Title: Semi-analytic methods for ultra-high resolution dark matter calculations

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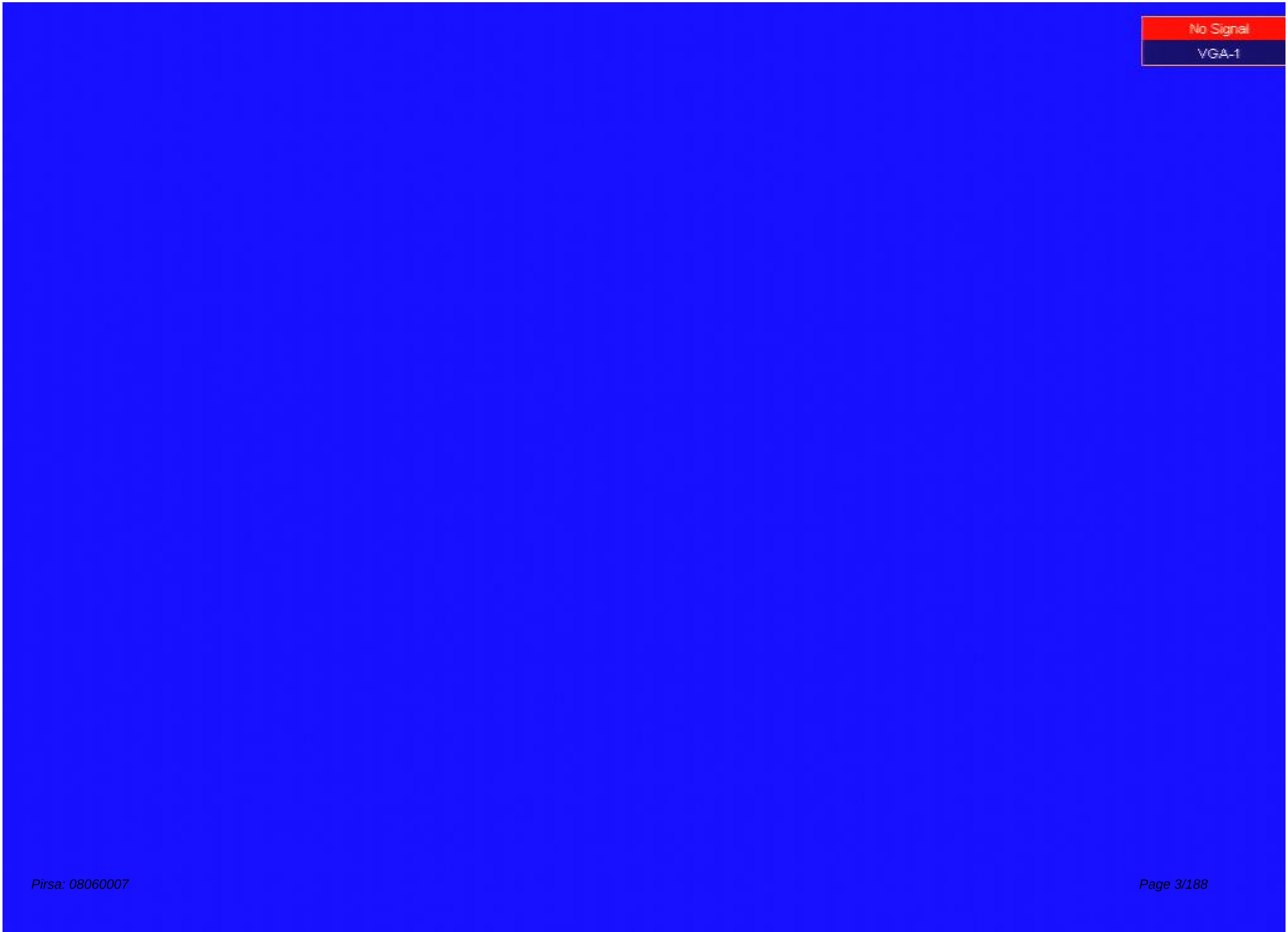
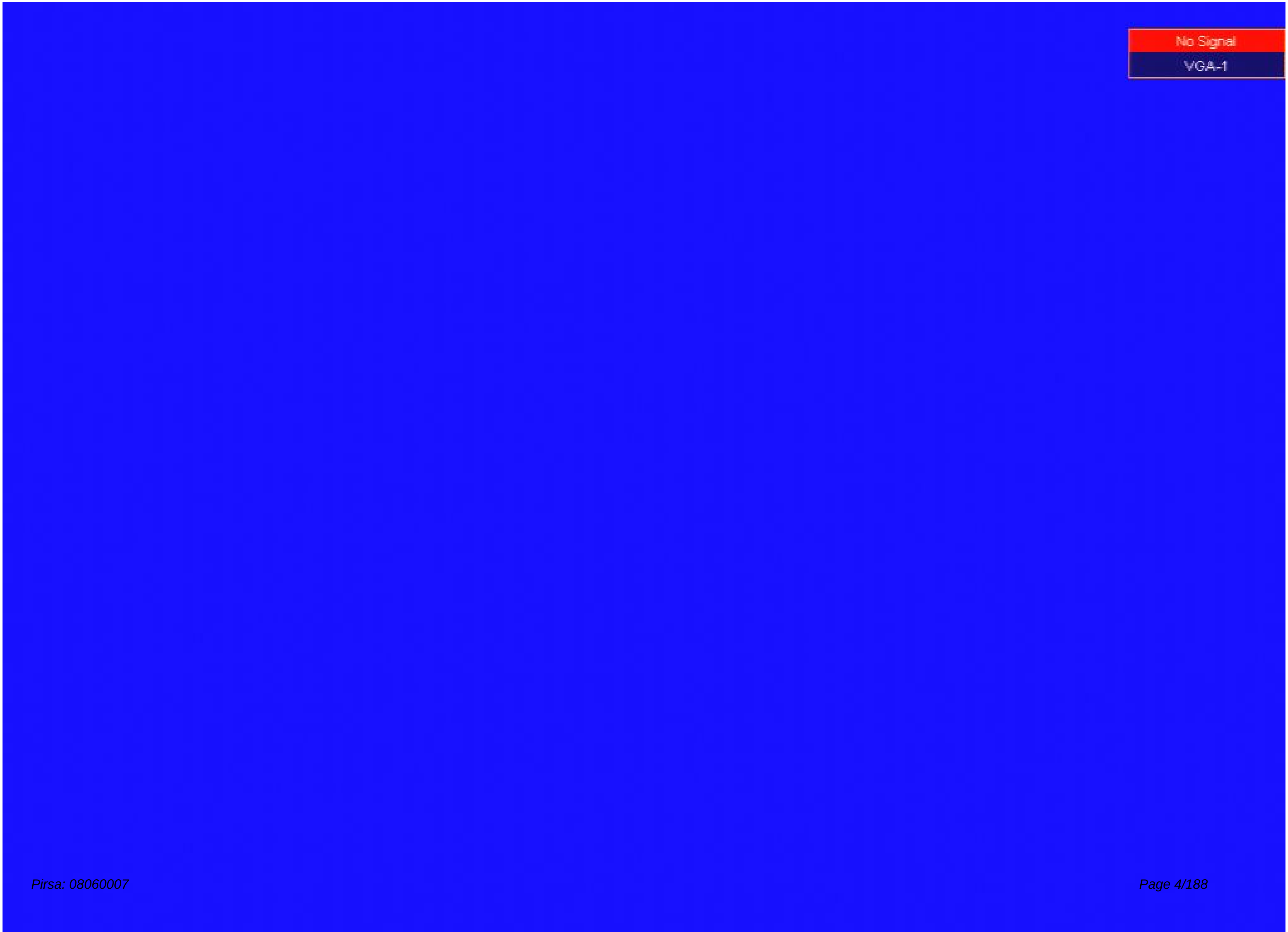
Abstract:

Semi-Analytic Methods for Ultra-High Resolution Dark Matter Calculations

Andrew Benson (Caltech)


No Signal
VGA-1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Semi-Analytic Methods for Ultra-High Resolution Dark Matter Calculations

Andrew Benson (Caltech)

Overview

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- Goals
- Semi-analytic modeling

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  - Why do we need it? (Do we need it.....)

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  - Orbits
  - Substructure etc. etc. etc.

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- Prospects and Outlook

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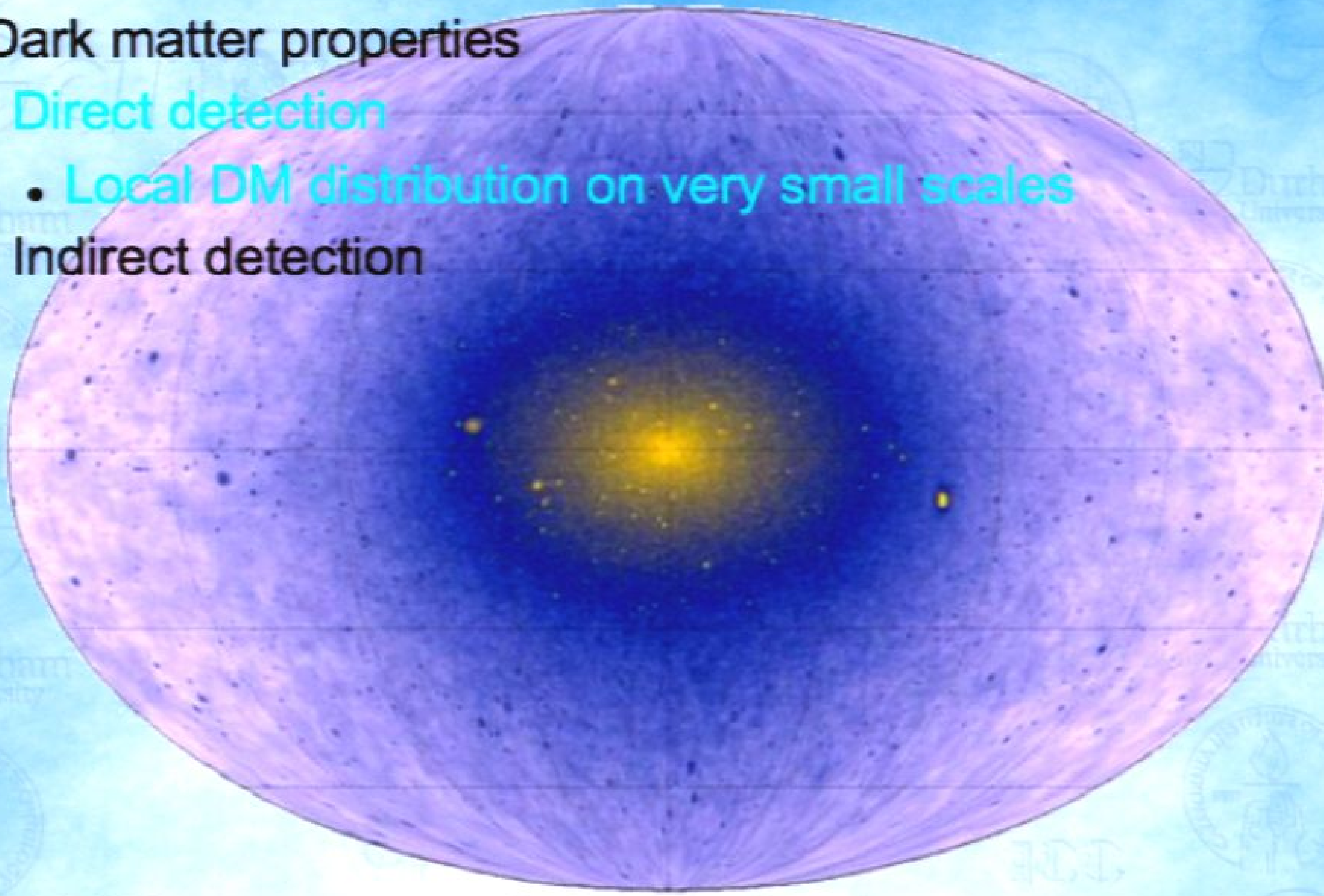

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    - Small-scale structure throughout the halo

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  - Interaction of substructure with disk
  - Prevalence of dwarf galaxies

Need for Semi-Analytic Calculations

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- Limitations of N-body approaches

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  - Statistics

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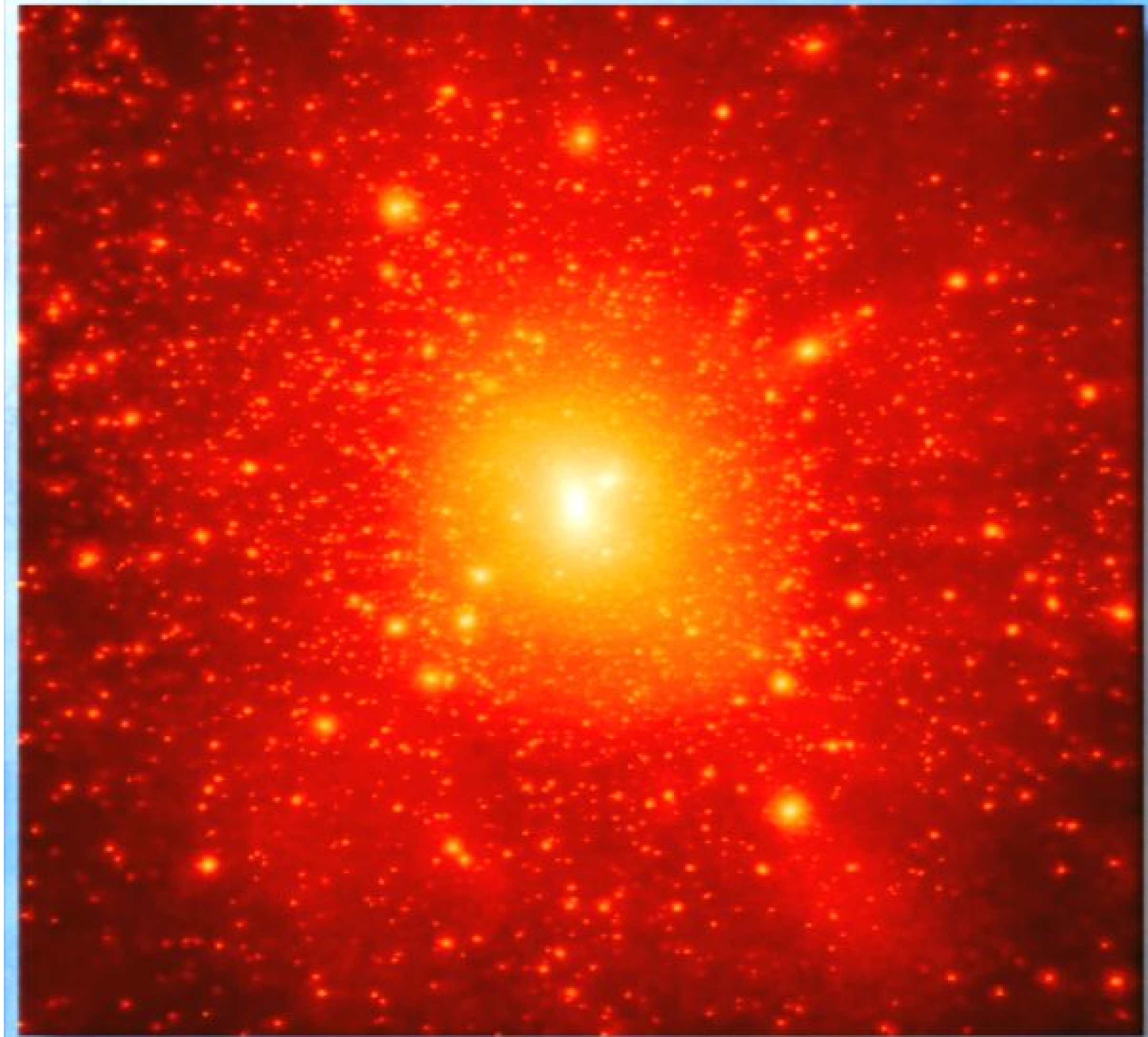
    - ....we don't know

Merger Trees

Merger Trees



- Halos form through merging of sub-units

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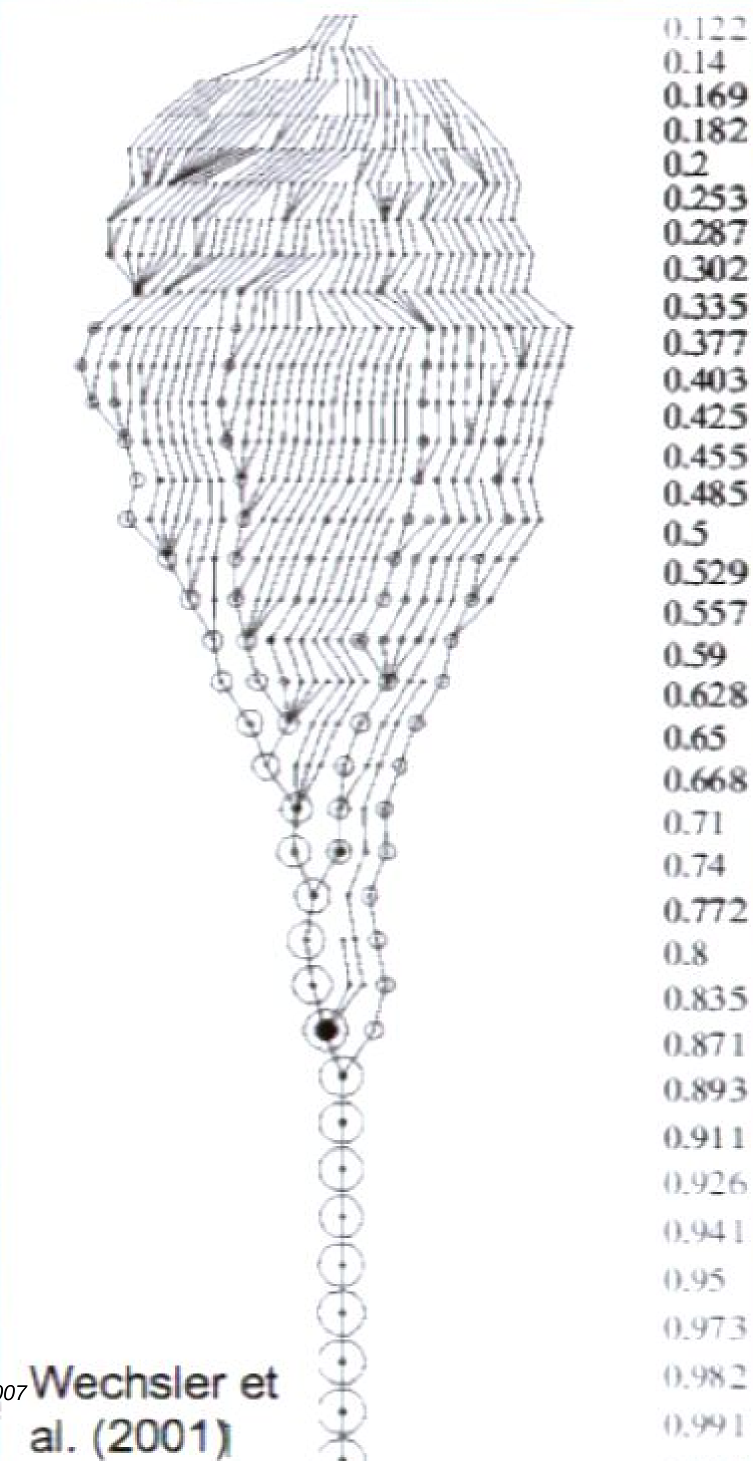

Wechsler et al. (2001)

- Halos form through merging of sub-units
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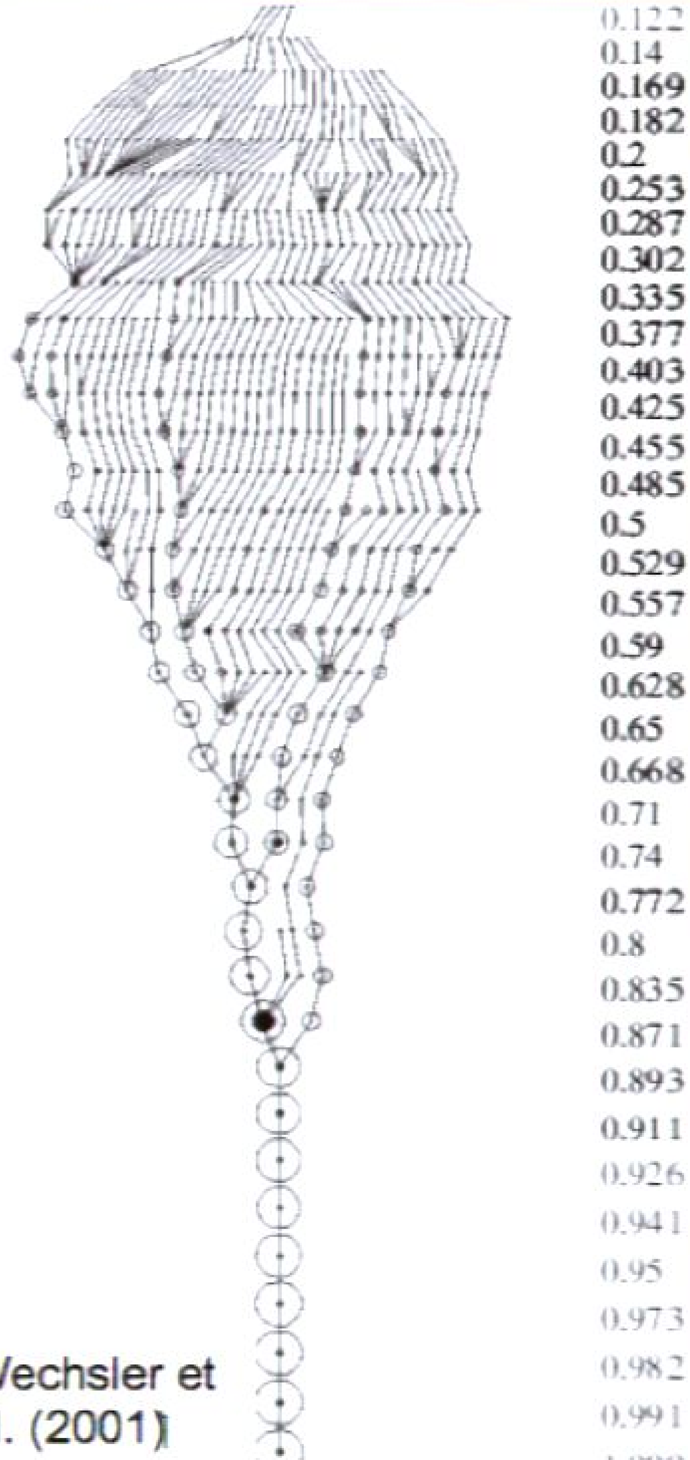

Wechsler et al. (2001)

- Halos form through merging of sub-units
- Process of merging described by merger trees
- Extended Press-Schechter (or better) can be used to construct these statistically

