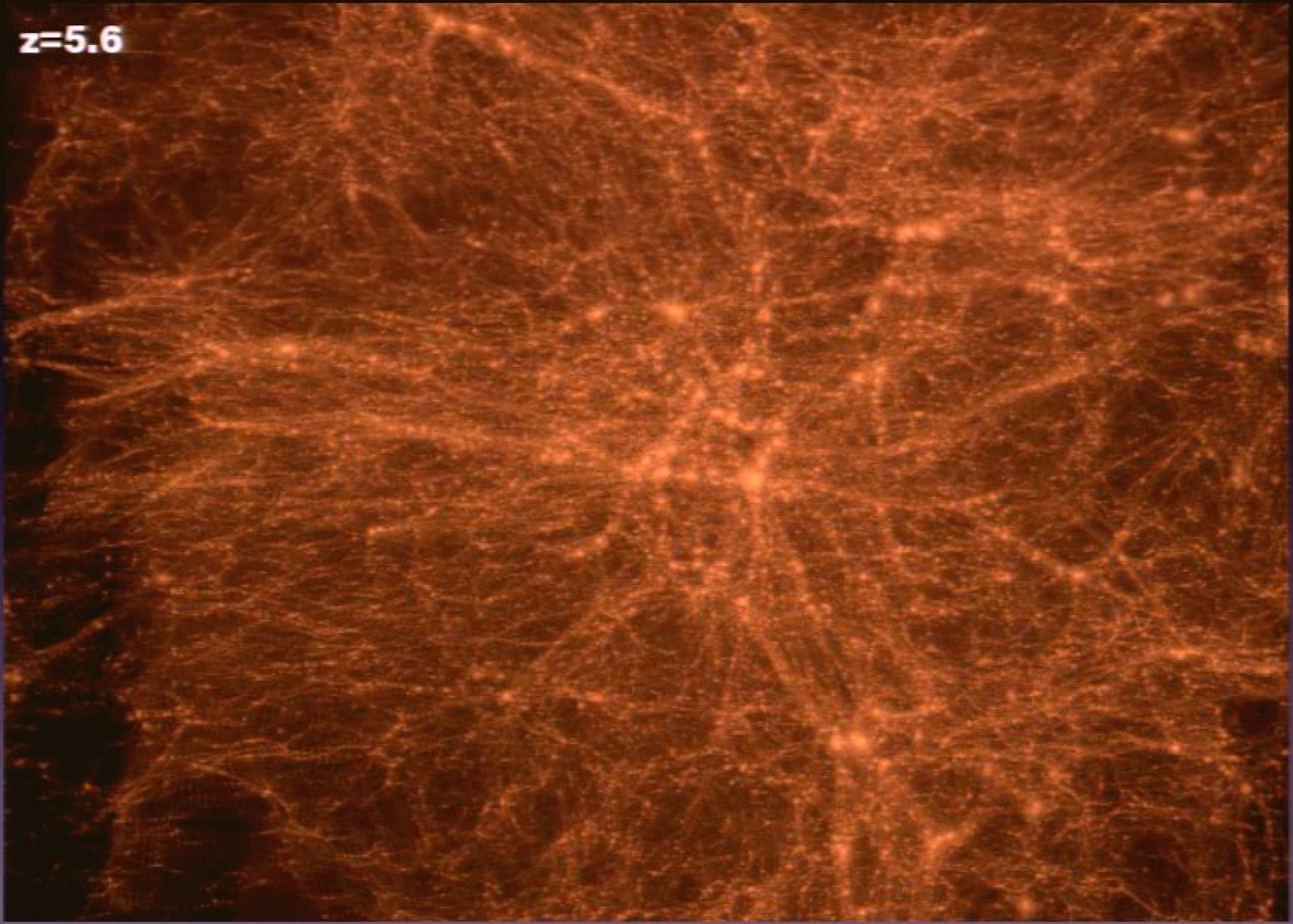
Jürg Diemand

UC Santa Cruz

June 7, 2008, Perimeter Institute



Diemand, Kuhlen, Madau 2006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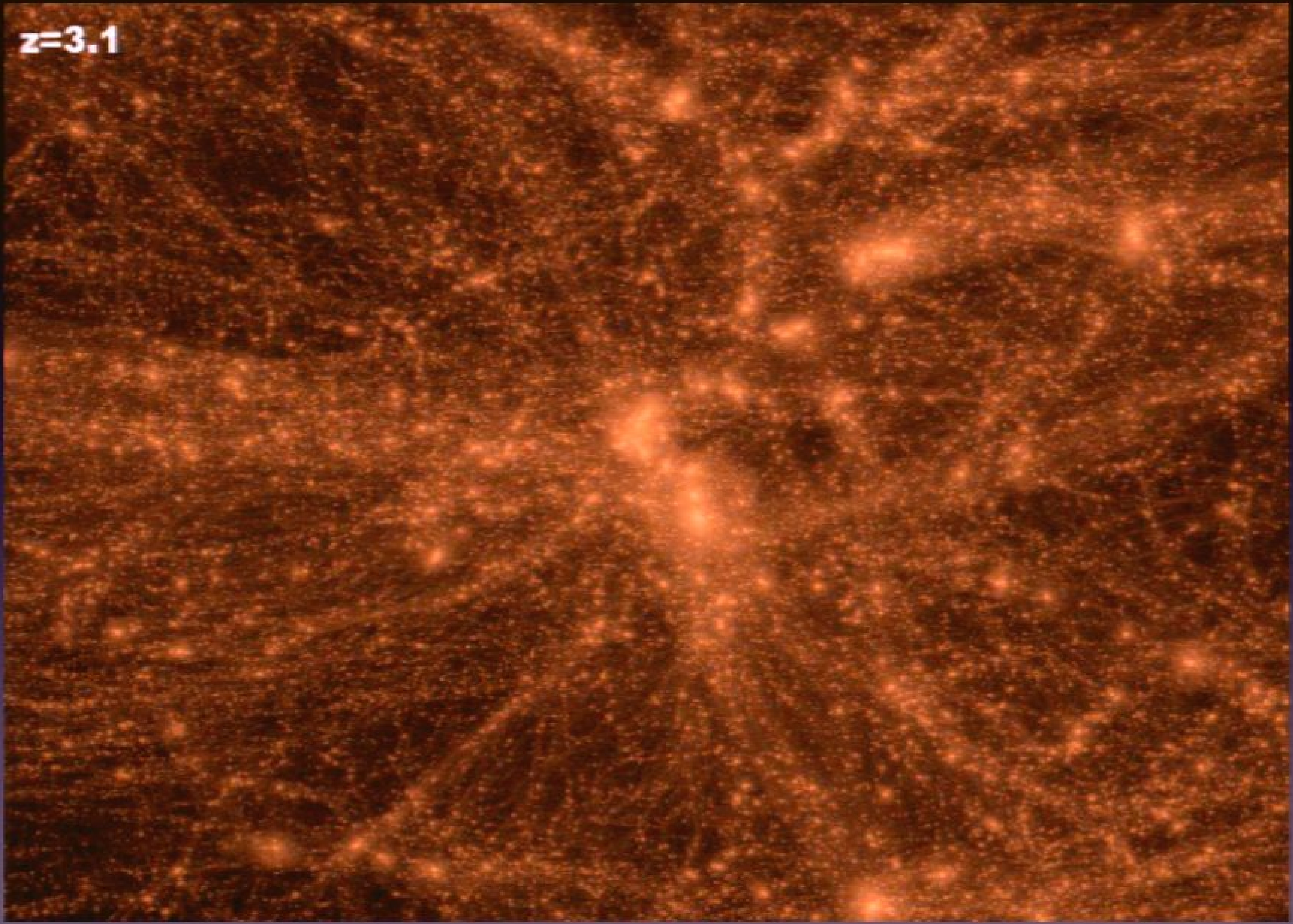
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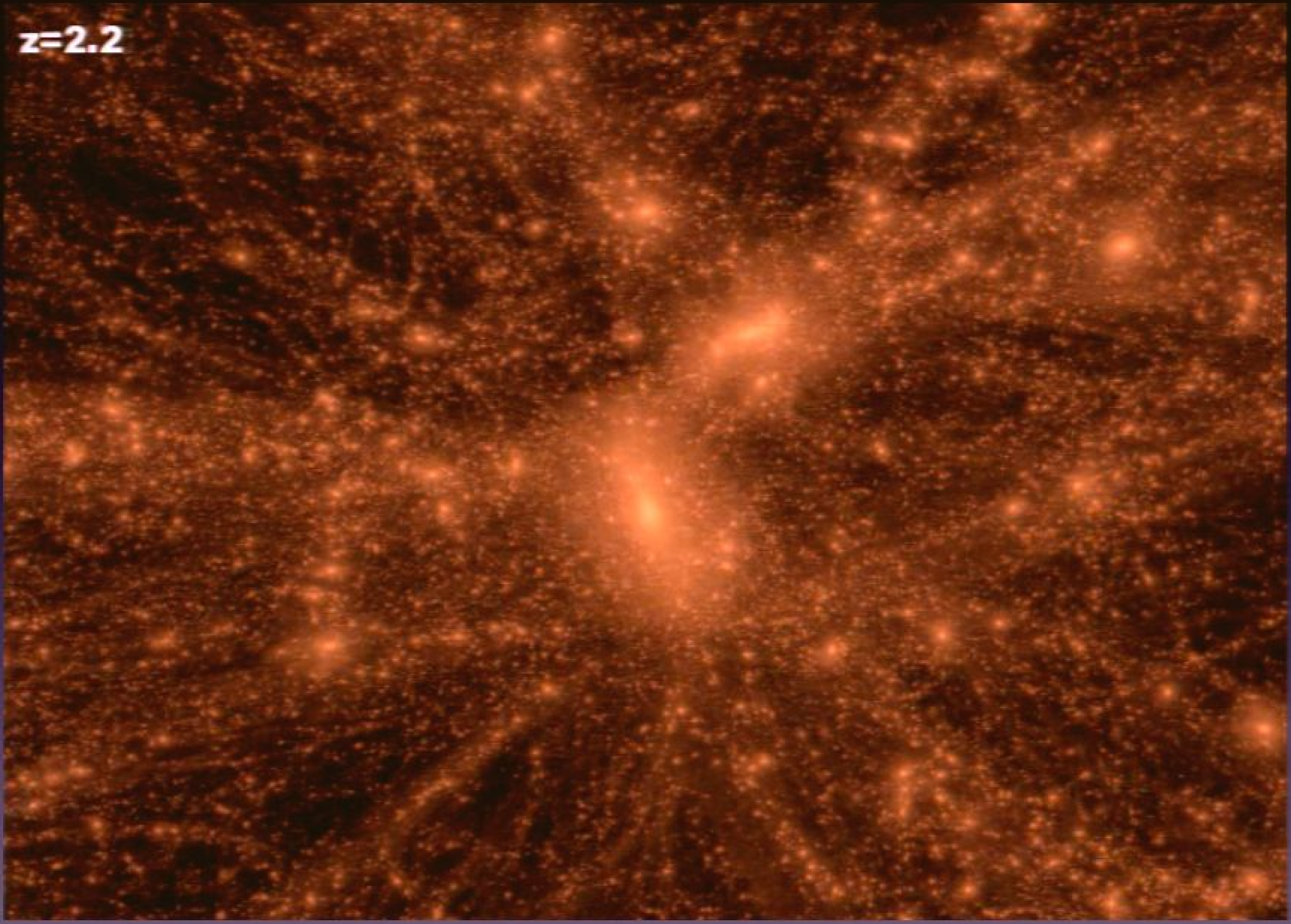
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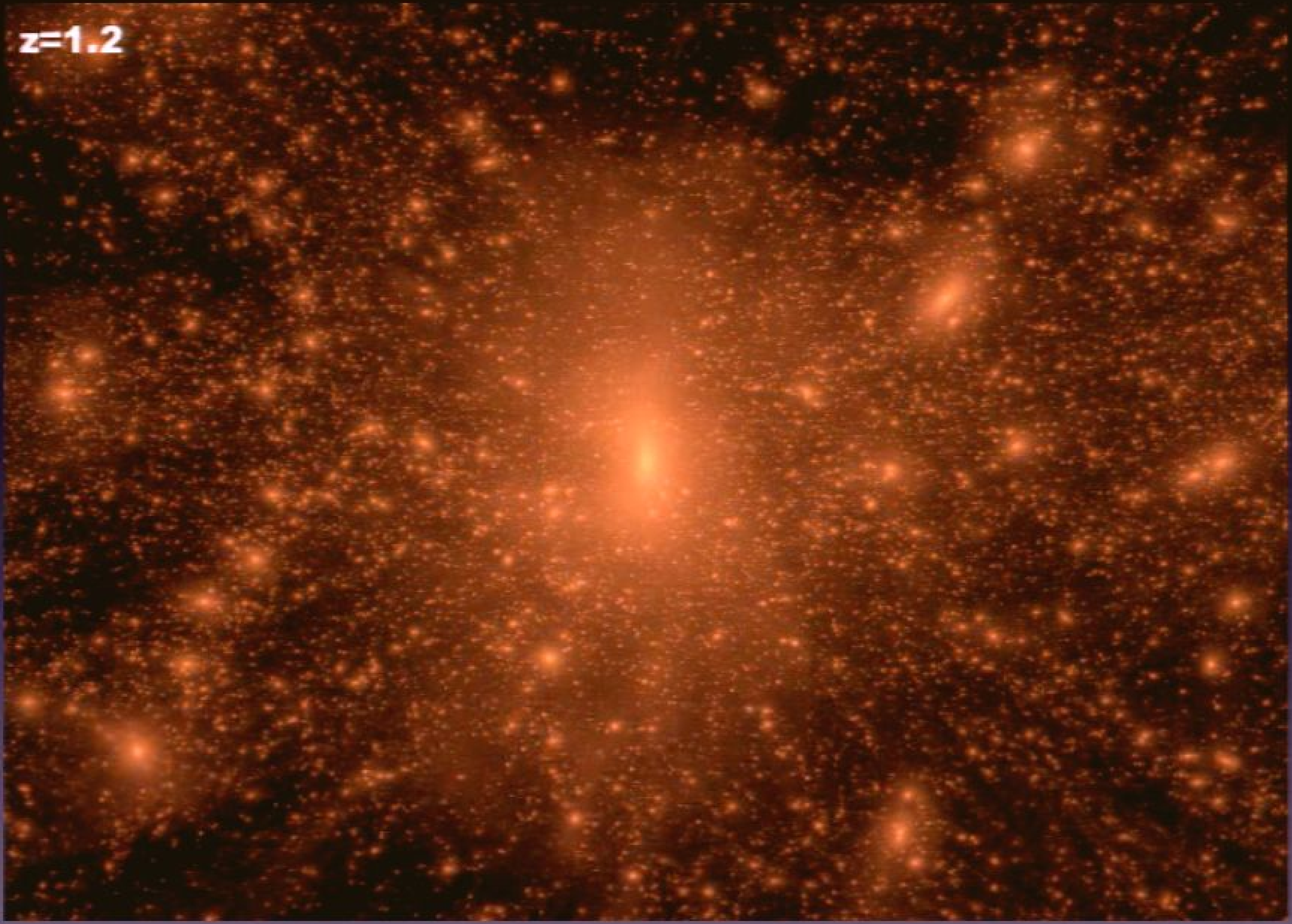
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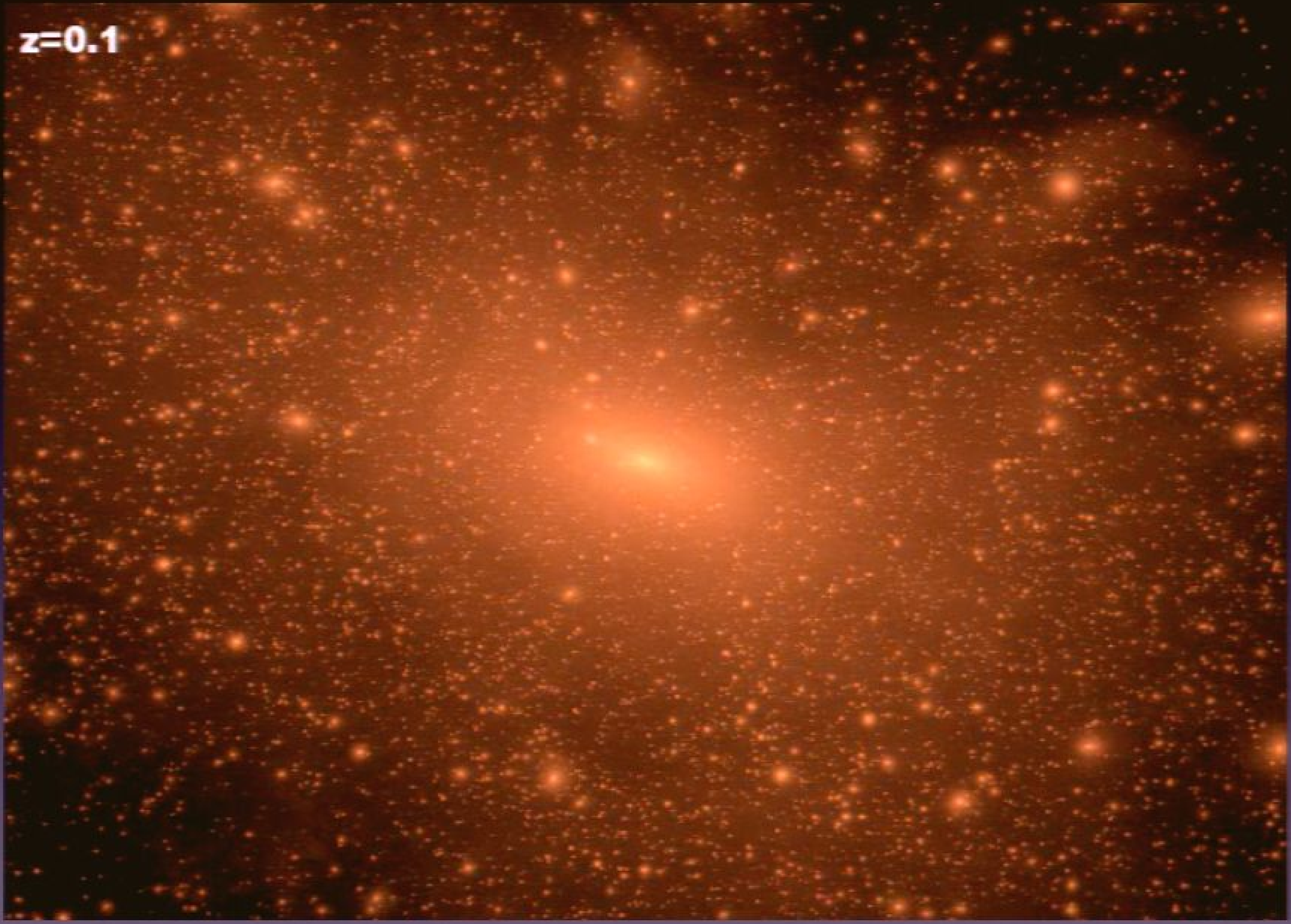
z=0.5


z=0.4


z=0.3


z=0.2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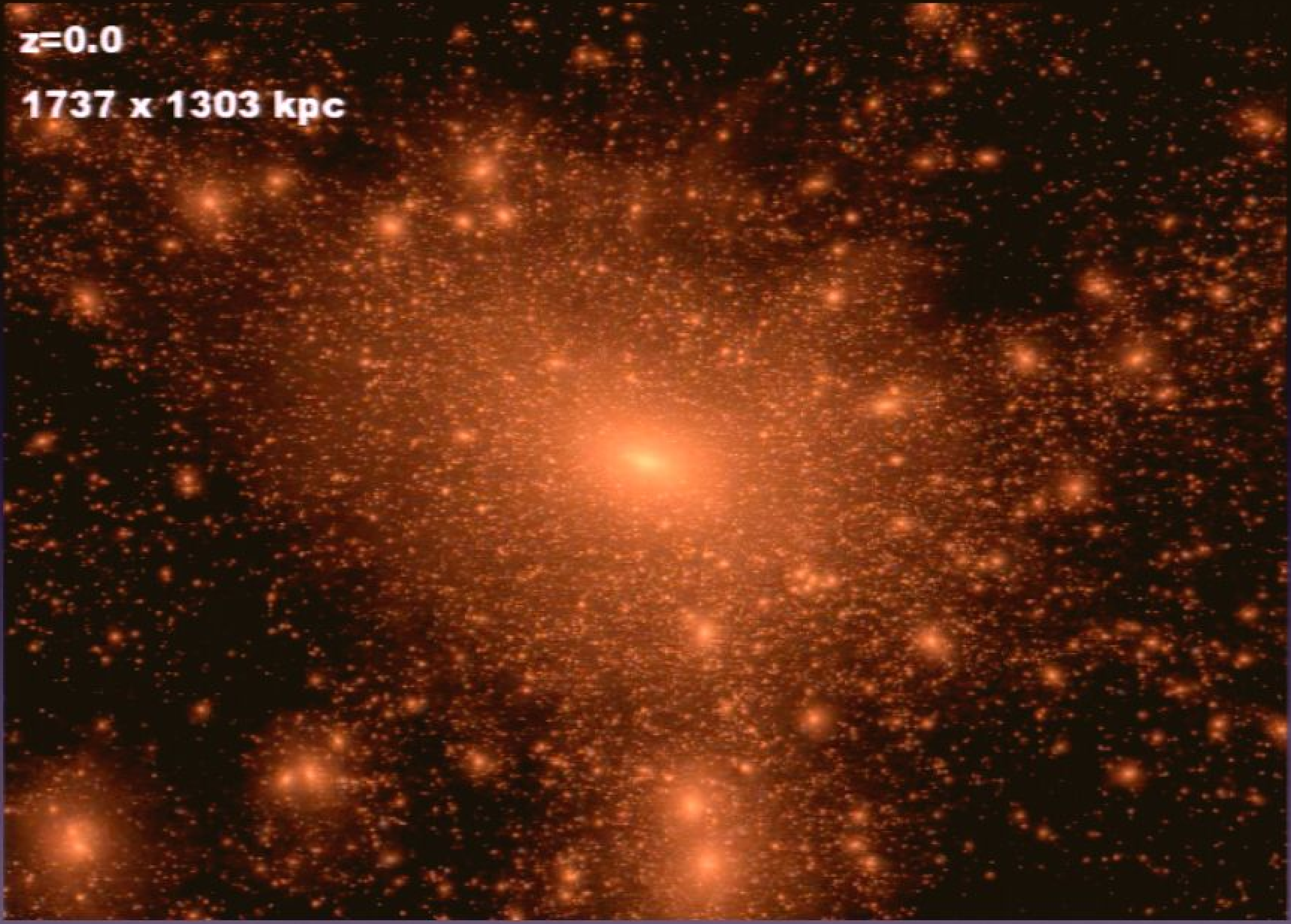
z=0.0
1035 x 776 kpc


z=0.0
3632 x 2724 kpc


z=0.0
3167 x 2375 kpc


z=0.0
2372 x 1779 kpc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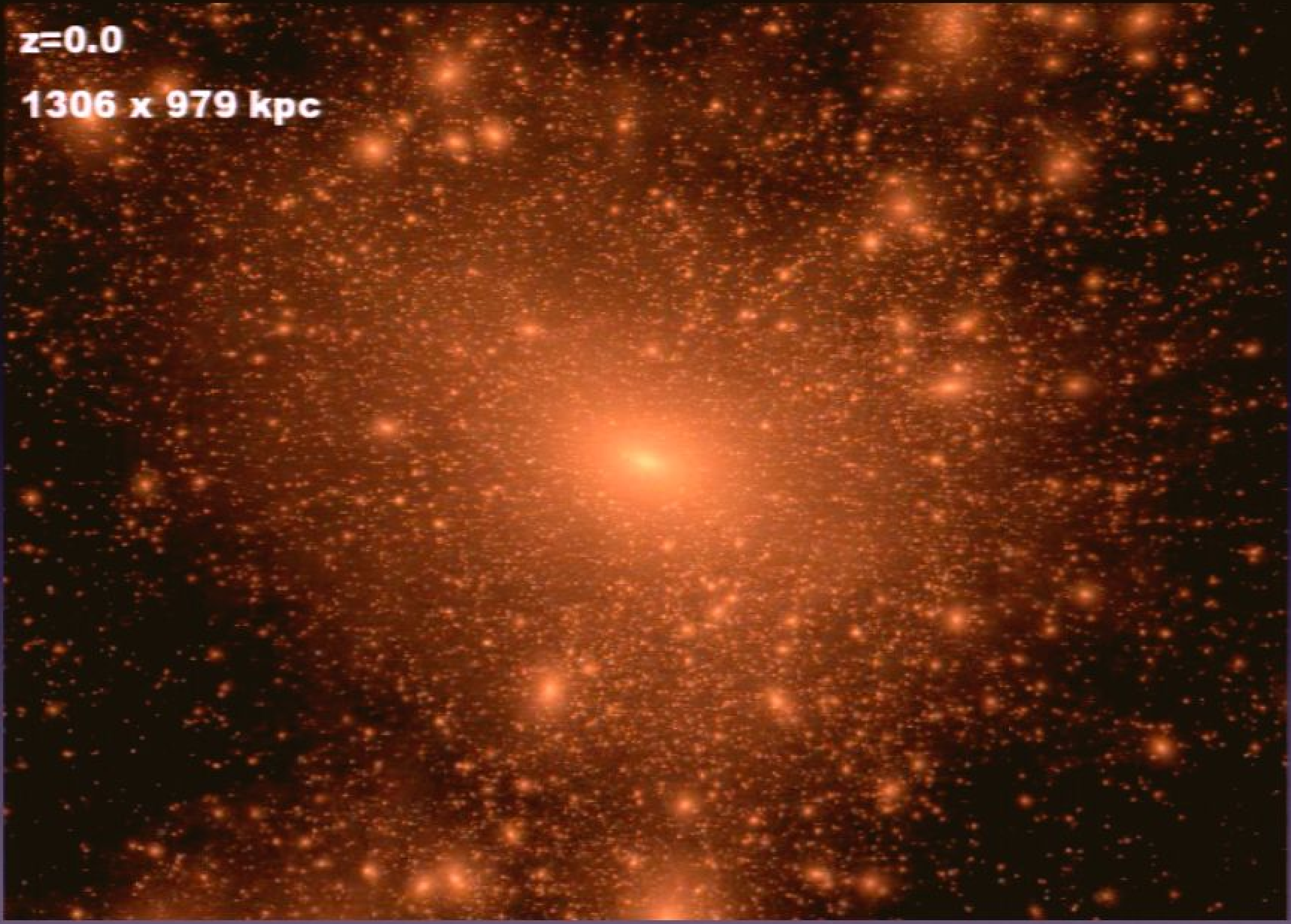
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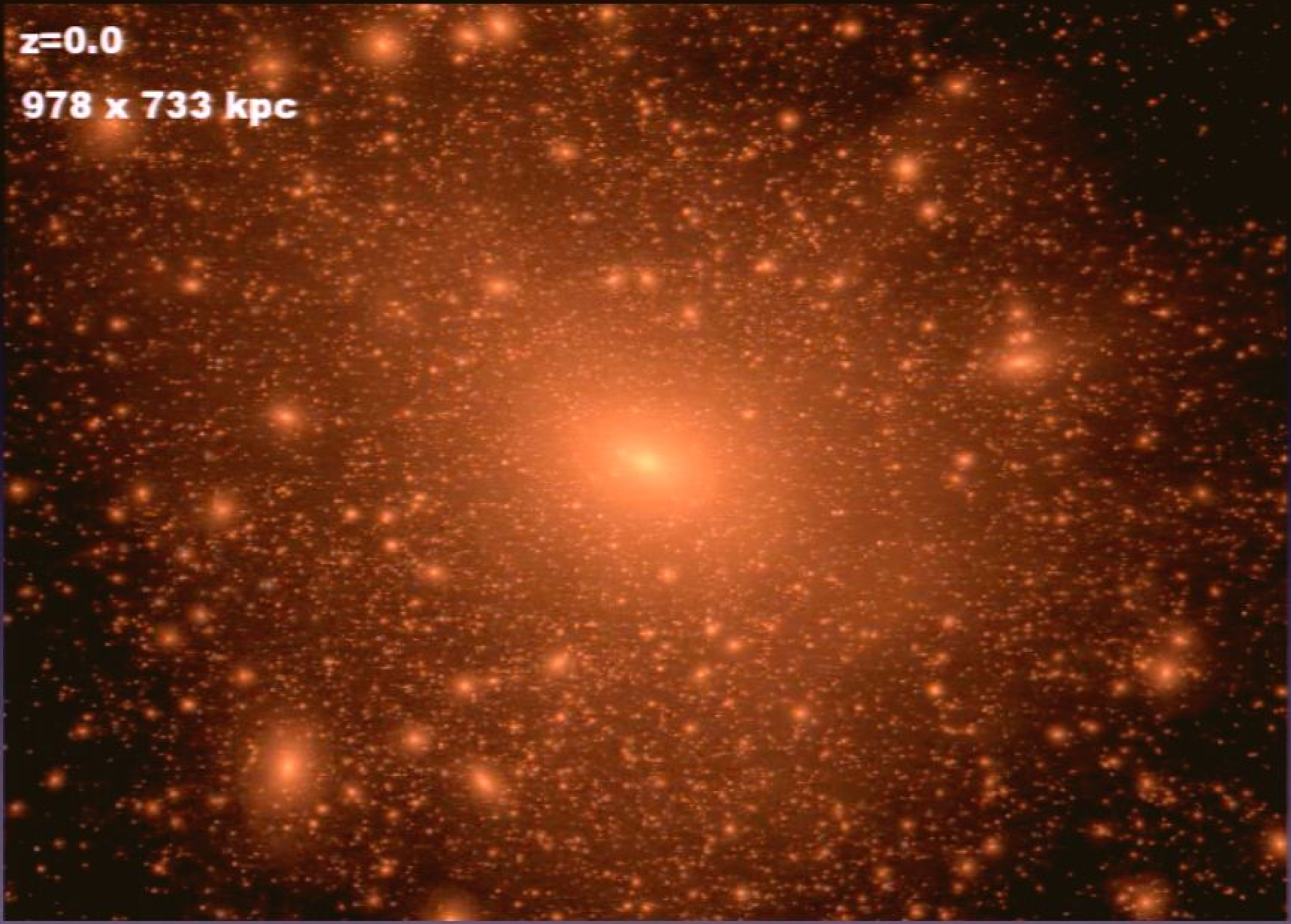
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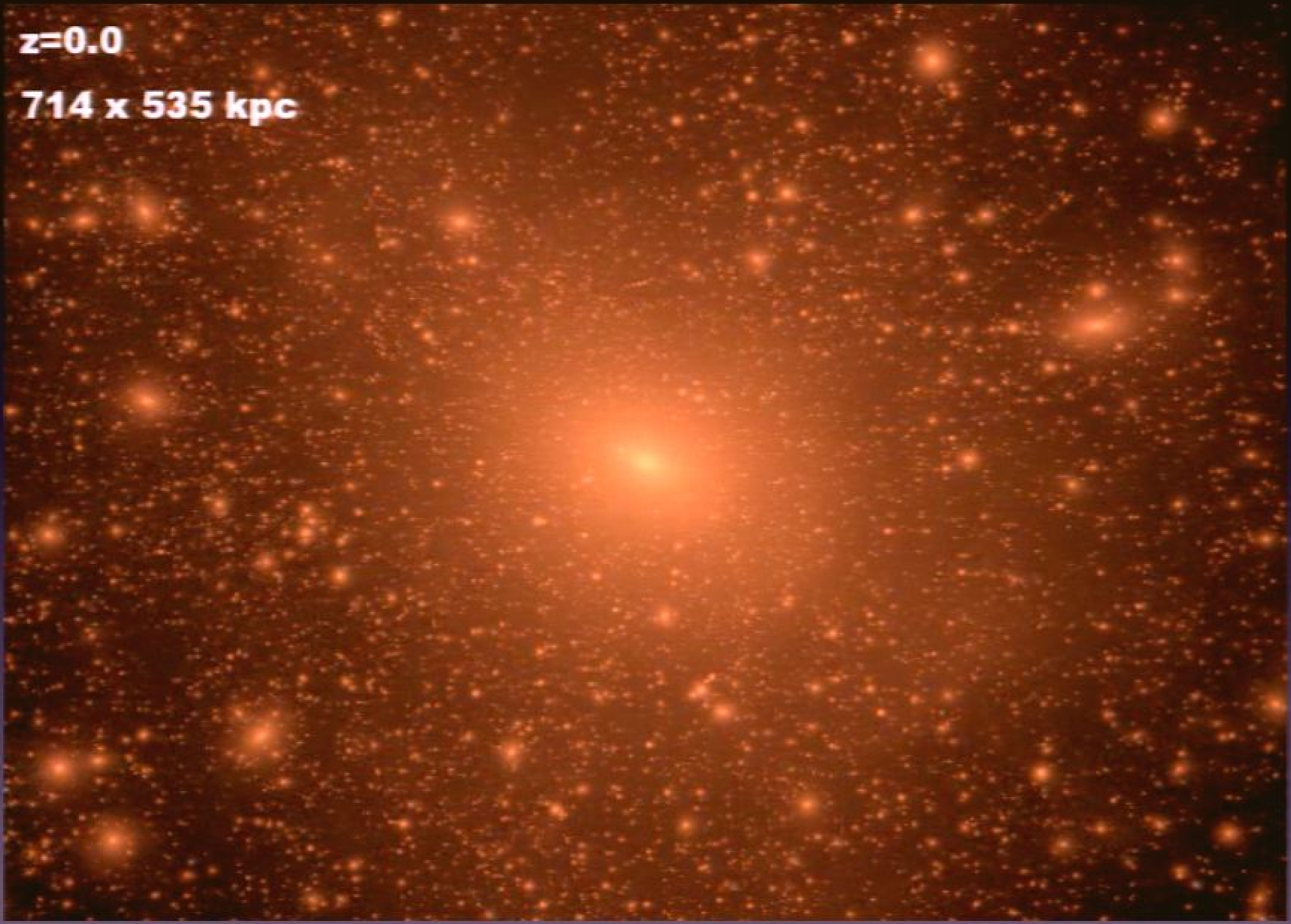
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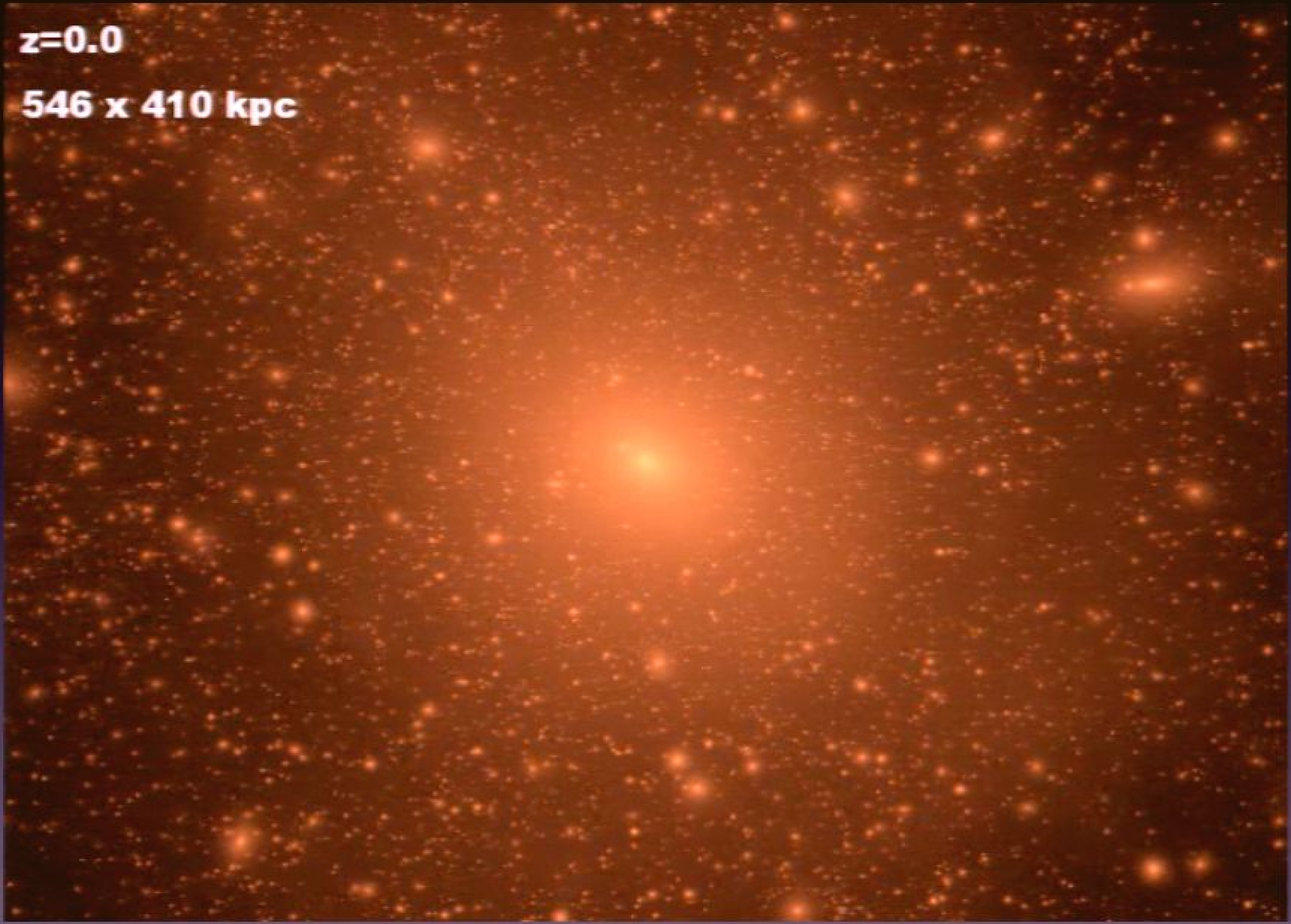
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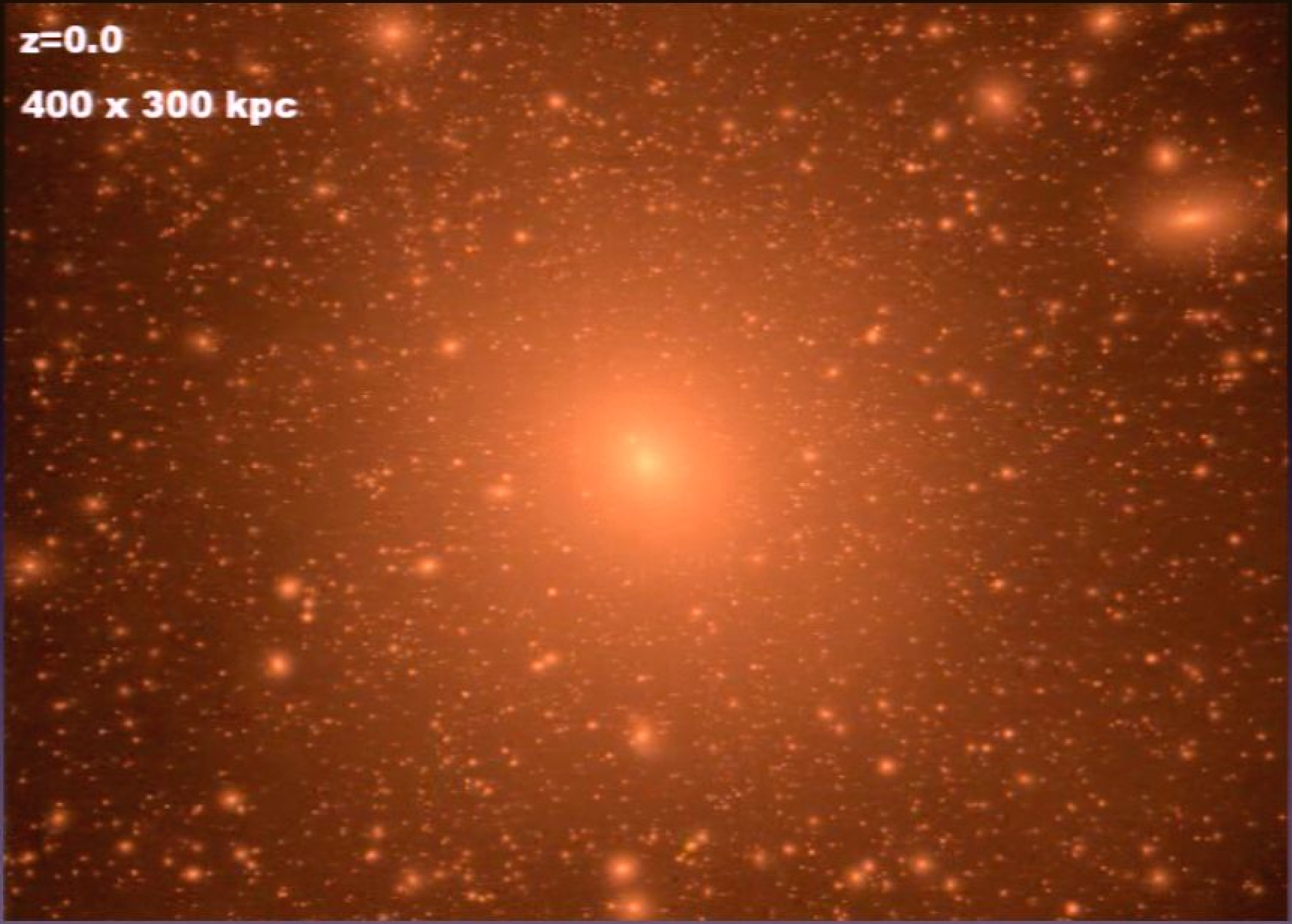
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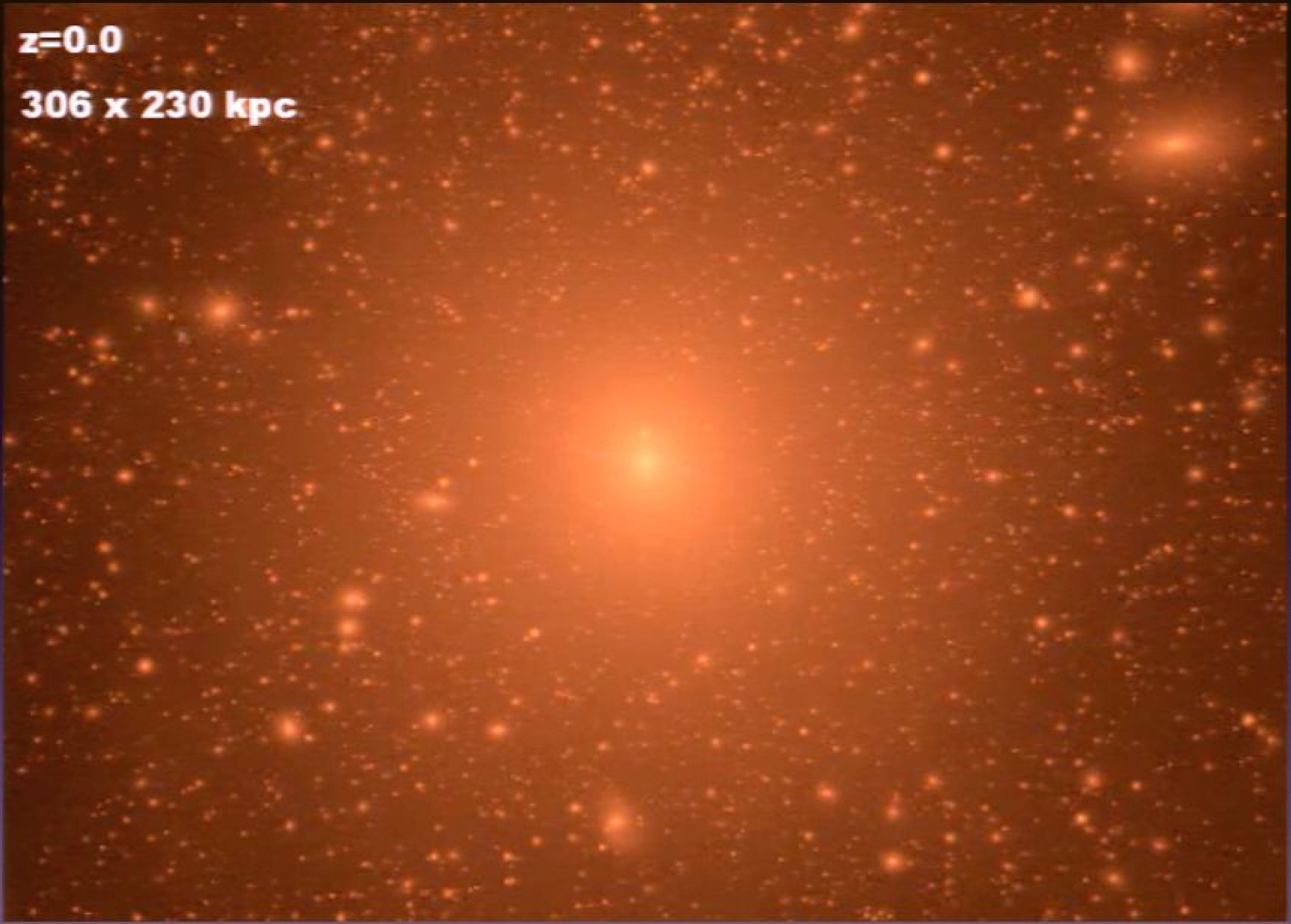
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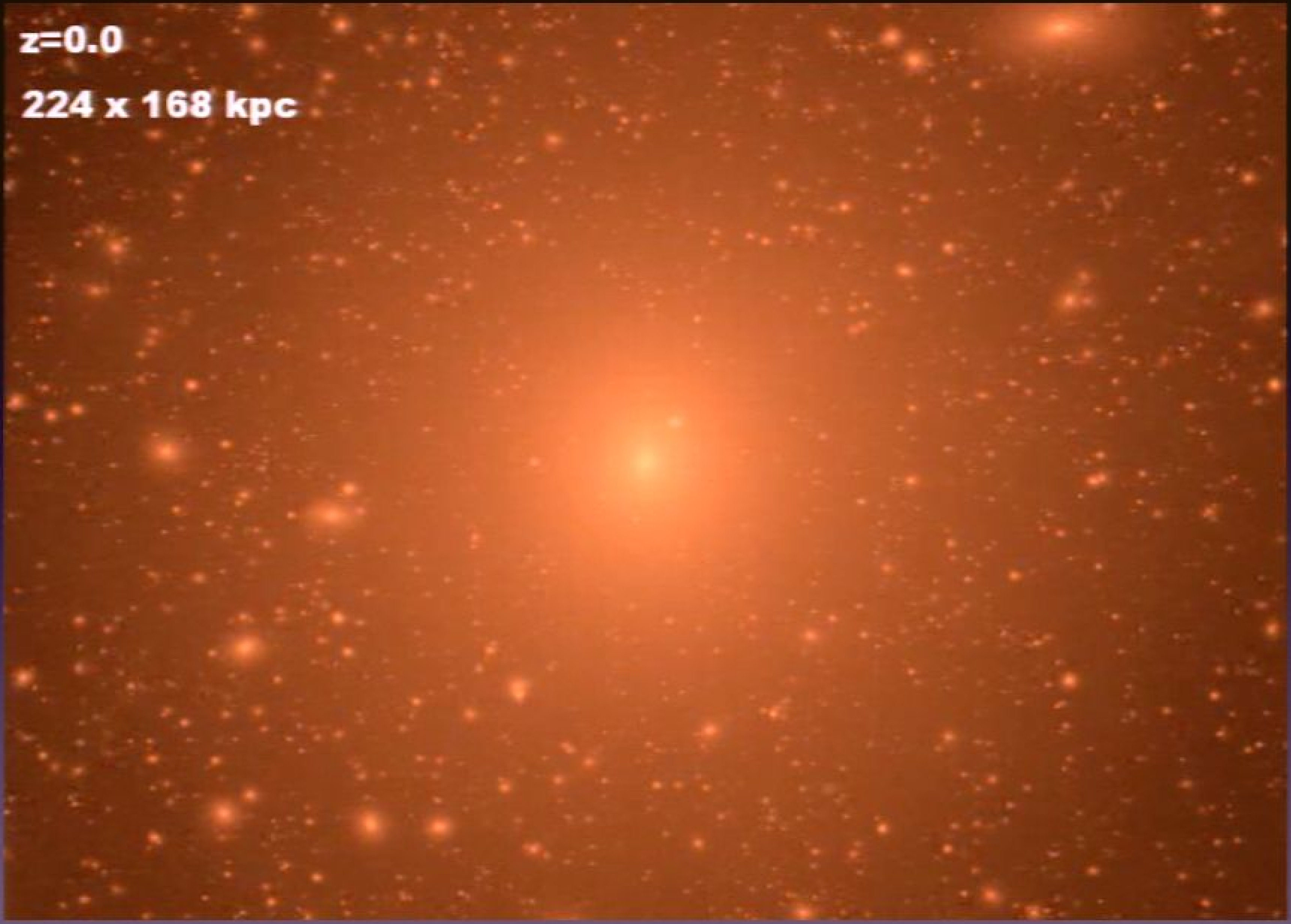
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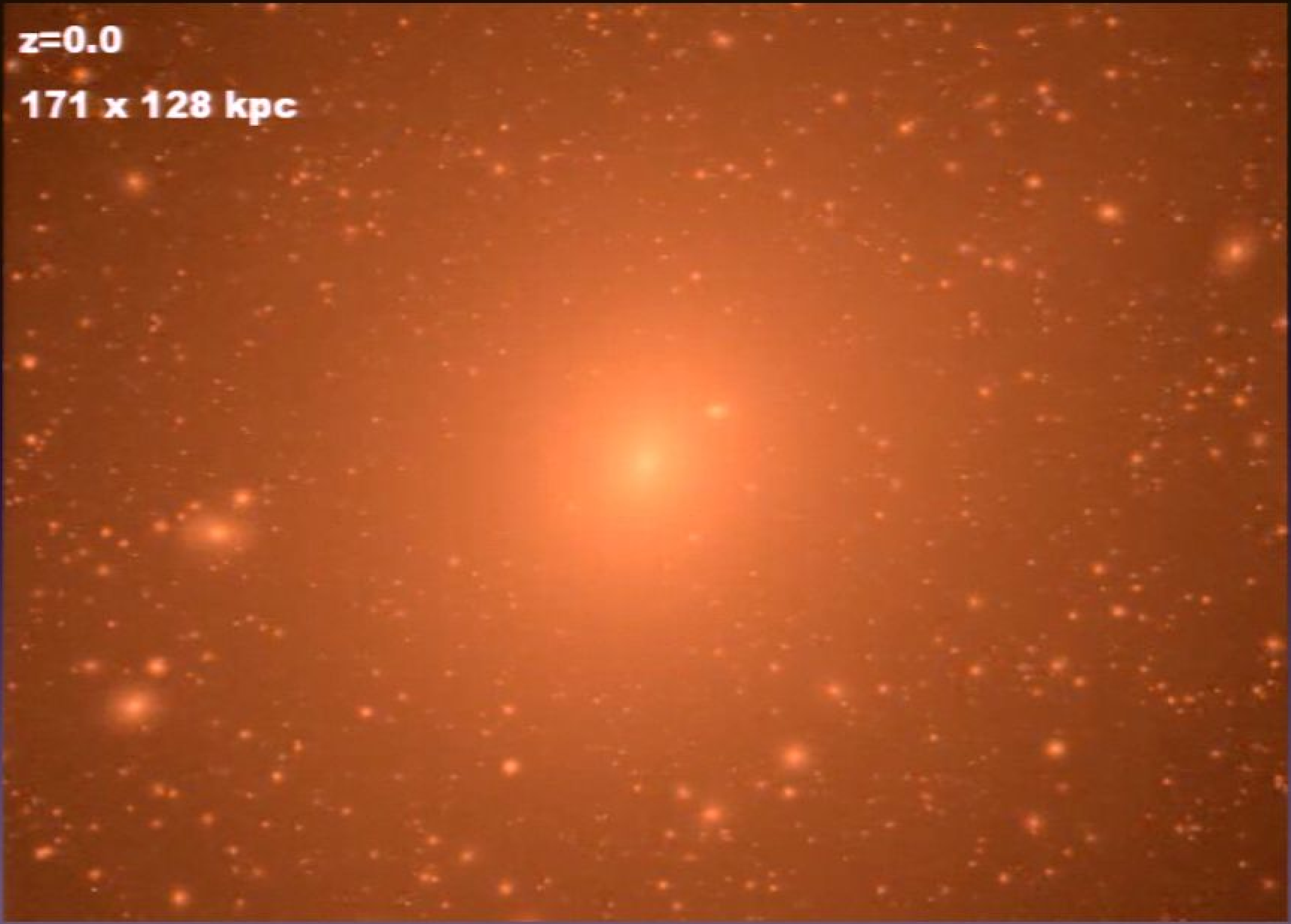
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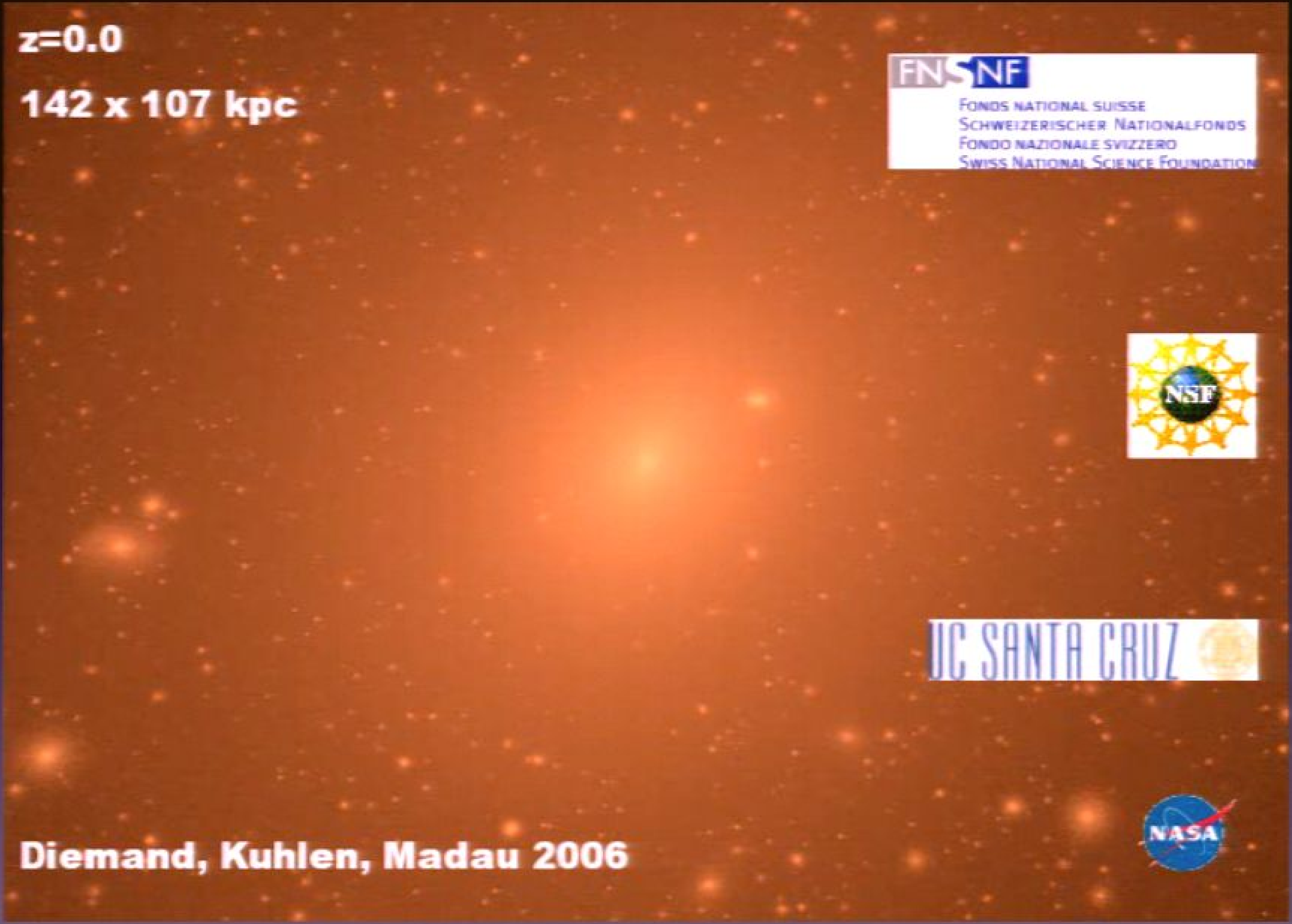
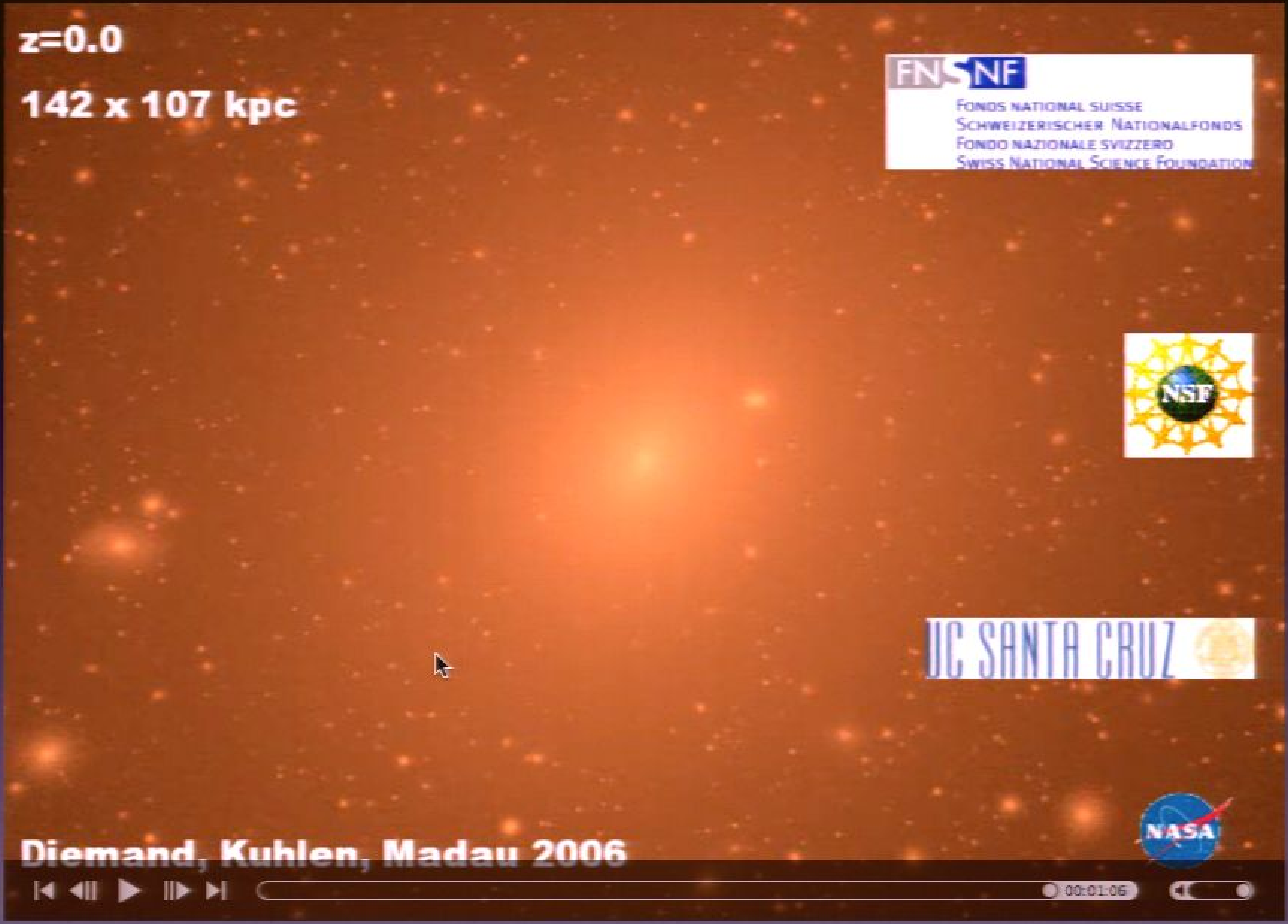

z=0.0
142 x 107 kpc
FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation
NSF
UC SANTA CRUZ
NASA
Diemand, Kuhlen, Madau 2006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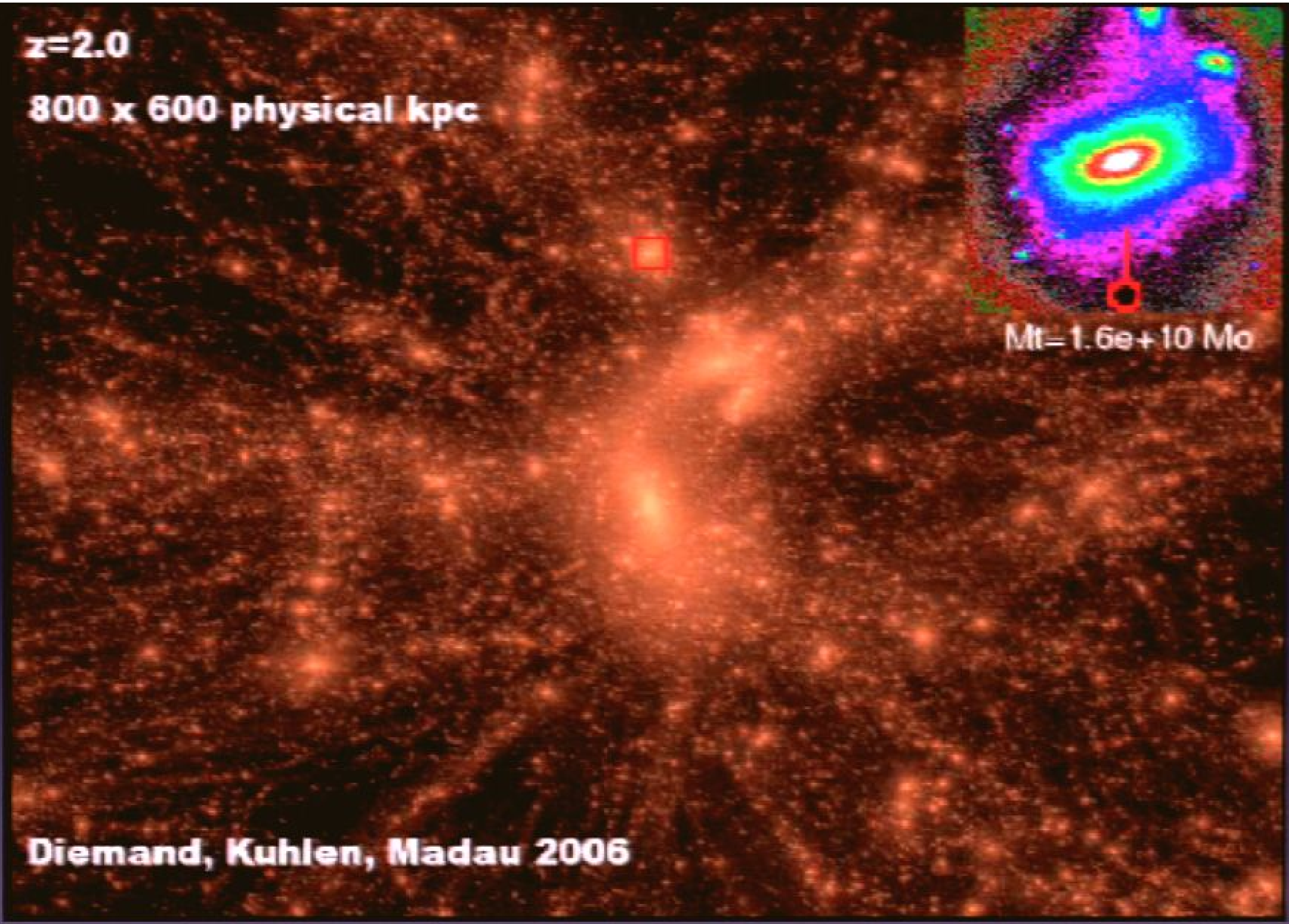
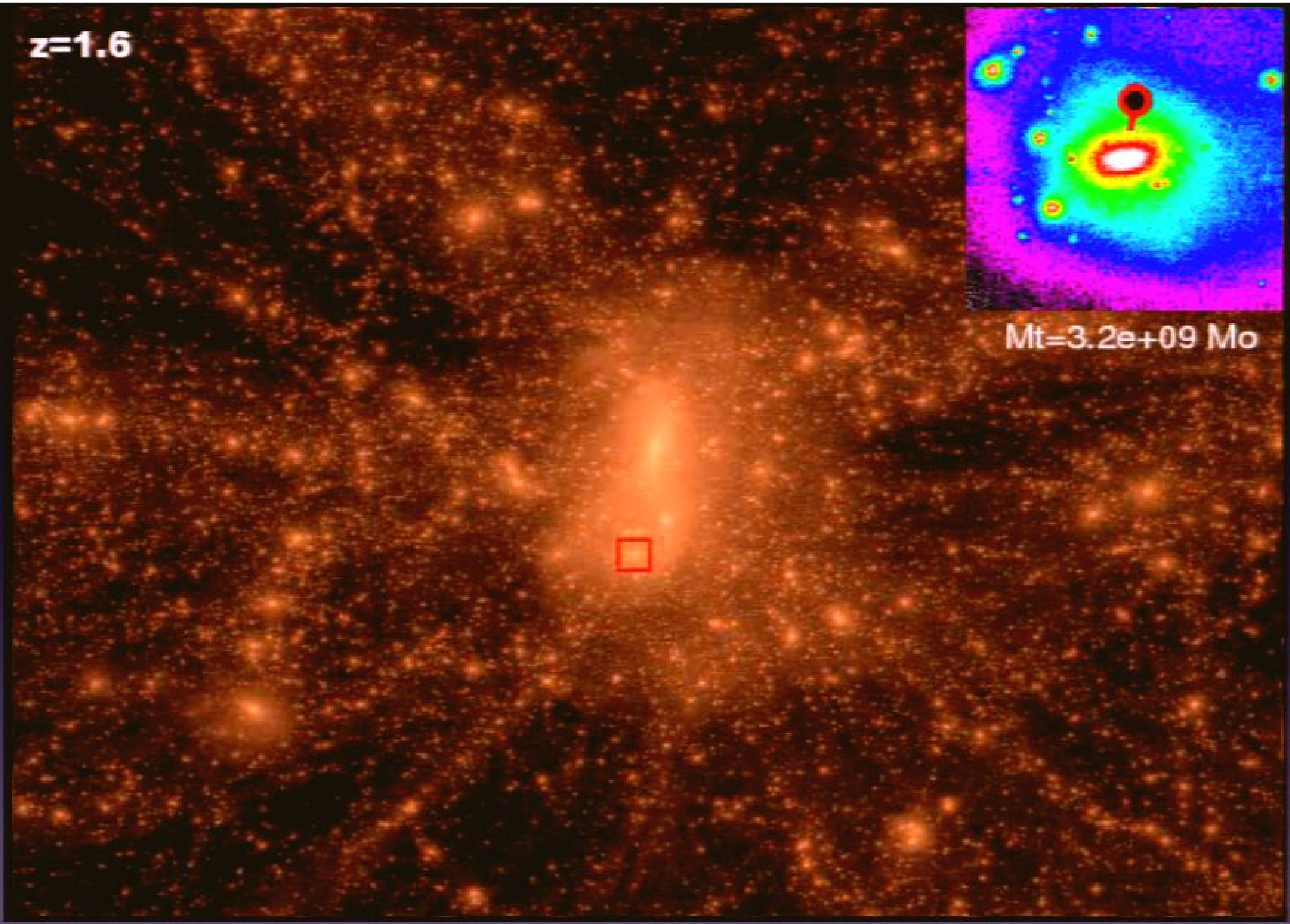
NASA
Diemand, Kuhlen, Madau 2006
00:01:06


z=0.0
3092 x 2319 kpc
00:00:35


z=0.4



survives several close pericenter passages (comes within 5.1 kpc)
becomes rounder with time and major axes tend to point towards the host center
(Kuhlen, JD, Madau 0705.2037, Faltenbacher+0706.0262, Pereira+0707.1702, Knebe+2008)



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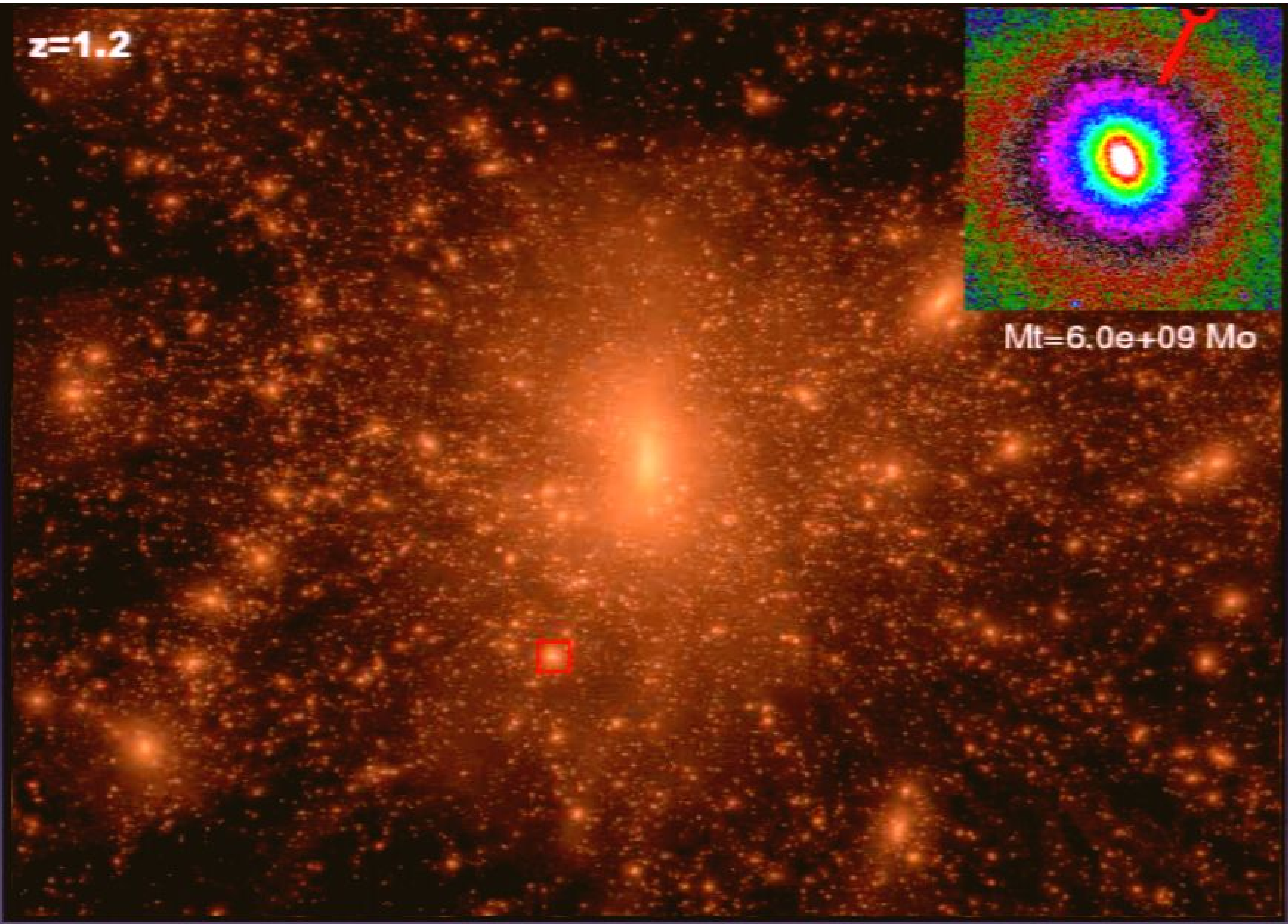