Accurate Merger Tree Construction

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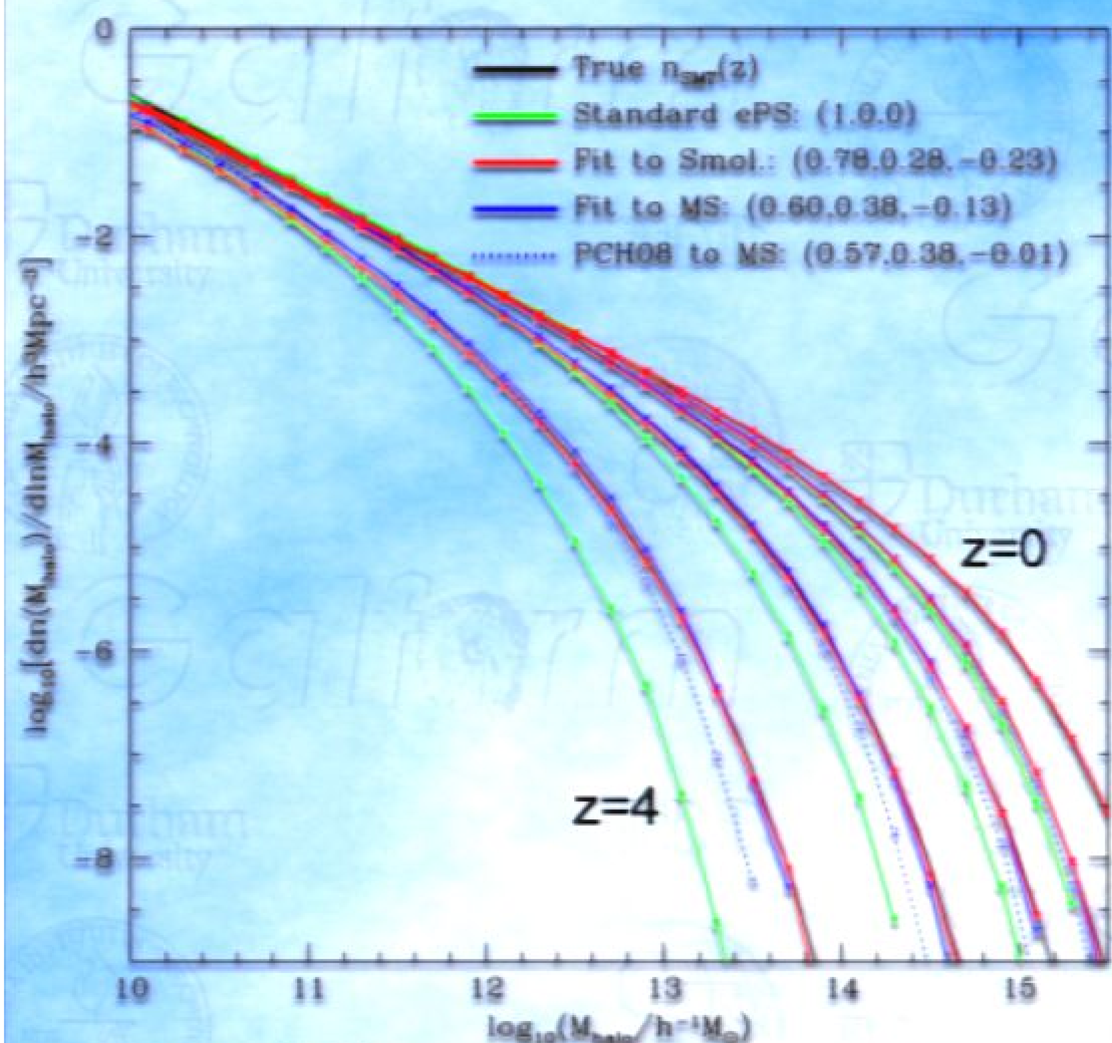
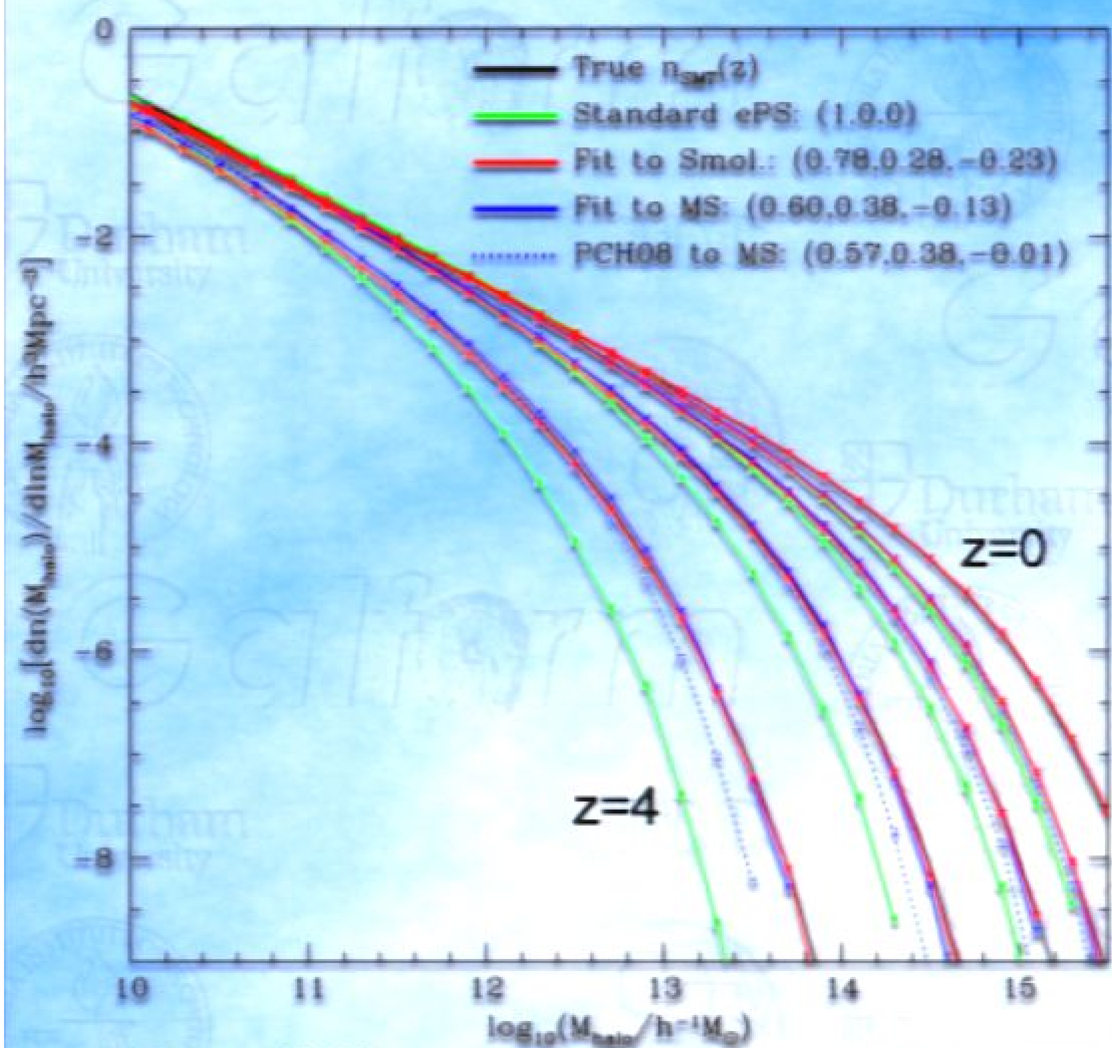


Benson (2008)

- Derive merger rates by fitting to N-body conditional mass functions....

Accurate Merger Tree Construction



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No Signal
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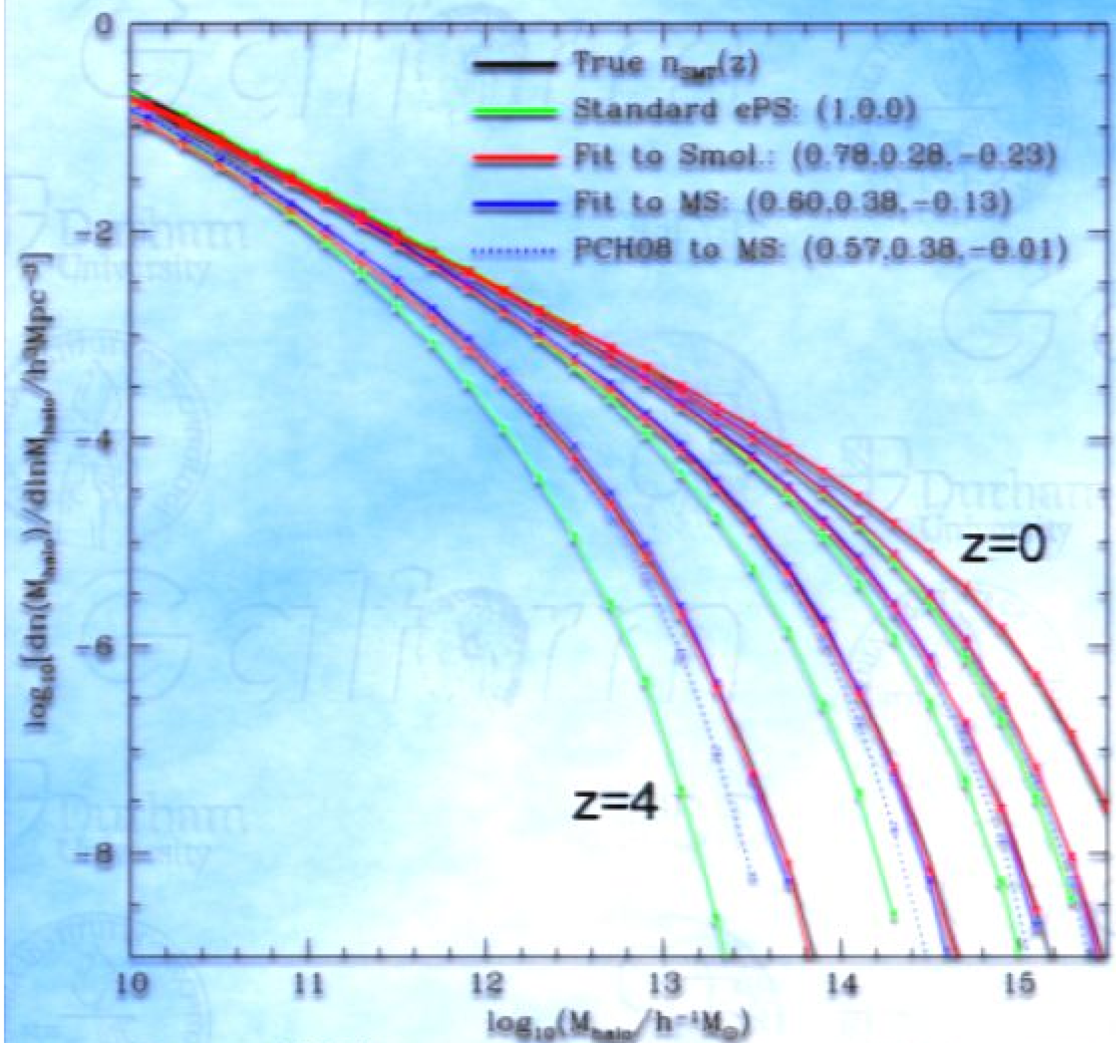

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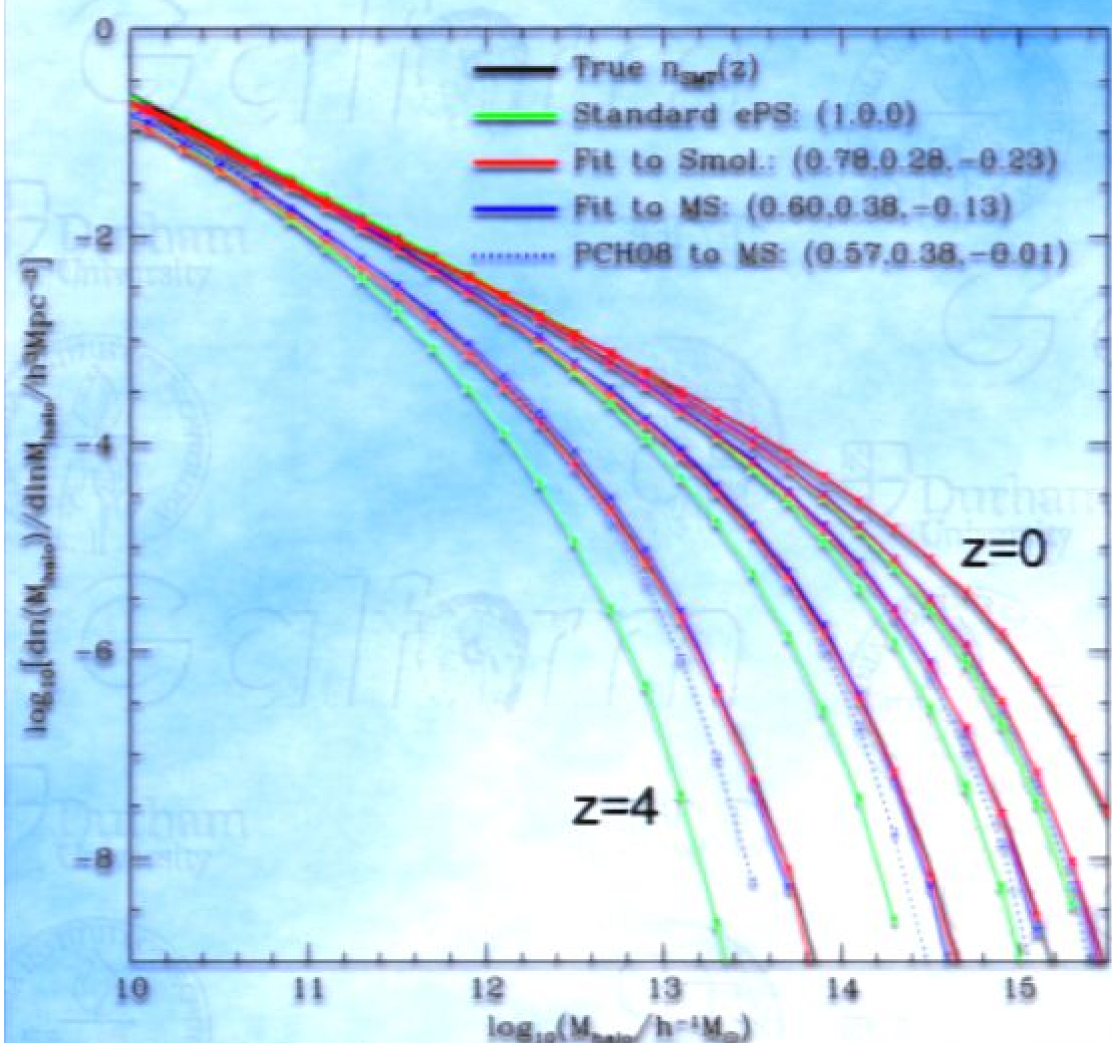

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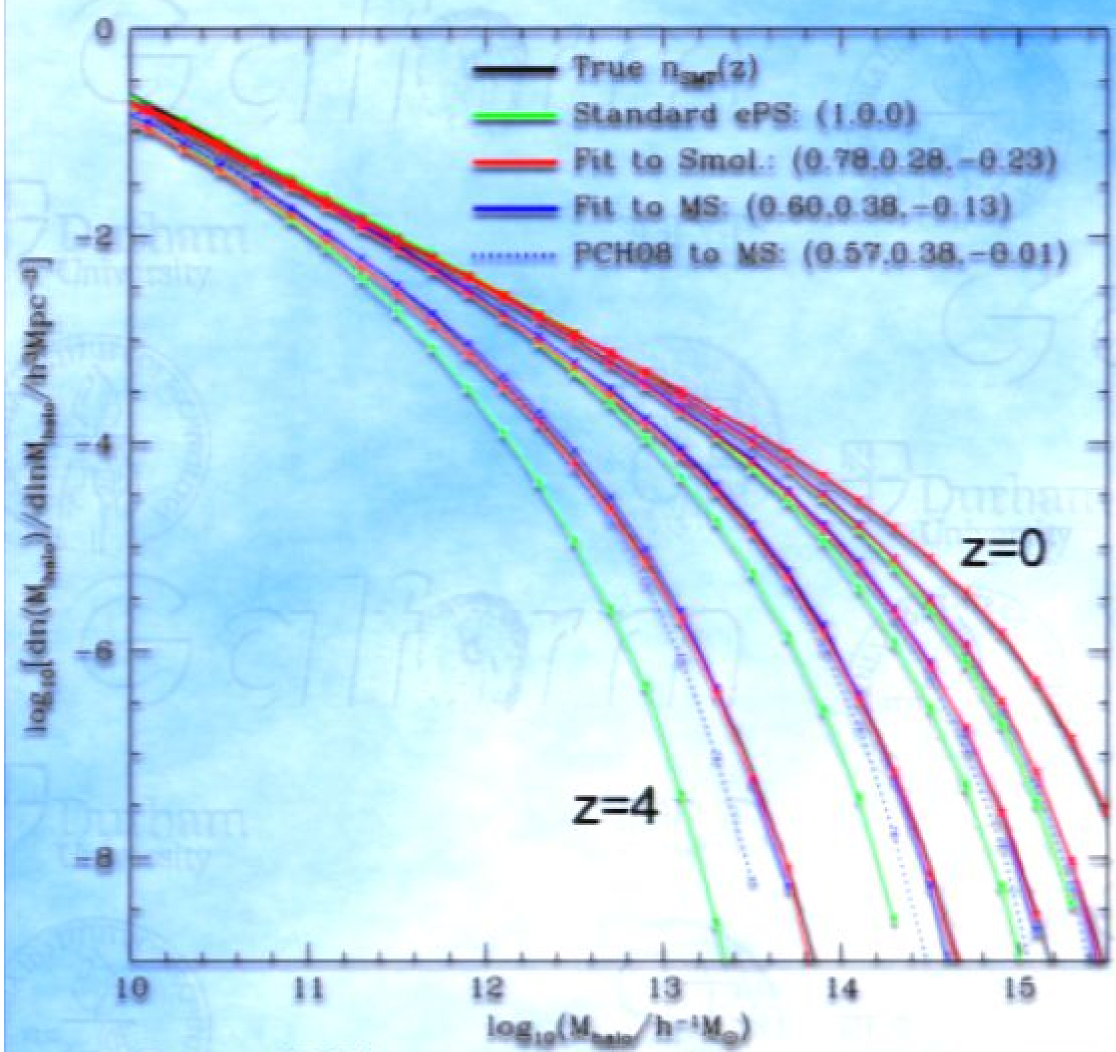


Benson (2008)

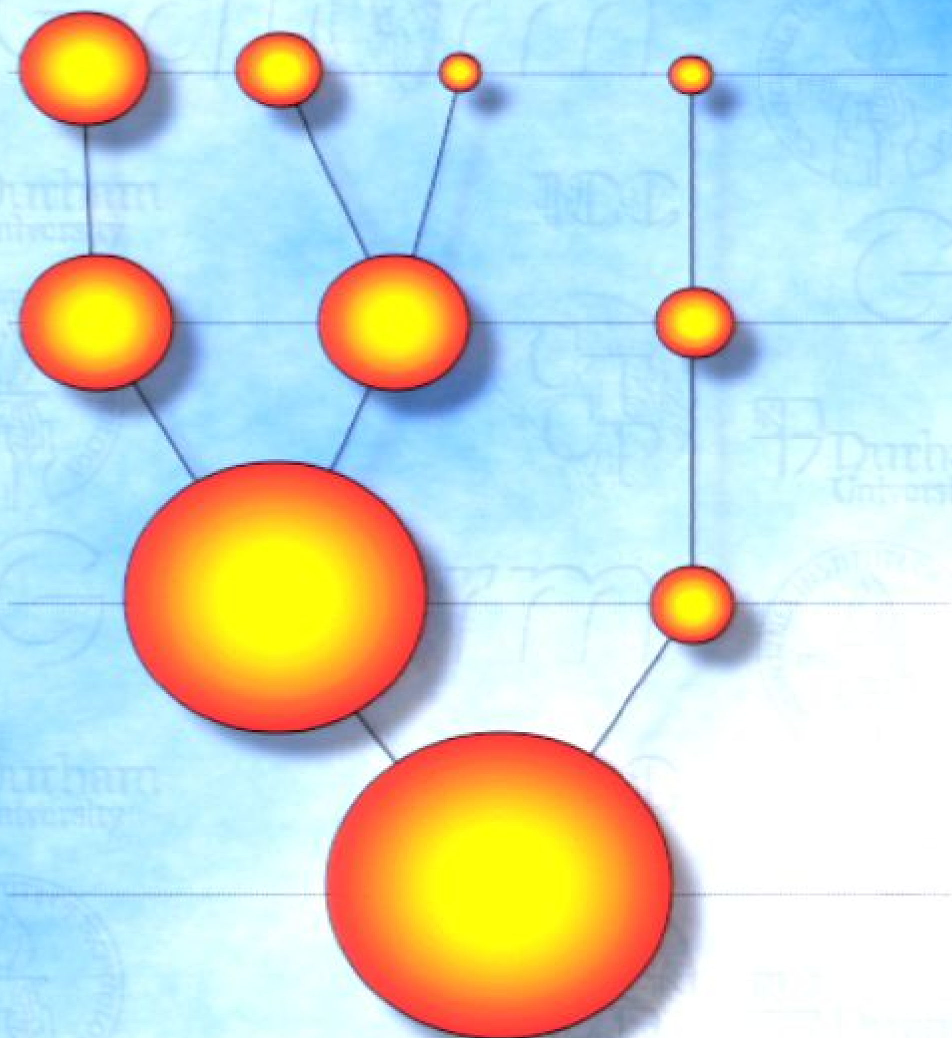
- Derive merger rates by fitting to N-body conditional mass functions....
- ....and requiring them to solve Smoluchowski's equation
- Evolve Sheth-Tormen mass function over large redshift intervals
- New fits work extremely well, even for very low abundance halos