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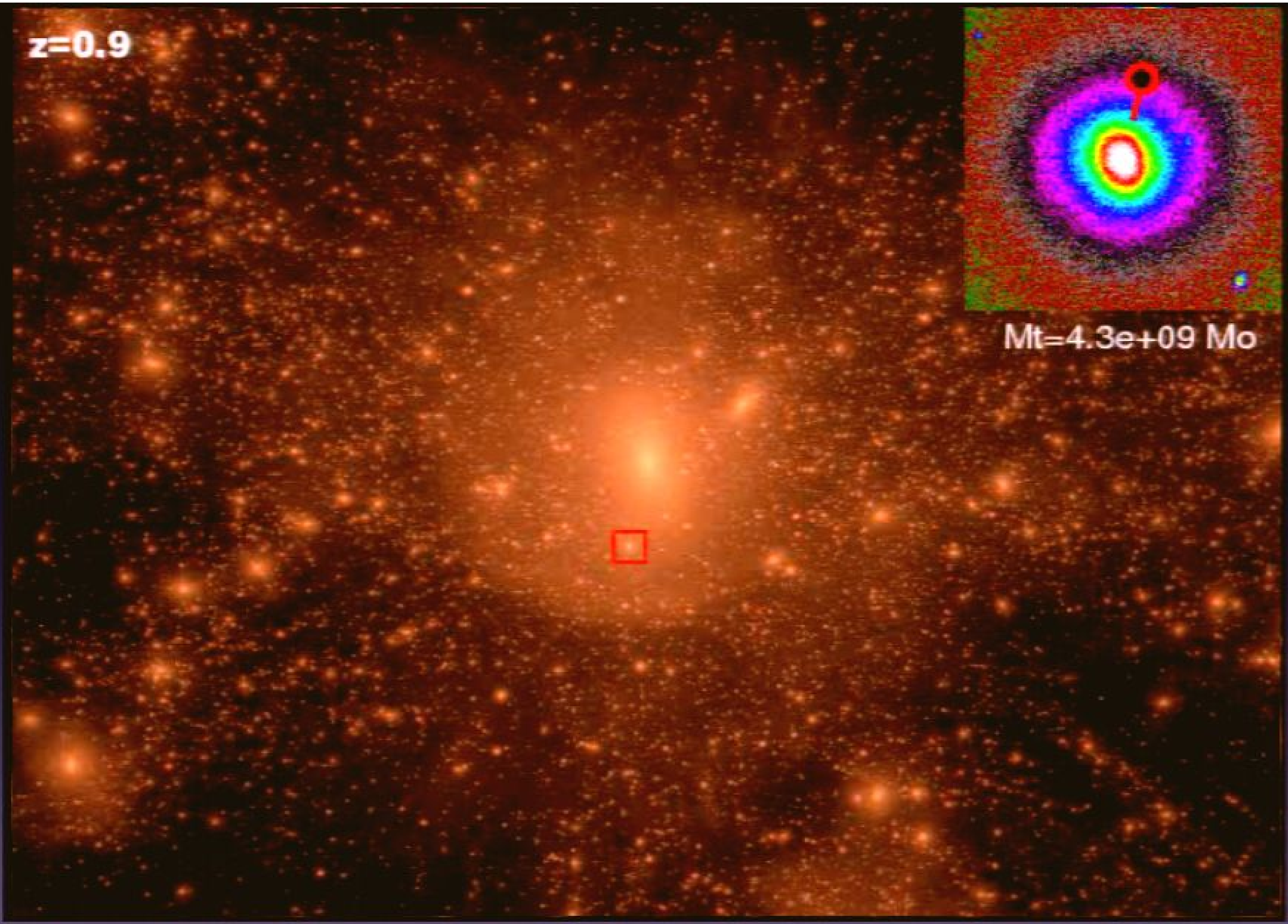

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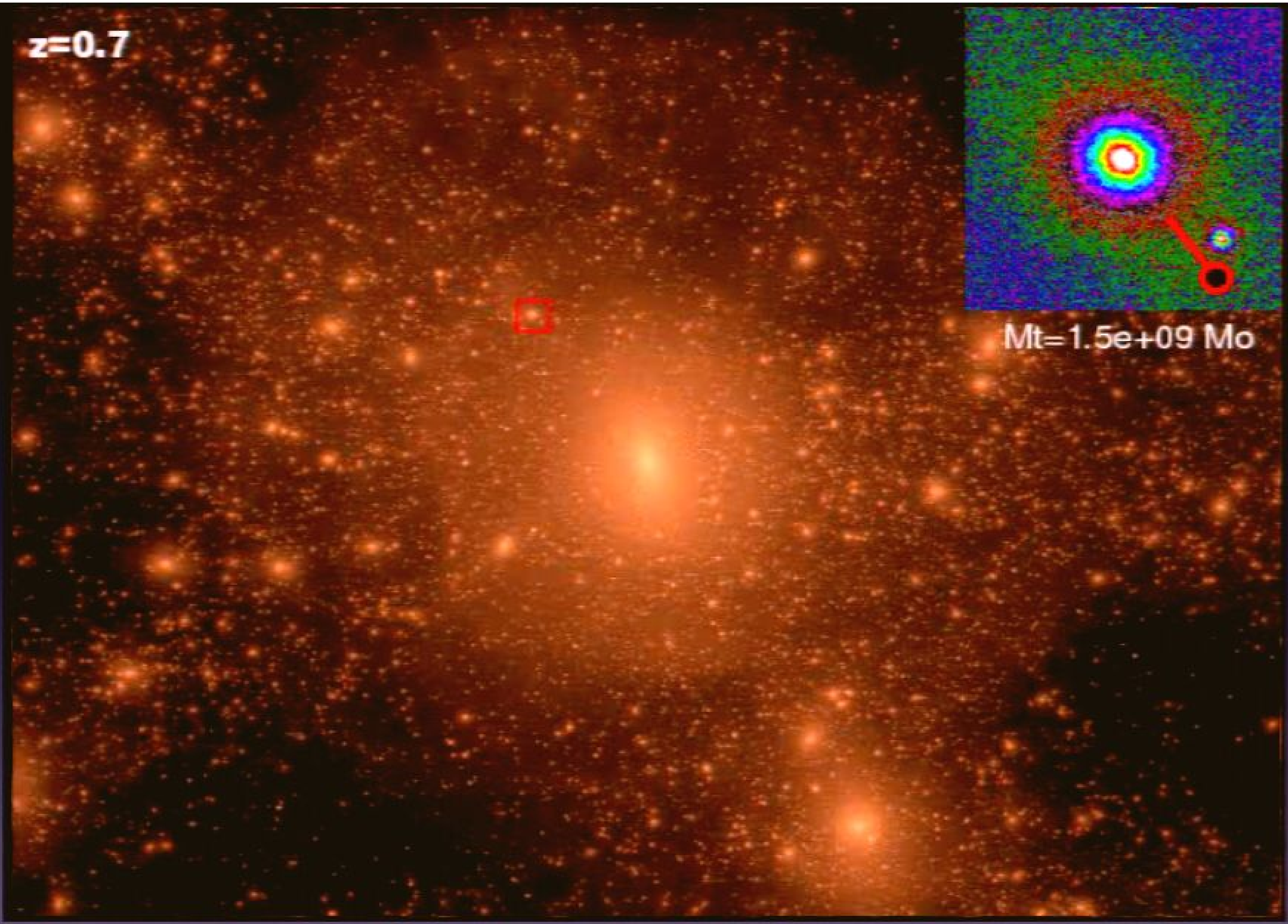

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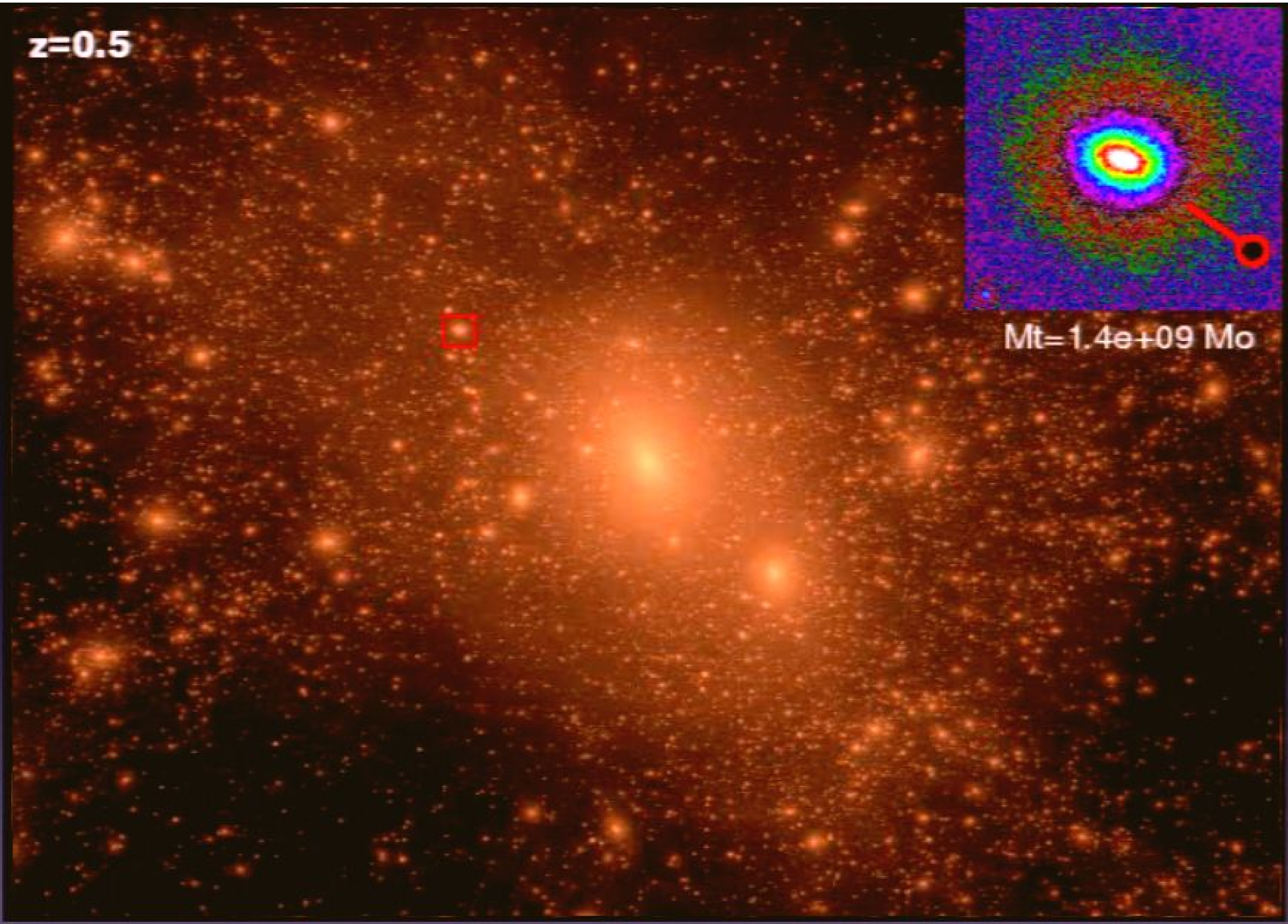

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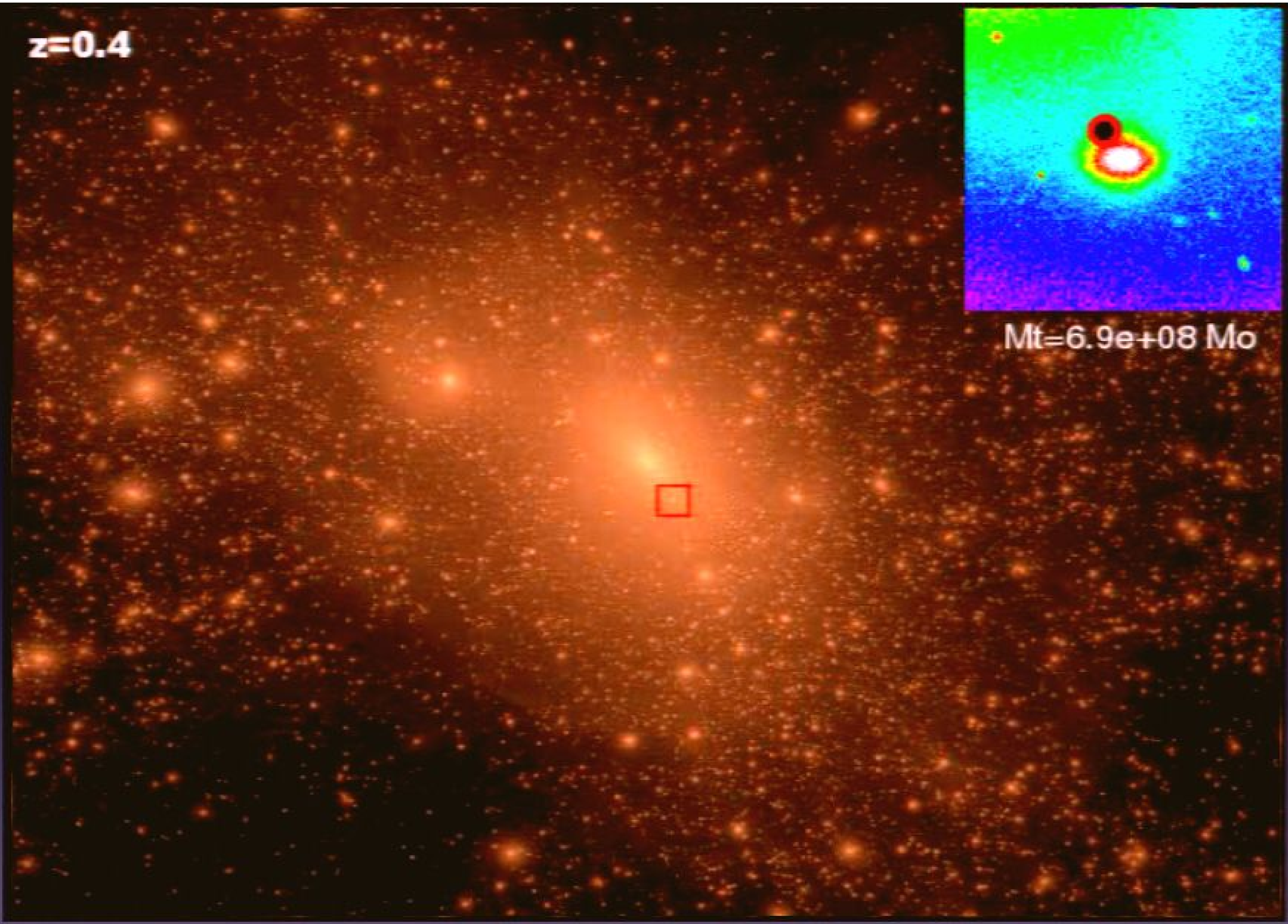

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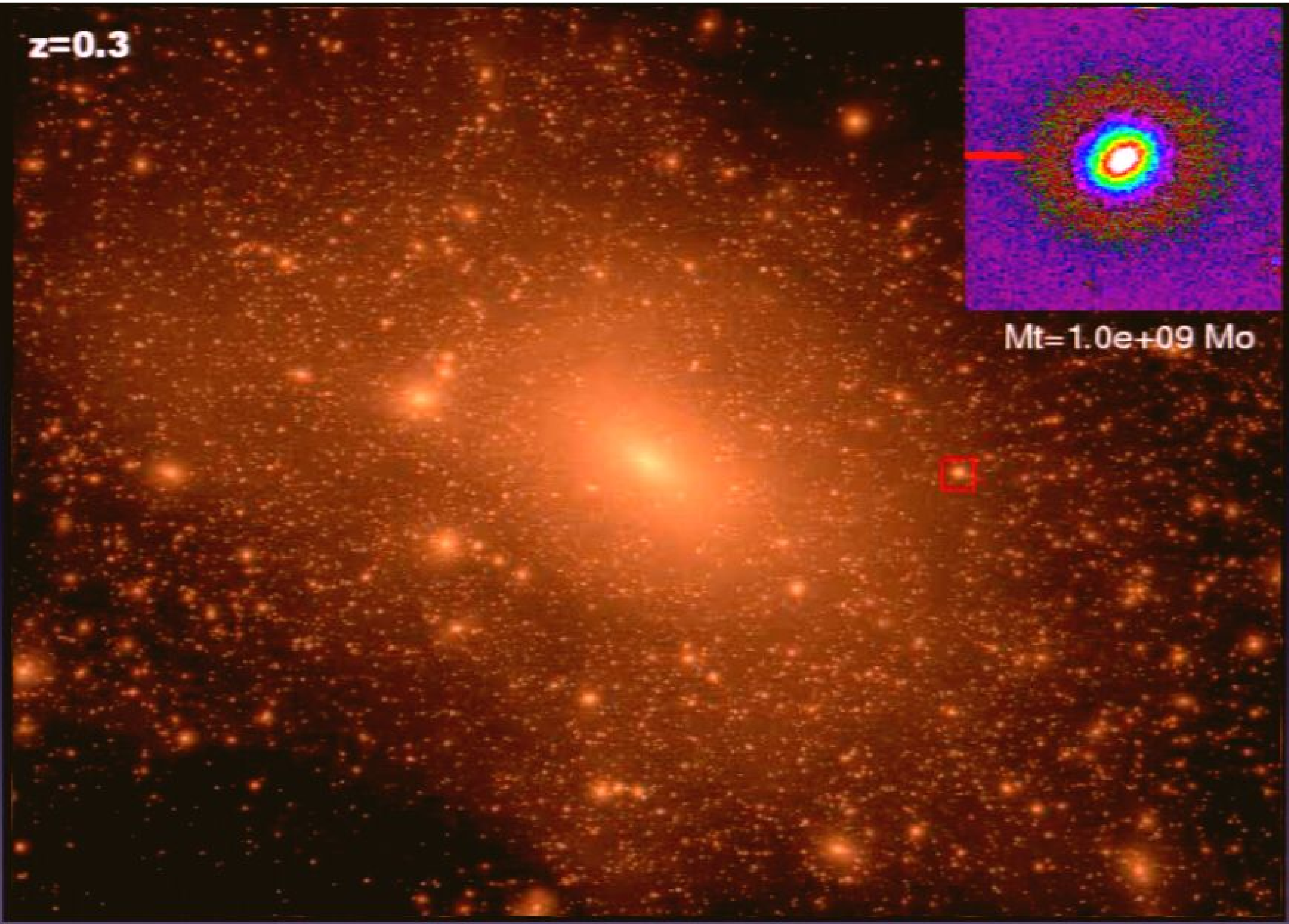

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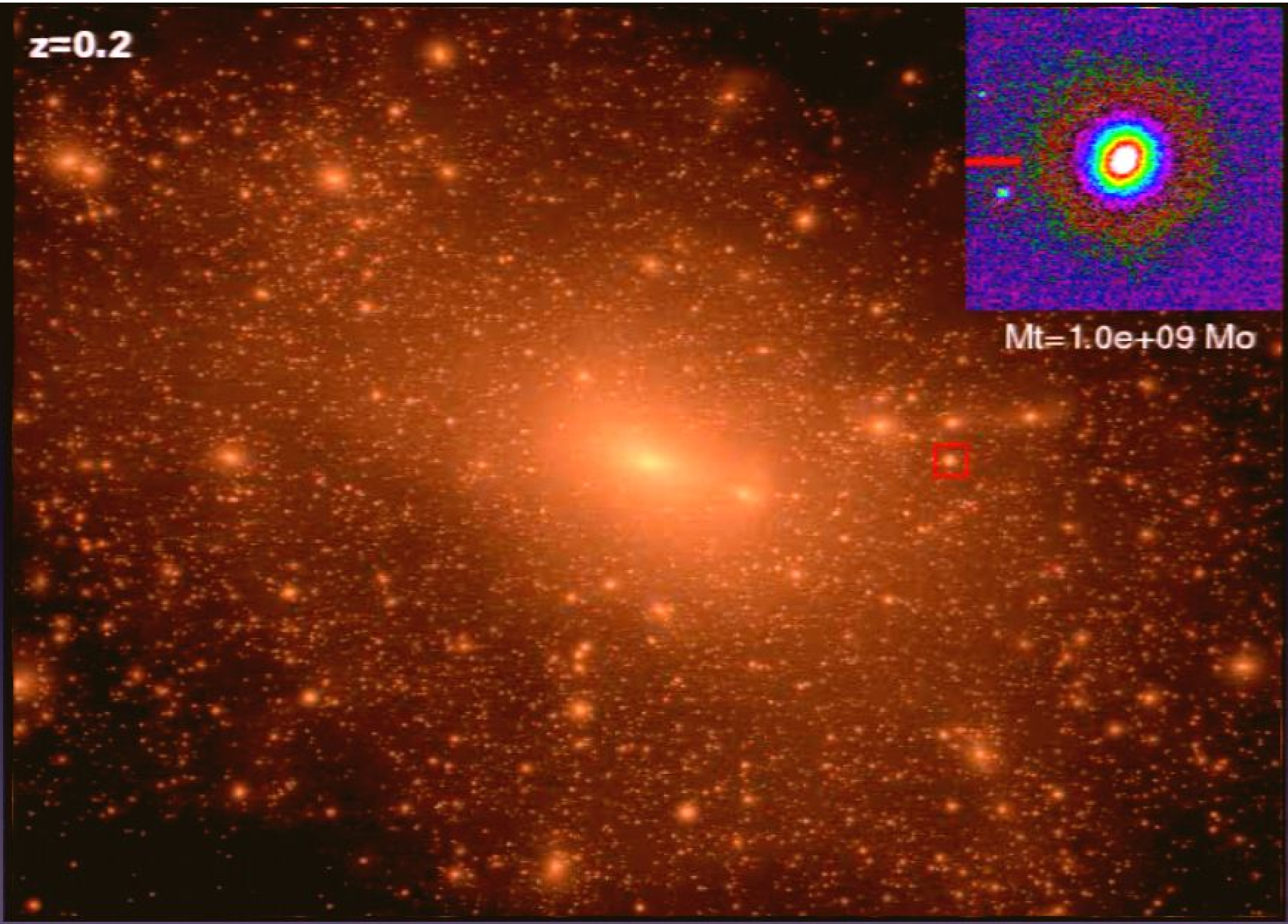

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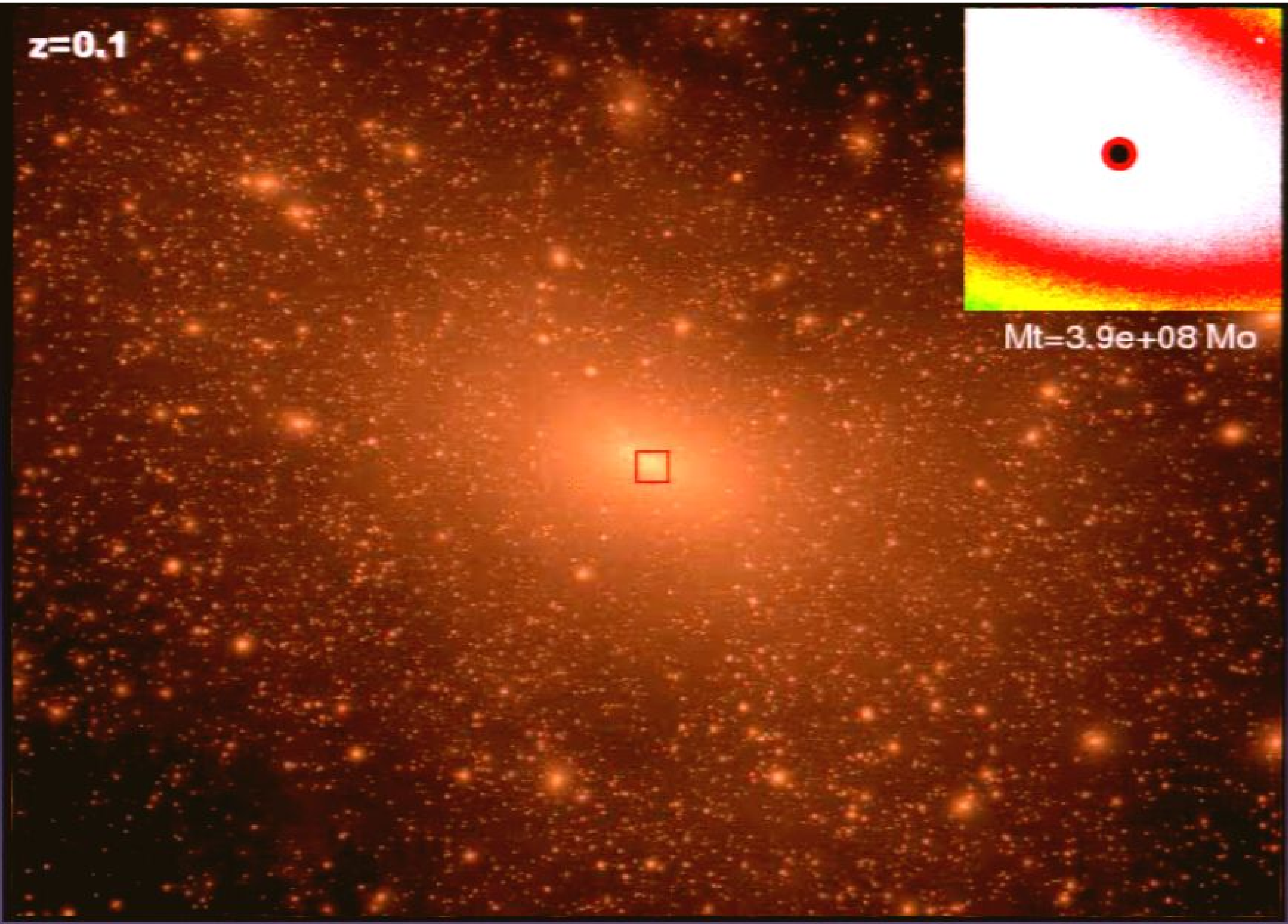

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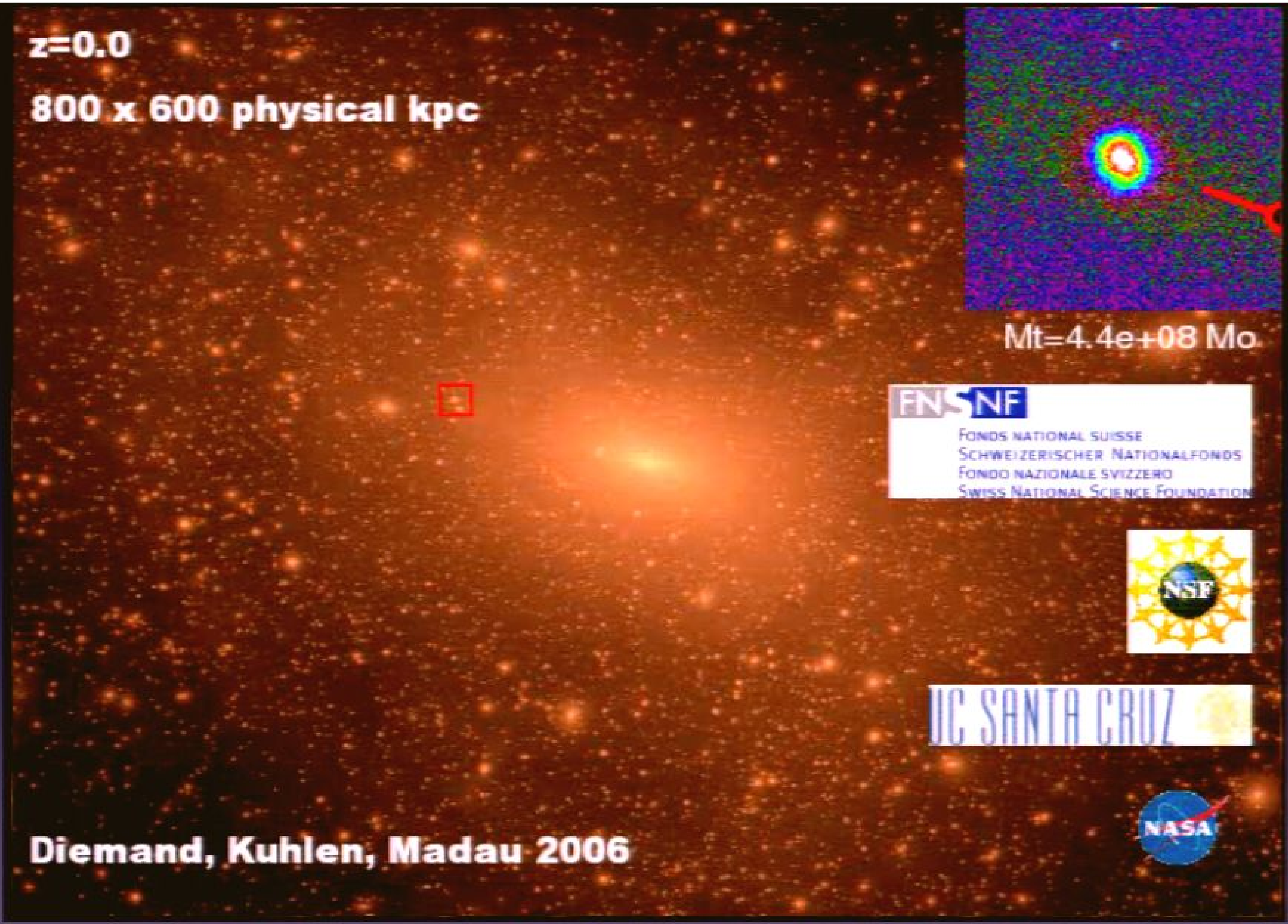

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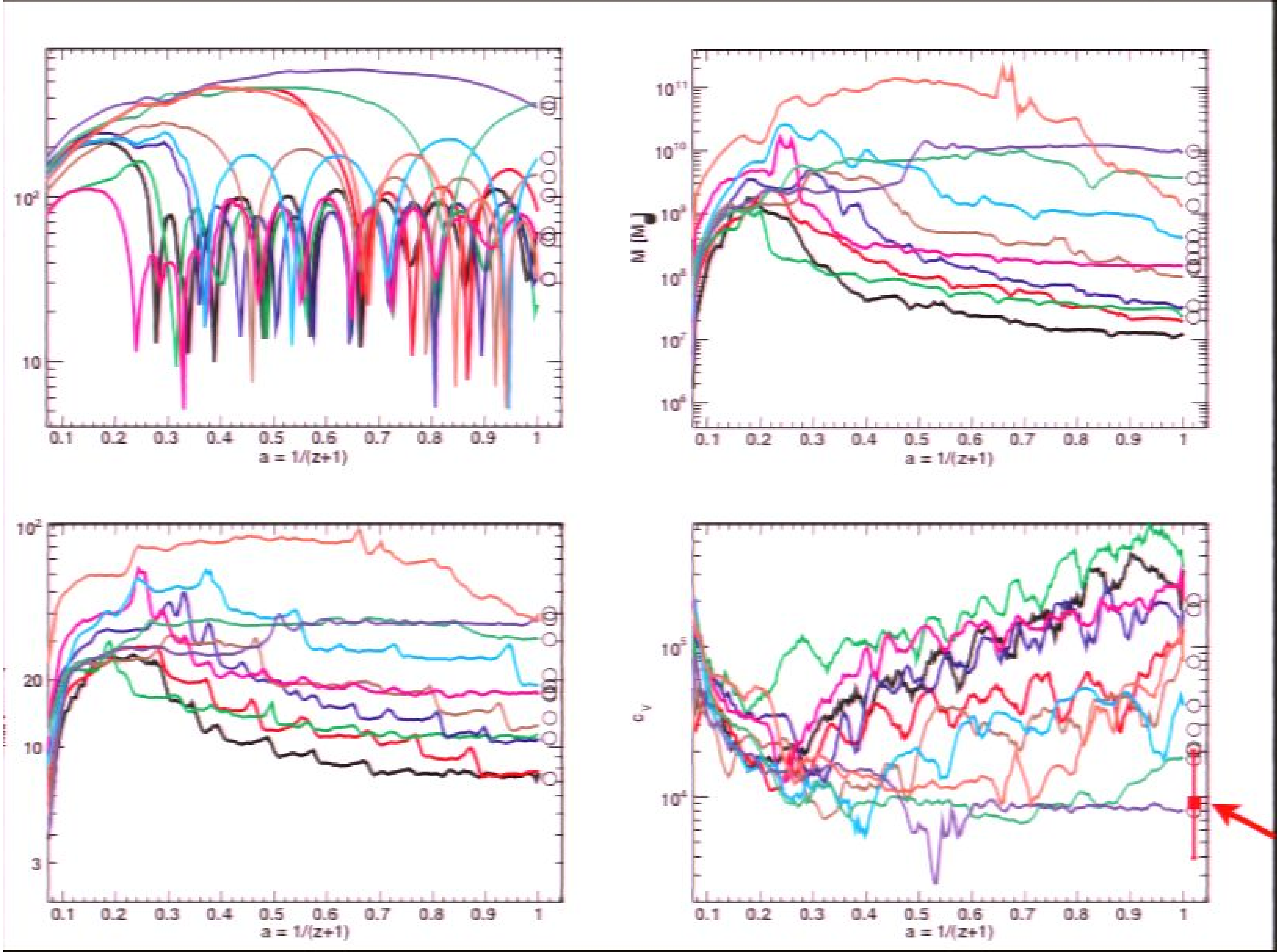
possible hosts for Local Group dwarfs



diverse histories:

0 to 11 pericenter
inner subhalos
tend to have more
of them and
starting earlier

none to very large
mass loss

concentrations
increase during
tidal mass loss

field halo
concentrations

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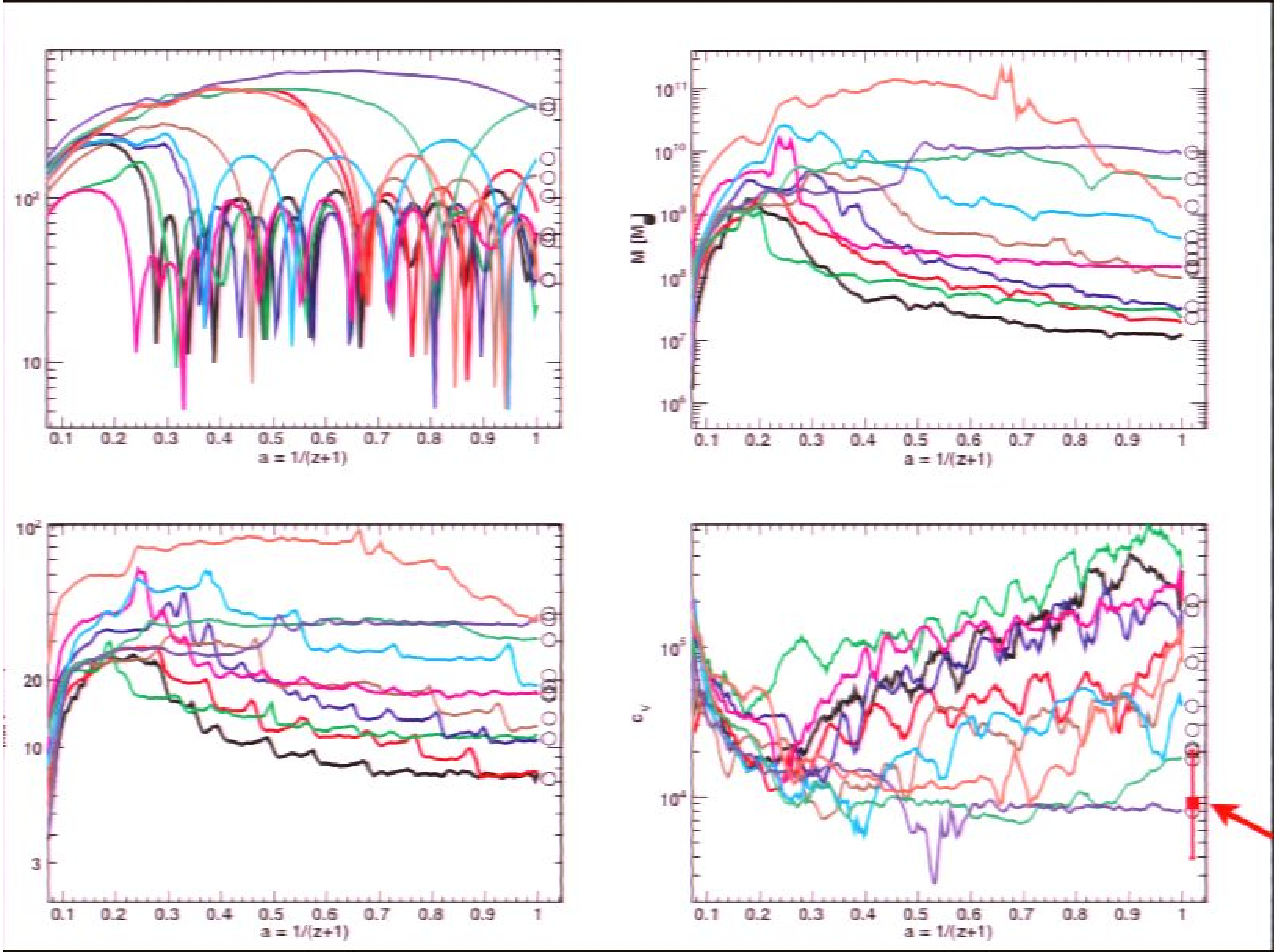

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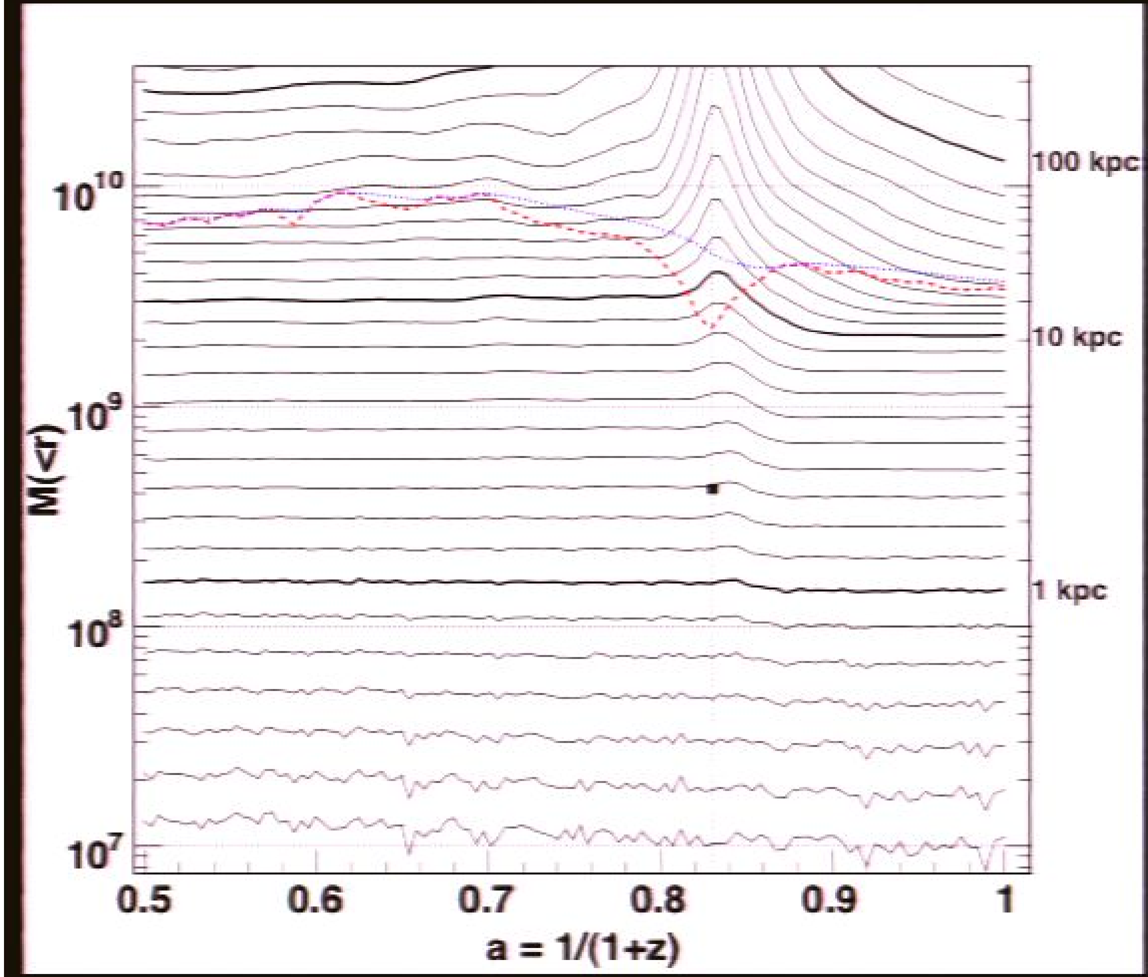
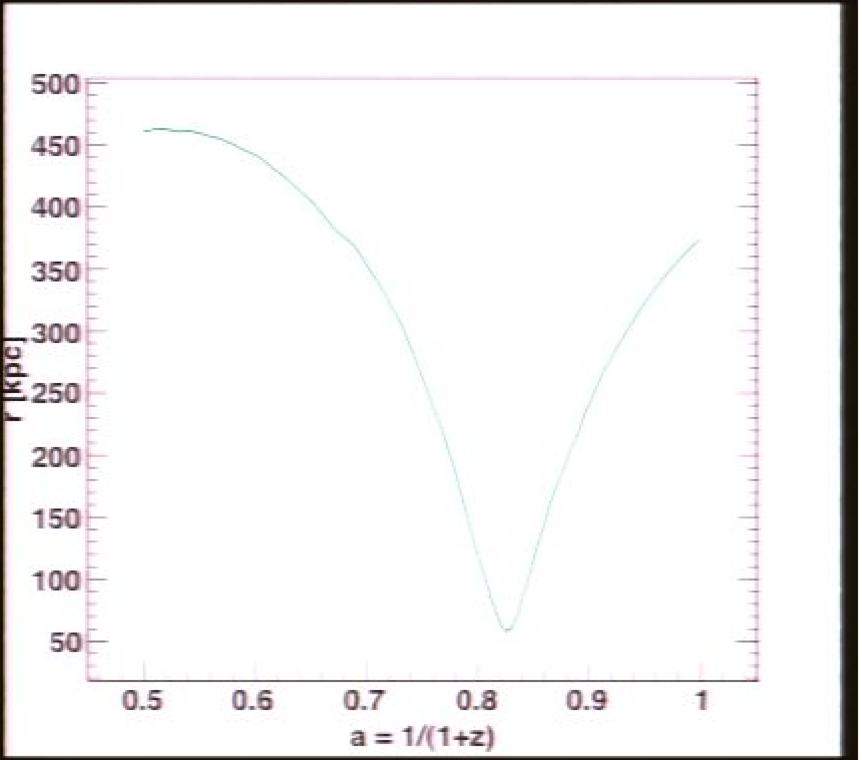
evolution of subhalo density profiles



total mass in spheres around subhalo center

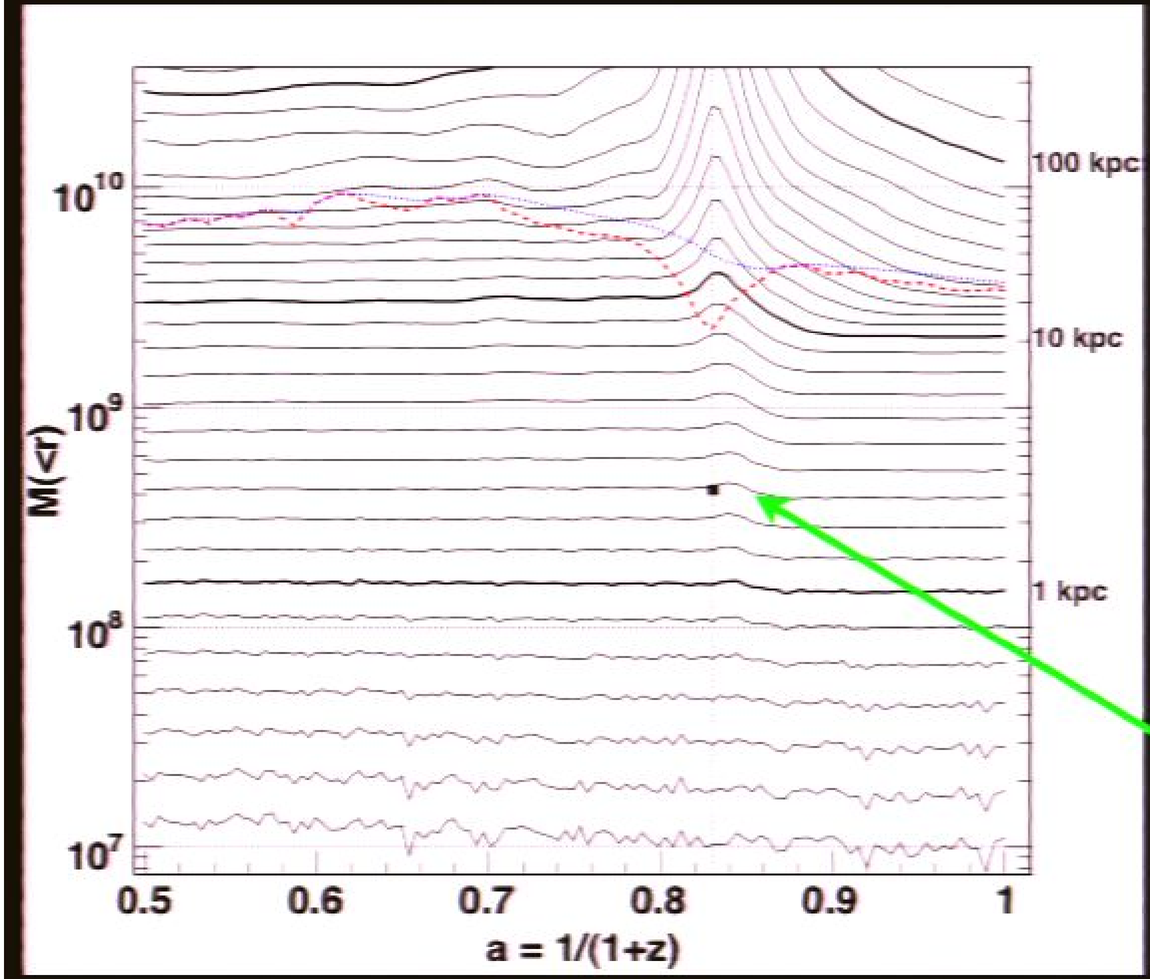
this subhalo has one pericenter passage at 56 kpc



weak, long tidal shock

duration : $\tau = \pi(56\,\mathrm{kpc})/(423\,\mathrm{km/s}) = 406\ \mathrm{Myr}$

evolution of subhalo density profiles



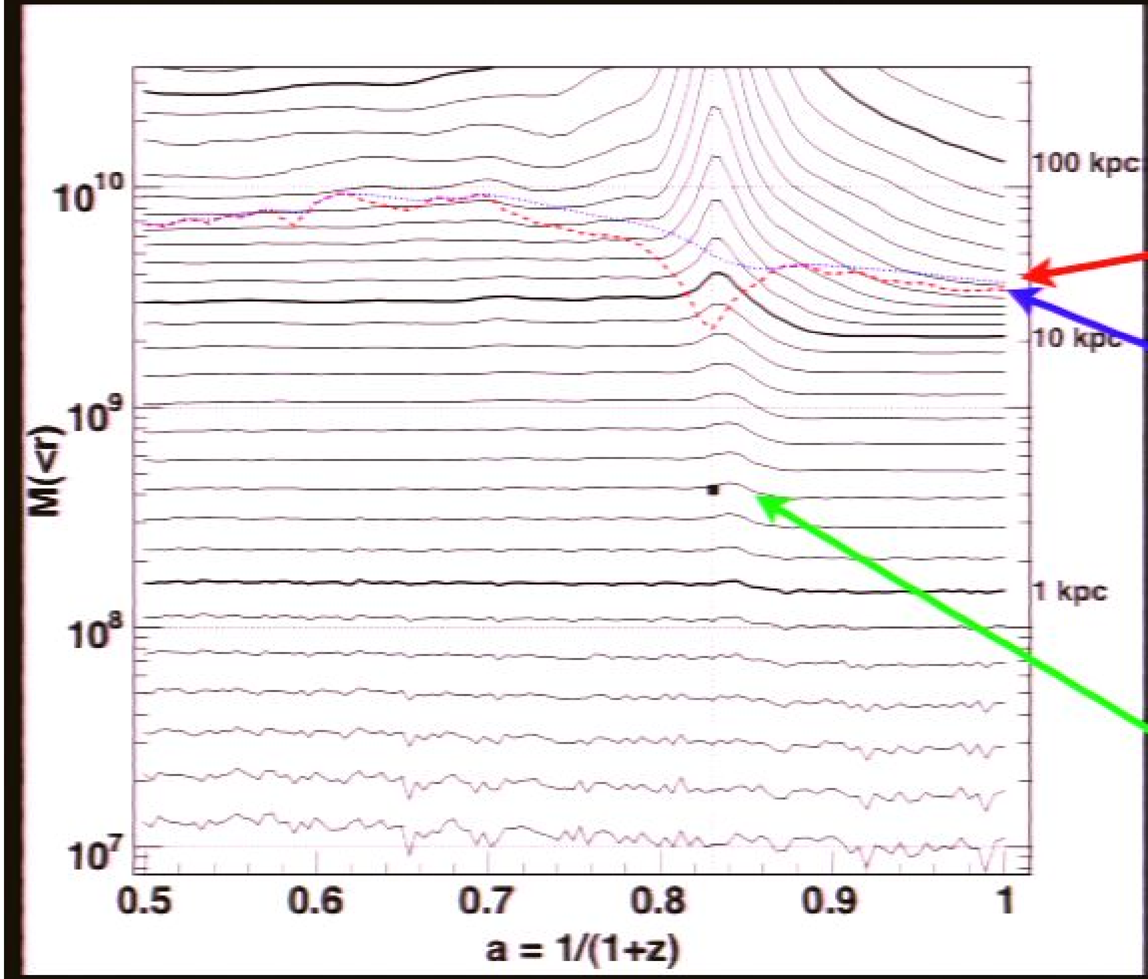
total mass in spheres around subhalo center

shock duration = internal subhalo orbital time

weak, long tidal shock
causes quick compression followed by expansion

mass loss is larger further out

evolution of subhalo density profiles



total mass in spheres around subhalo center

tidal mass, smaller than the bound mass at pericenter

“delayed” tidal mass

$$\Delta m = M(> r_t)\delta t/T_s$$

with $T_s = T_{\rm orbit}/6$

shock duration =
internal subhalo orbital time

weak, long tidal shock
causes quick compression followed by expansion

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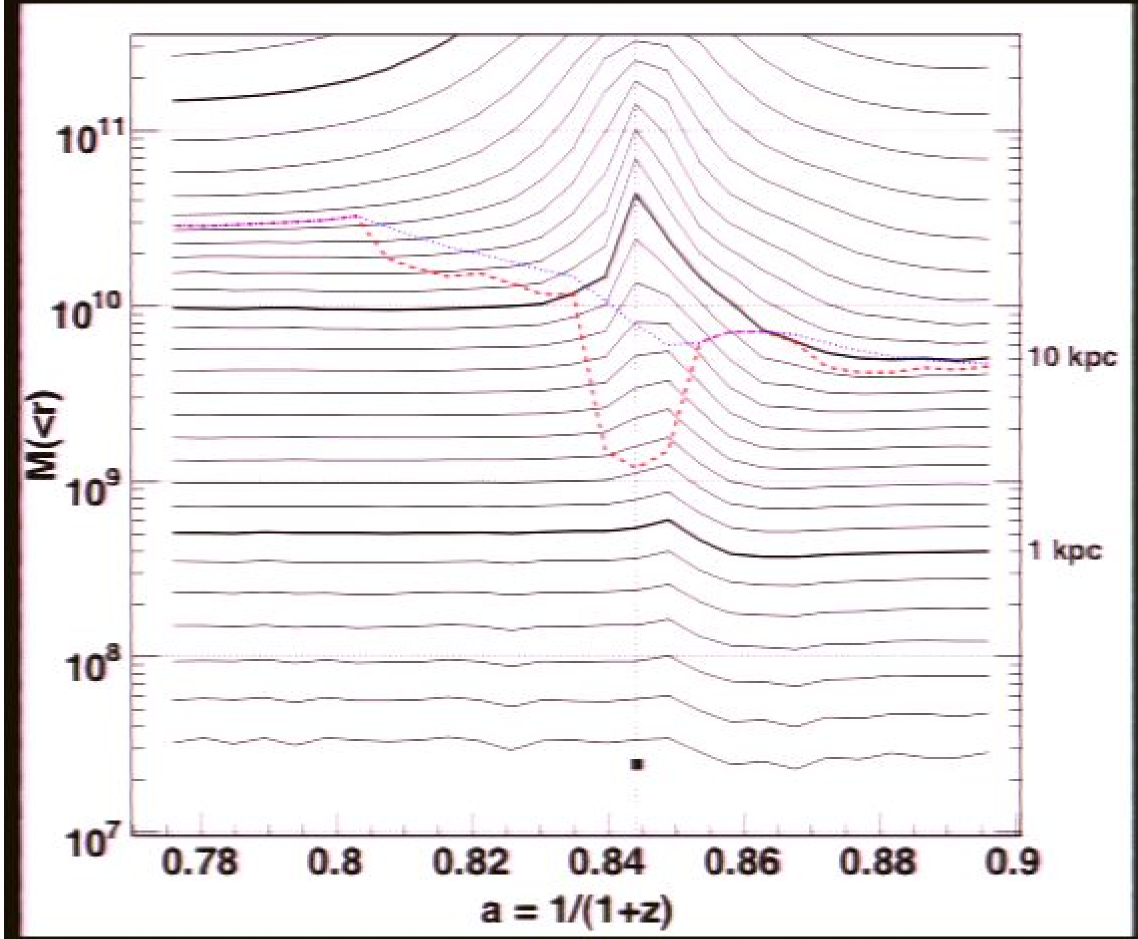
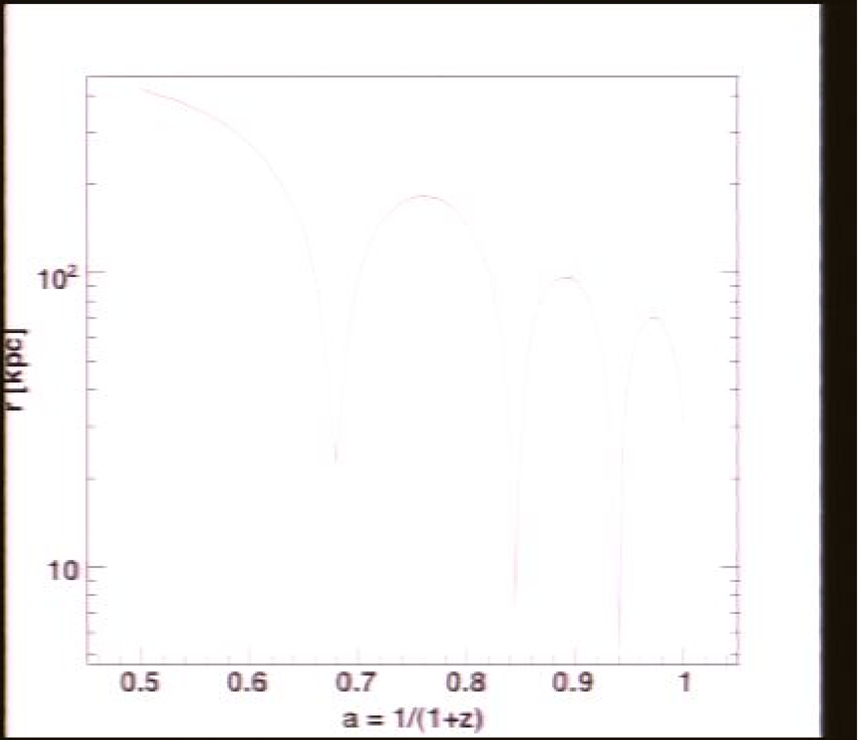
evolution of subhalo density profiles



total mass in spheres around subhalo center

this subhalo has its second of three pericenter passages at 7.0 kpc



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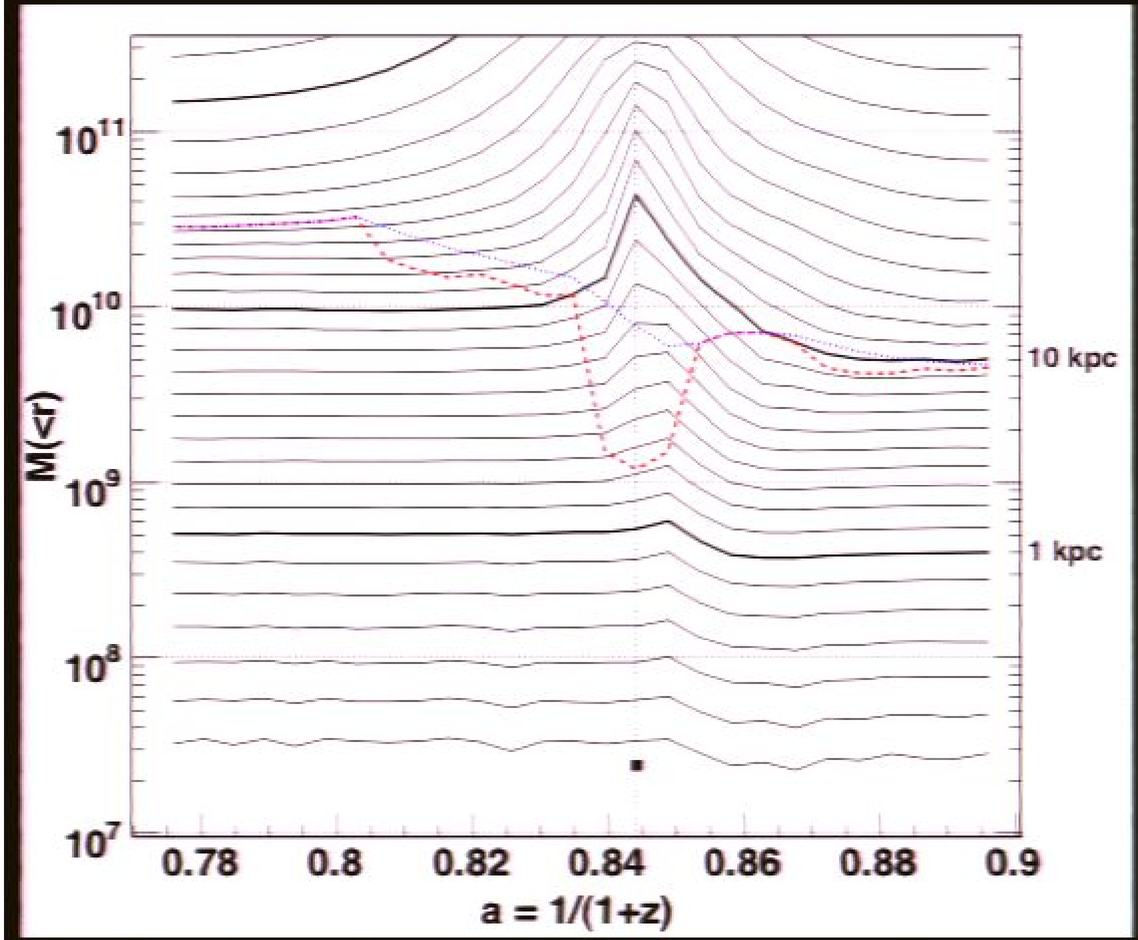

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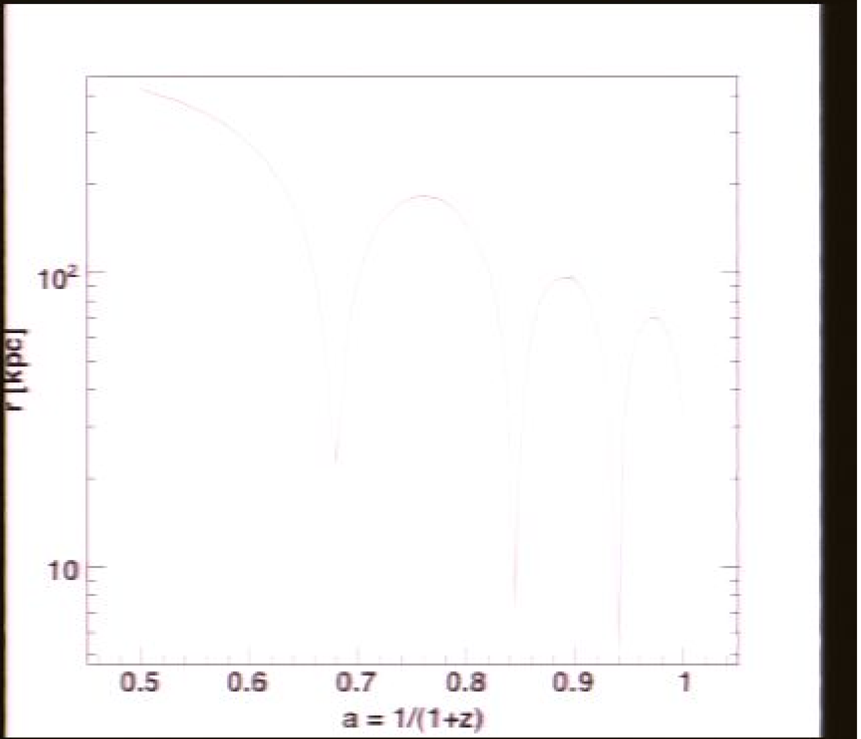

strong, short tidal shock

short duration : 43 Myr ➡ also affects inner halo, but mass loss still grows with radius

at pericenter $r_{\mathrm{tidal}} = 0.2\ r_{\mathrm{Vmax}}$, but the subhalo survives this and even the next pericente

subhalo survival and merging

out of 1542 well resolved (Vmax >5 km/s)
z=1 subhalos:

97 % survive until z=0

(only 1.3% merge into a larger subhalo)

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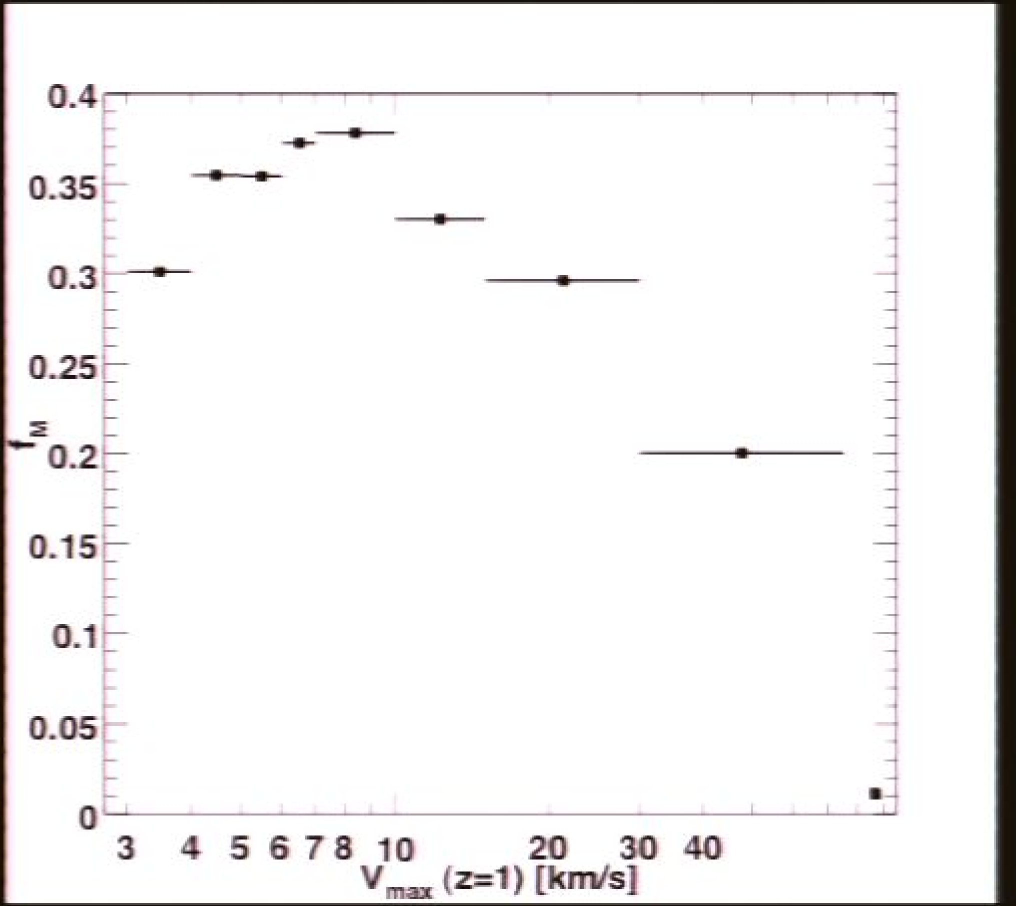
The average mass fraction that remains bound to them until z=0 depends on their (inital) size



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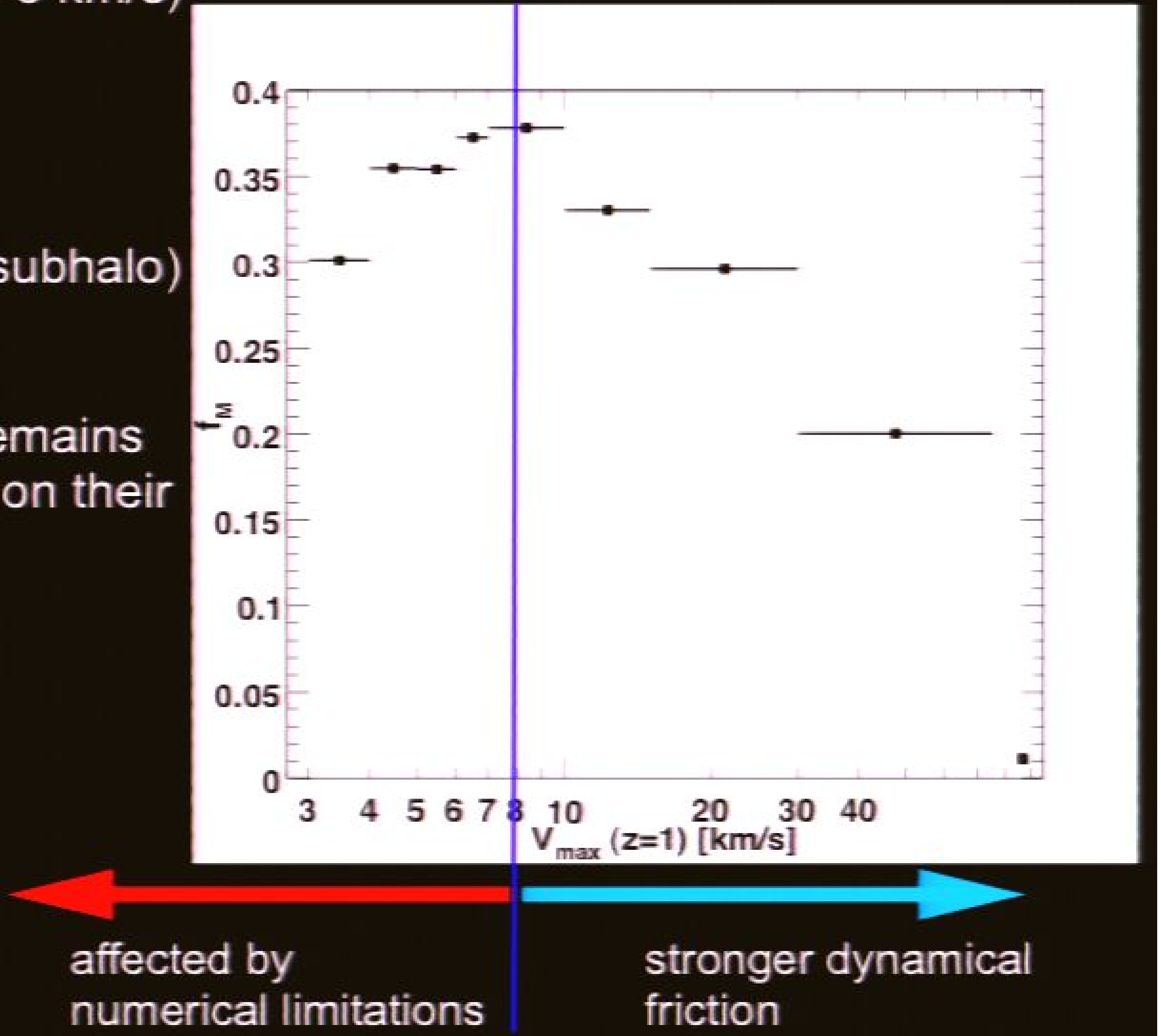

affected by numerical limitations

stronger dynamical friction

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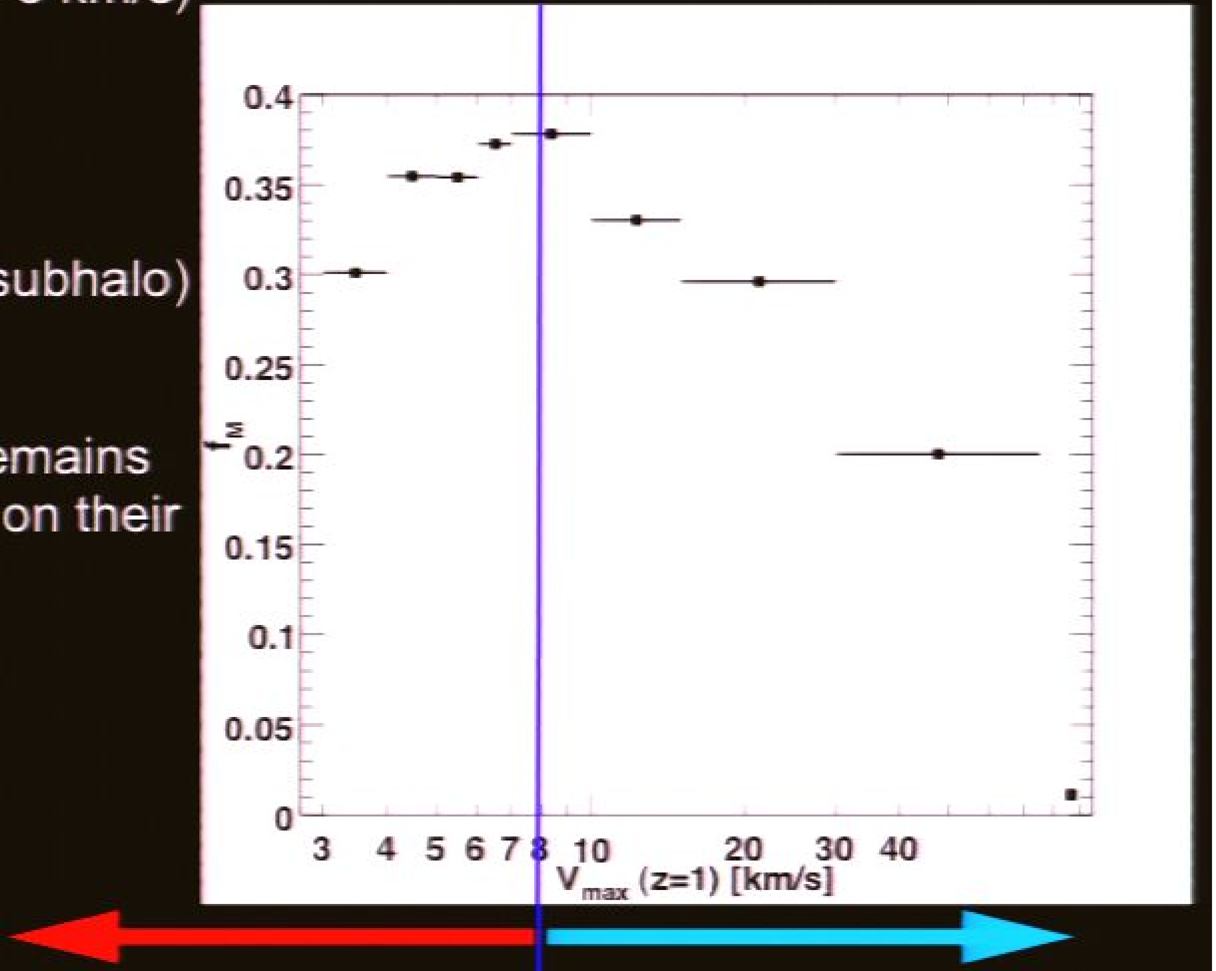
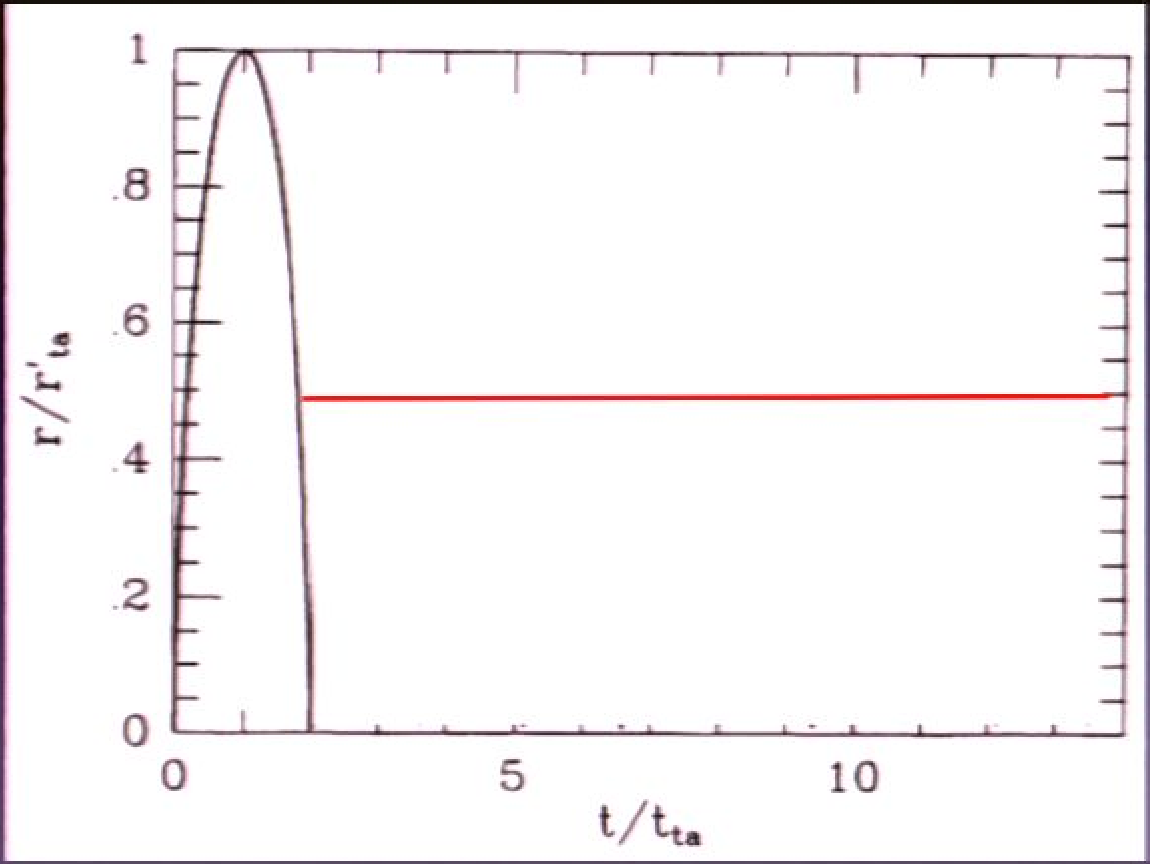


affected by numerical limitations

stronger dynamical friction

2) how do halos accrete their mass?

spherical radial top-hat collapse

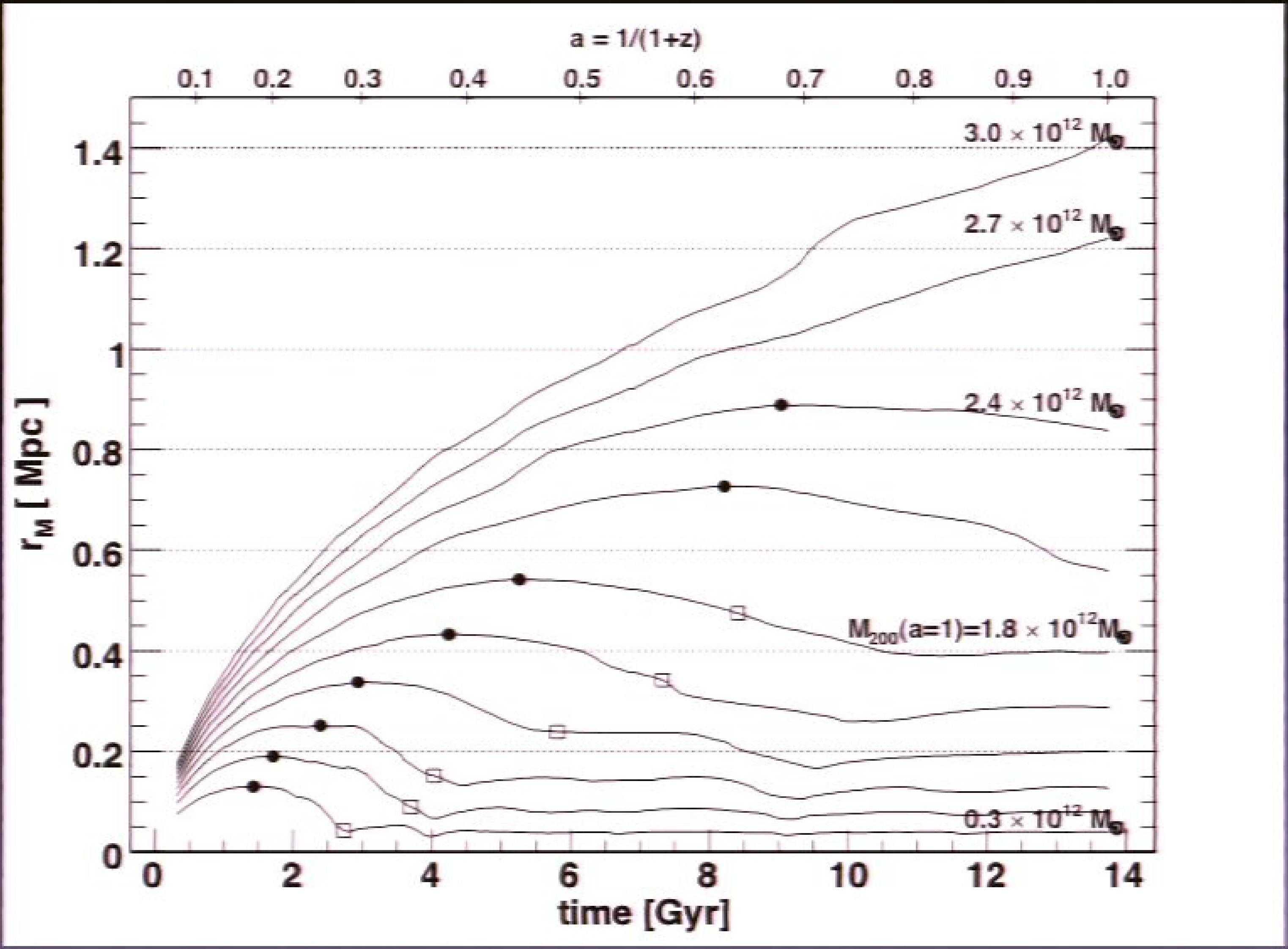


assumes virialisation at
half the turnaround radius

basis for definition of
virial radius:
r_178 for EdS
r_340 LambdaCDM z=
(contrast over mean
matter density)

(Gunn, Gott ... 1970ies)

Spherical shells of fixed mass



JD, Kuhlen, Madau 2007

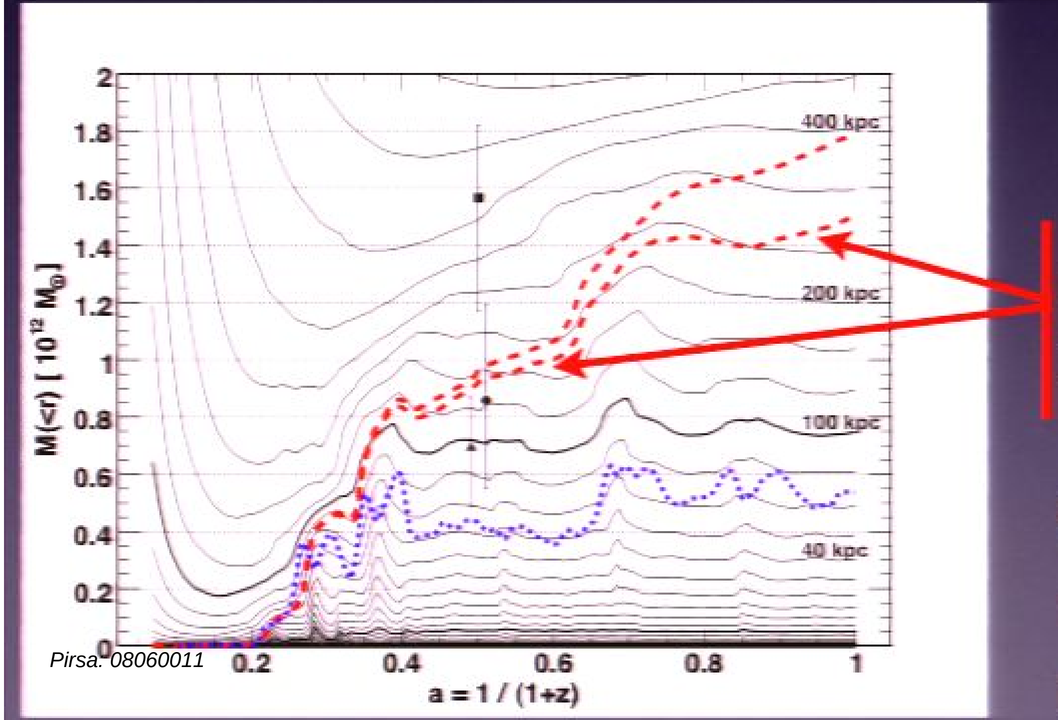
2) how do halos accrete their mass?

spherical radial top-hat collapse : problems

- galaxy halos are stationary to about 2 virial radii (Prada,Klypin+2005)
- mass accretion history ≠ M_vir(z)

  collapse factor only 1.36 not 2 for the virial mass shell

  shells constantly exchange mass (JD,Kuhlen,Madau2007)

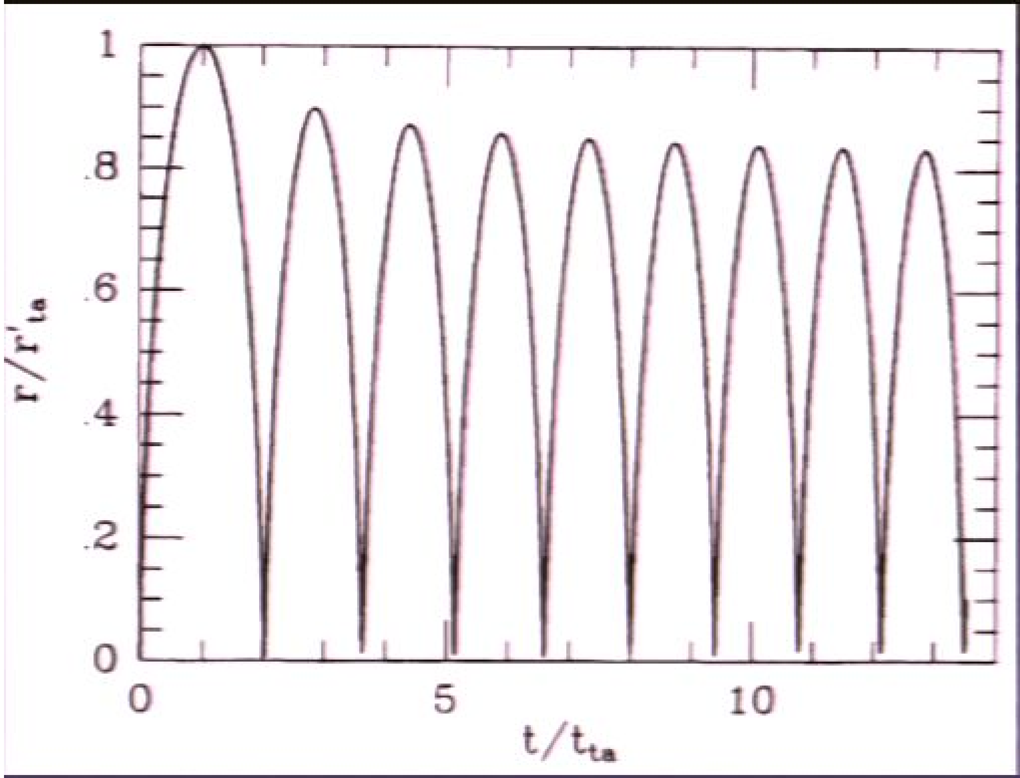


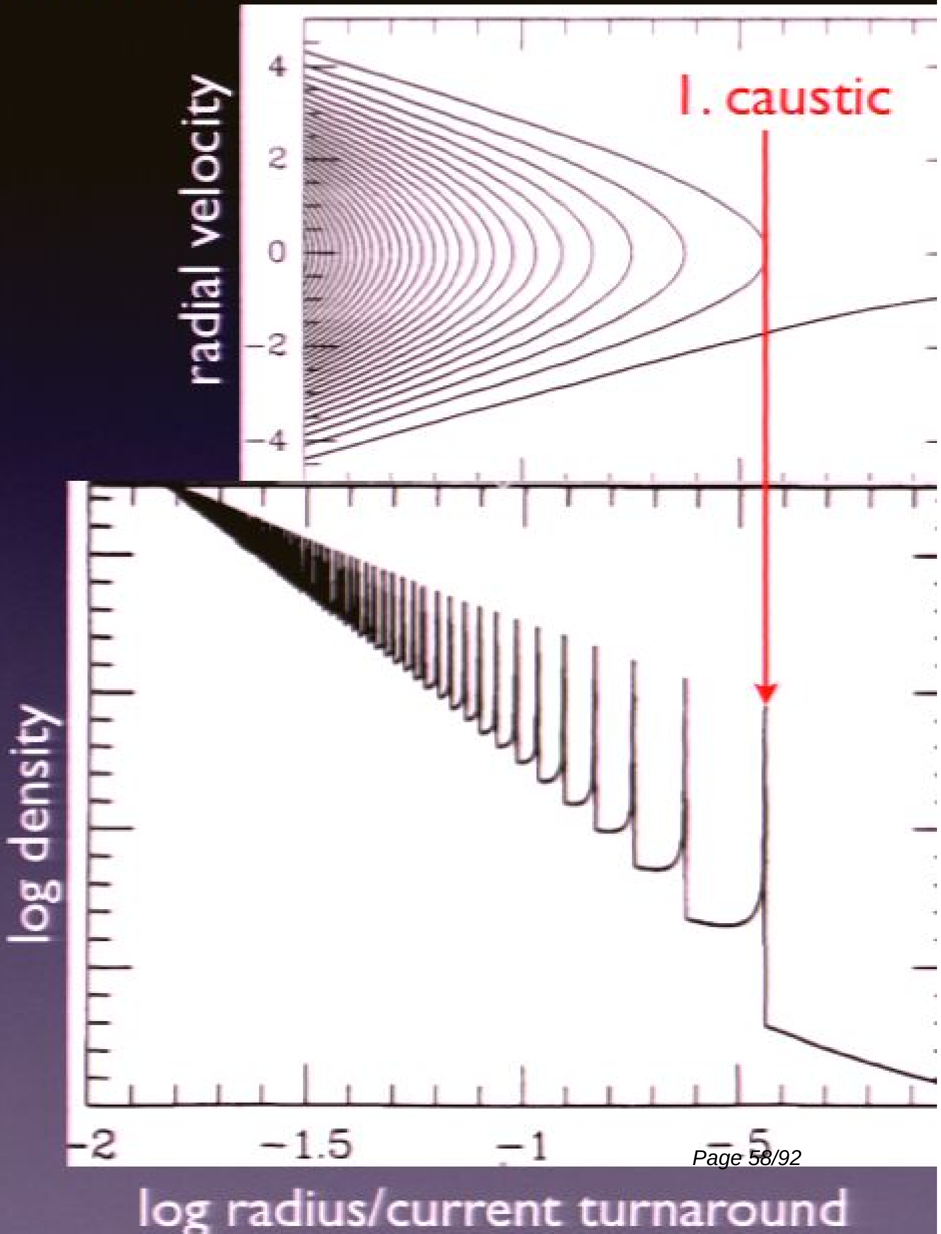
nominal growth in M_vir
in epochs without real growth

97.5% contributed by infalling, resolved clumps
no smooth accretion (Madau+2008)

2) how do halos accrete their mass?

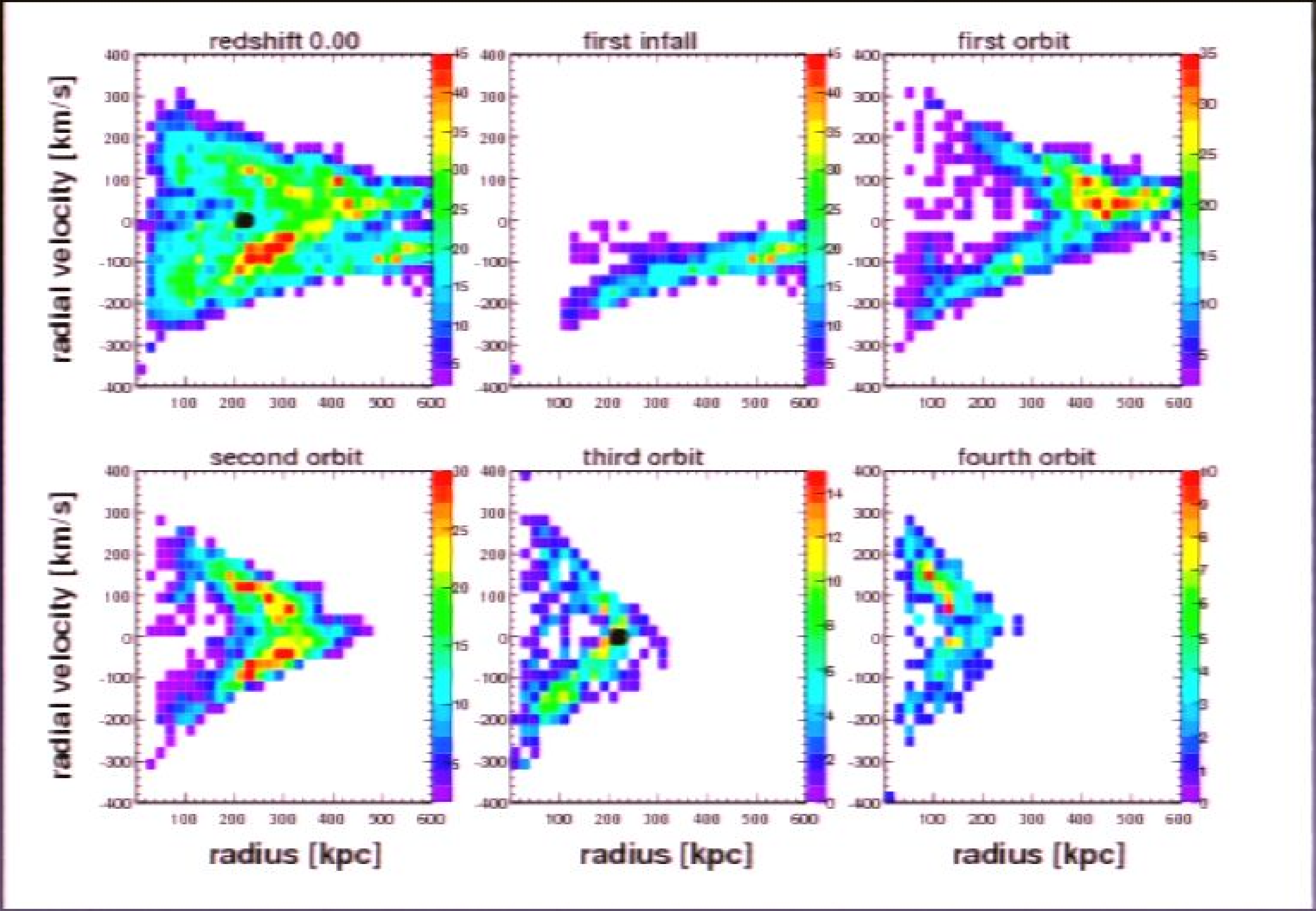
self-similar secondary spherical radial infall model:



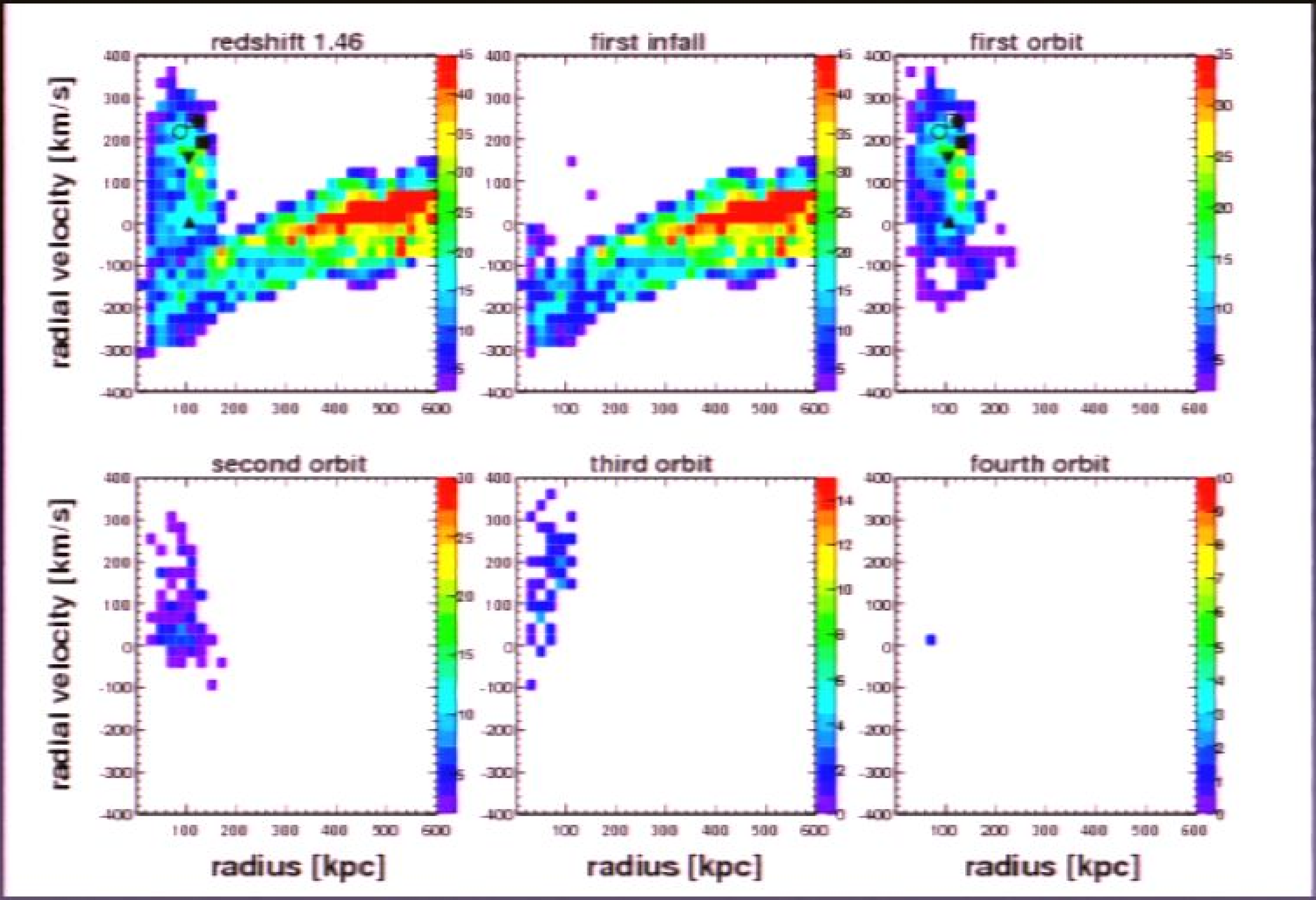


Fillmore&Goldreich1984;Bertschinger1985

small collapse factors of 12% to 18%
rho ~ r^-2.25 with infinite density caustics



JD, Kuhlen, ApJL in press



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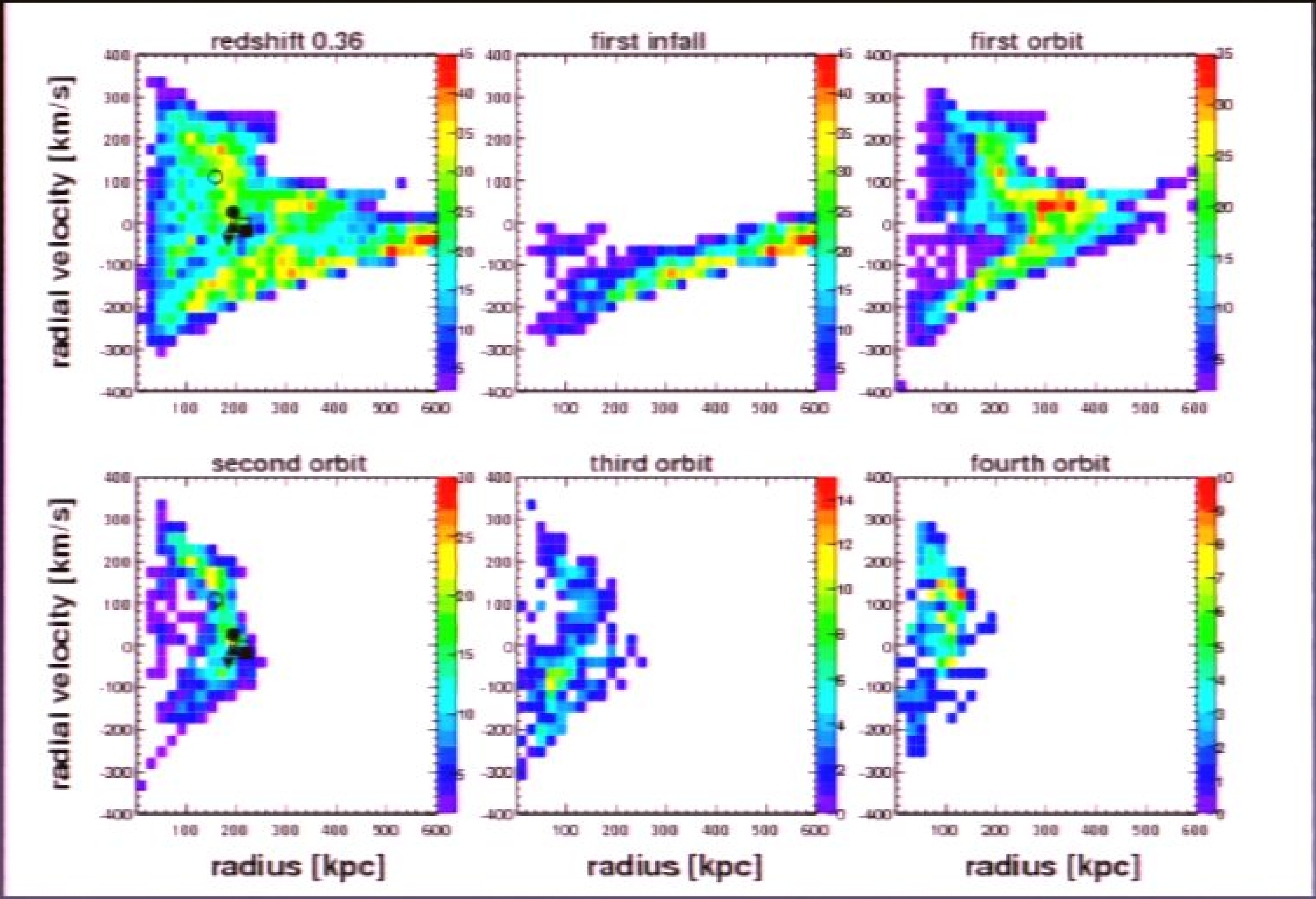

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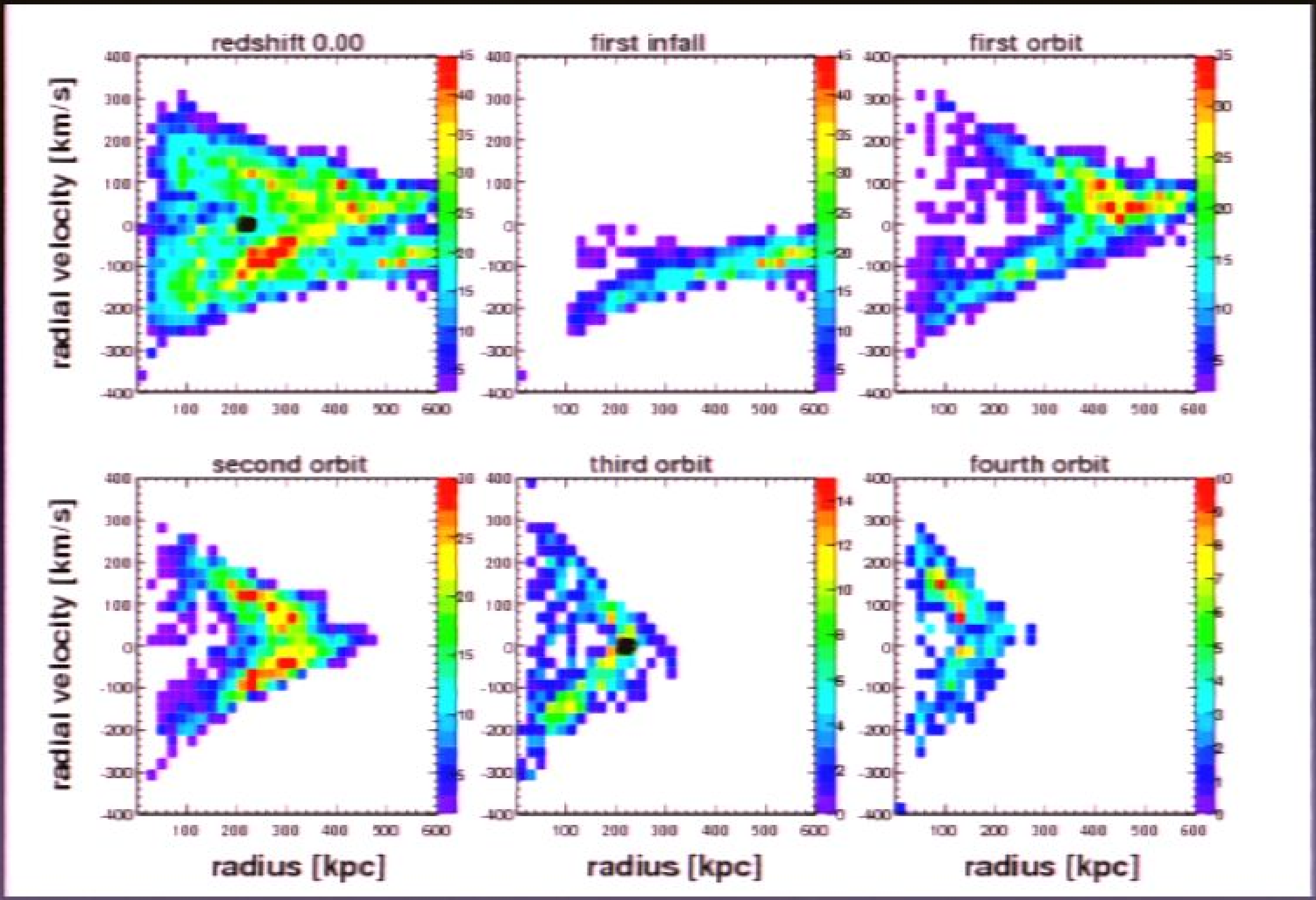
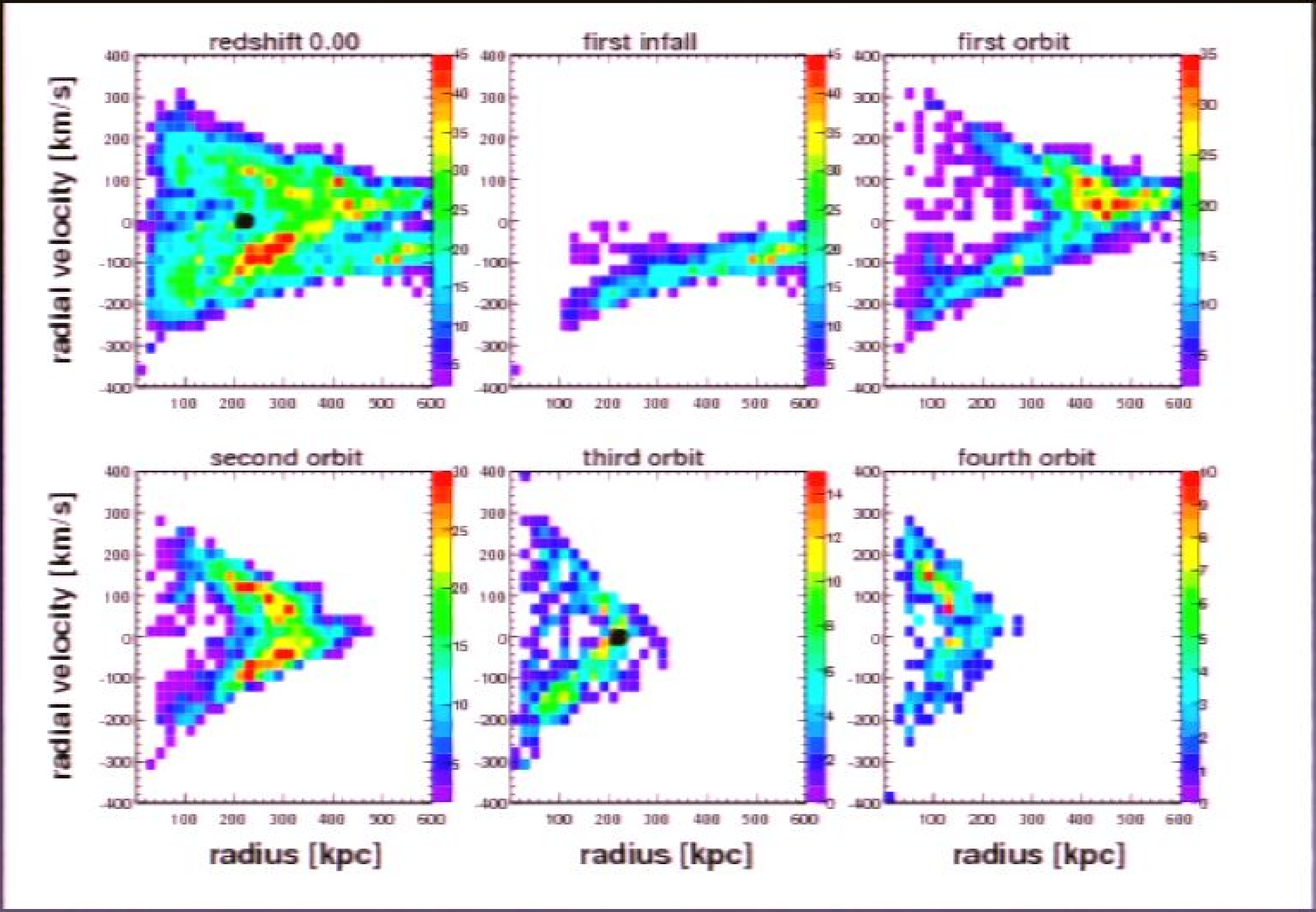