Adaptive Merger Trees

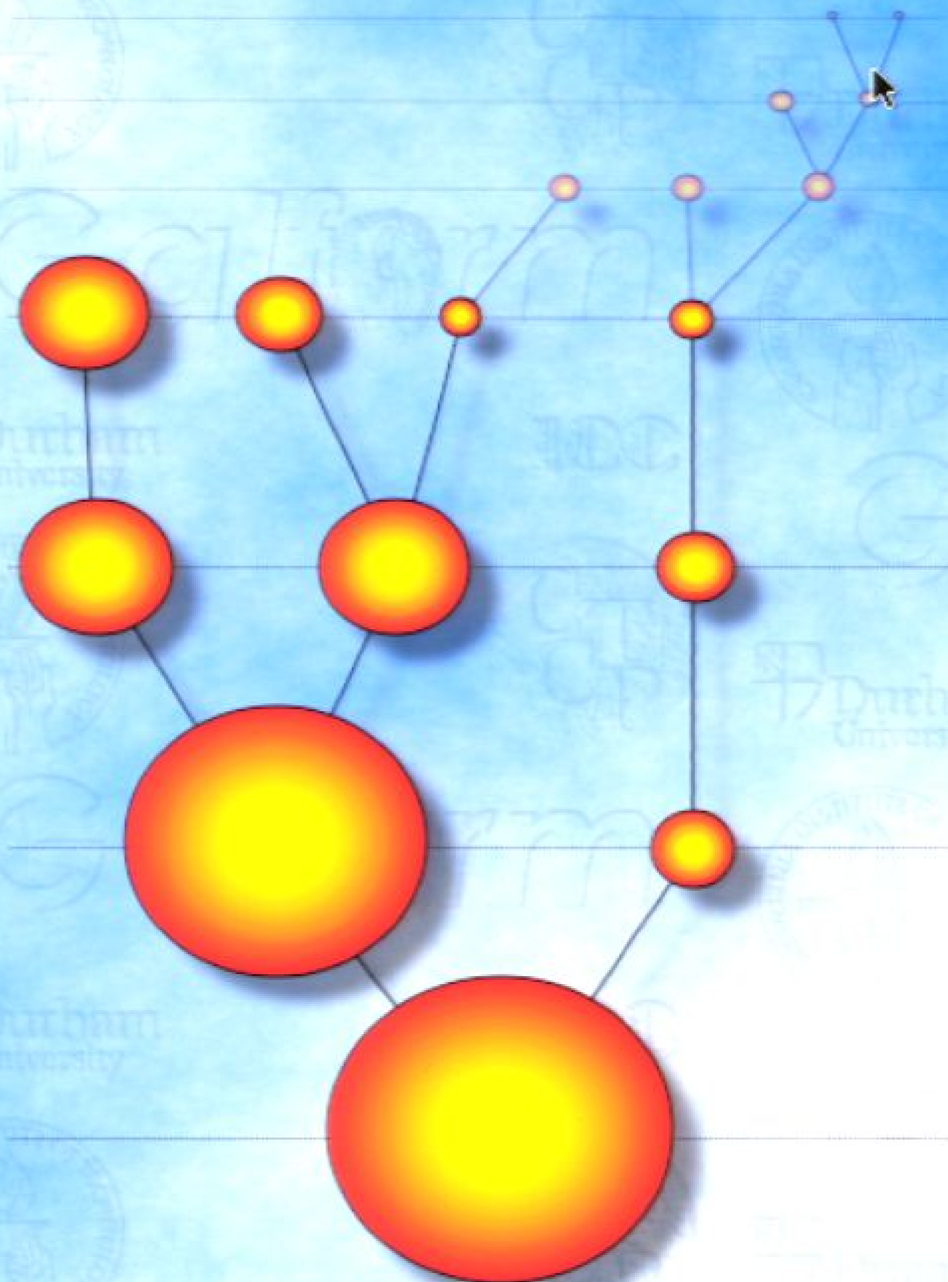
Adaptive Merger Trees

- Ultra-high resolution can be reached in some branches

Adaptive Merger Trees



- Ultra-high resolution can be reached in some branches
- Traditional method



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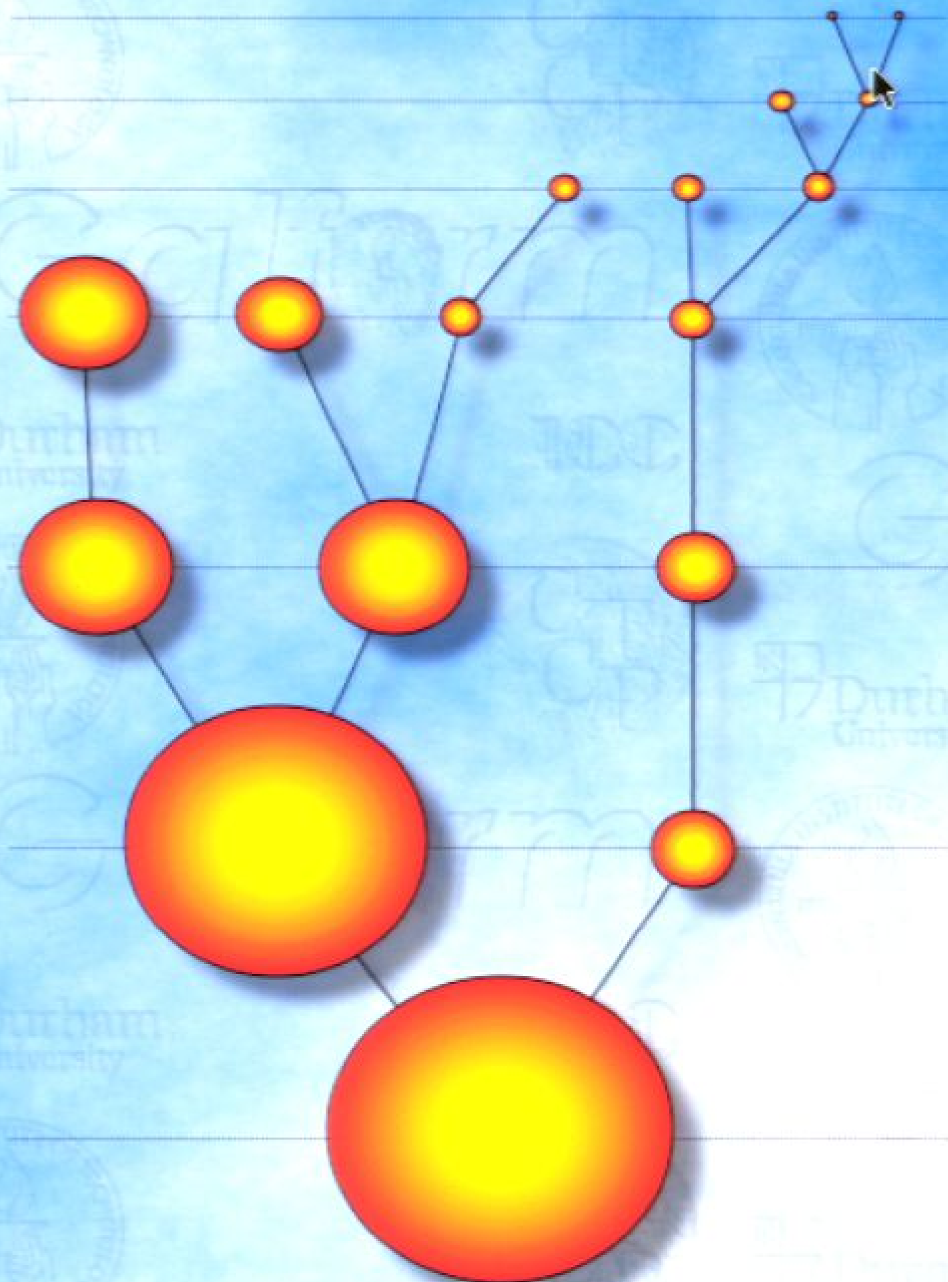

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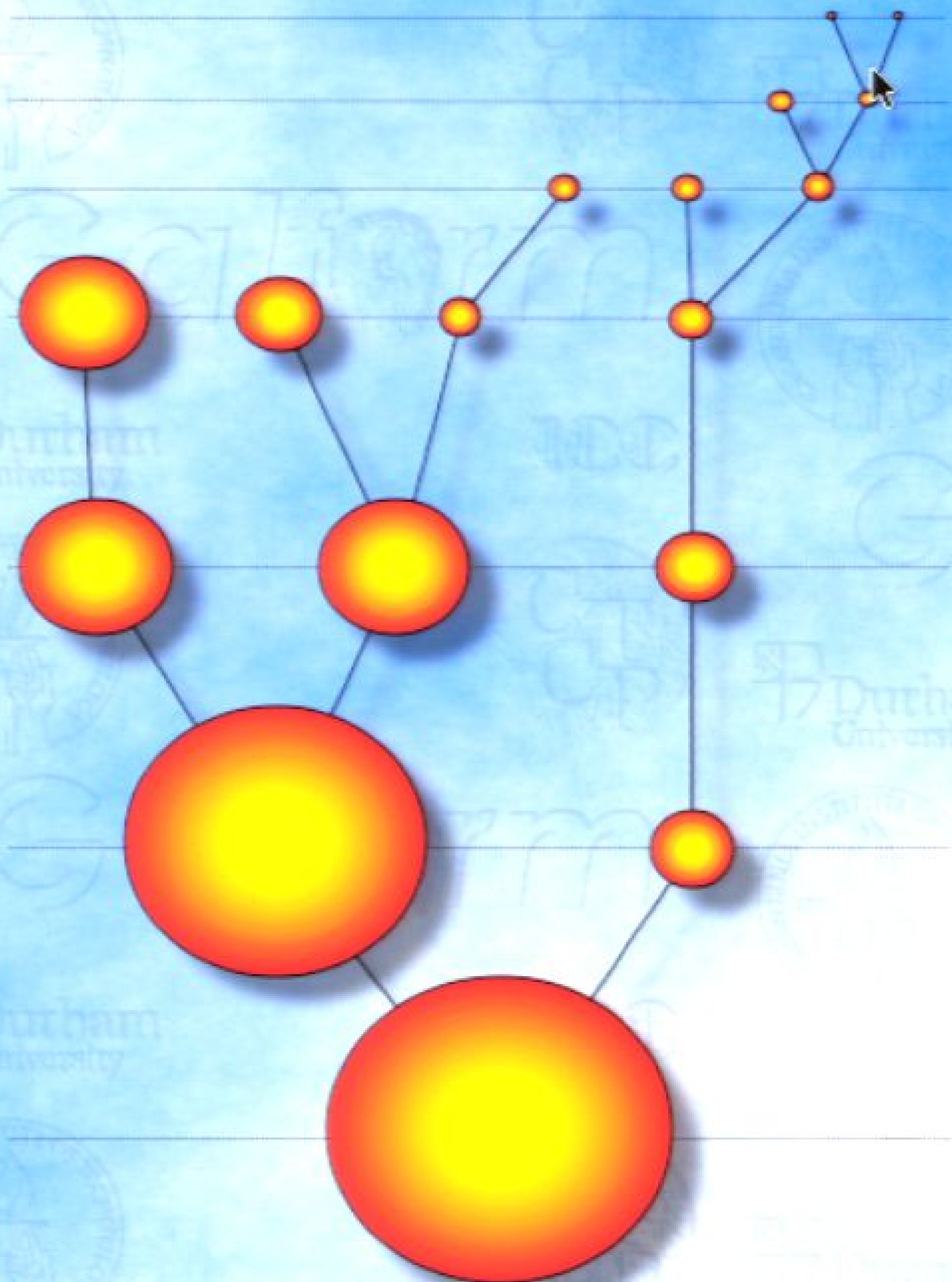
- Traditional method
- Adaptive method
- Low-res calculation to find branches of interest?



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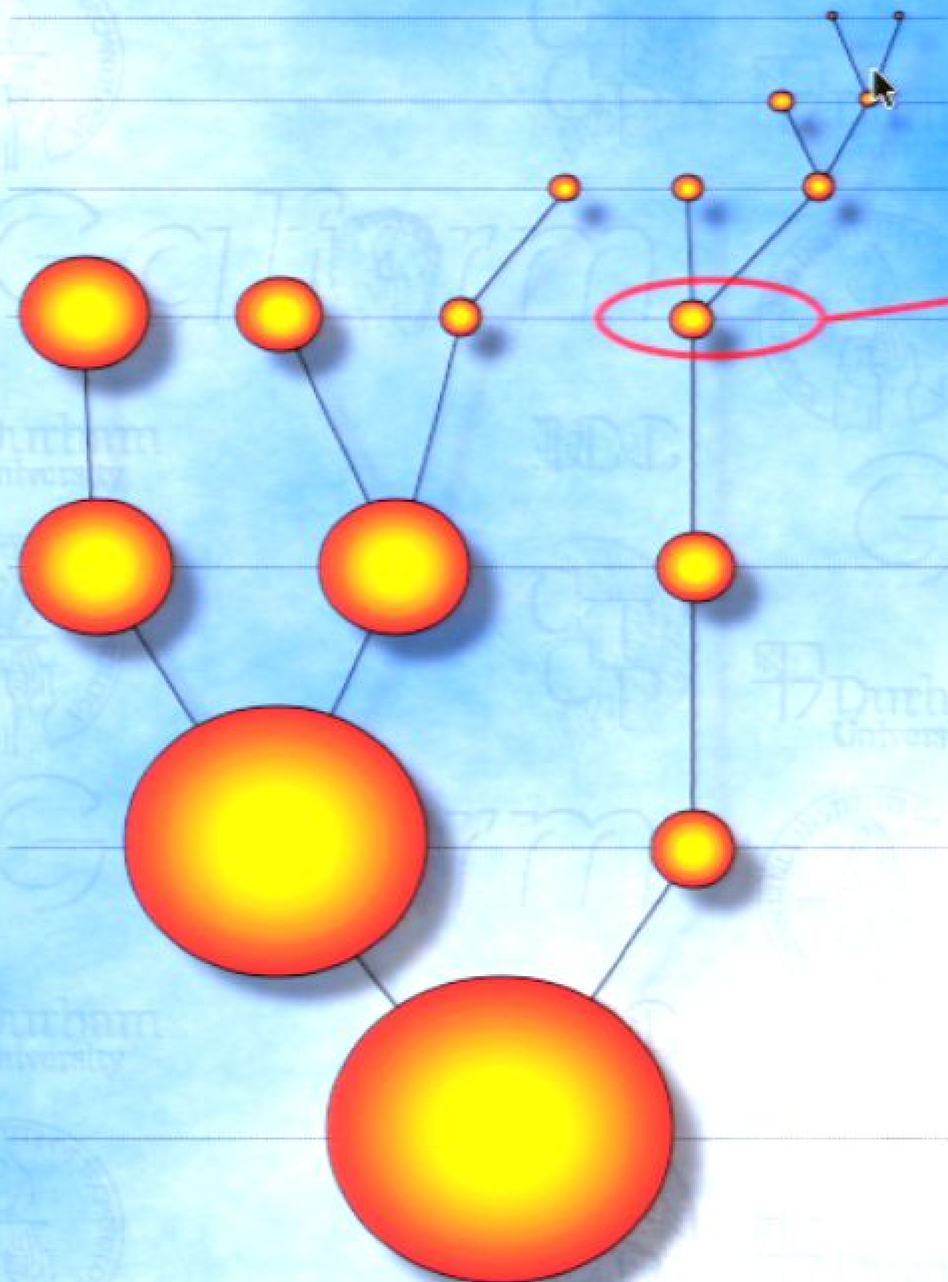

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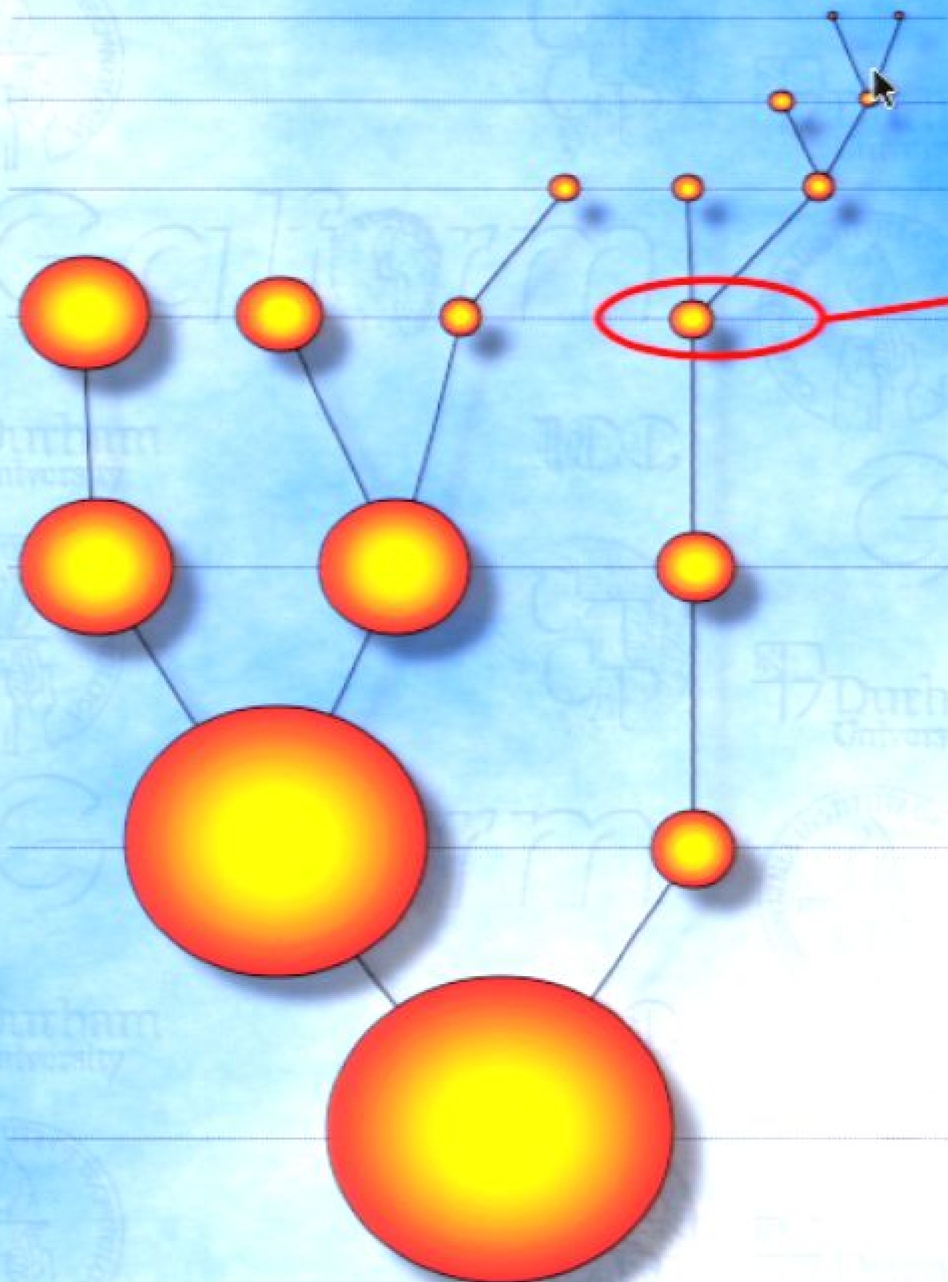

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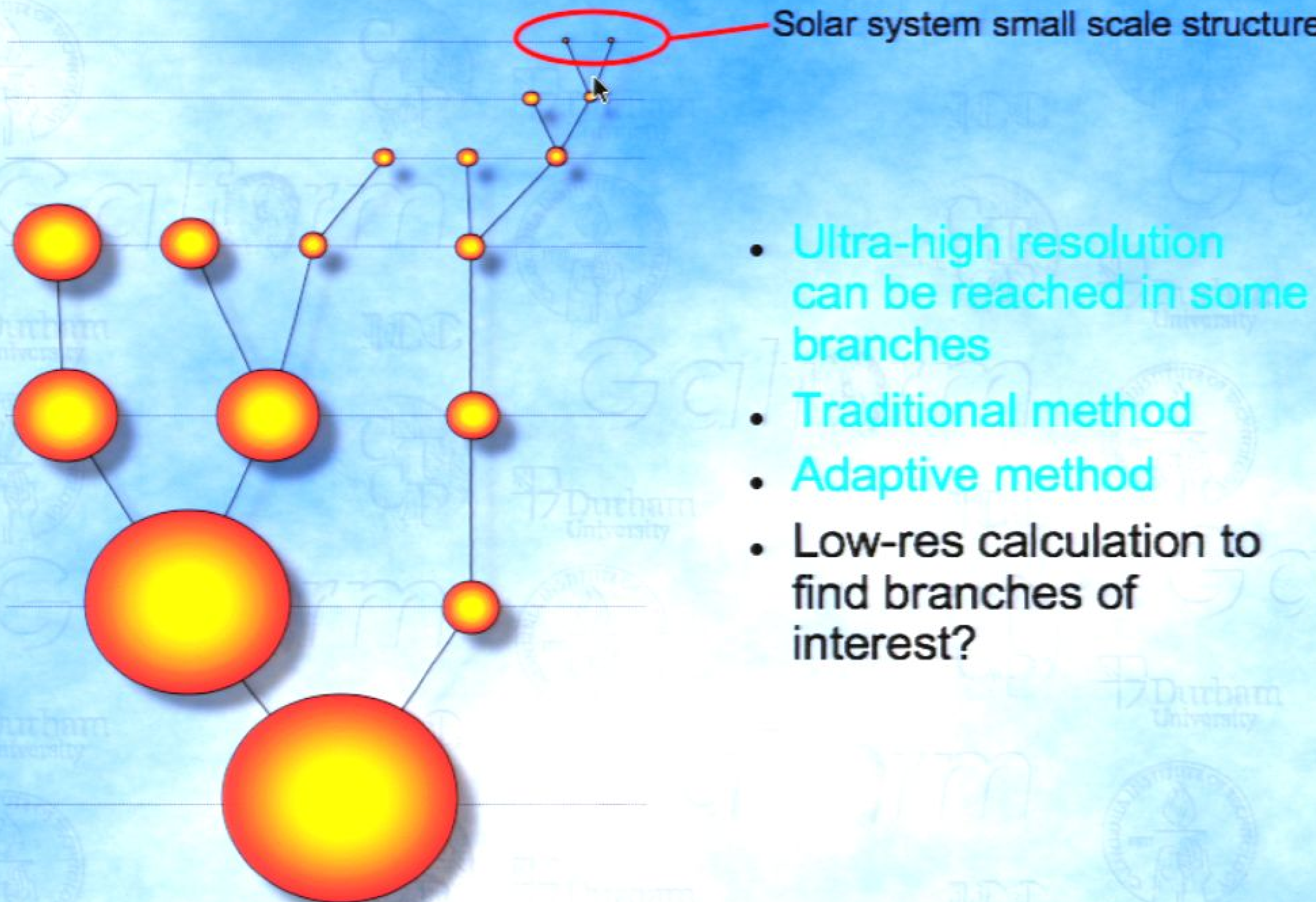

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Halo Mass-Concentration

Dan Grin & AJB

ta

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Halo concentrations well measured

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- + *C(M,z)*

– Scatter larger than current analytic models predict (<30%

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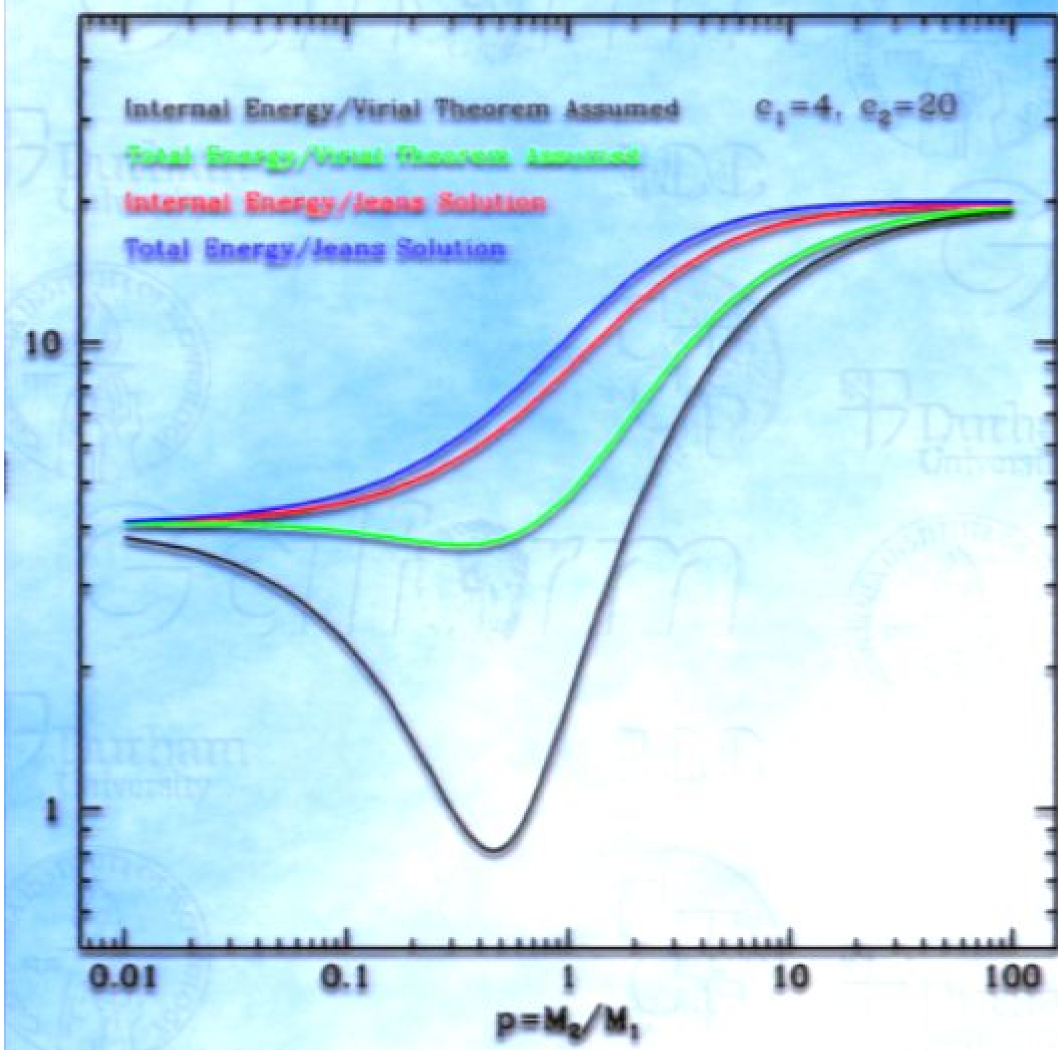

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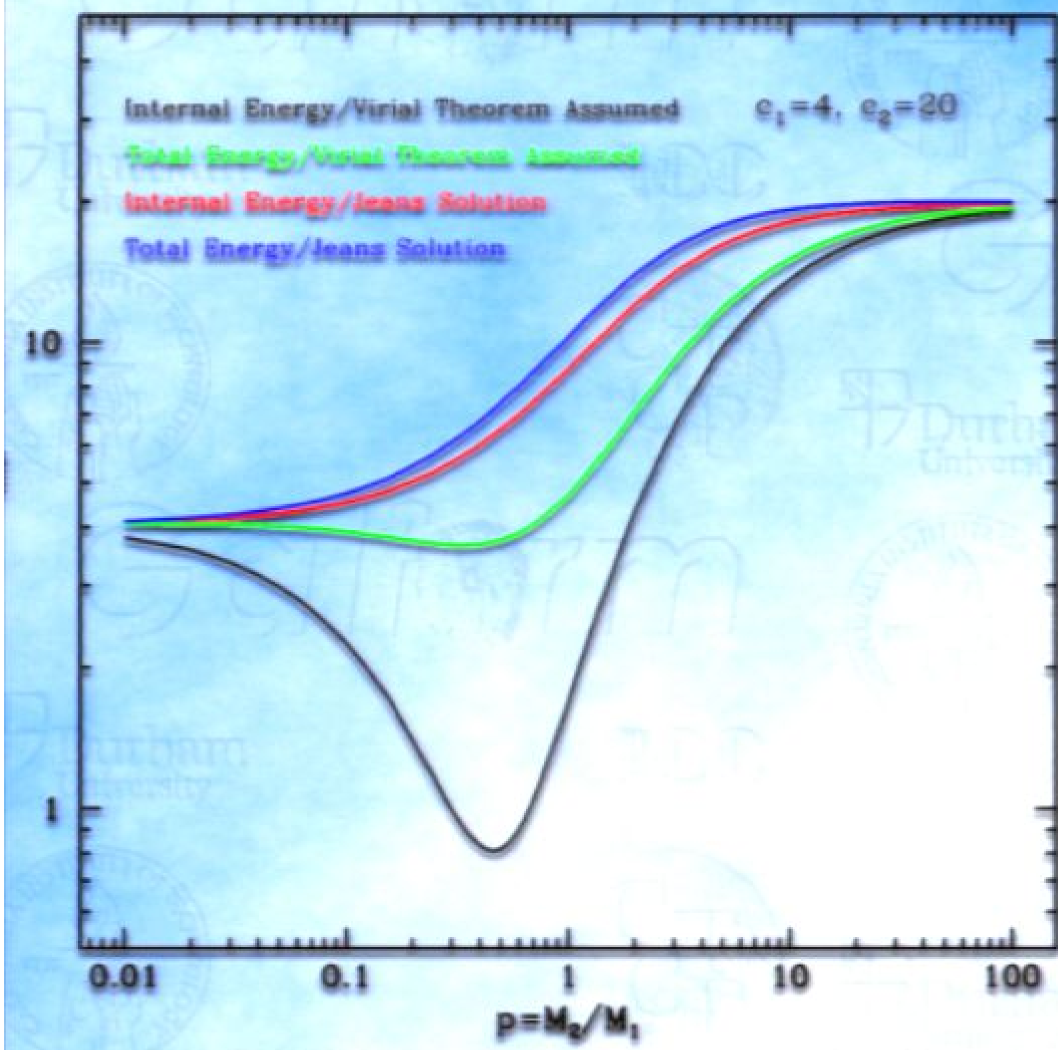

Halo concentrations well measured

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- Scatter larger than current analytic models predict (<30%)
- Can we rectify this by considering complete merging history?
- Currently testing this hypothesis using Millennium Simulation data

Halo Spins

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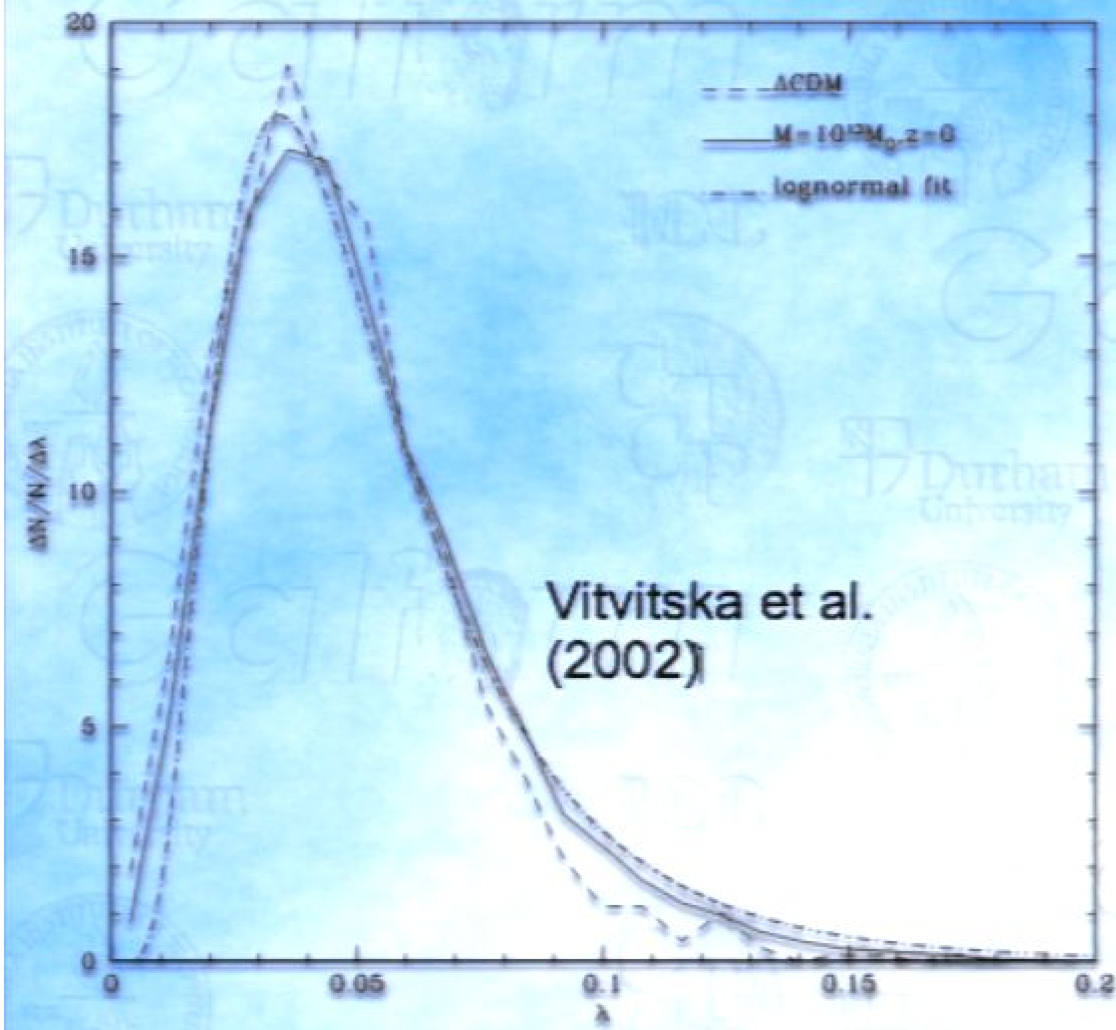
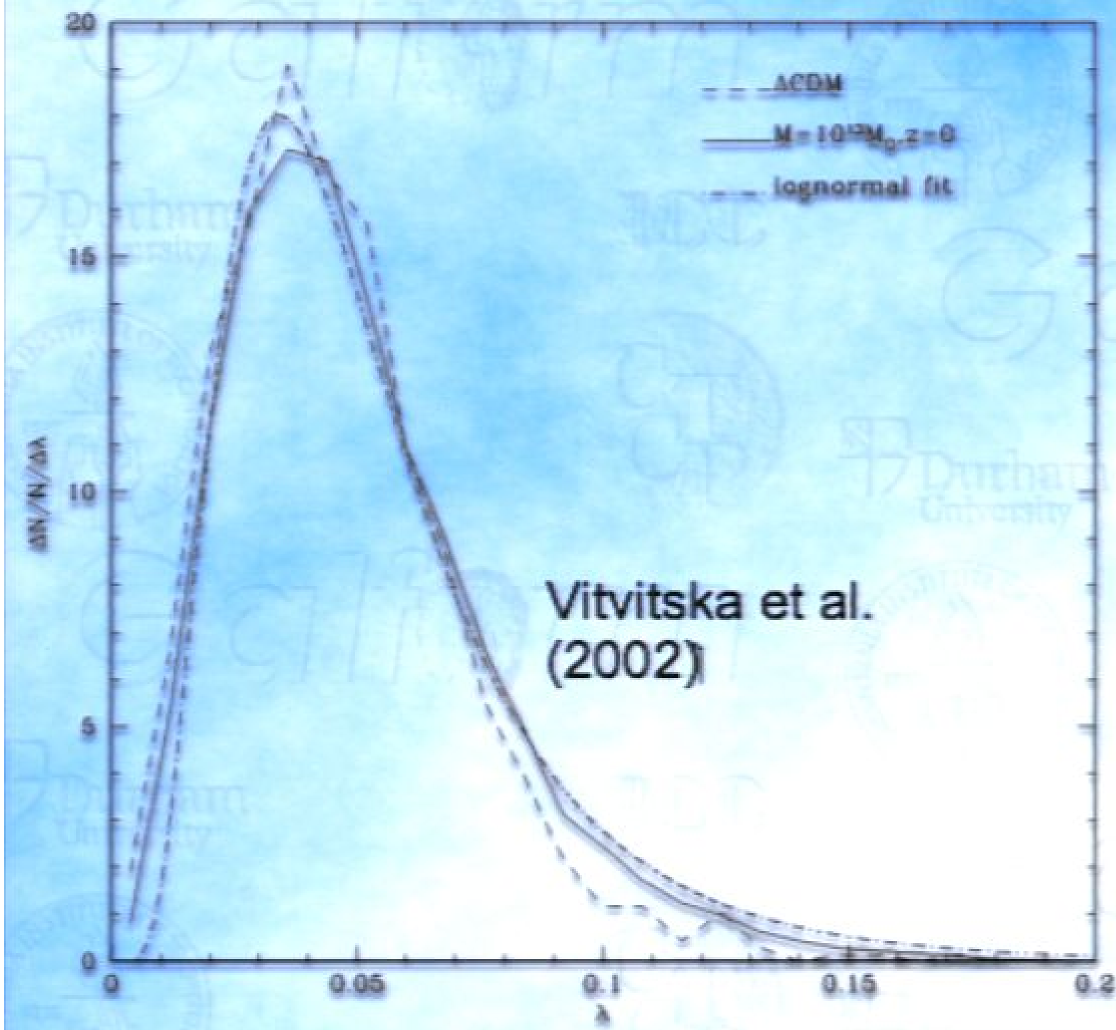


Vitvitska et al. (2002)

- Assume that halo angular momentum arises from orbits of merging subhalos
- Gives reasonable (log-normal) distributions

Halo Spins



Vitvitska et al. (2002)

- Assume that halo angular momentum arises from orbits of merging subhalos
- Gives reasonable (log-normal) distributions
- Currently working on testing this using new orbital parameter distributions

Environmental Effects

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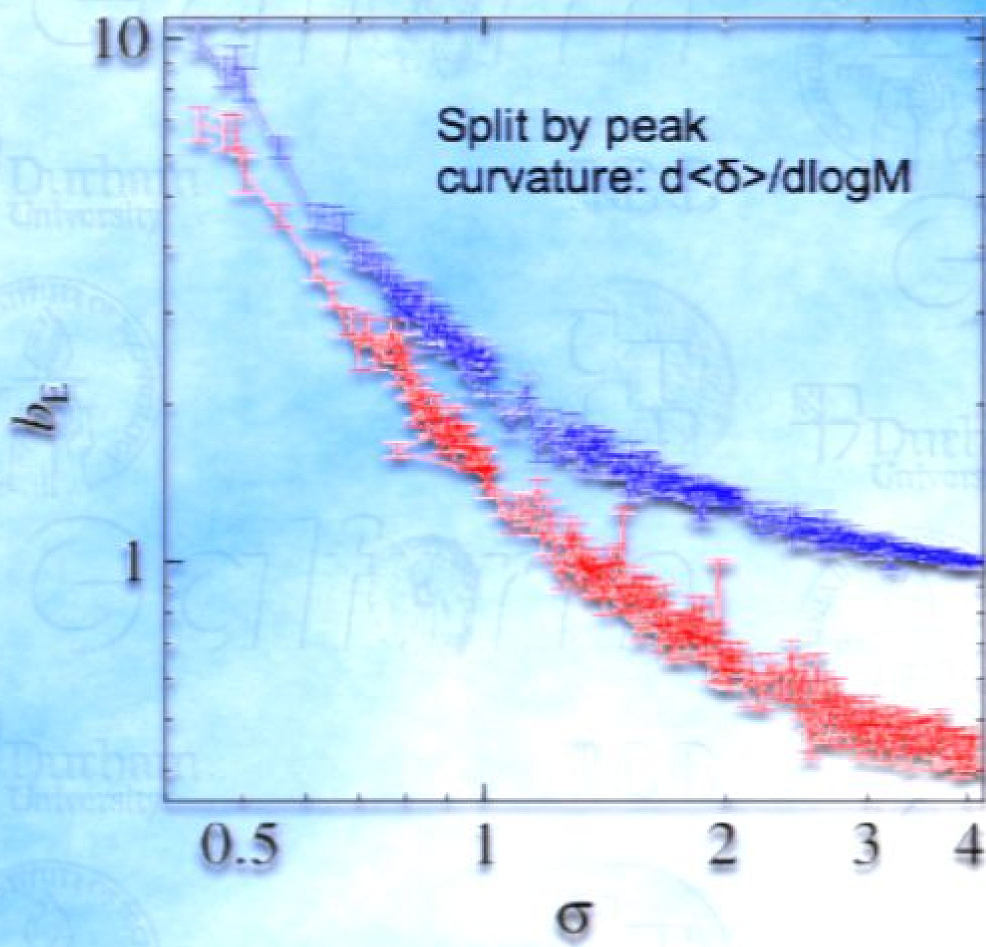
- Recently shown that many environmental effects derivable from Lagriangian density field

Environmental Effects



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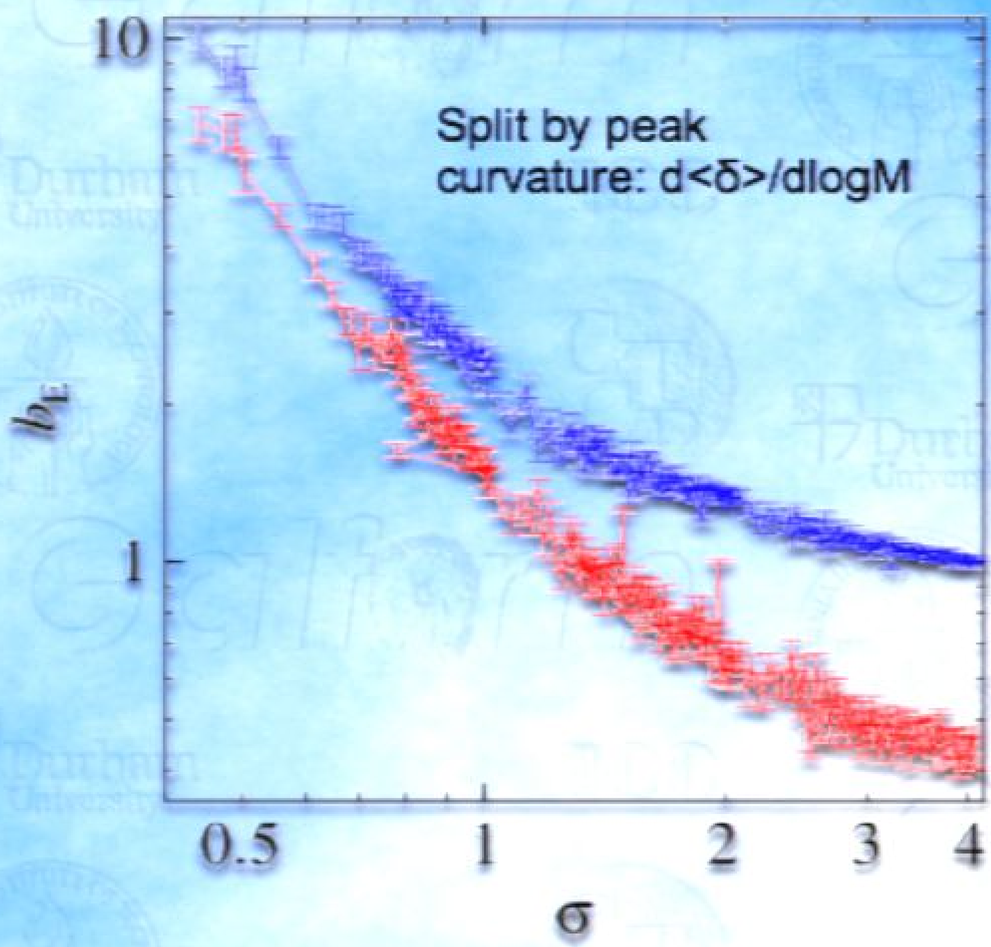

Dalal, White & Bond (2008)

- Recently shown that many environmental effects derivable from Lagriangian density field
- Utilizes curvature etc.
- This could be built into merger trees if some suitable "environment" parameter were attached to them

Merger Dynamics: Orbits

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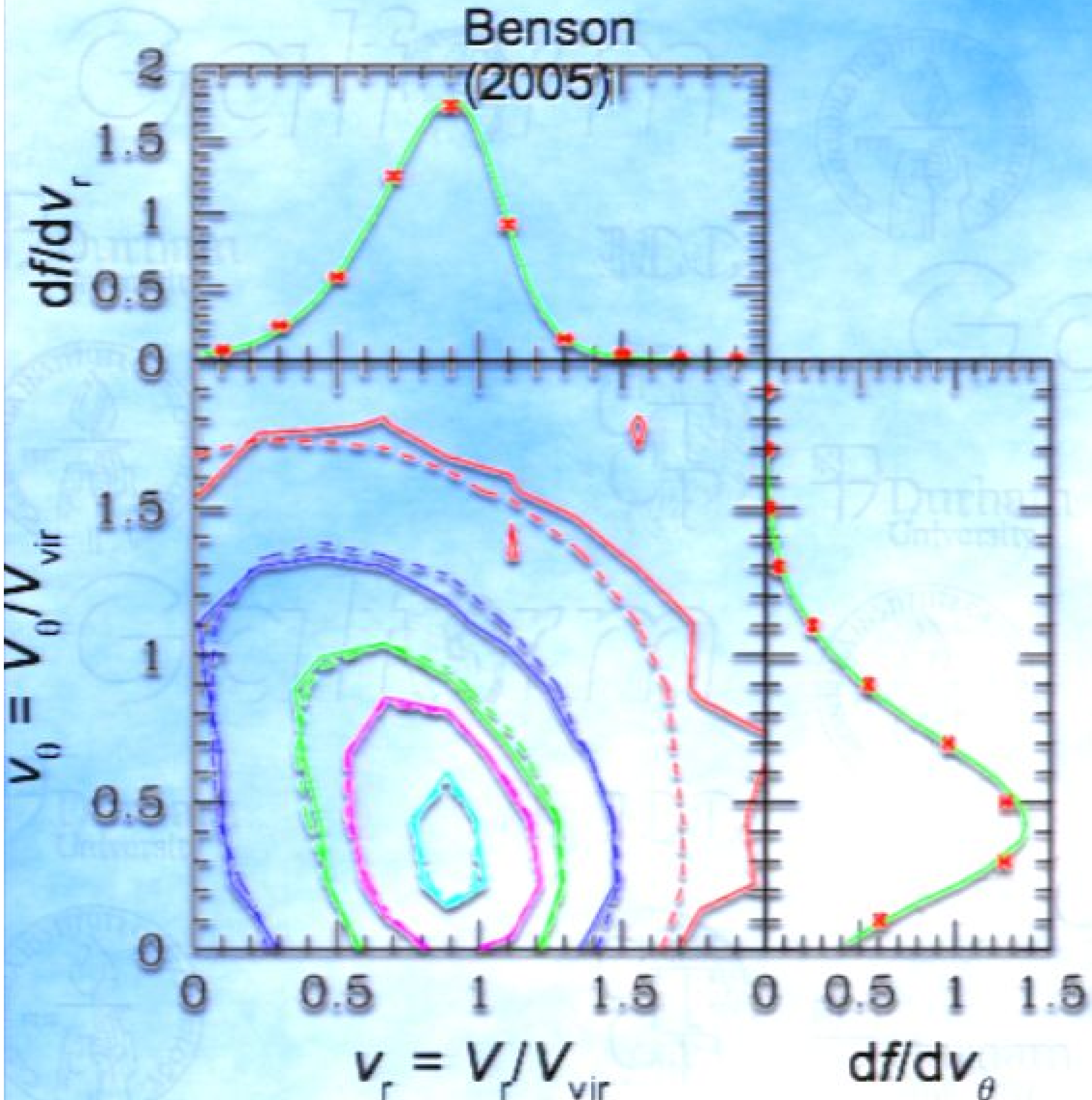