JD, Kuhlen, ApJL in press



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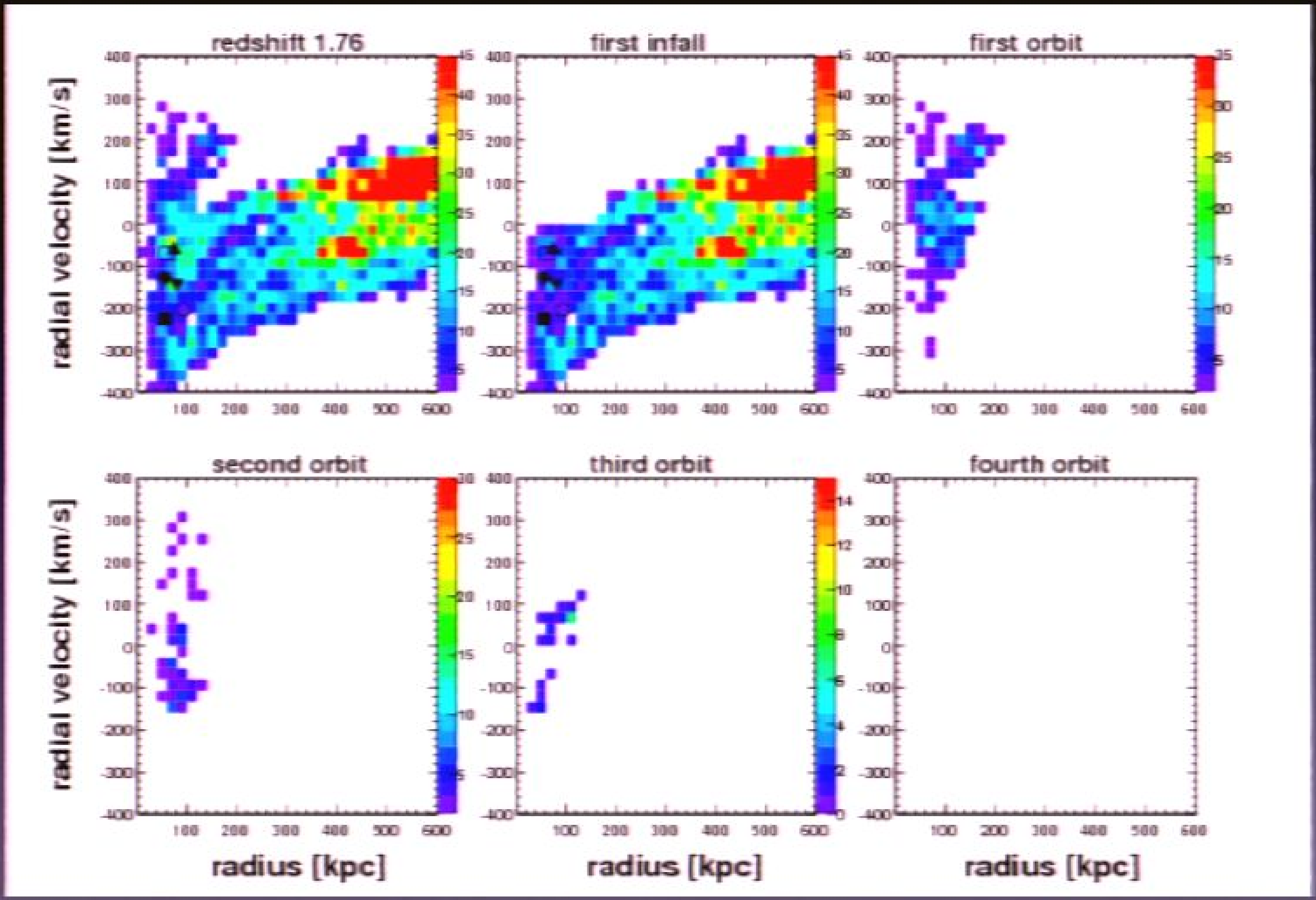

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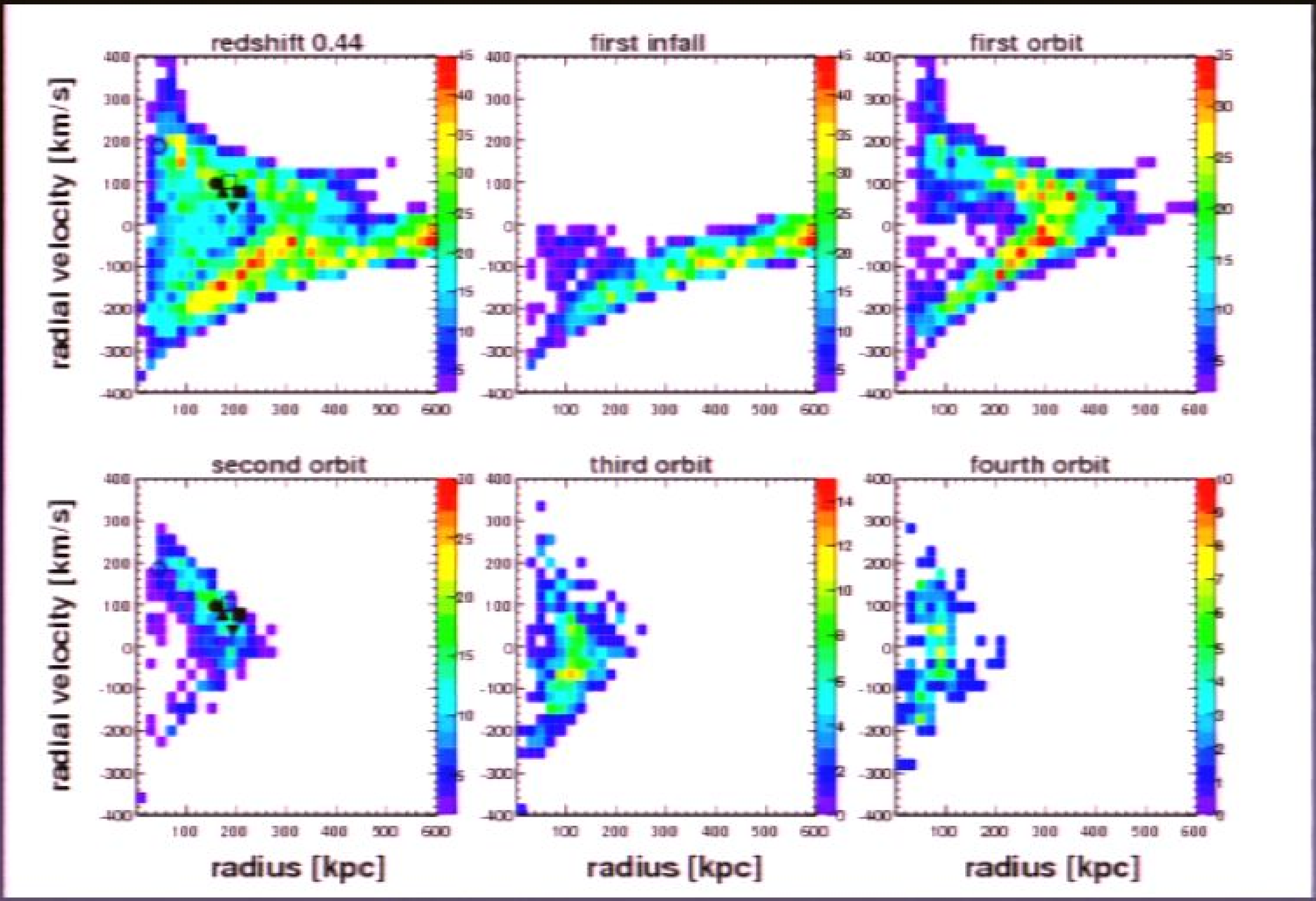

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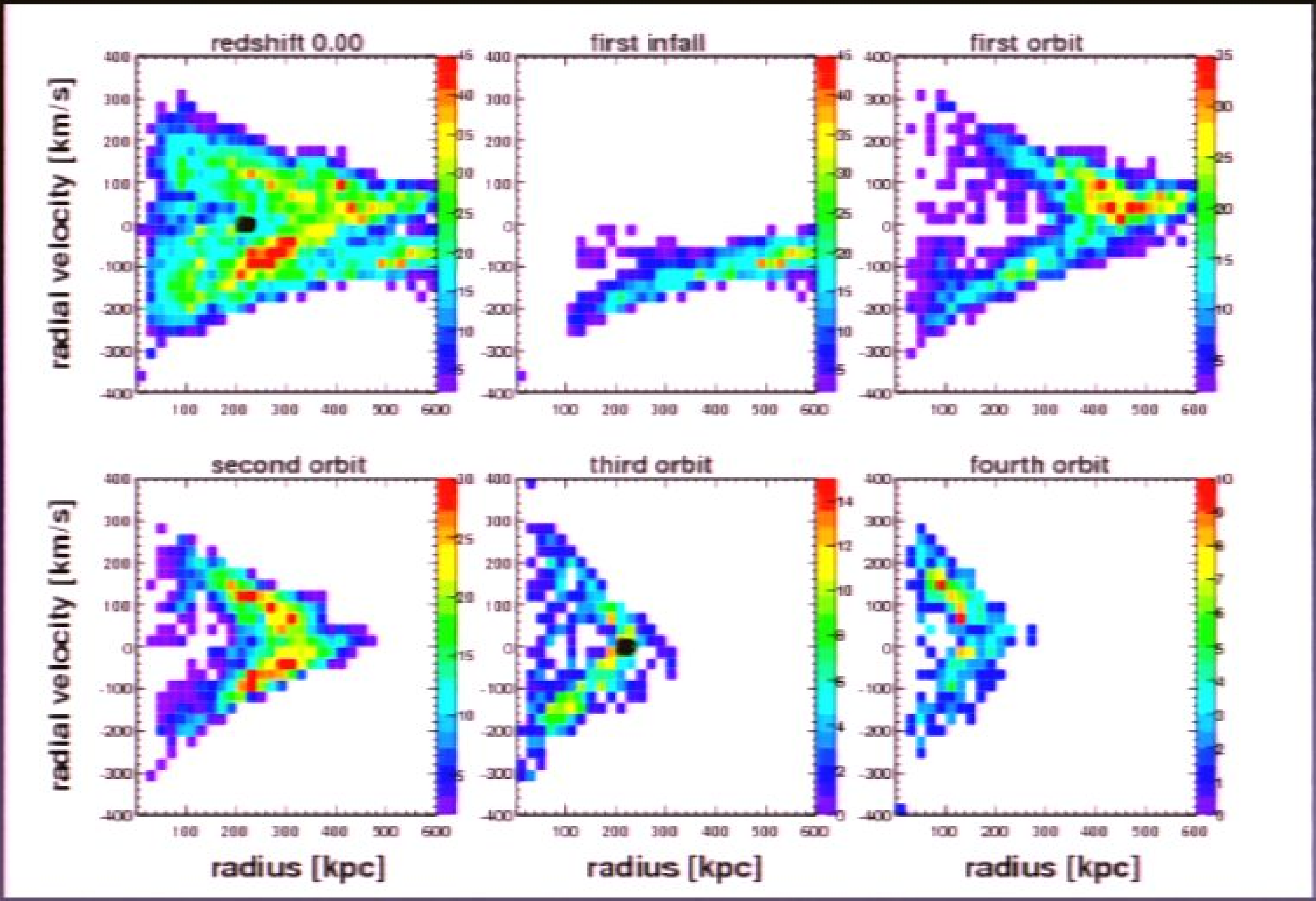

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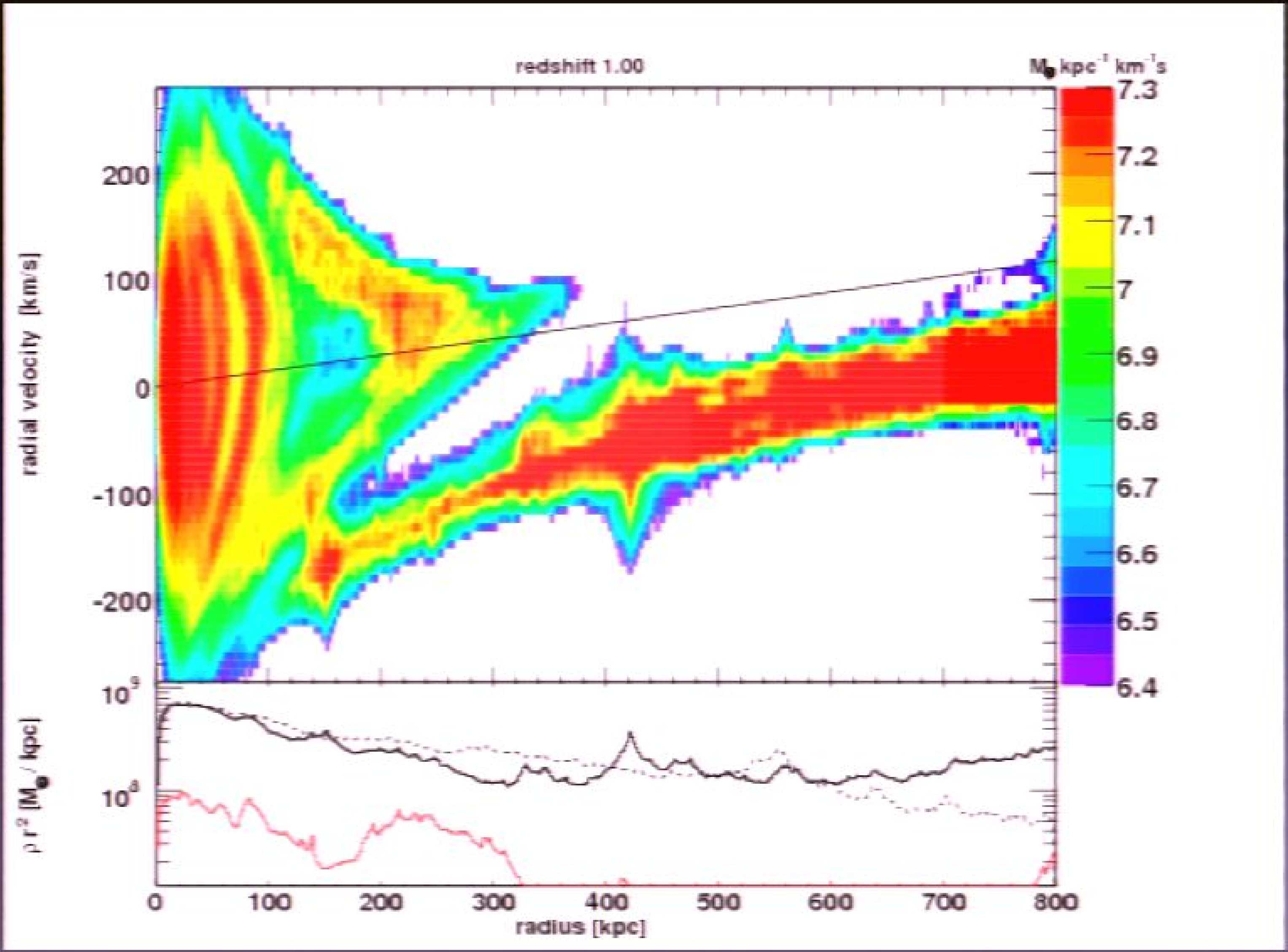

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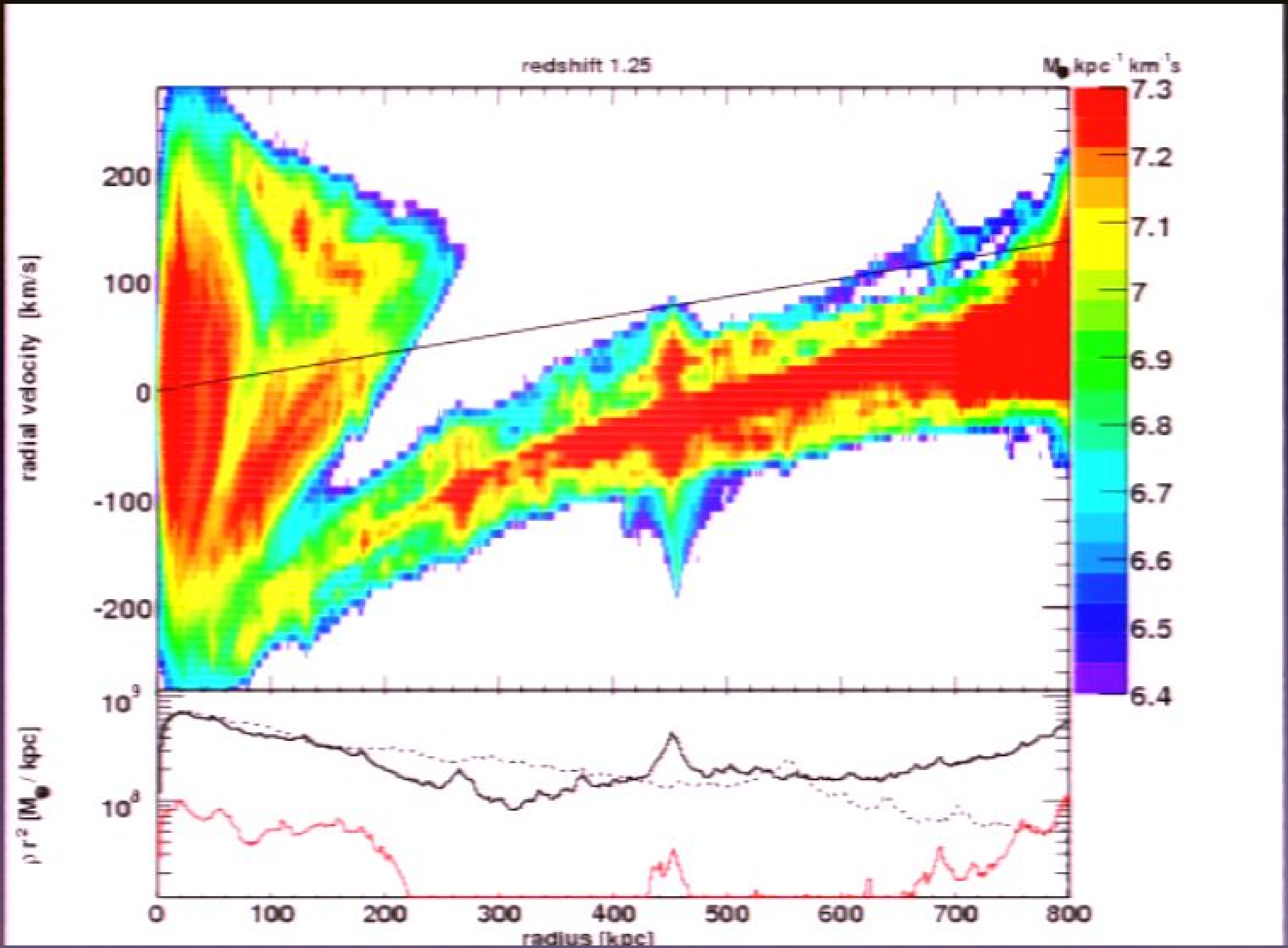

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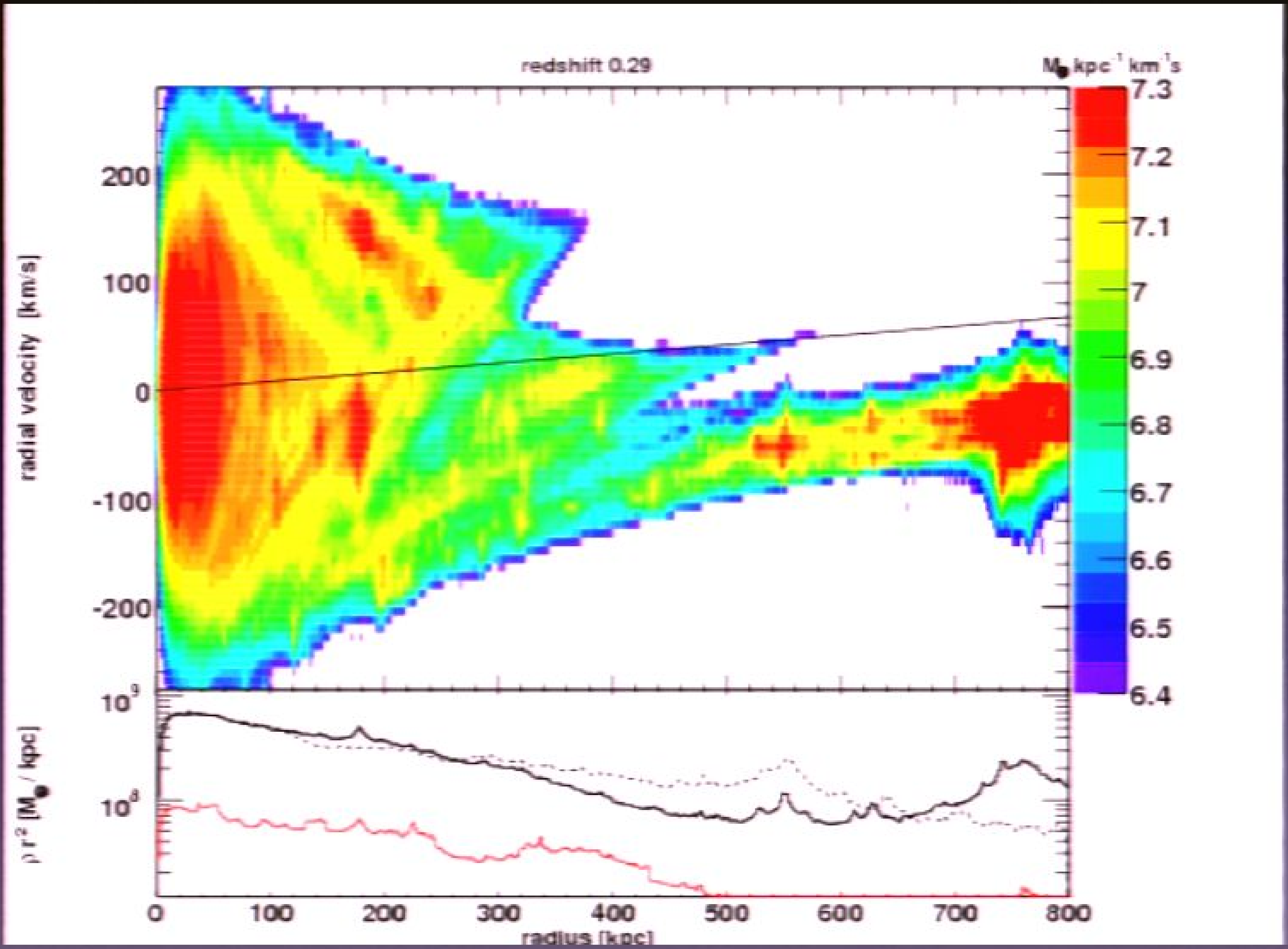

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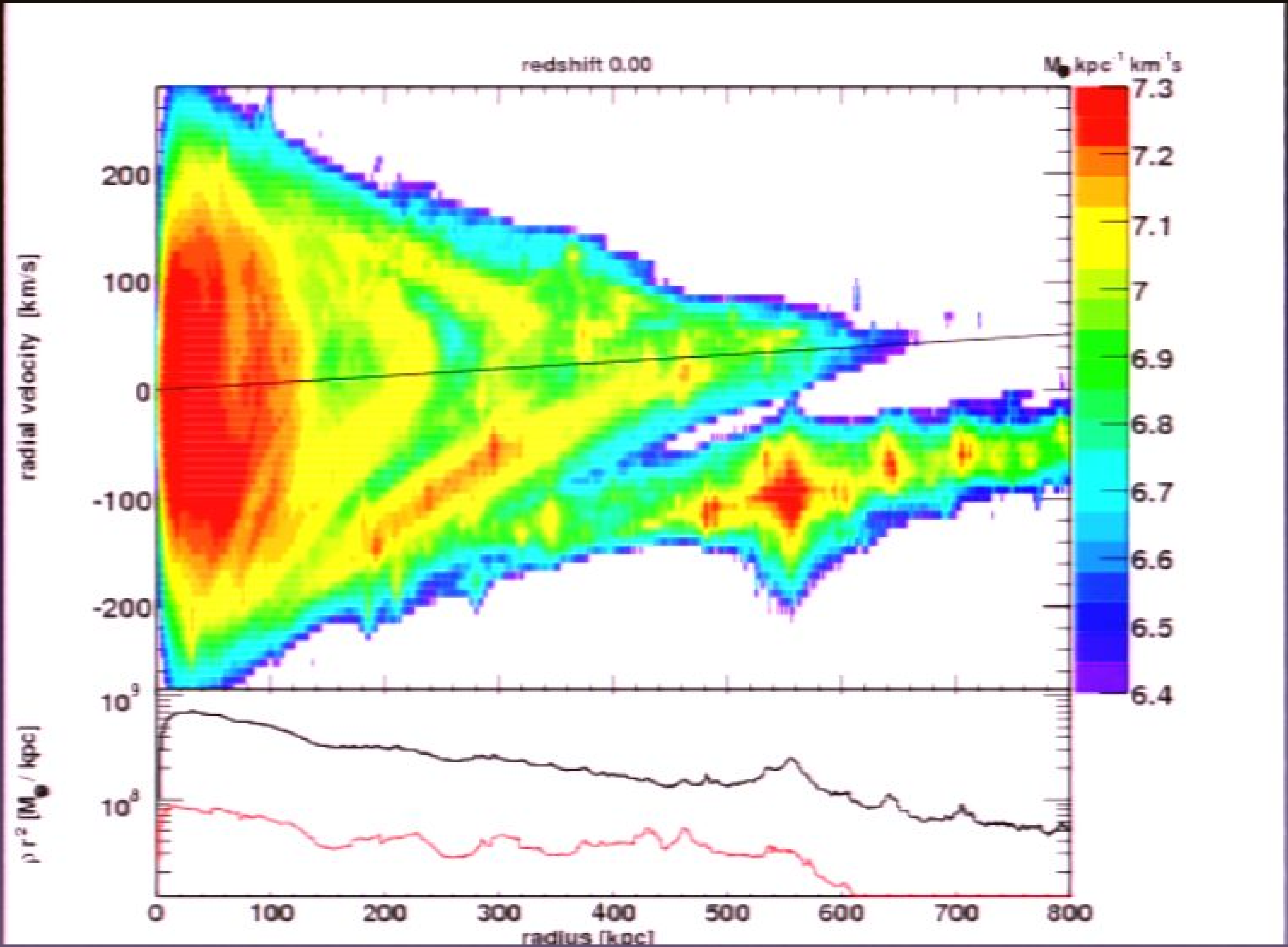

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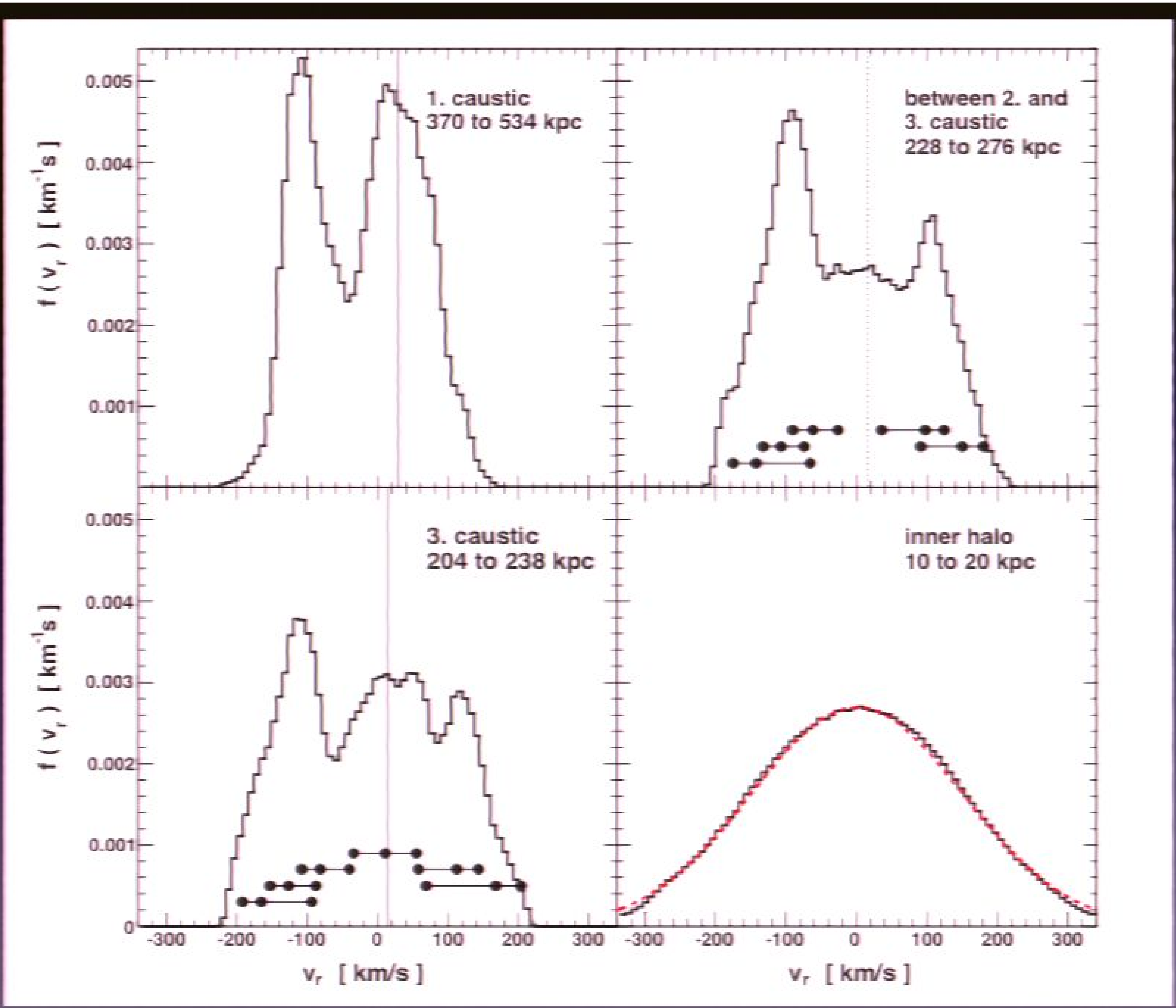

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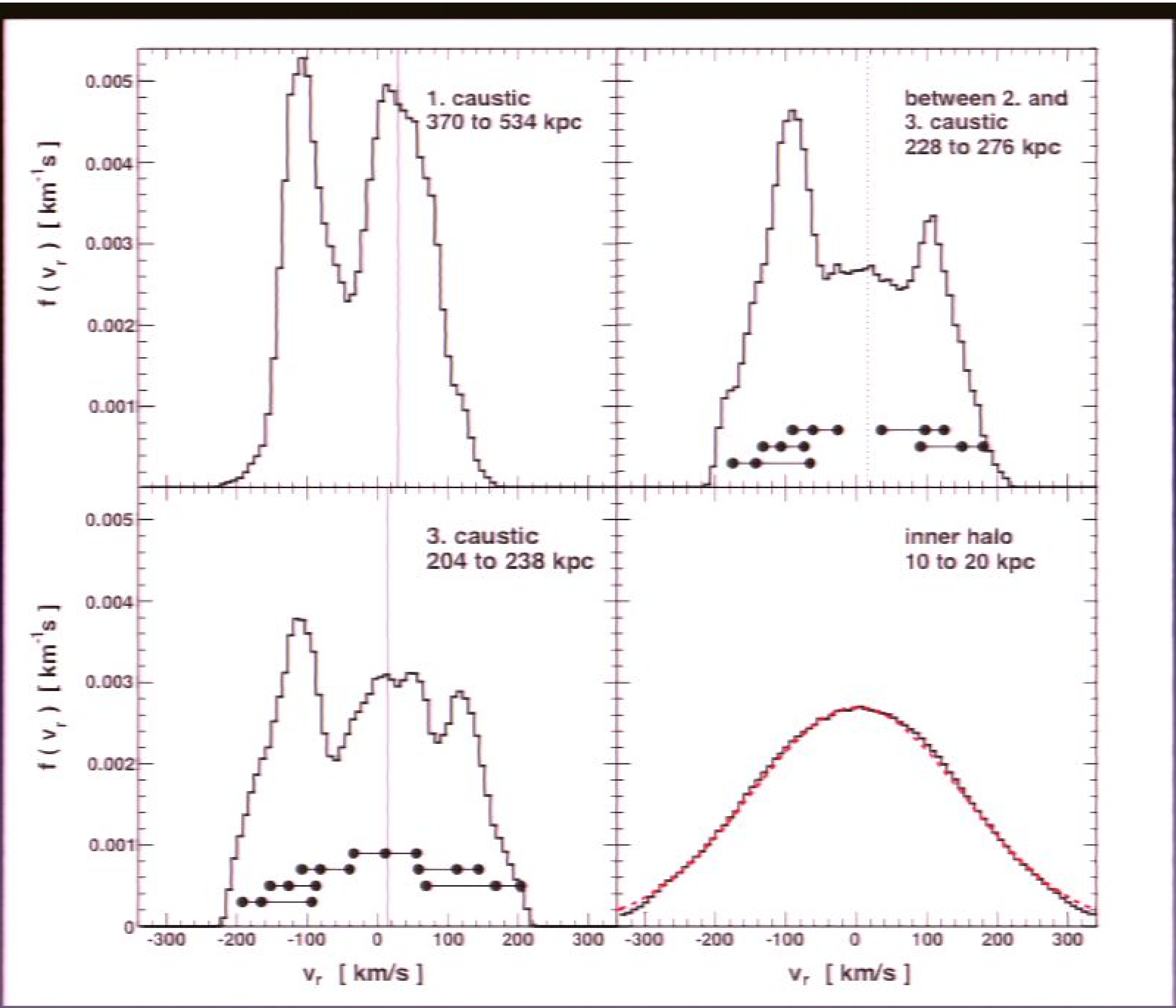