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- Distribution of orbital velocities

No Signal

VGA-1

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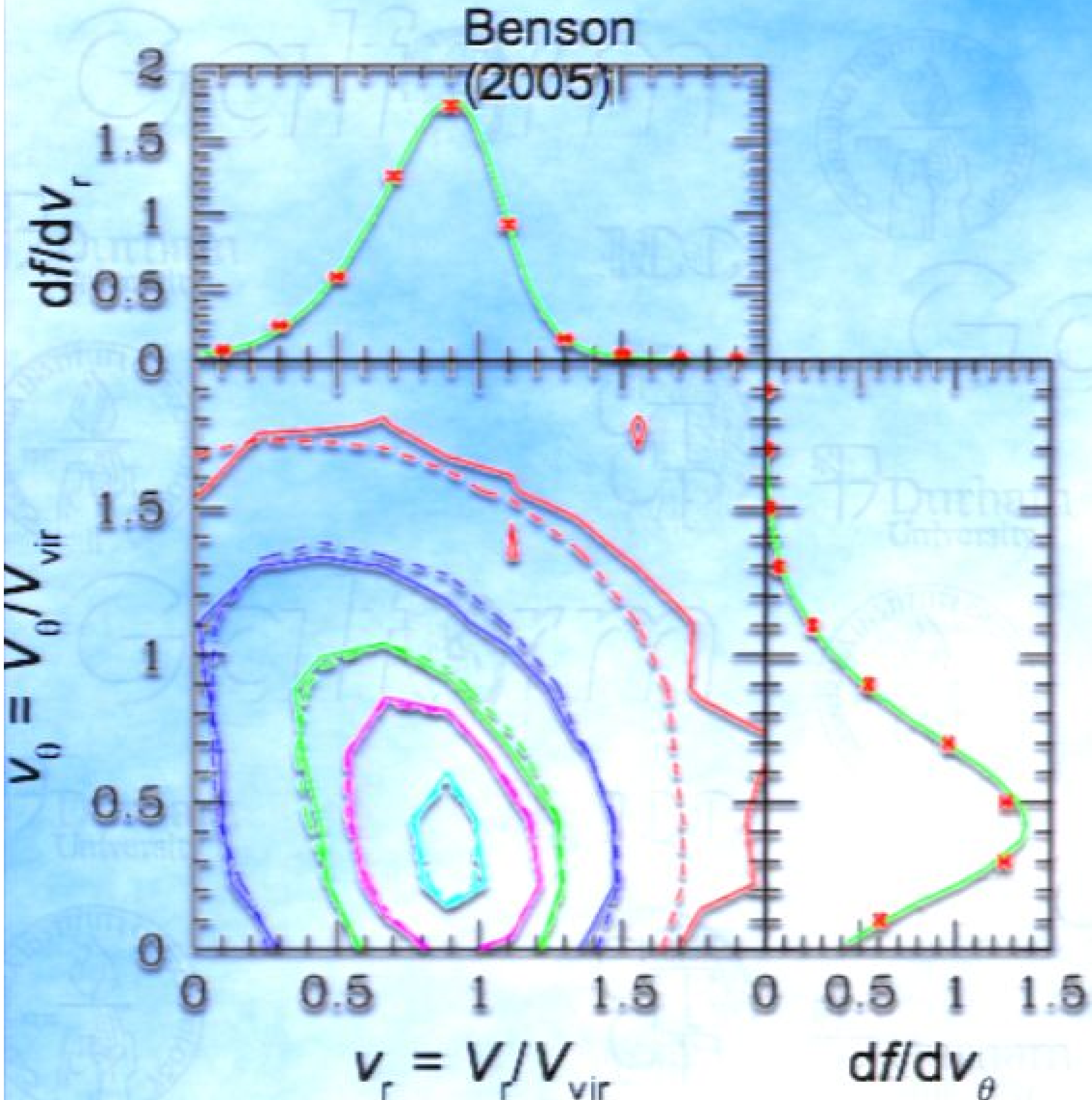
Merger Dynamics: Orbits



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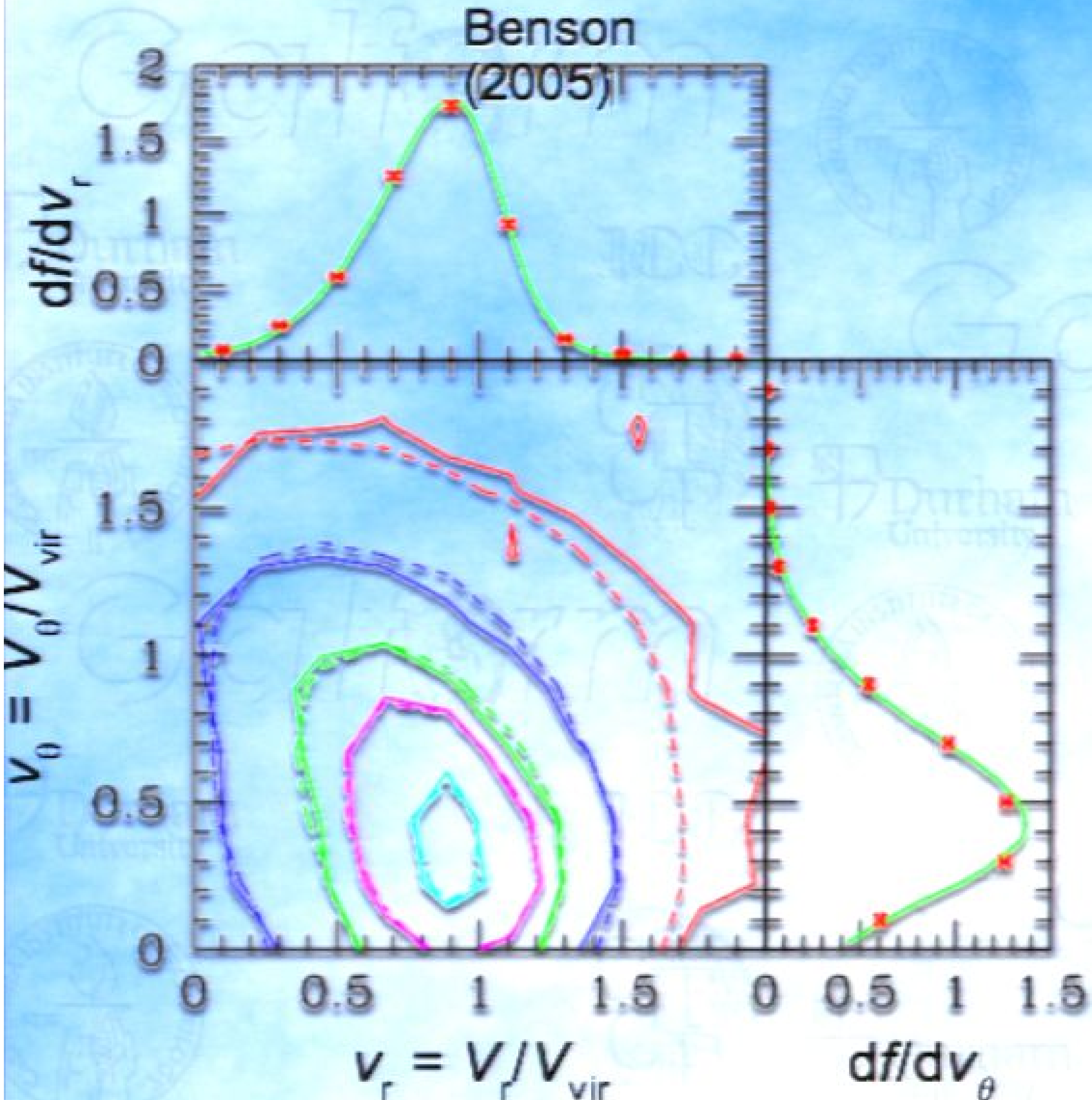

- What are orbital properties of just merged halos?
- How to find them
  - *N-body simulation*
  - *Find all the halos*
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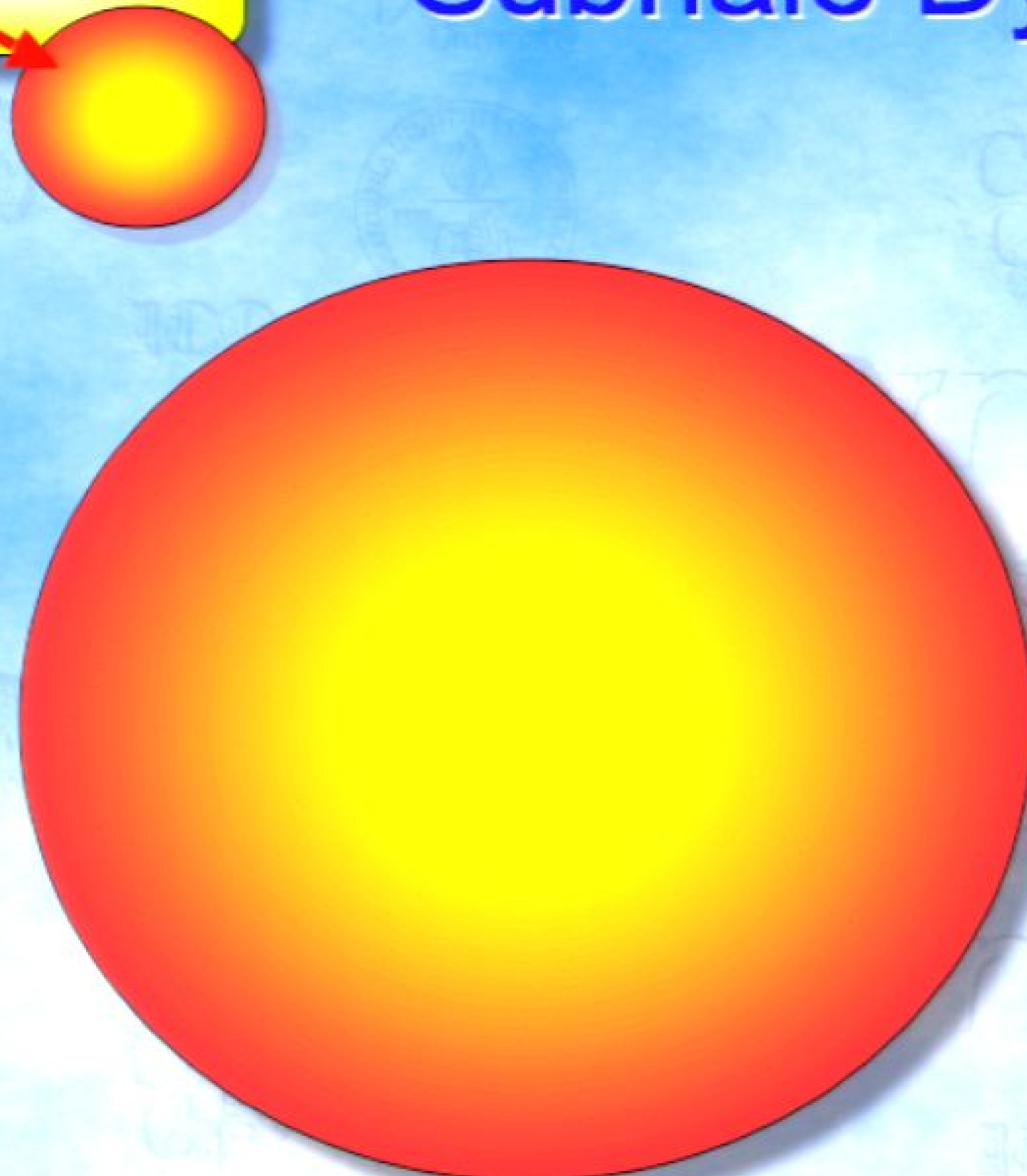
- Distribution of orbital velocities
- Measured to very good precision

Subhalo Dynamics

Subhalo Dynamics

Dark matter halo forms.
Later becomes a satellite
in a larger halo

Subhalo Dynamics



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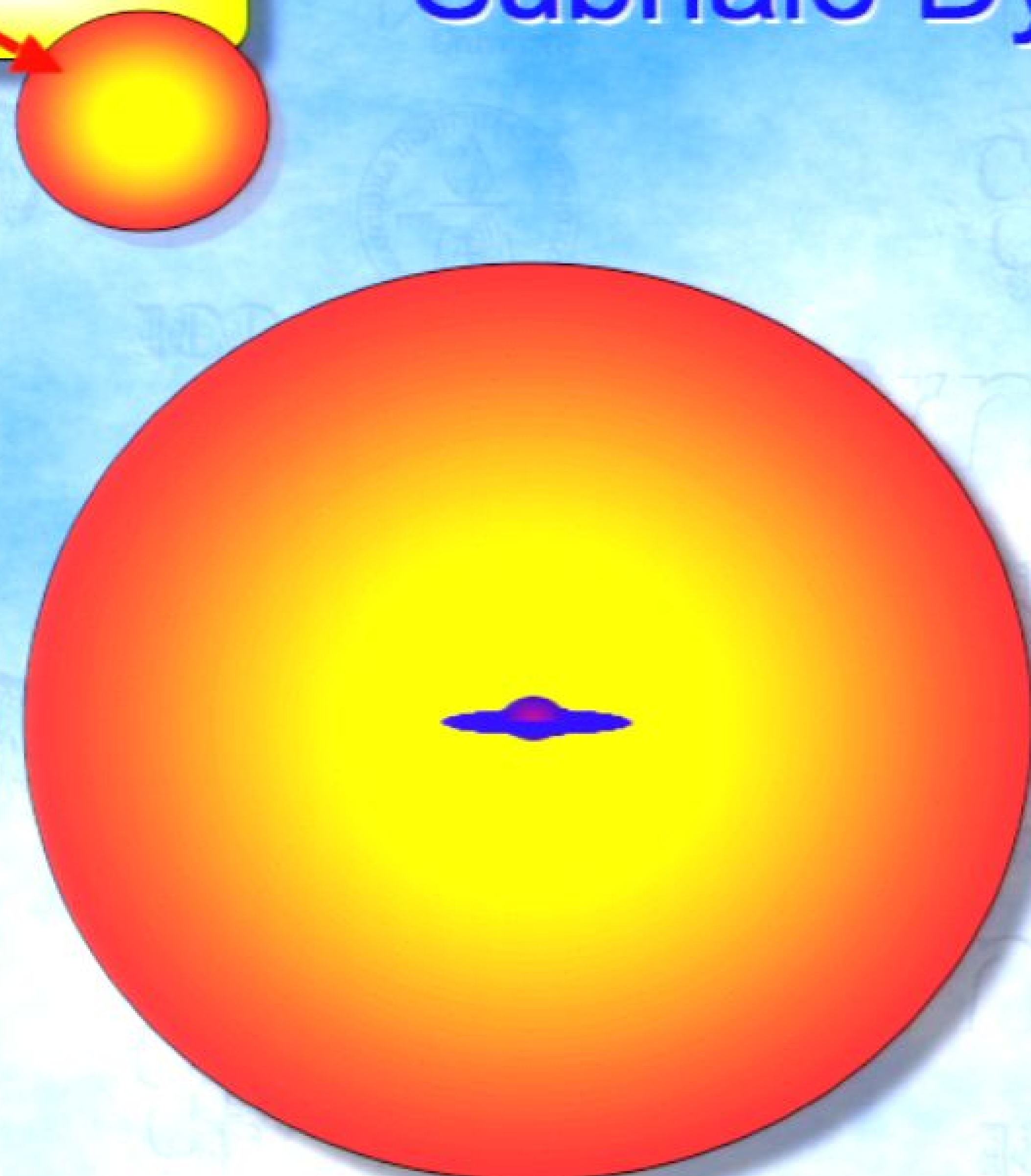

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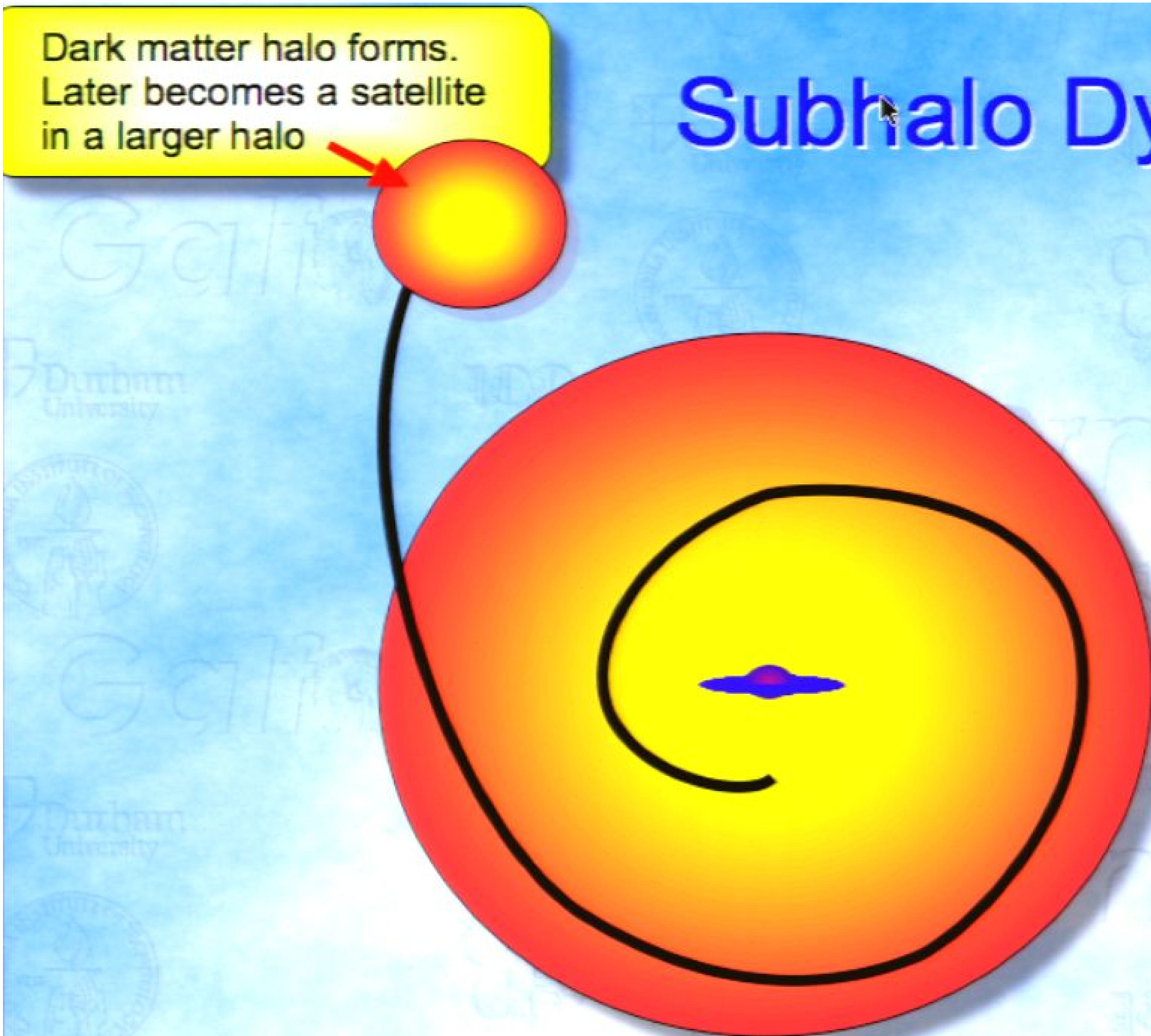

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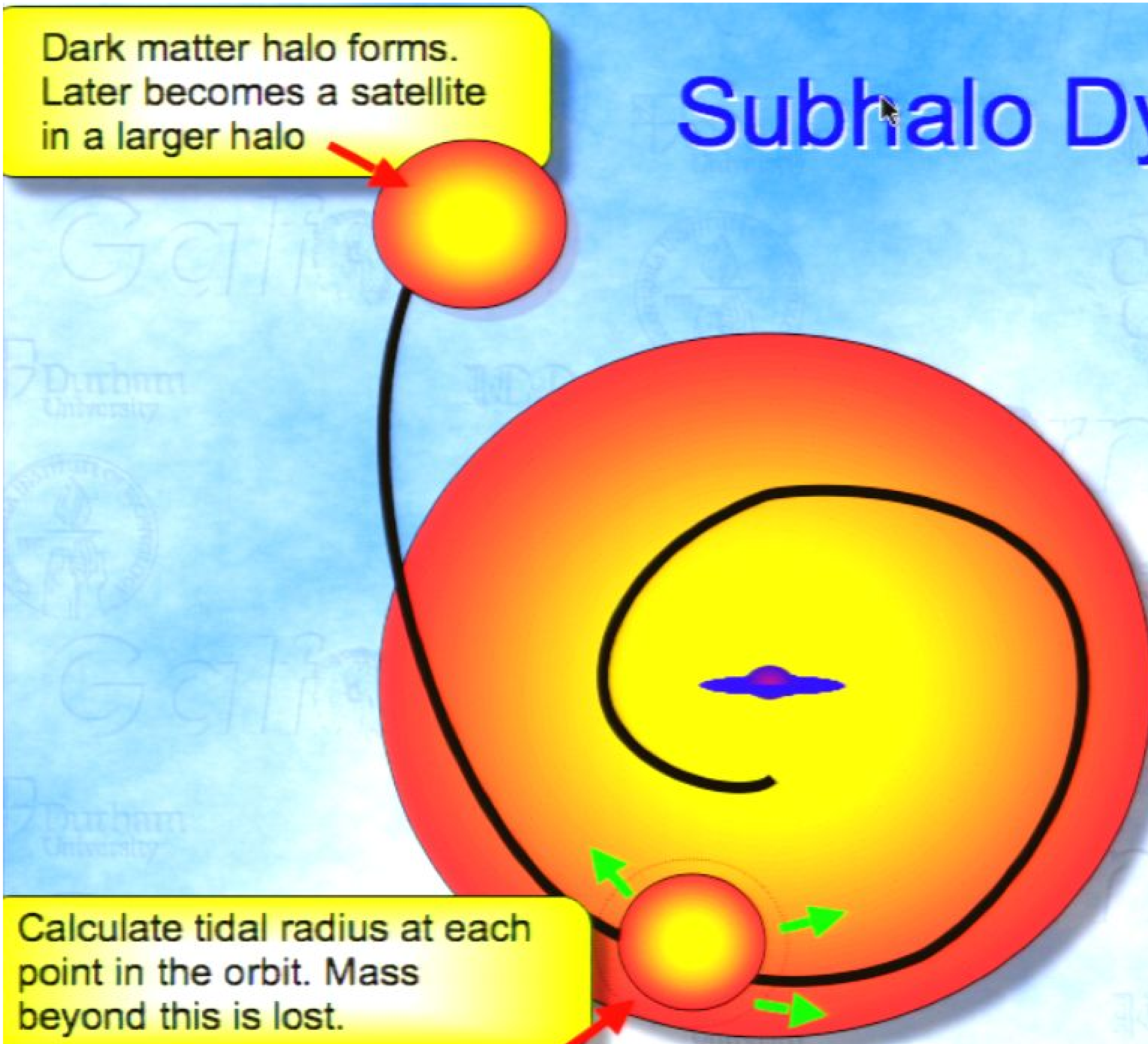
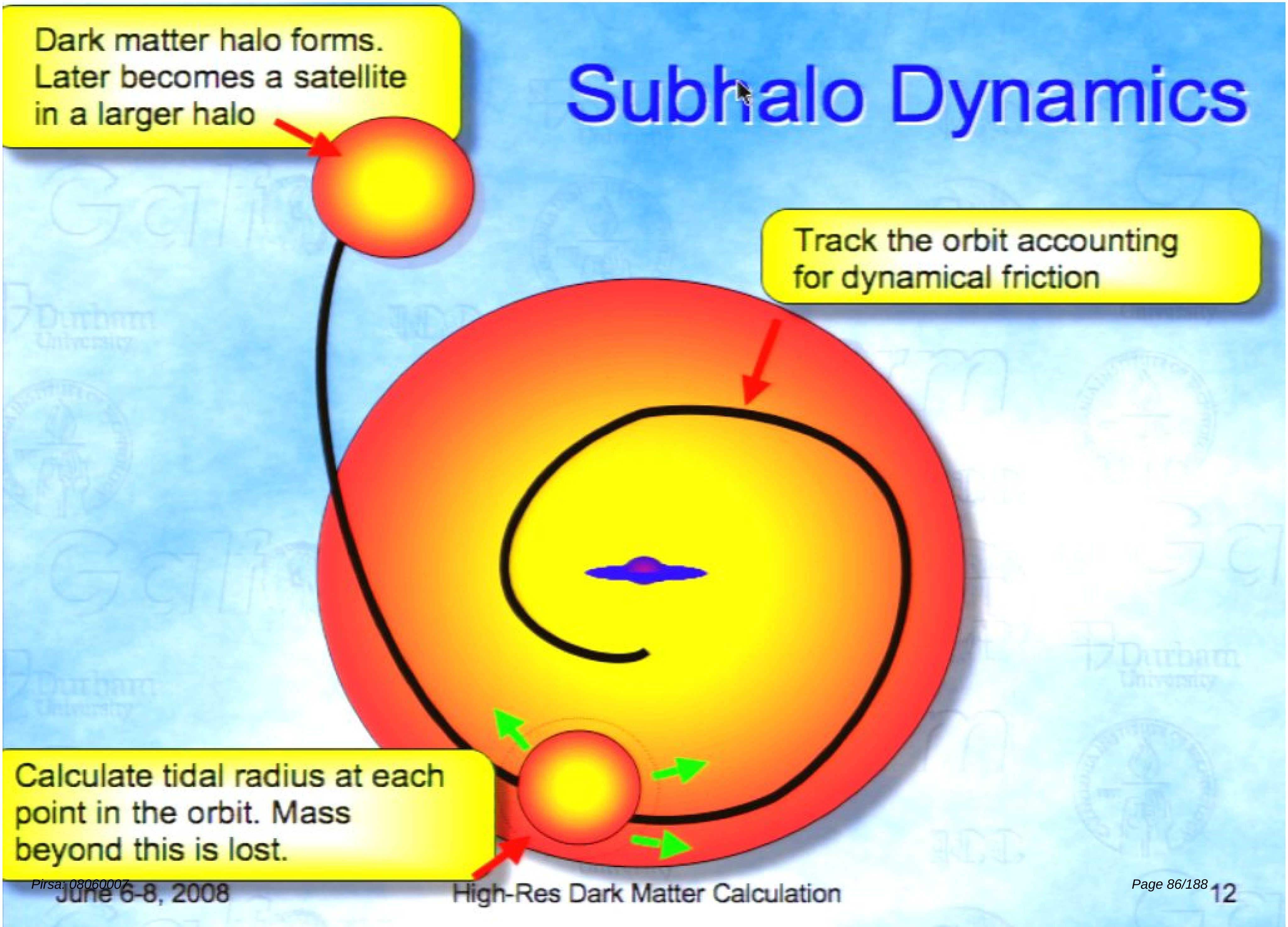
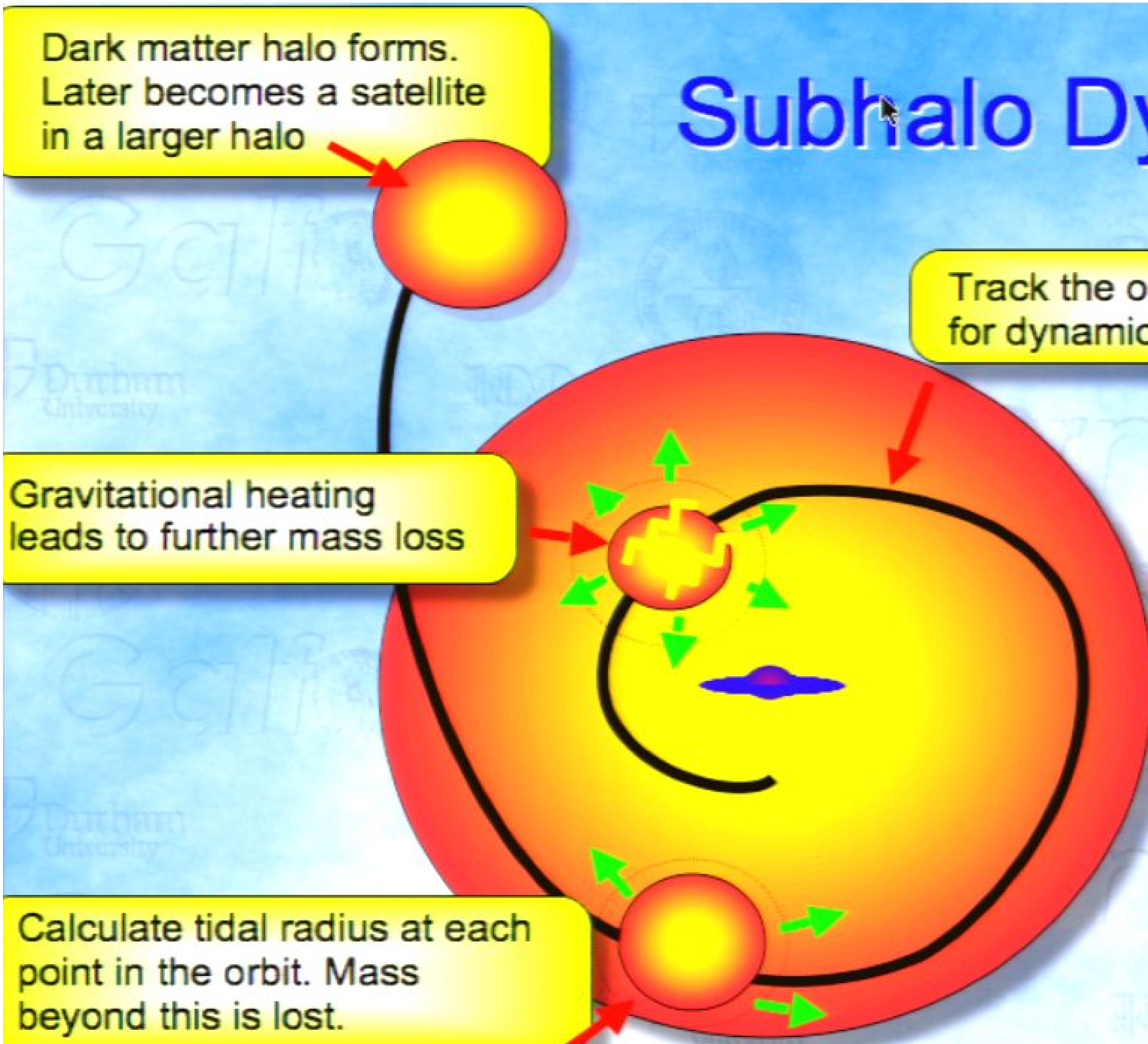




Subhalo Dynamics
Dark matter halo forms. Later becomes a satellite in a larger halo
Track the orbit accounting for dynamical friction
Calculate tidal radius at each point in the orbit. Mass beyond this is lost.
June 6-8, 2008
High-Res Dark Matter Calculation
12

Subhalo Dynamics



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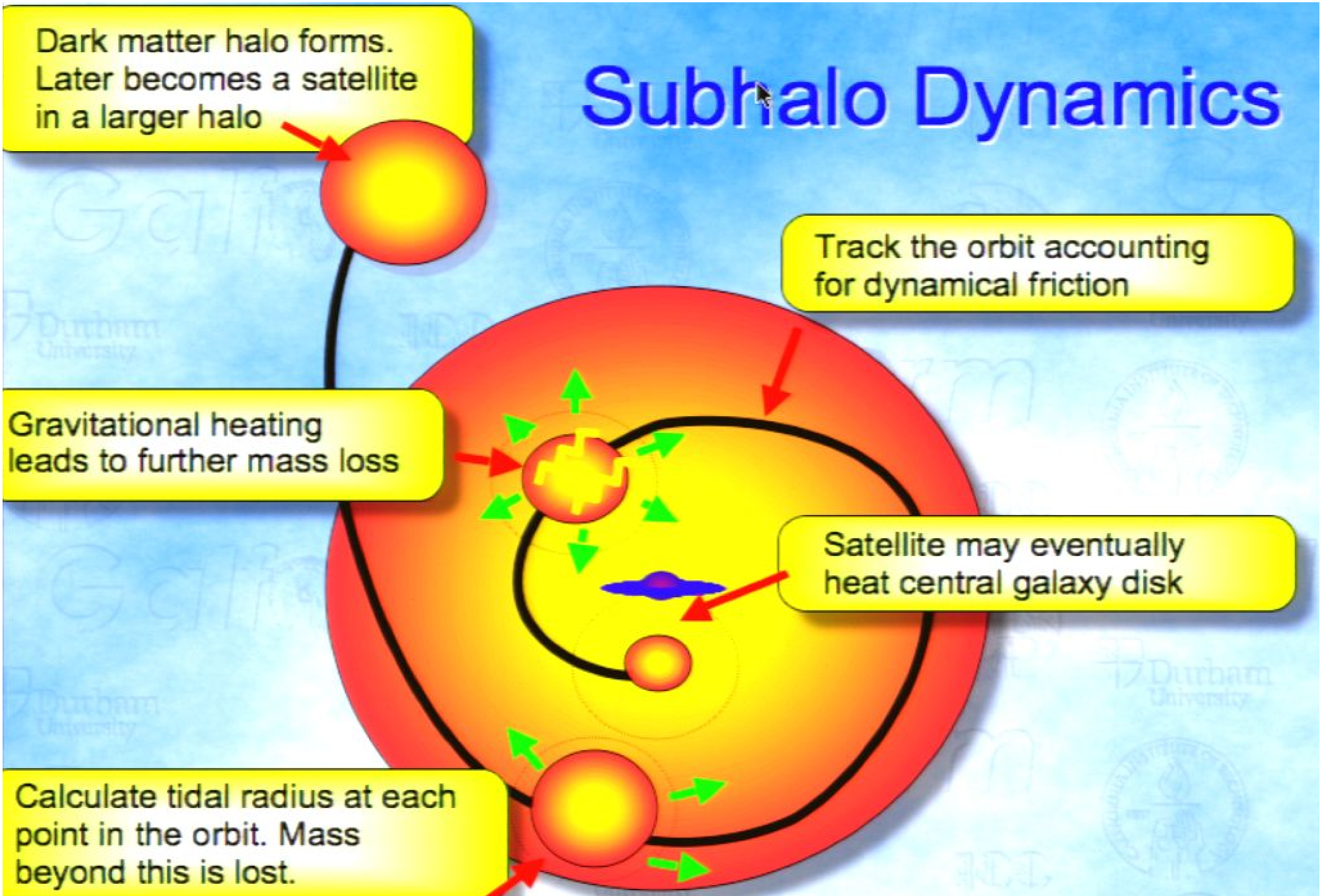

Subhalo Mass Function

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- Dynamics of substructures followed by model
- Tracks:

Subhalo Mass Function

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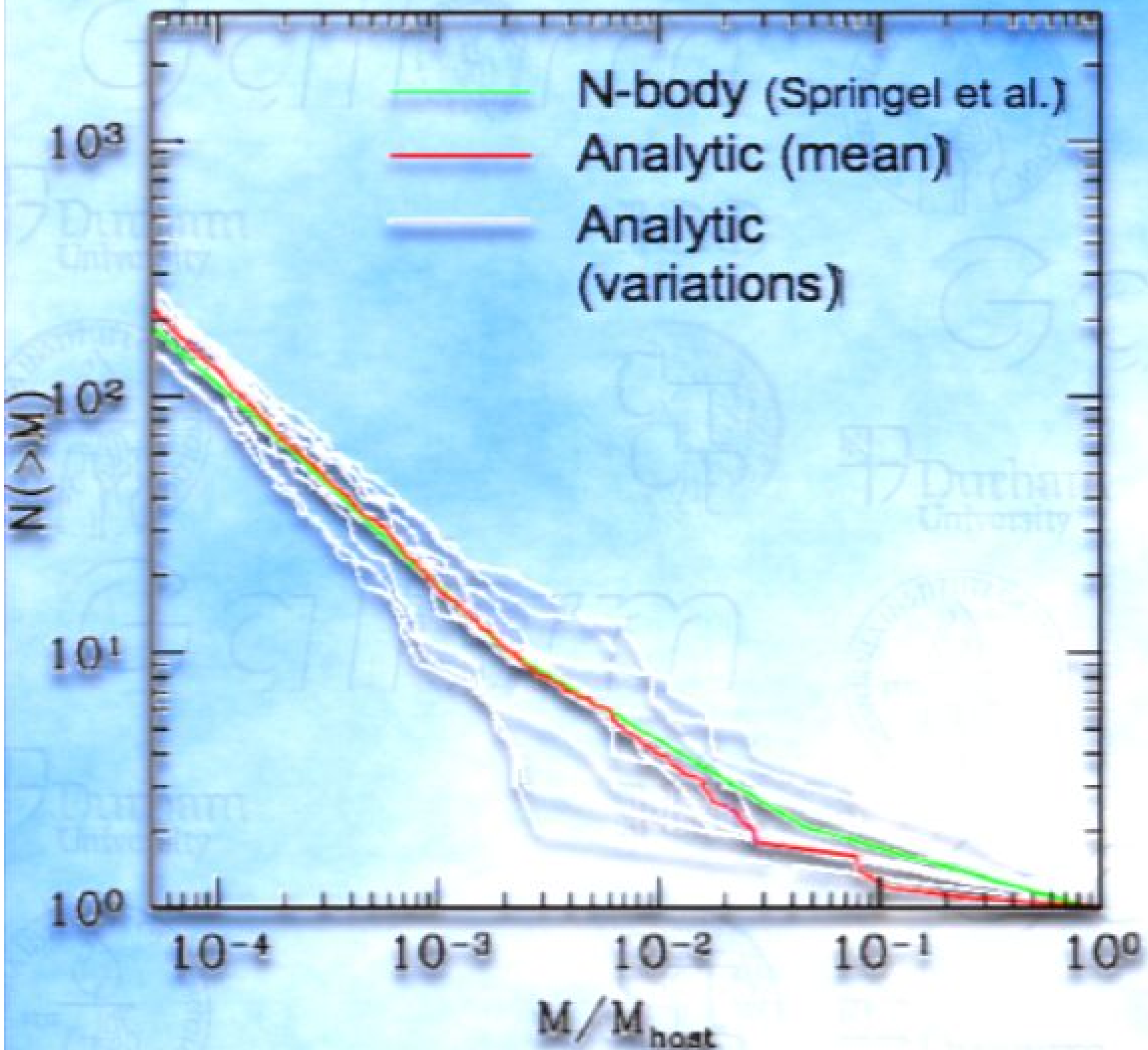

- Dynamics of substructures followed by model
- Tracks:
  - *Orbit*
  - *Dynamical friction*
  - *Tidal mass loss*
  - *Gravitational heating*
- Number of substructures agrees well with N-body calculations

Comparison with N-body: Orbits

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- Best fit parameters:
  f_{orb}=2.0,
  f_{halo}=1.5,f_{disk}=3.5,
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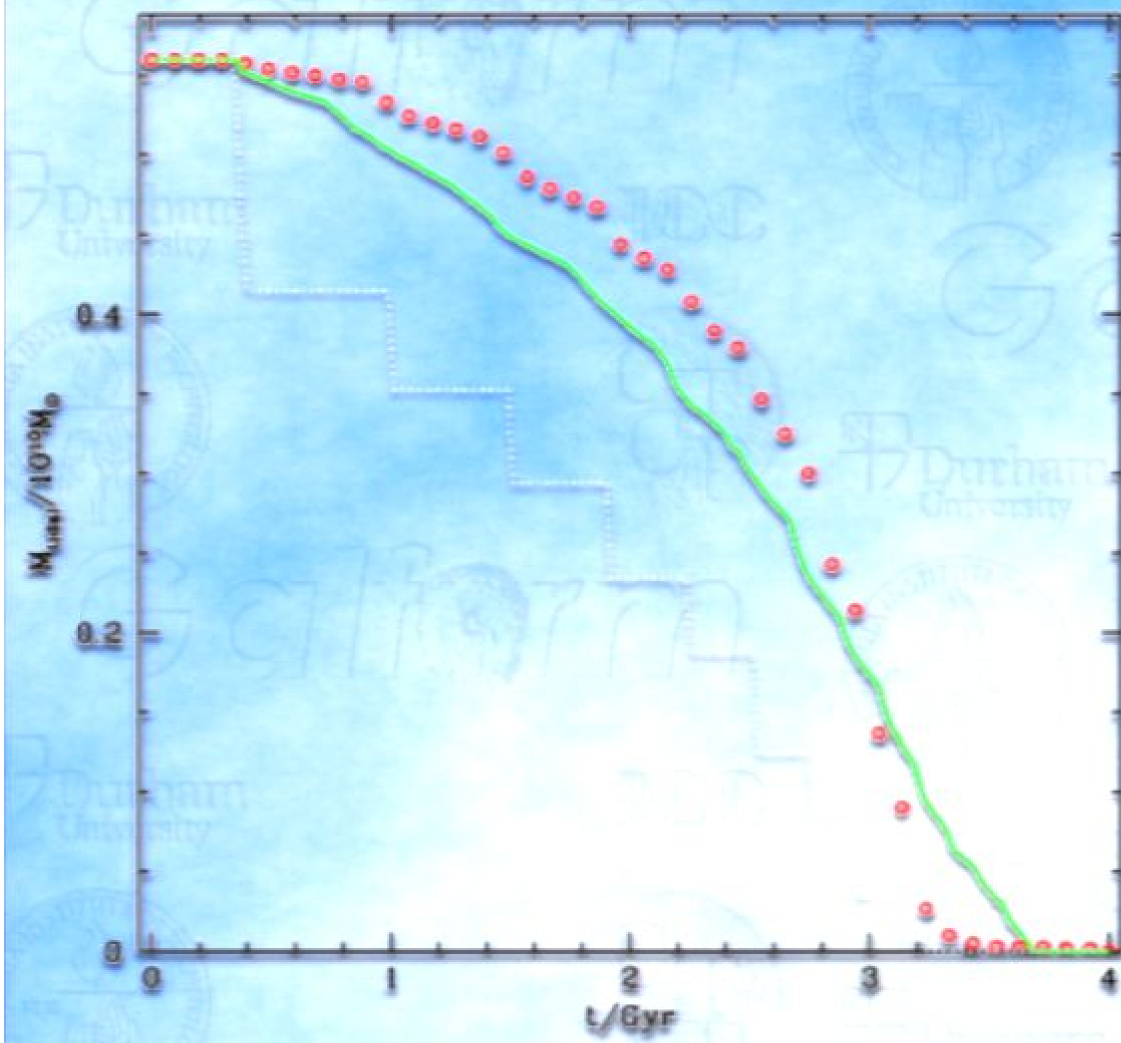
Comparison with N-body: Orbits



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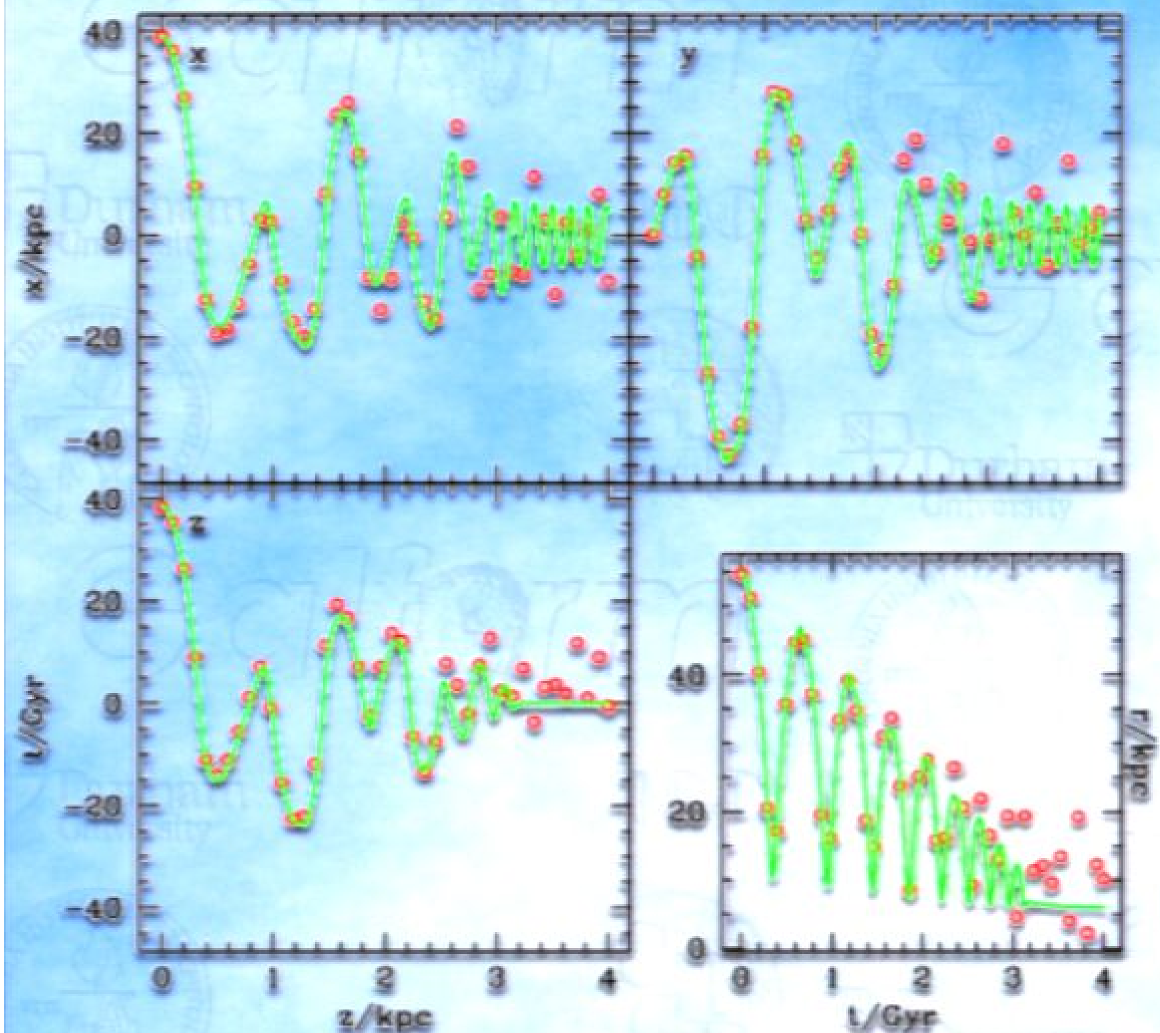