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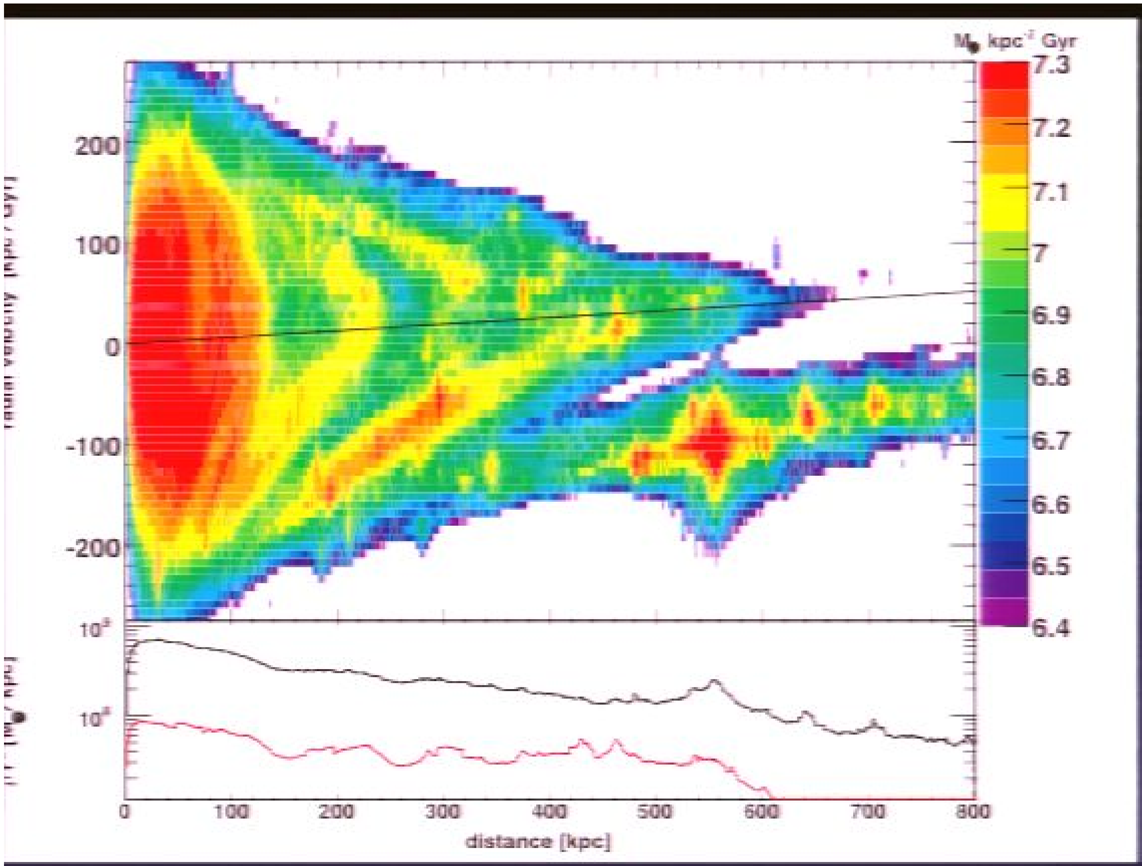

typical particles and subhalos go out to 0.8 to 0.9 of where they turned around, as in the FGB model

But the scatter is too large to allow the formation of high density caustics

only weak features in v_r - r plane detection extremely challenging!

note r_vir = 289 kpc

$r_{k,\mathrm{med}}$ [kpc]	$r_{k,68\%}$ [kpc]	$\frac{\Delta r_k}{r_{k,\mathrm{med}}}$	$t_{k,\mathrm{med}}$ [kpc]	$t_{k,68\%}$ [kpc]	$\frac{\Delta t_k}{t_{k,\mathrm{med}}}$	$\left(\frac{r_k}{t_k}\right)_{\mathrm{med}}$	$\left(\frac{r_k}{t_k}\right)_{68\%}$	$\left(\frac{r_k}{t_k}\right)_{\mathrm{FGB}}$
453	370−534	0.36	491	443−551	0.22	0.92	0.77−1.12	0.876
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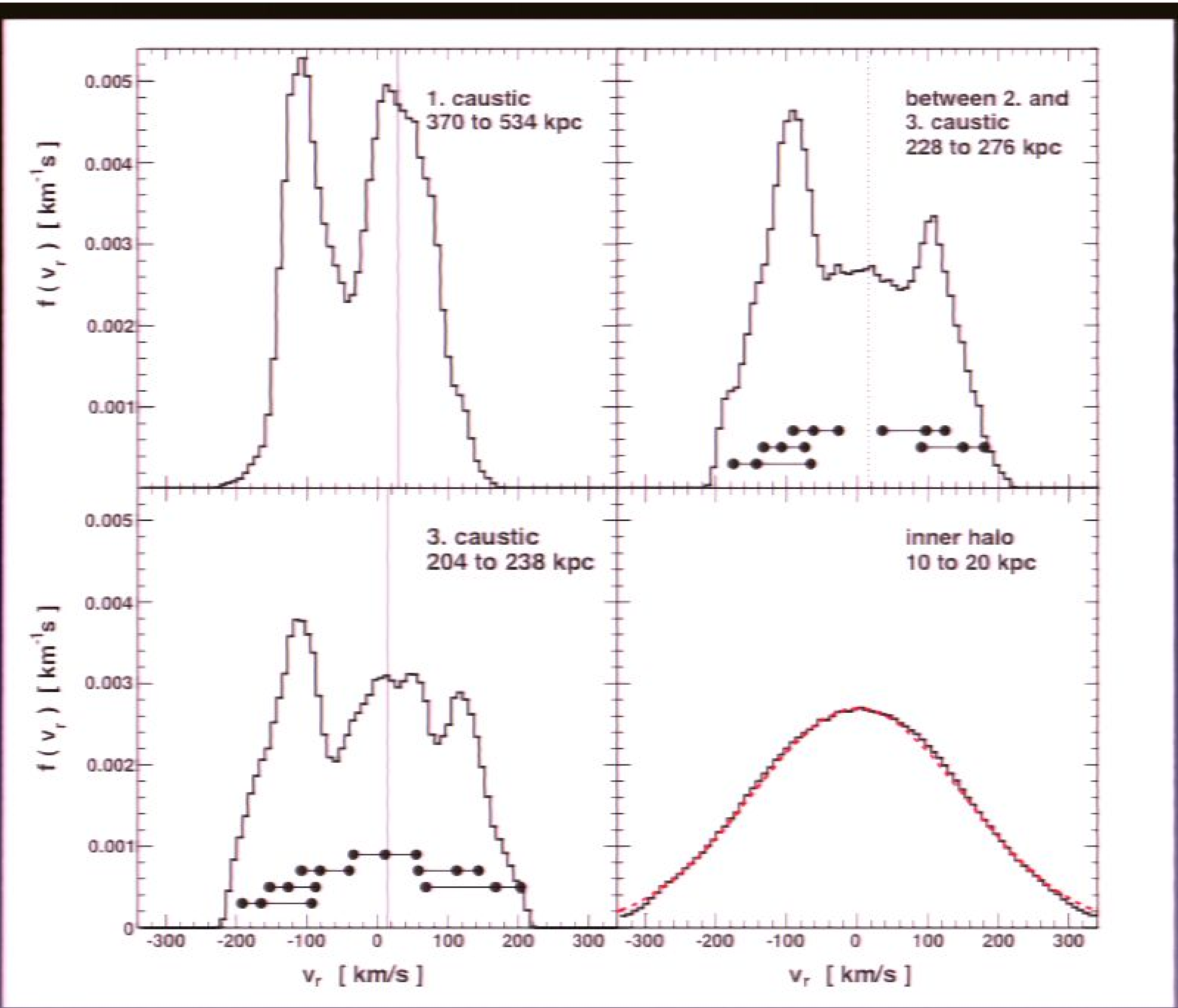
JD & Kuhlen, submitted to ApJL



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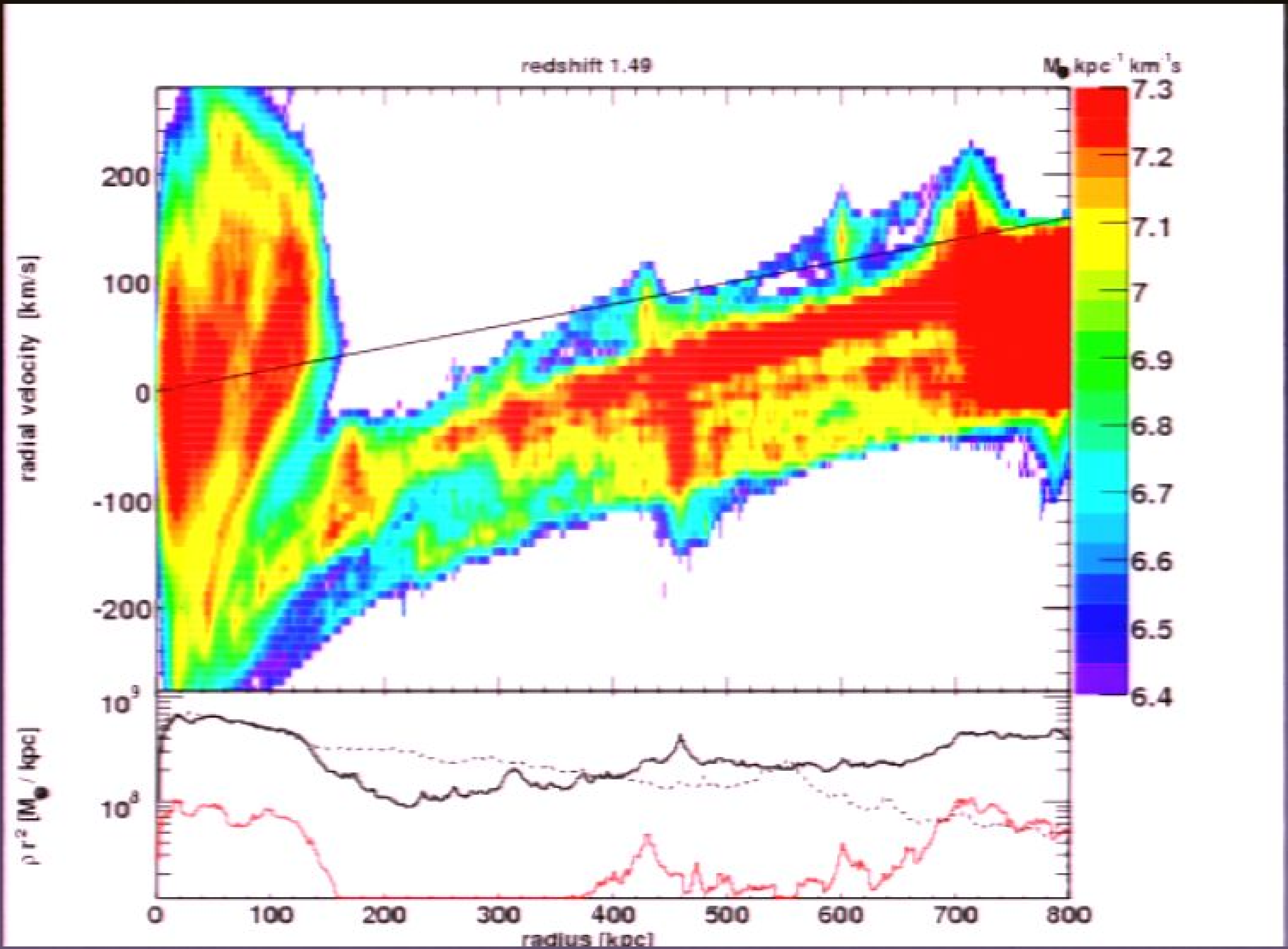

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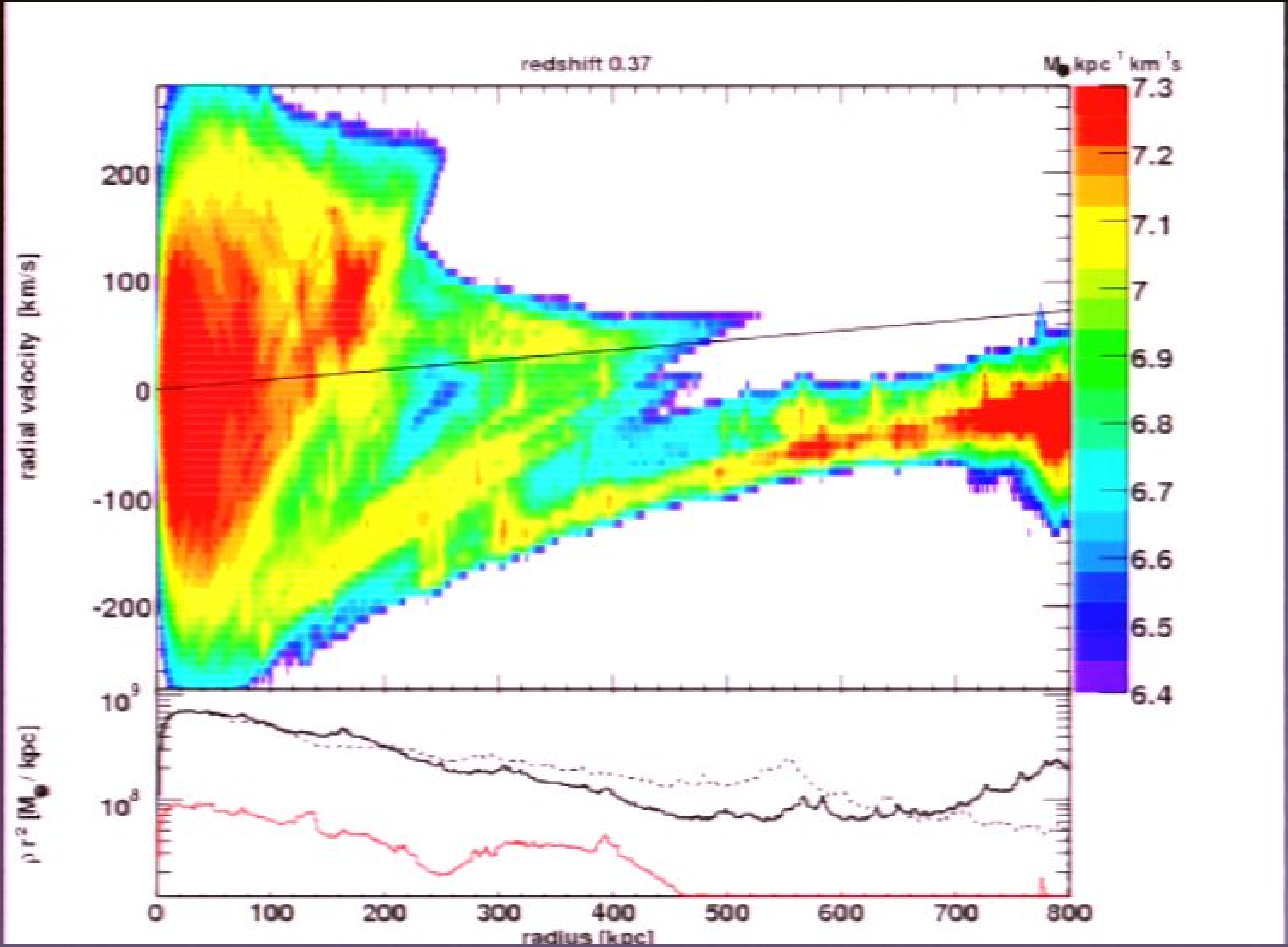

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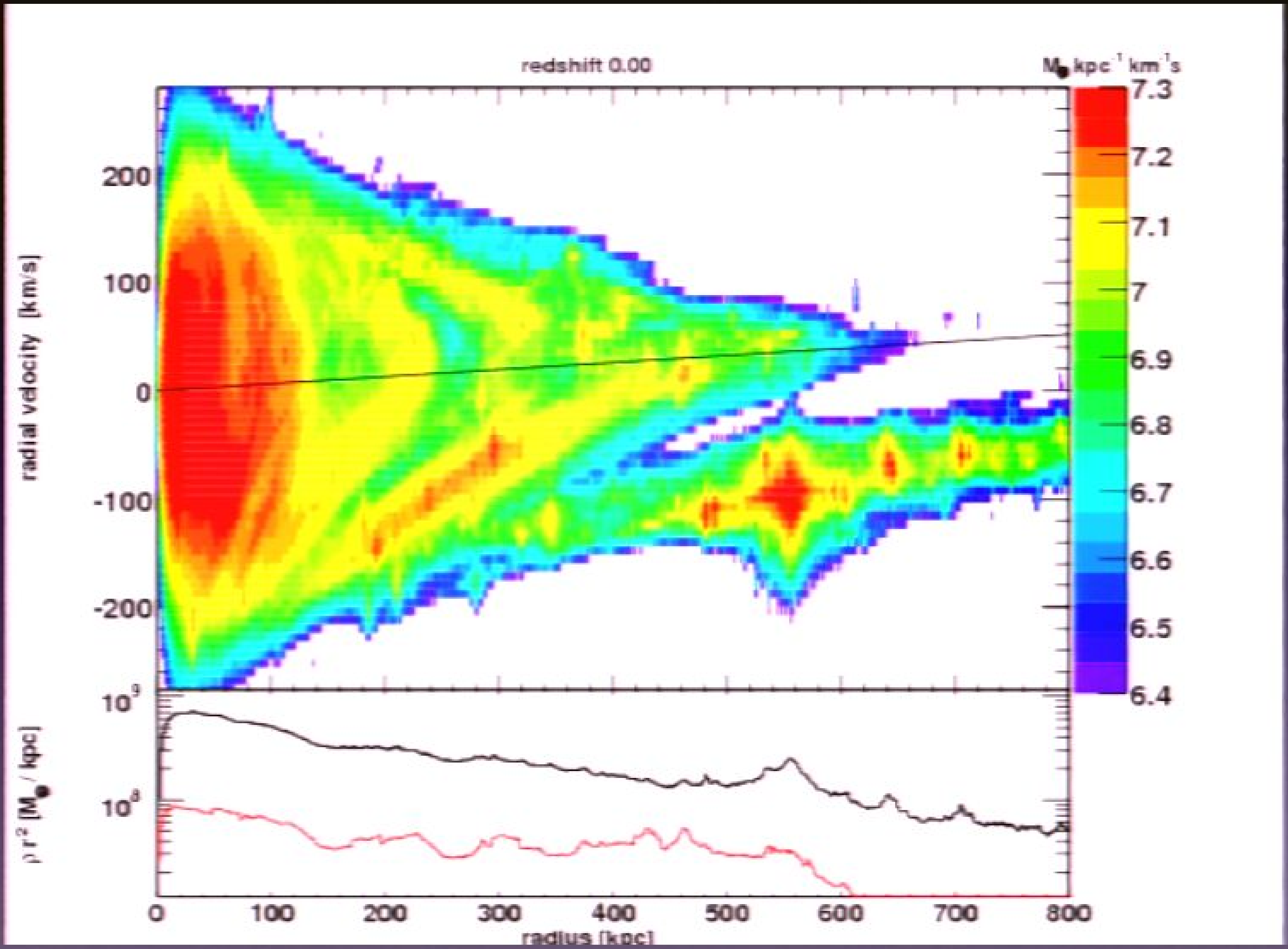

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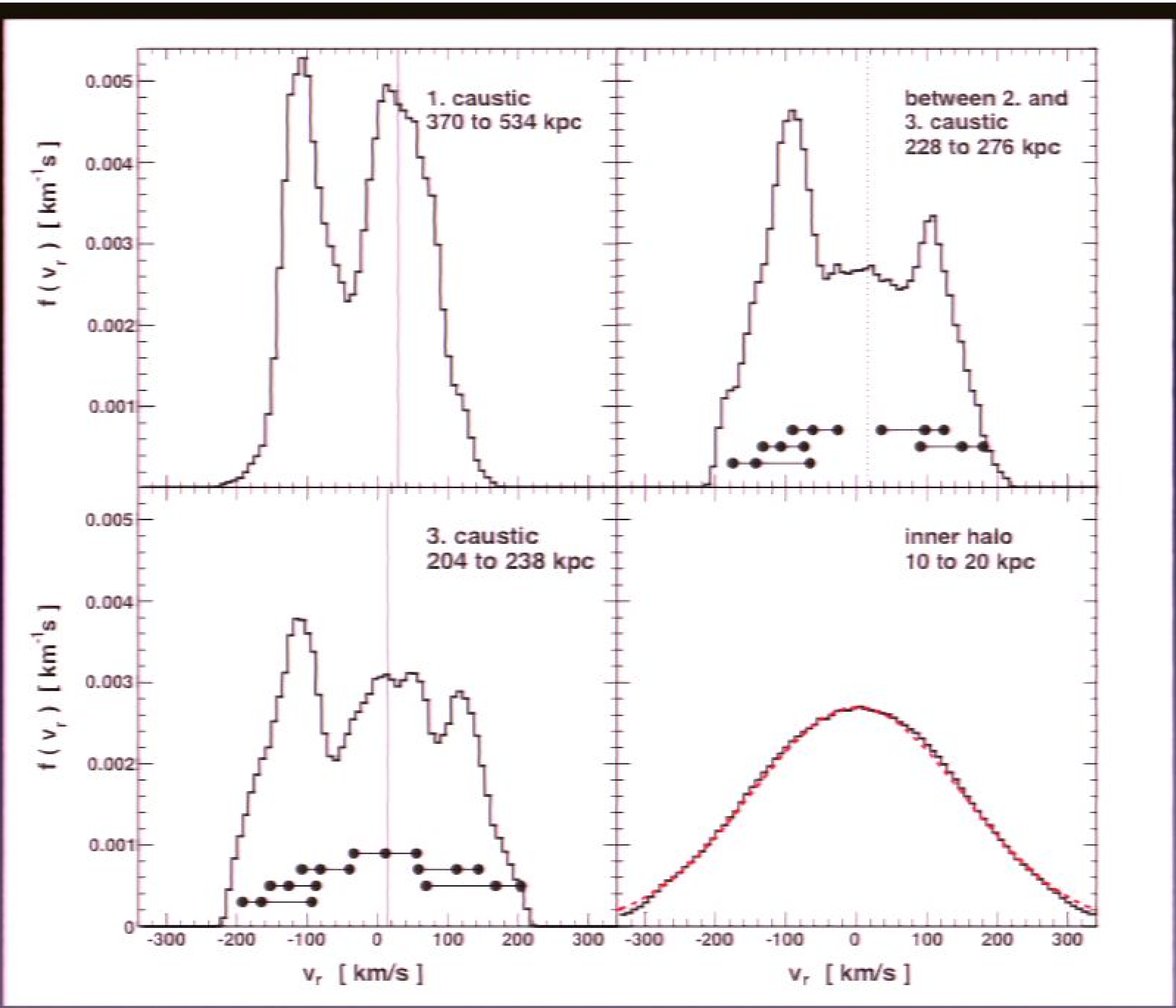

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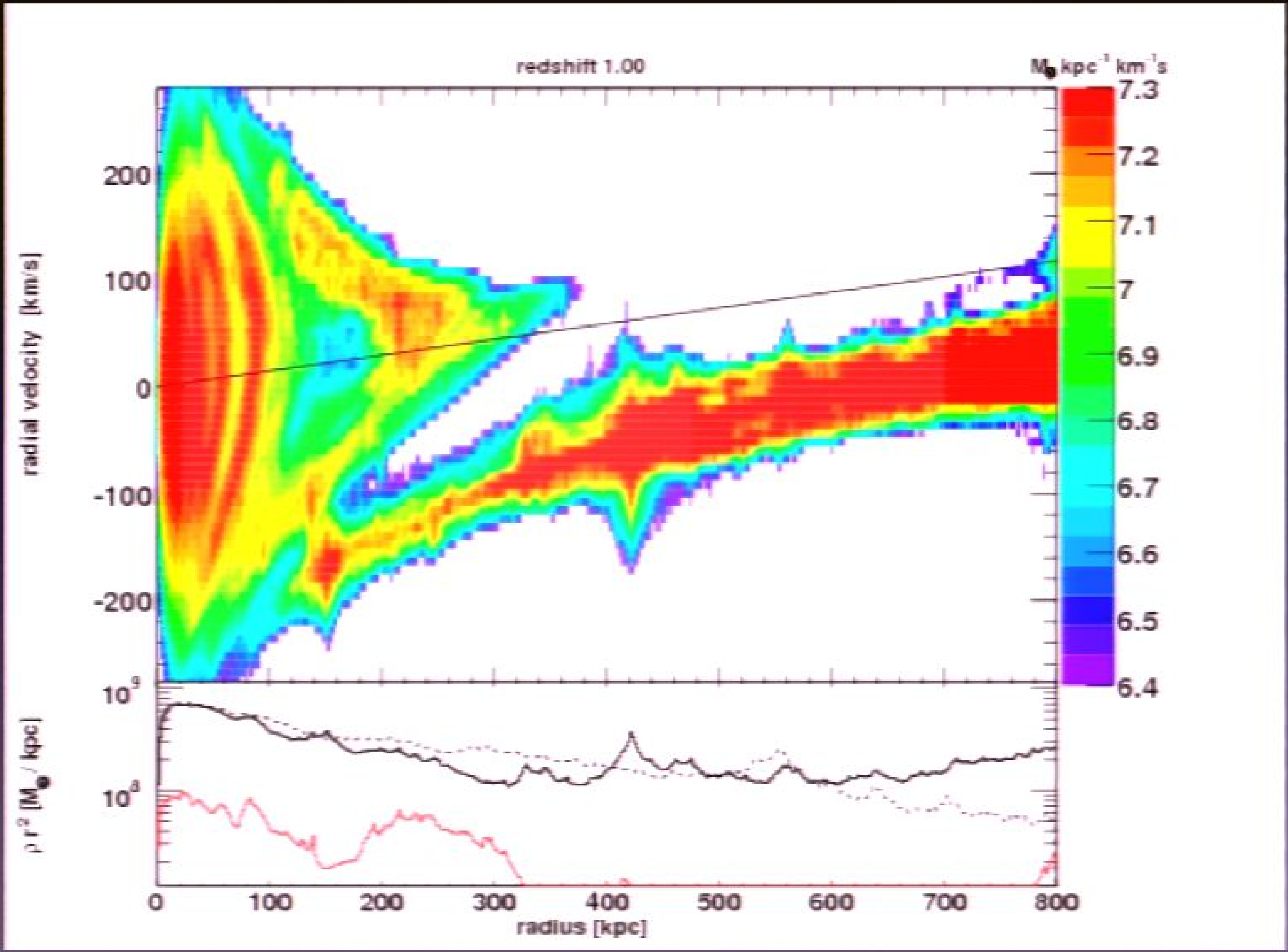

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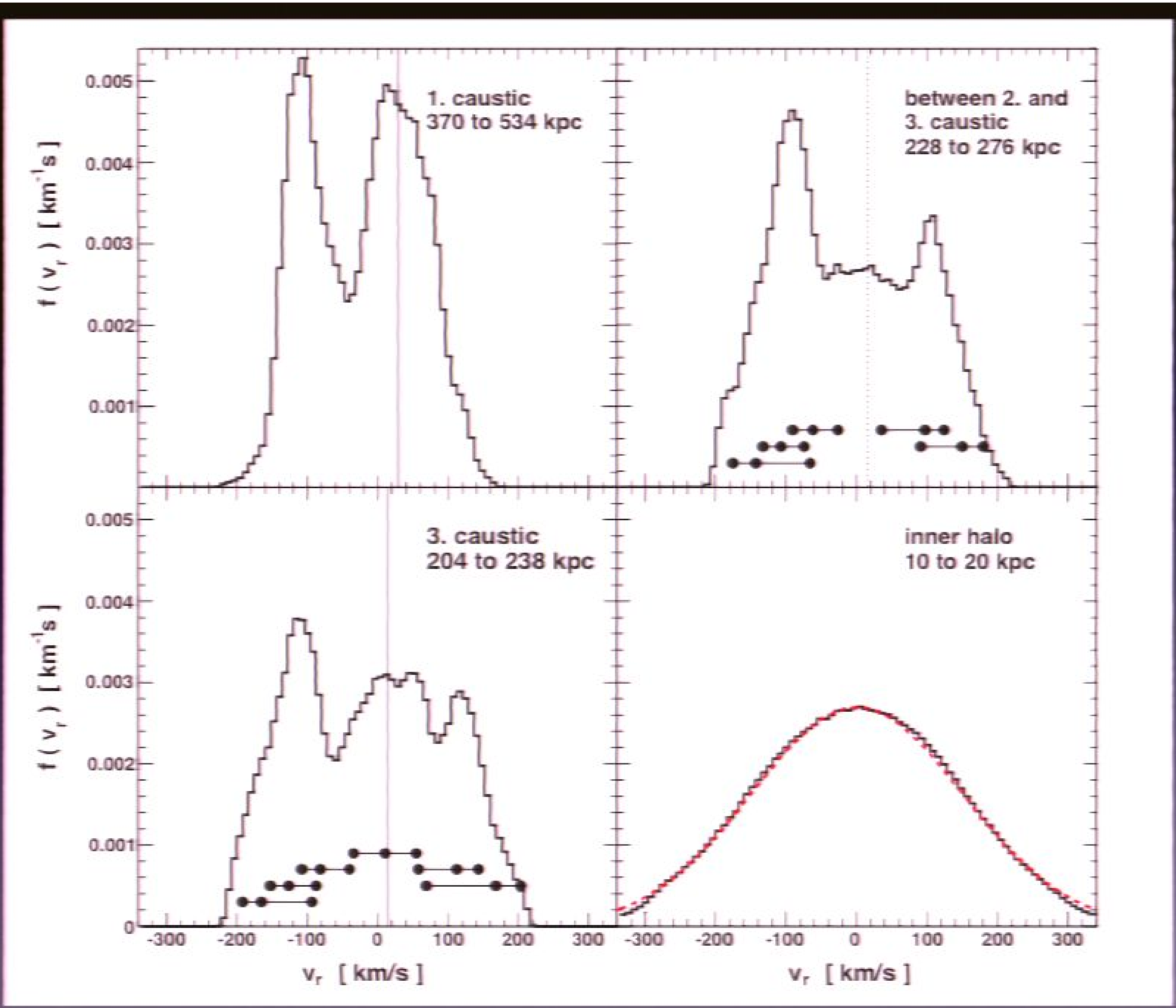

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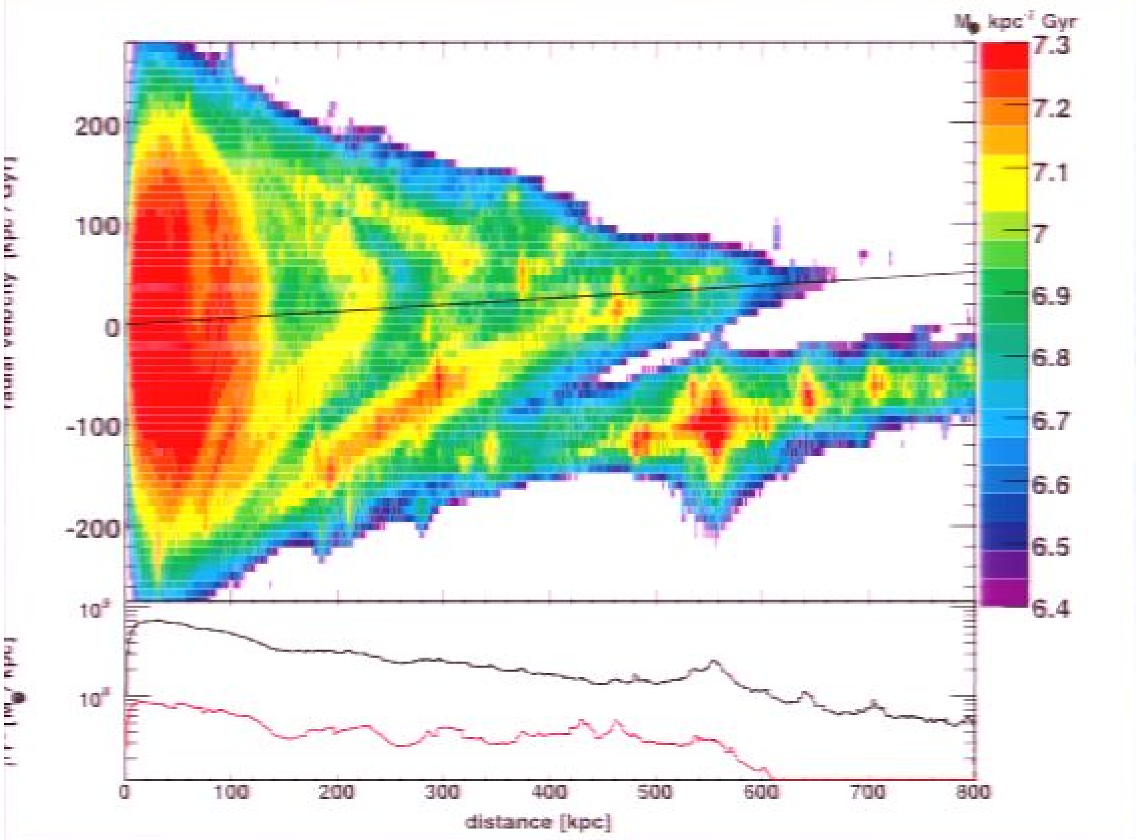

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spherical radial top-hat collapse : problems

- Press-Schechter mass function does not fit simulated "virial" mass functions well