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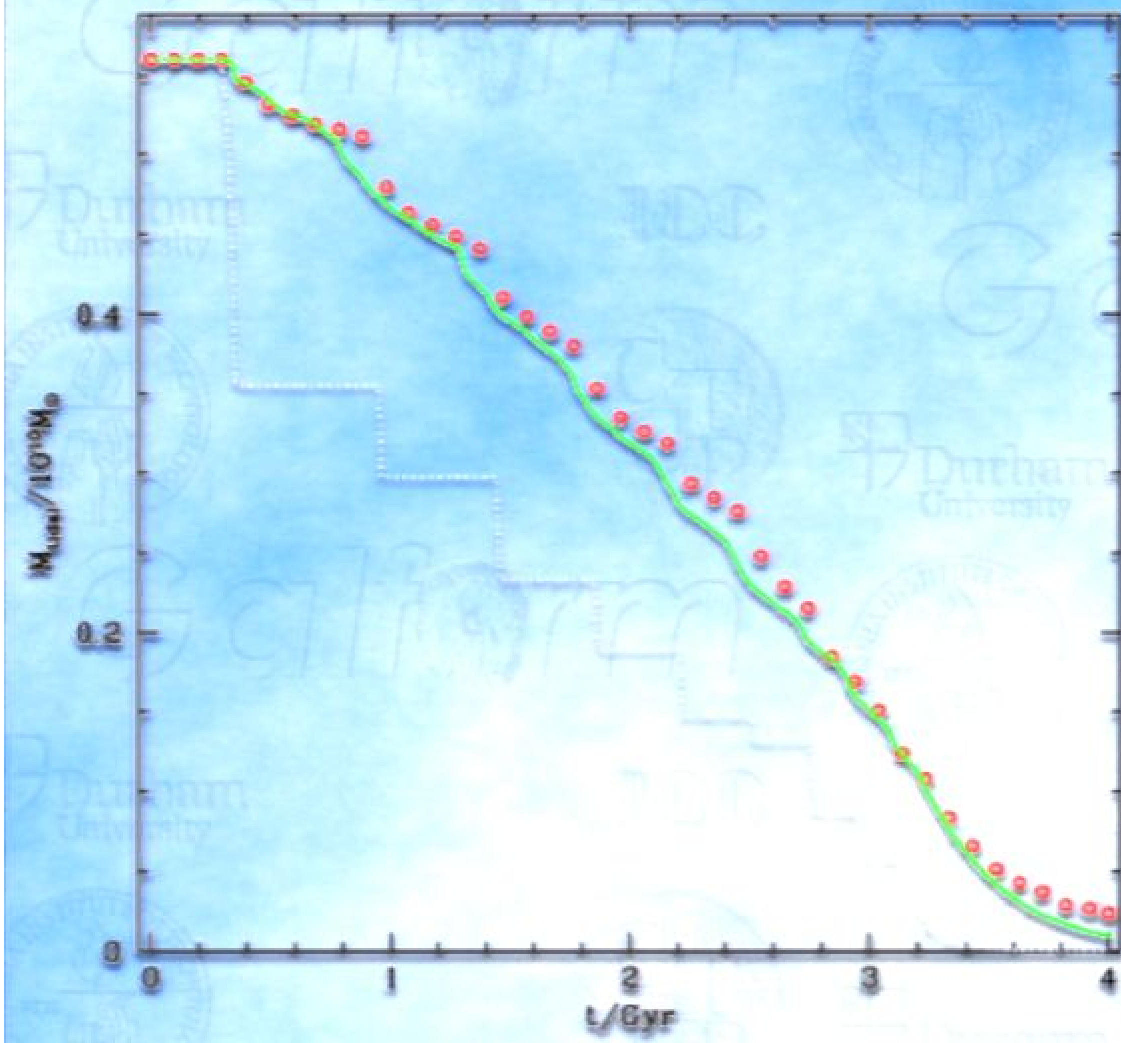

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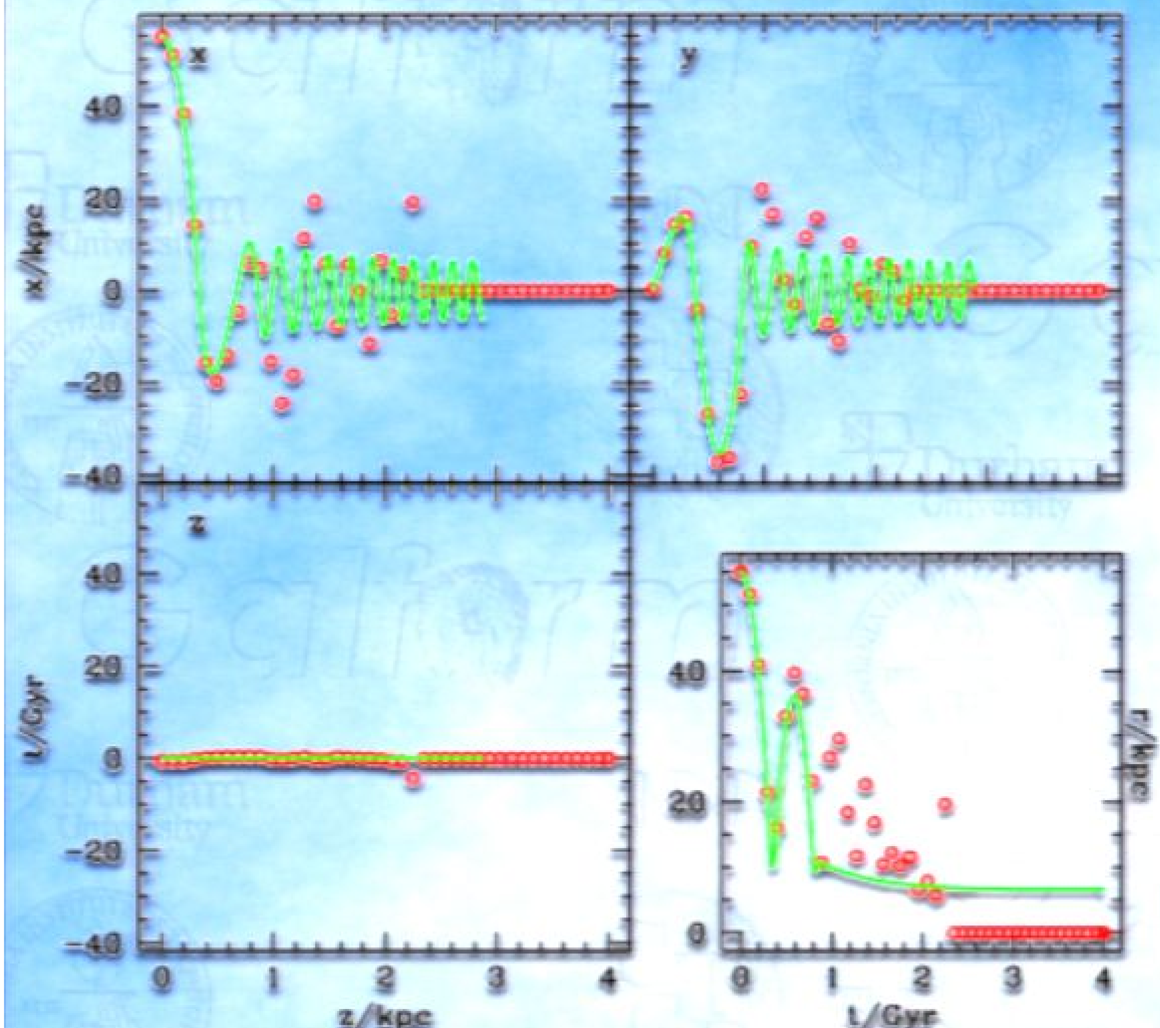

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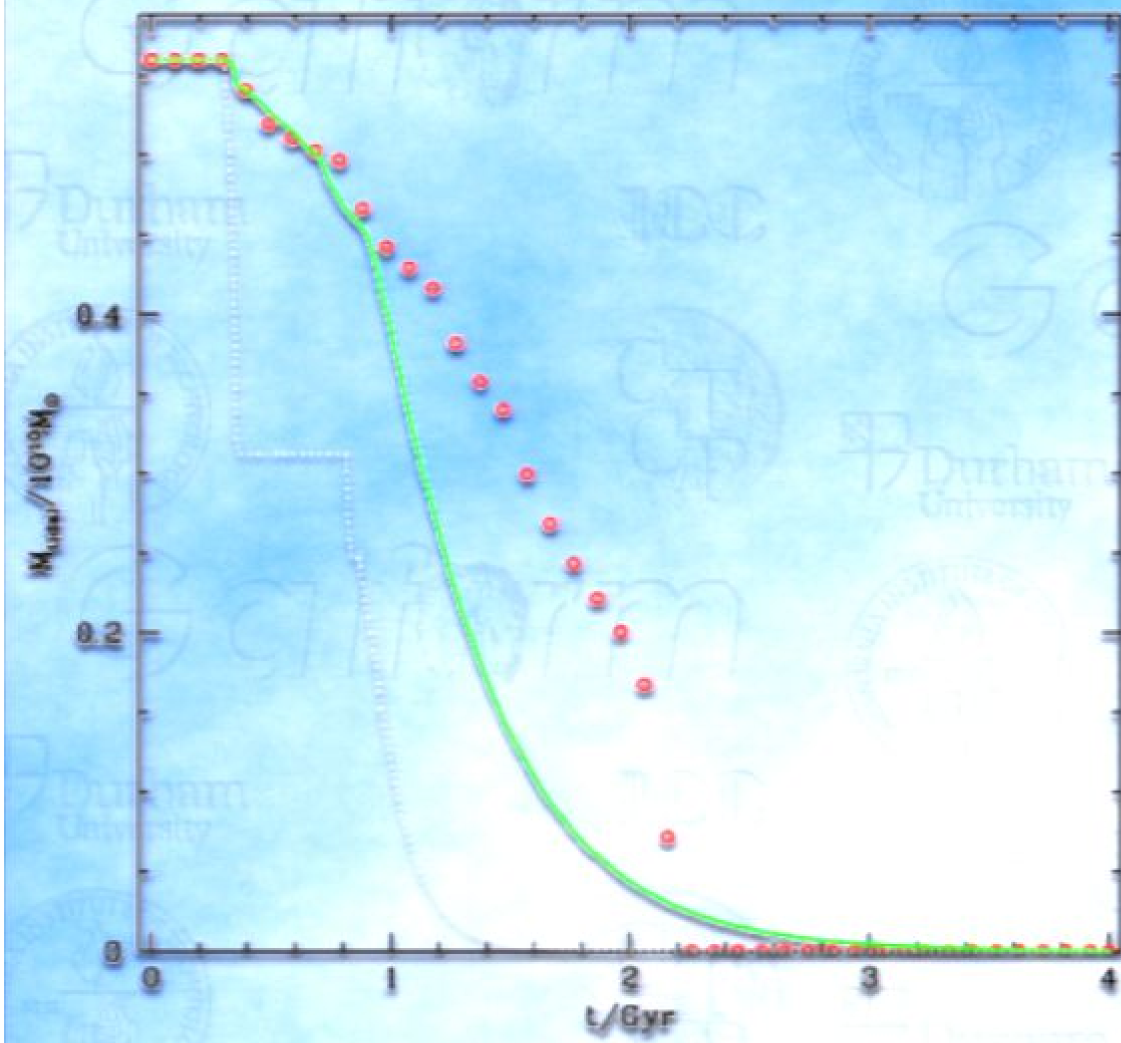

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- ...except for orbits in the disk plane

Comparison with N-body: Trends

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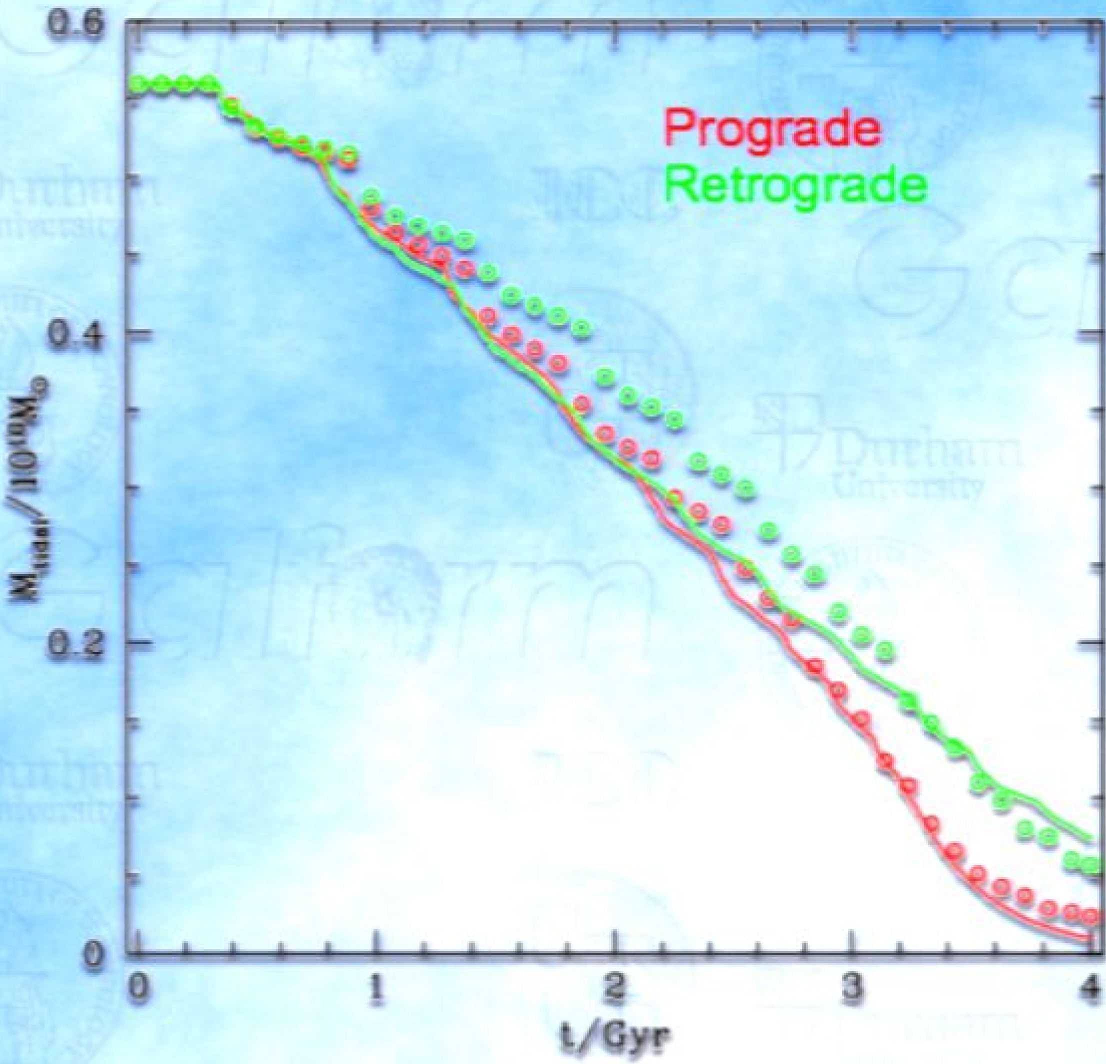
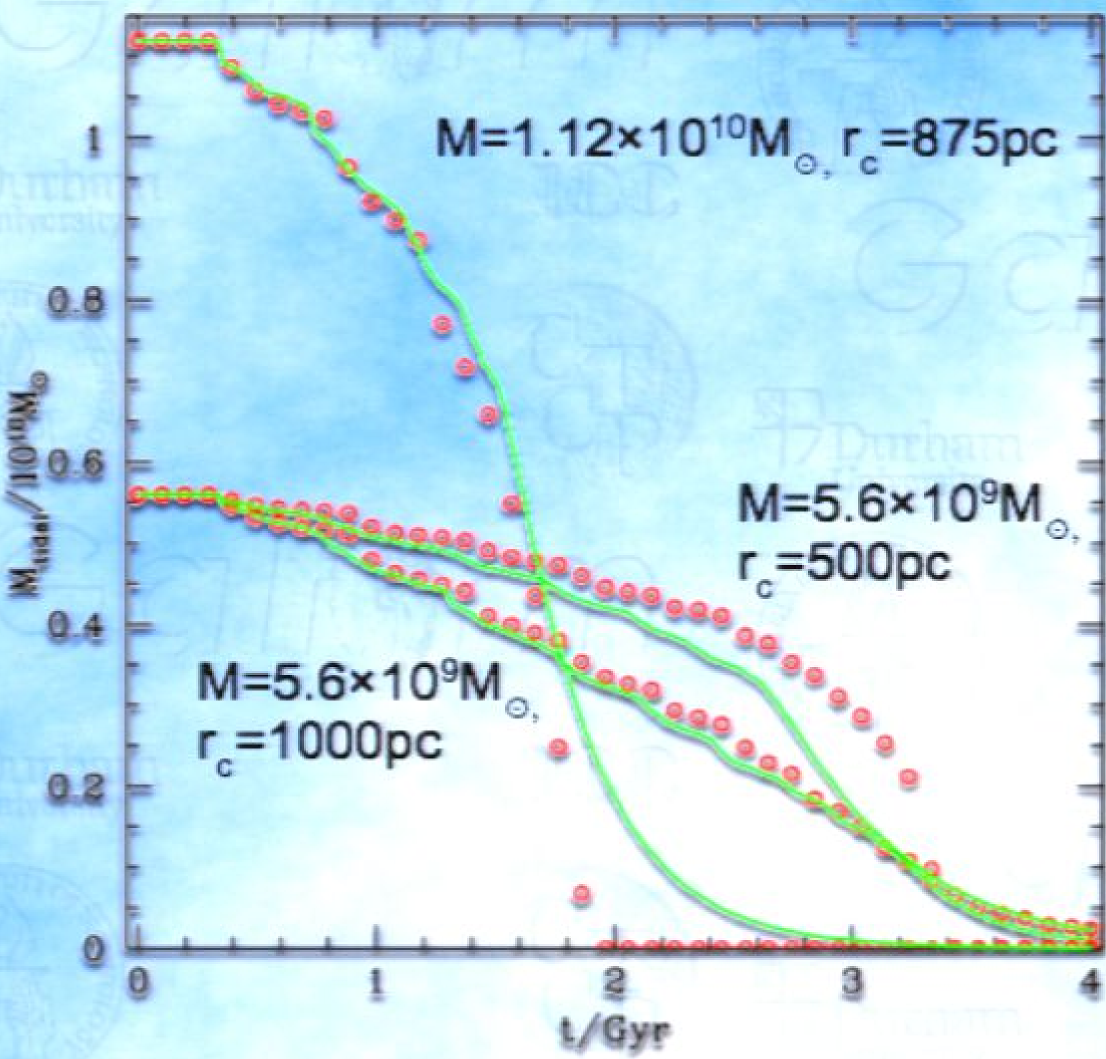