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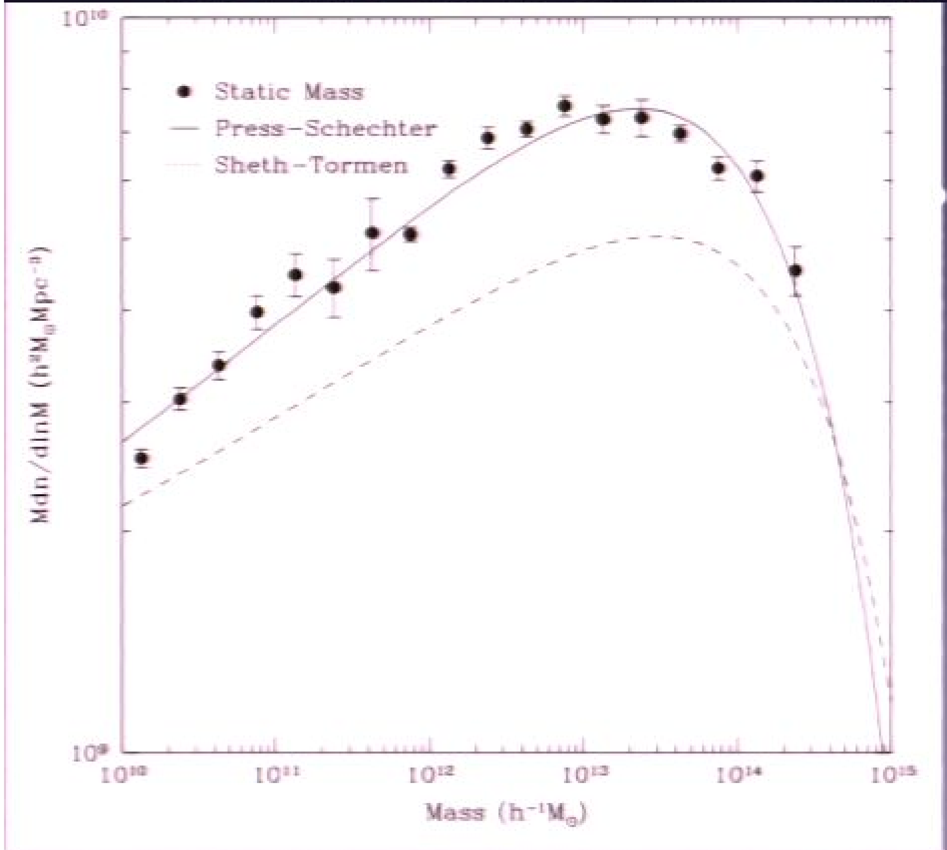
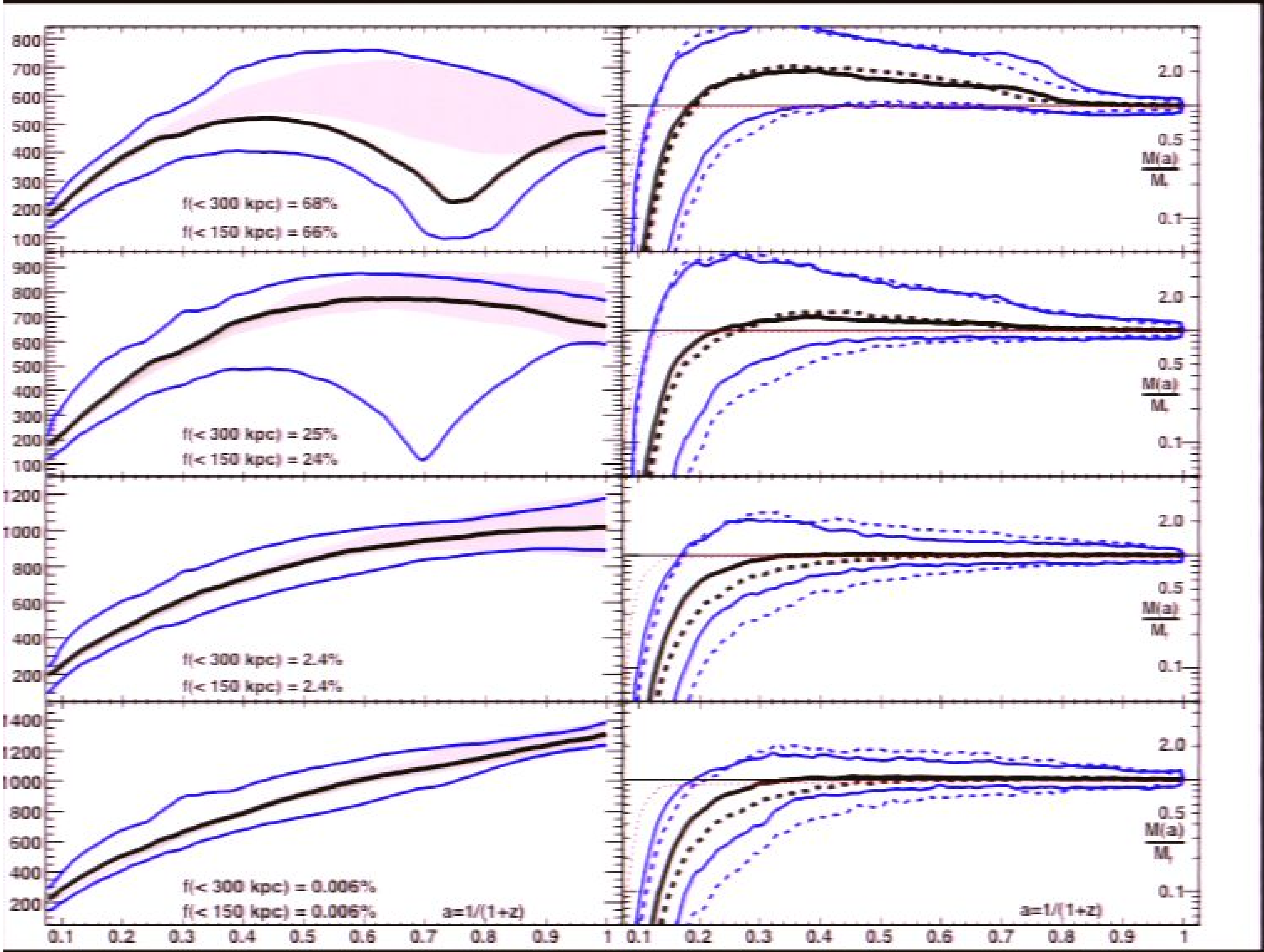


- BUT: Press-Schechter matches simulated "stationary" mass function (Cuesta,Prada,Klypin,Morales2008)

suggest that collapse factors leading to "M_vir" were the main problem, and not the assumed spherical symmetry

average subhalo tracks

ins 7 to 10 (beyond r_{200})



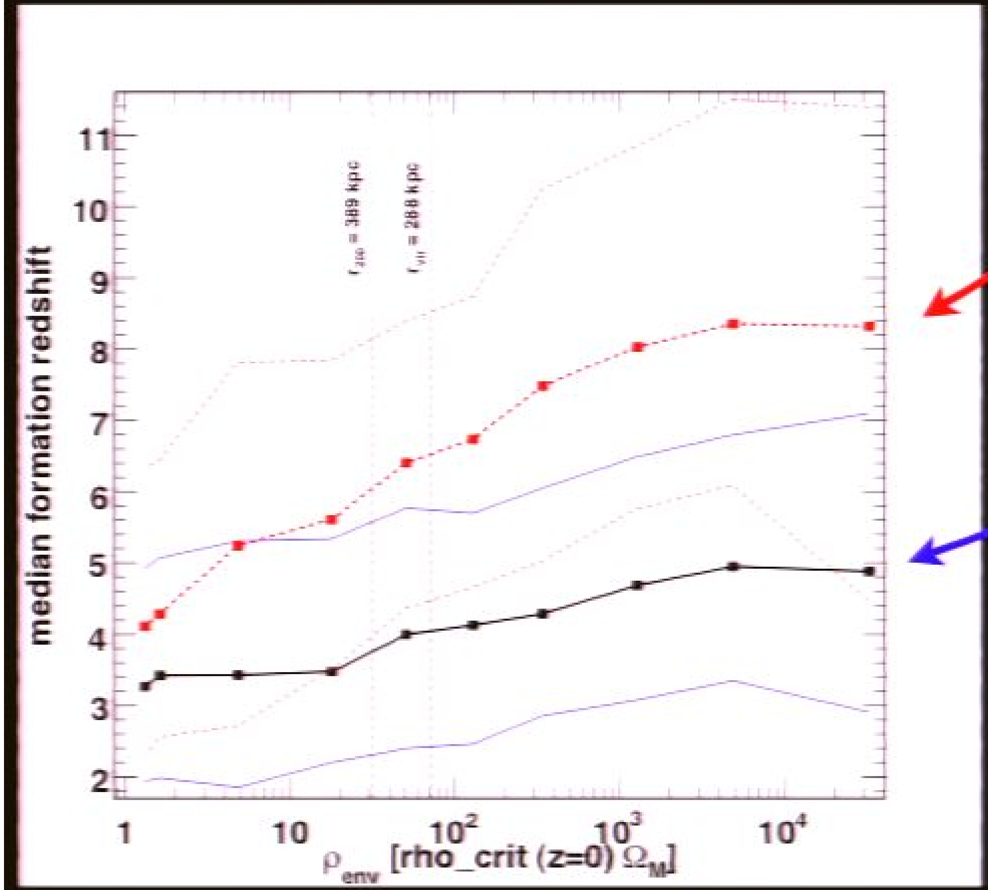
many of these “field” halos were inside the host halo earlier

they have lost mass

these former subhalos have formed very early, when formation times are defined relative to the z=0 mass or Vmax

JD, Kuhlen, Madau, 2007

(sub)halo formation times



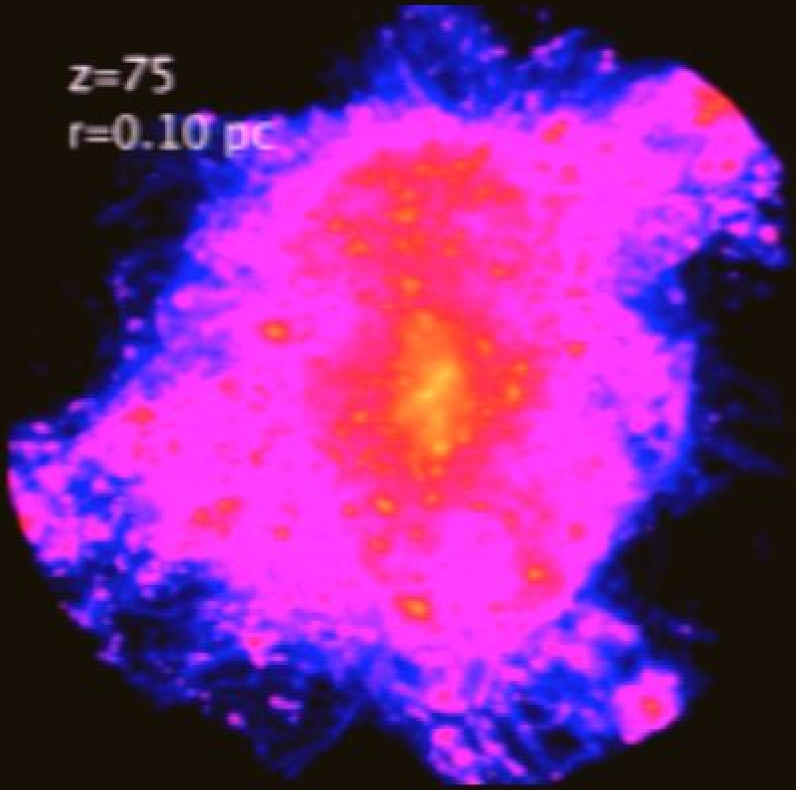
z_{85} (def. relative to z=0)
strong trend with environment
also for field halos

z_f (def. relative maximal size)
weak trend with environment
and only for subhalos

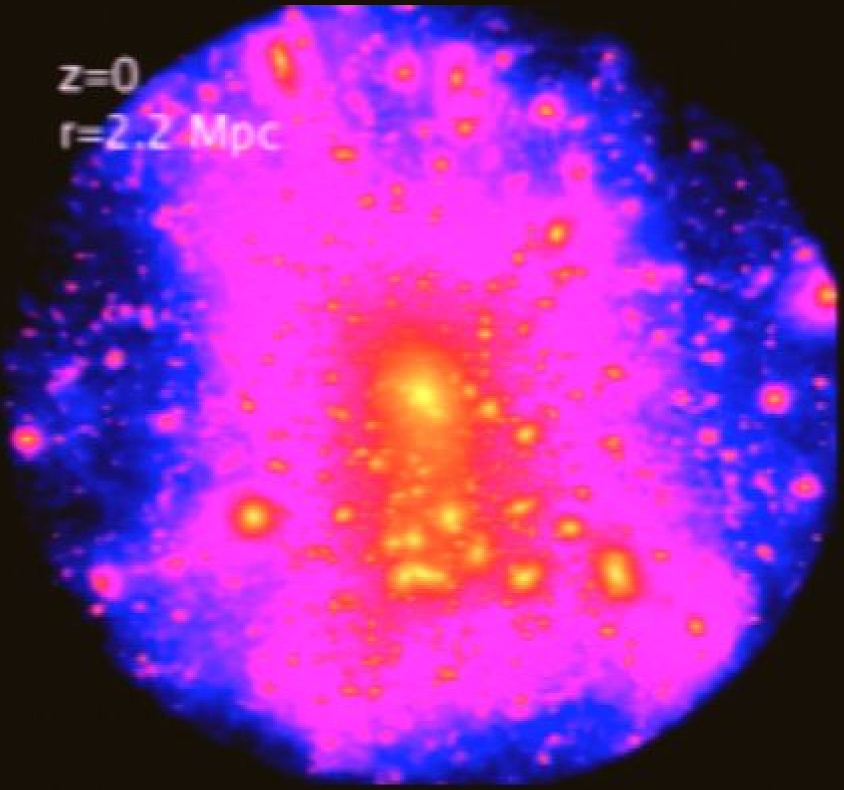
assembly histories of sub M*-field halos does depend on environment:
oldest ones more strongly clustered (Gao, Springel & White 2005)
earlier formation in dense environments (Harker et al 2006)

defining formation times relative to size **before** tidal mass loss removes most of the trend in the formation times, but the assembly histories still depend on environment

CDM forms (sub)structures on many scales



M ~ 0.01 Msun microhalo

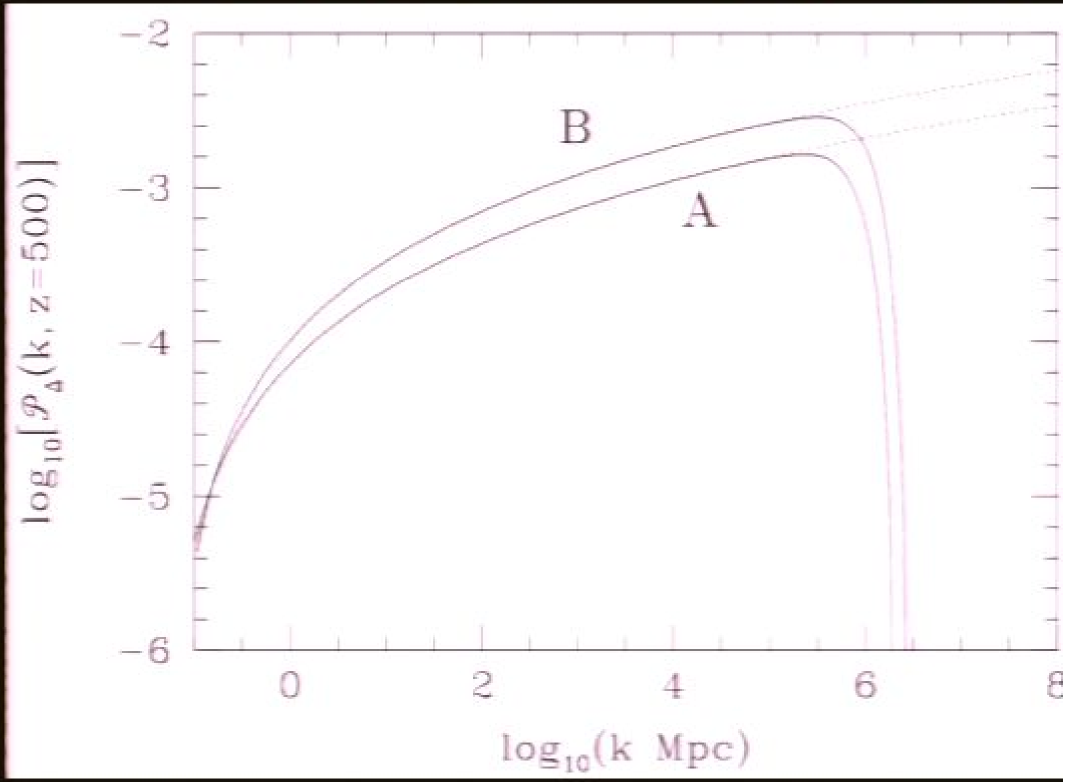


M=6e14 Msun galaxy cluster

smallest scale CDM structures in the field

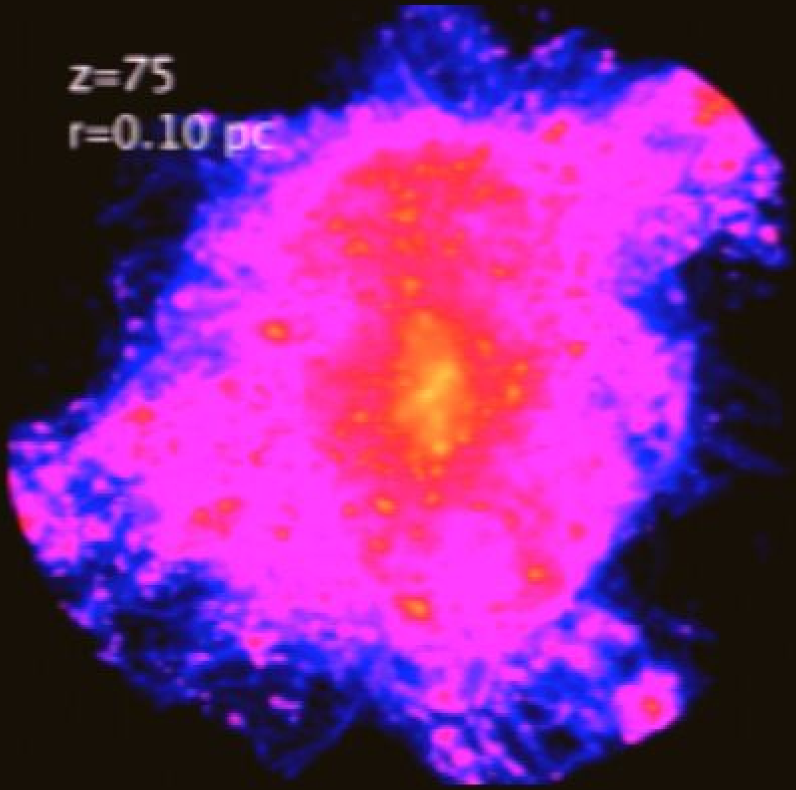
For a 100 GeV SUSY neutralino (a WIMP) there is a cutoff at about 10^{-6} Msun due to free streaming

from Green, Hoffmann & Schwarz 2003



small, “micro”-halos should forming around z=40 are the first and smallest CDM structures

CDM forms (sub)structures on many scales



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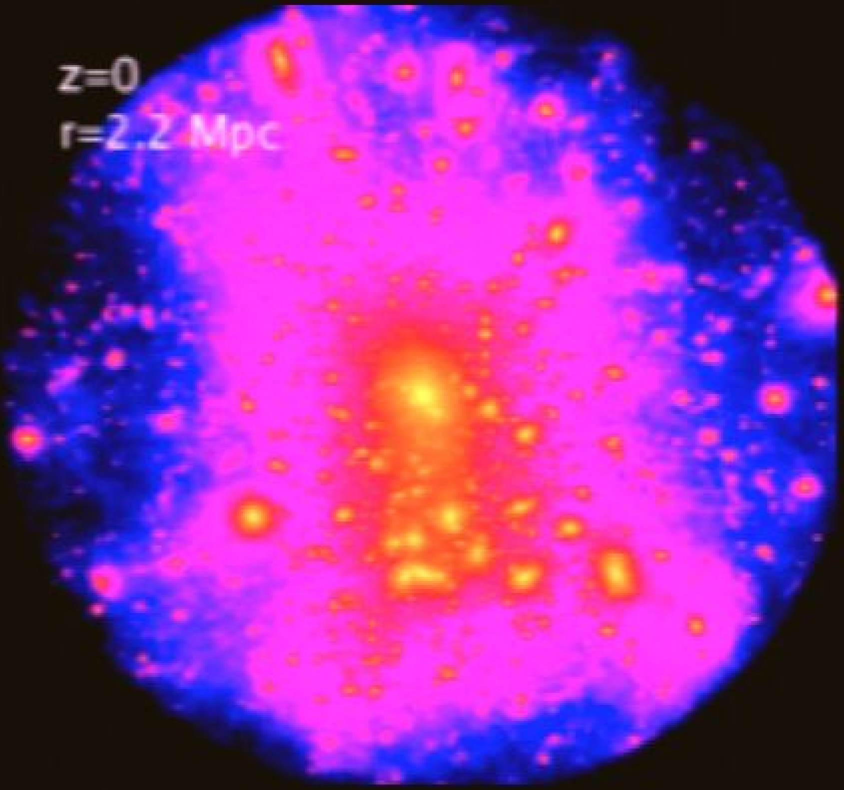

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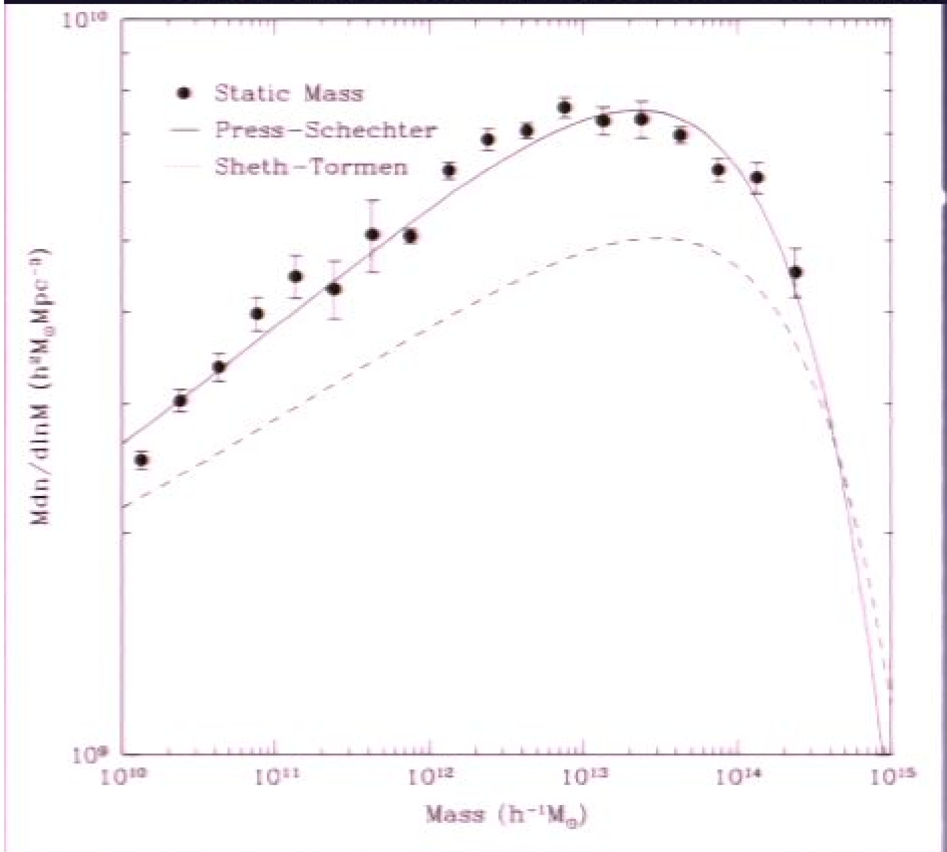

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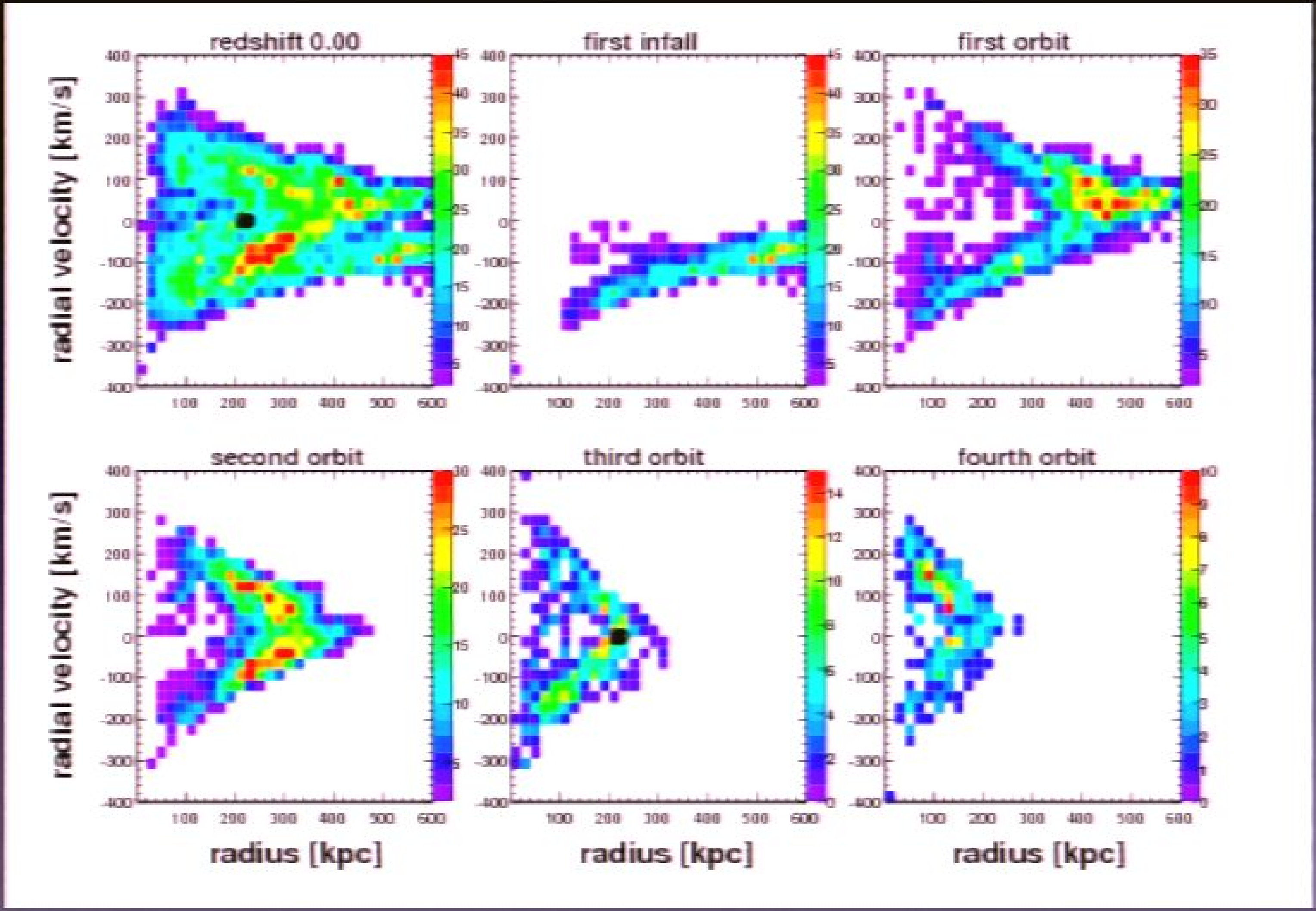
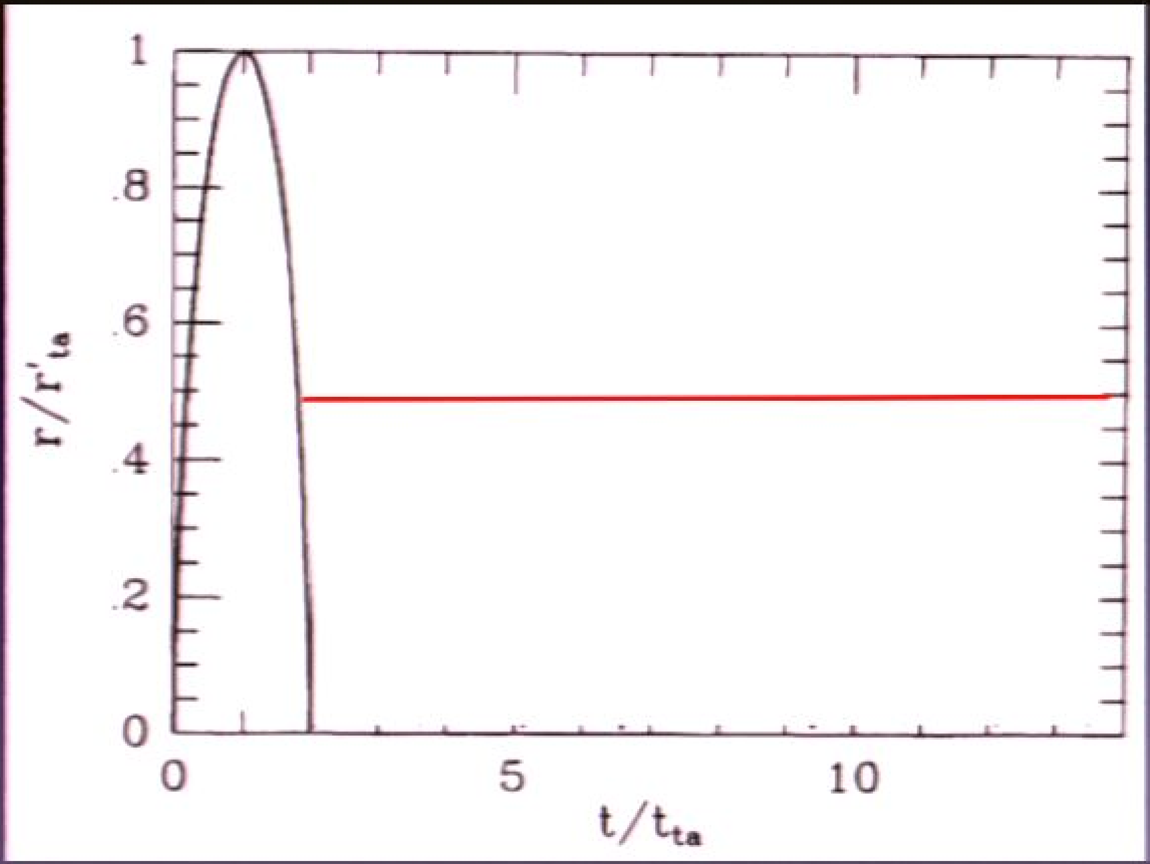


JD, Kuhlen, ApJL in press

2) how do halos accrete their mass?

spherical radial top-hat collapse



assumes virialisation at
half the turnaround radius

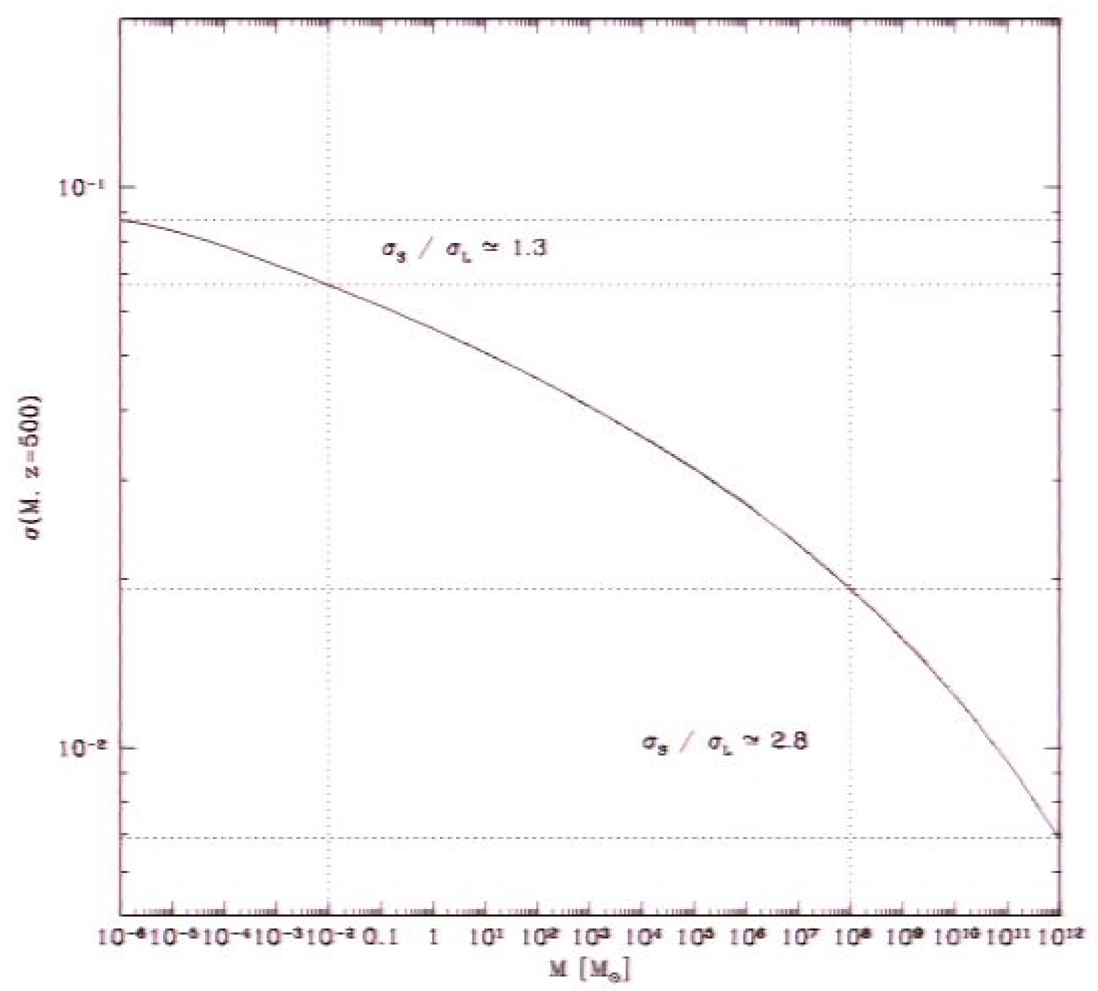
basis for definition of
virial radius:
r_178   for EdS
r_340   LambdaCDM z=
(contrast over mean
matter density)

(Gunn, Gott ... 1970ies)

smallest scale CDM substructures

since P(k) ~ $k^{-2.9}$
sigma(M) almost constant on microhalo scales

structures of different mass form almost simultaneous



summary

- CDM has structures and substructures on a wide range of scales

- most (97%) subhalos survive from z=1 until today. smaller ones loose less mass

- galaxy halos are assembled early in a series of mergers. the later “slow” accretion is mostly apparent accretion caused by the comoving definitions of Mvir and M200

- Mvir and M200 fail because CDM halo formation differs strongly from the spherical tophat model. Press-Schechter fits *physical* mass function (Cuesta +2008)

- typical subhalo and particle orbits go out to nearly their turnaround radius, as in the classic secondary infall model. But dispersion in pos + vel prevents the formation of high density caustics

- assembly histories of sub M*-field halos depend on environment, because of earlier tidal interactions with nearby larger hosts