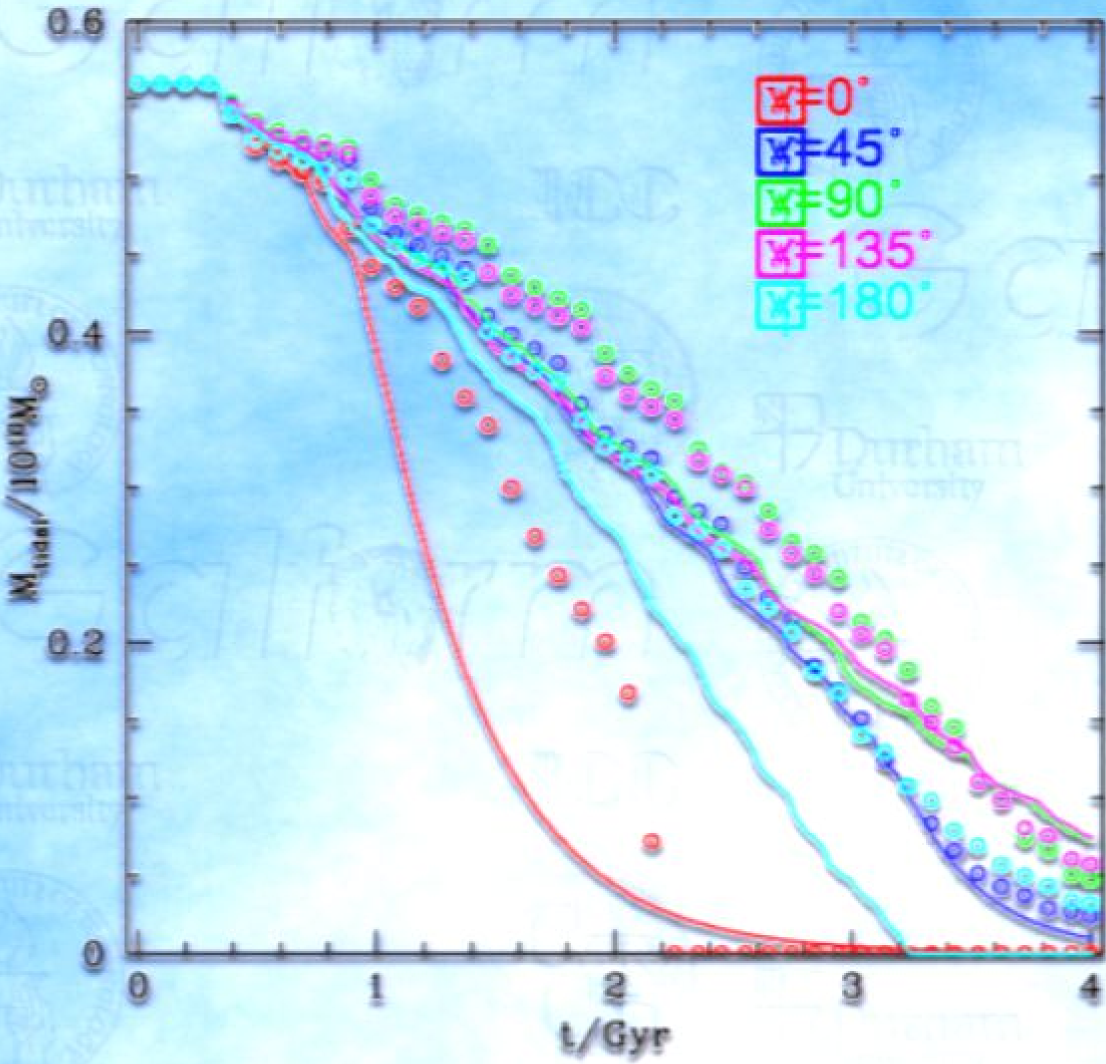
- Prograde/retrograde

Comparison with N-body: Trends



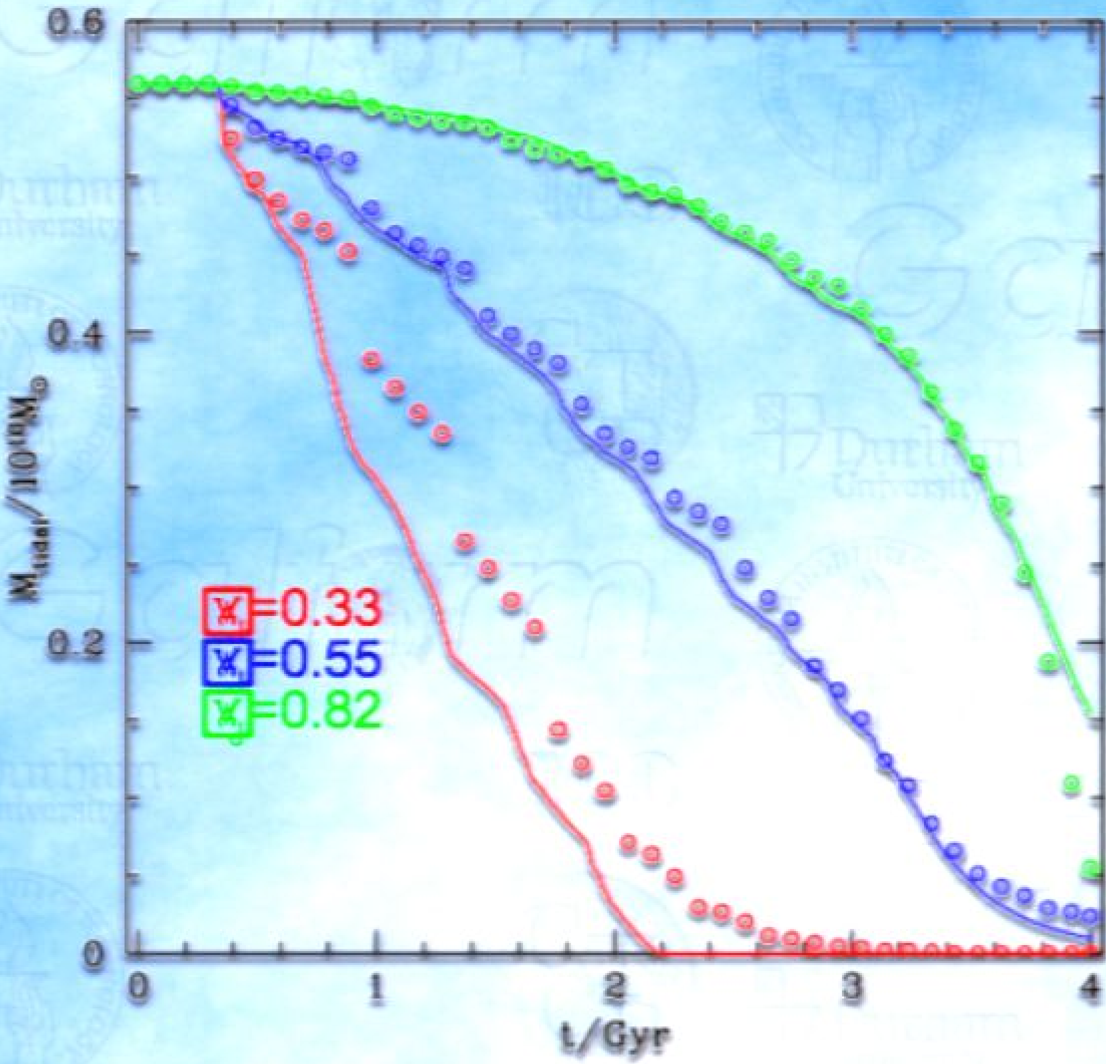
- Prograde/retrograde
- Satellite mass/profile

Comparison with N-body: Trends



- Prograde/retrograde
- Satellite mass/profile
- Orbital inclination

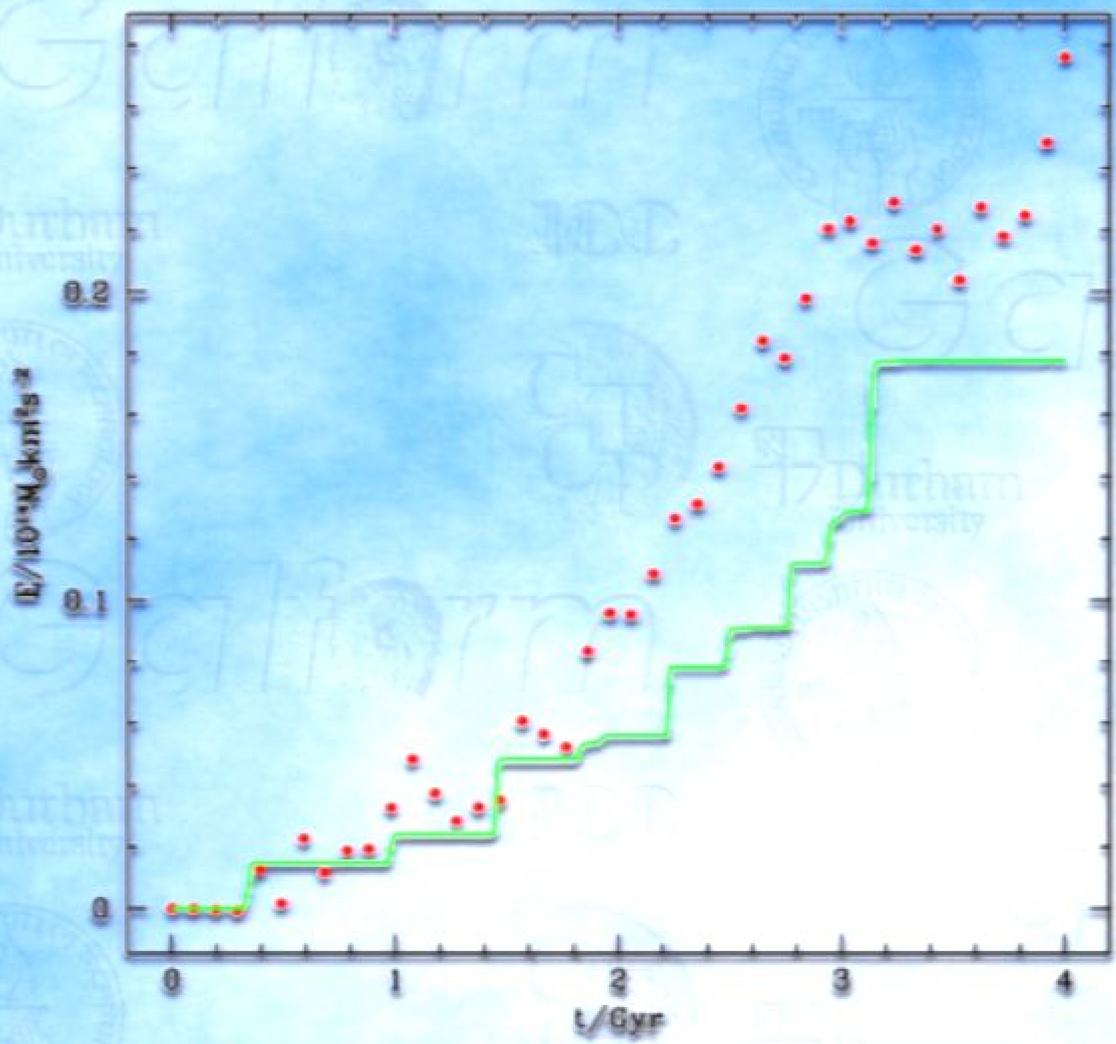
Comparison with N-body: Trends



- Prograde/retrograde
- Satellite mass/profile
- Orbital inclination
- Circularity

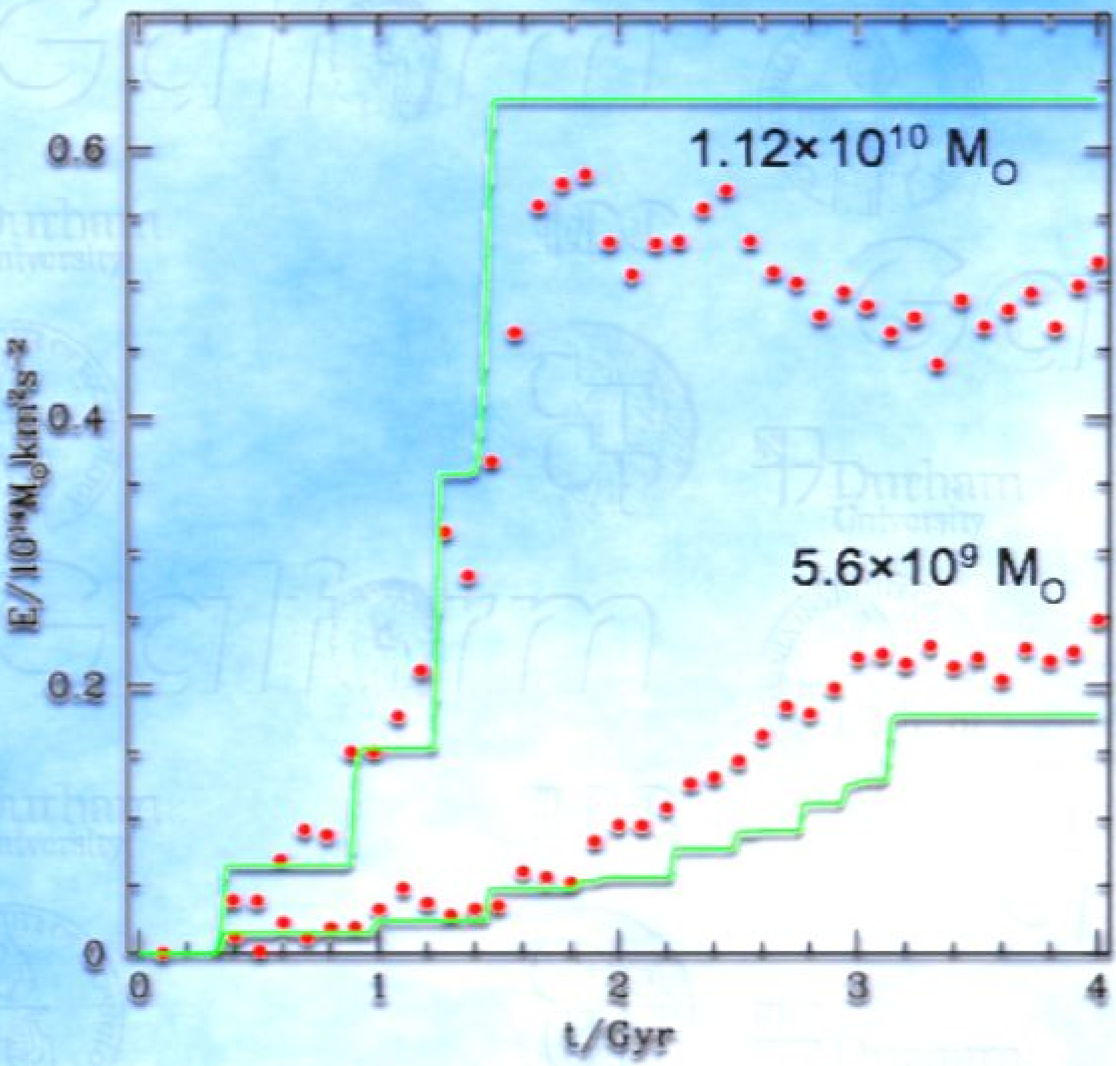
Comparison with N-body: Energy

Comparison with N-body: Energy



- Agreement not so good here, but the N-body results aren't reliable....

Comparison with N-body: Energy



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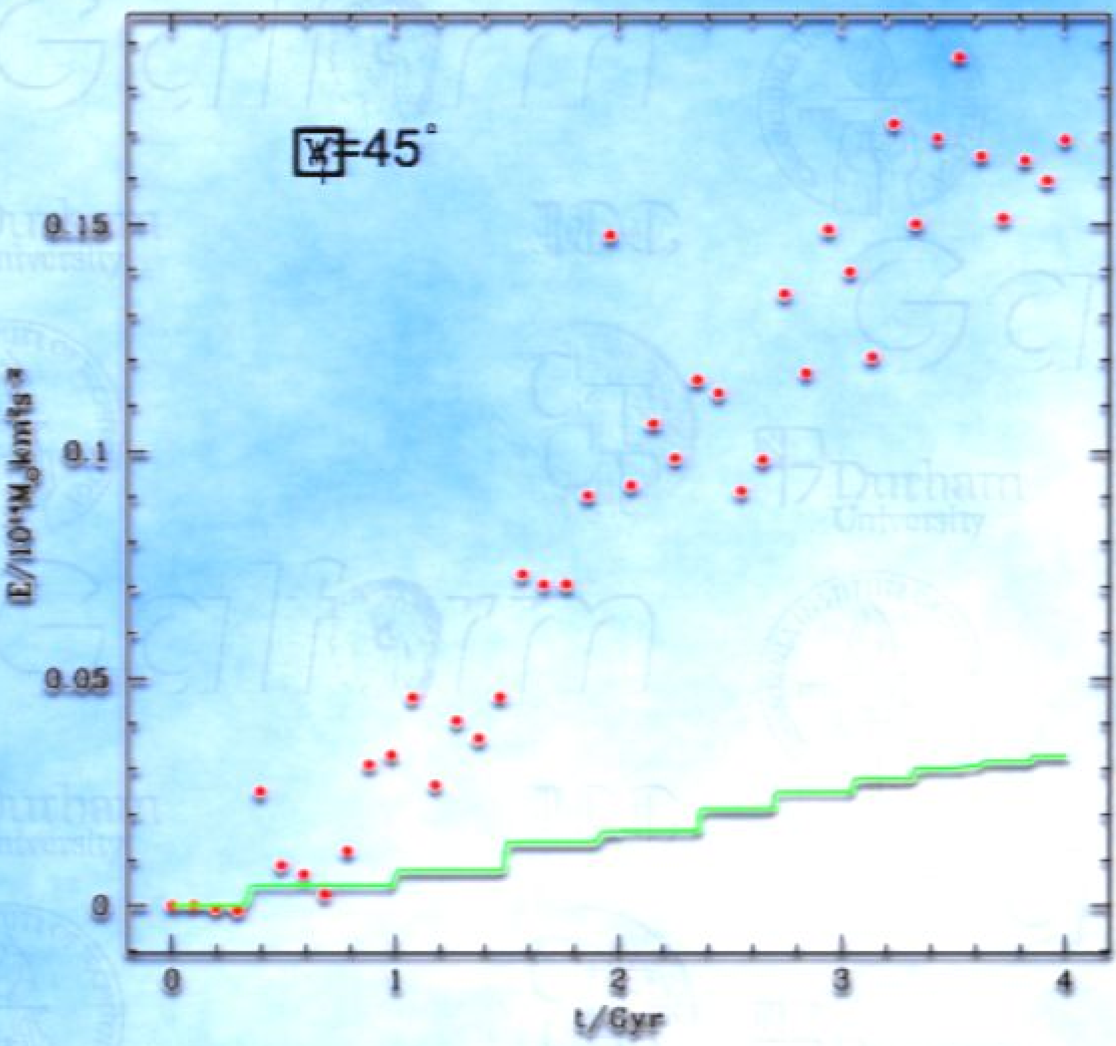
Comparison with N-body: Energy



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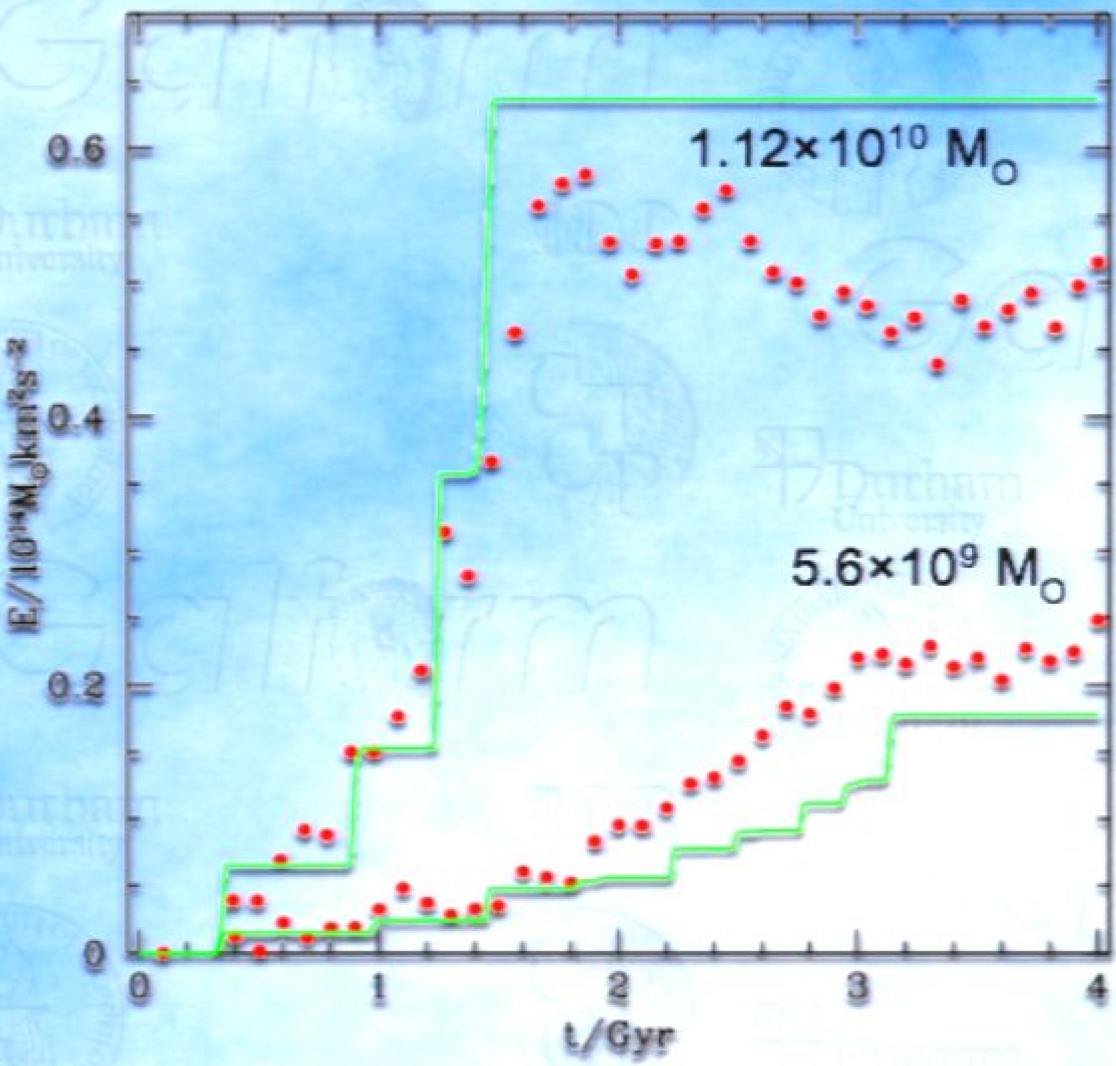

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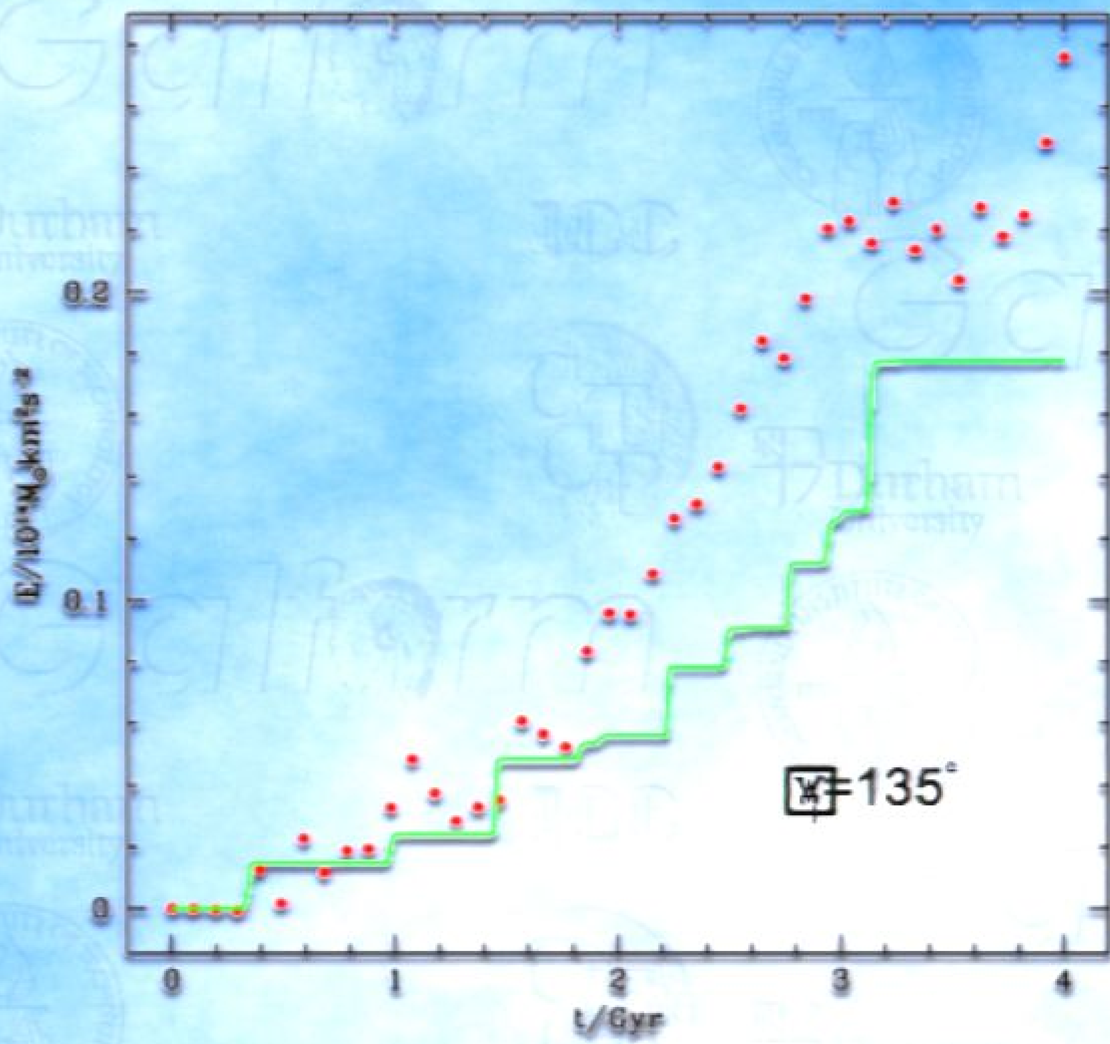
Comparison with N-body: Energy



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Application: Disk Scale Heights

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- Performed the calculation in a ΛCD cosmology

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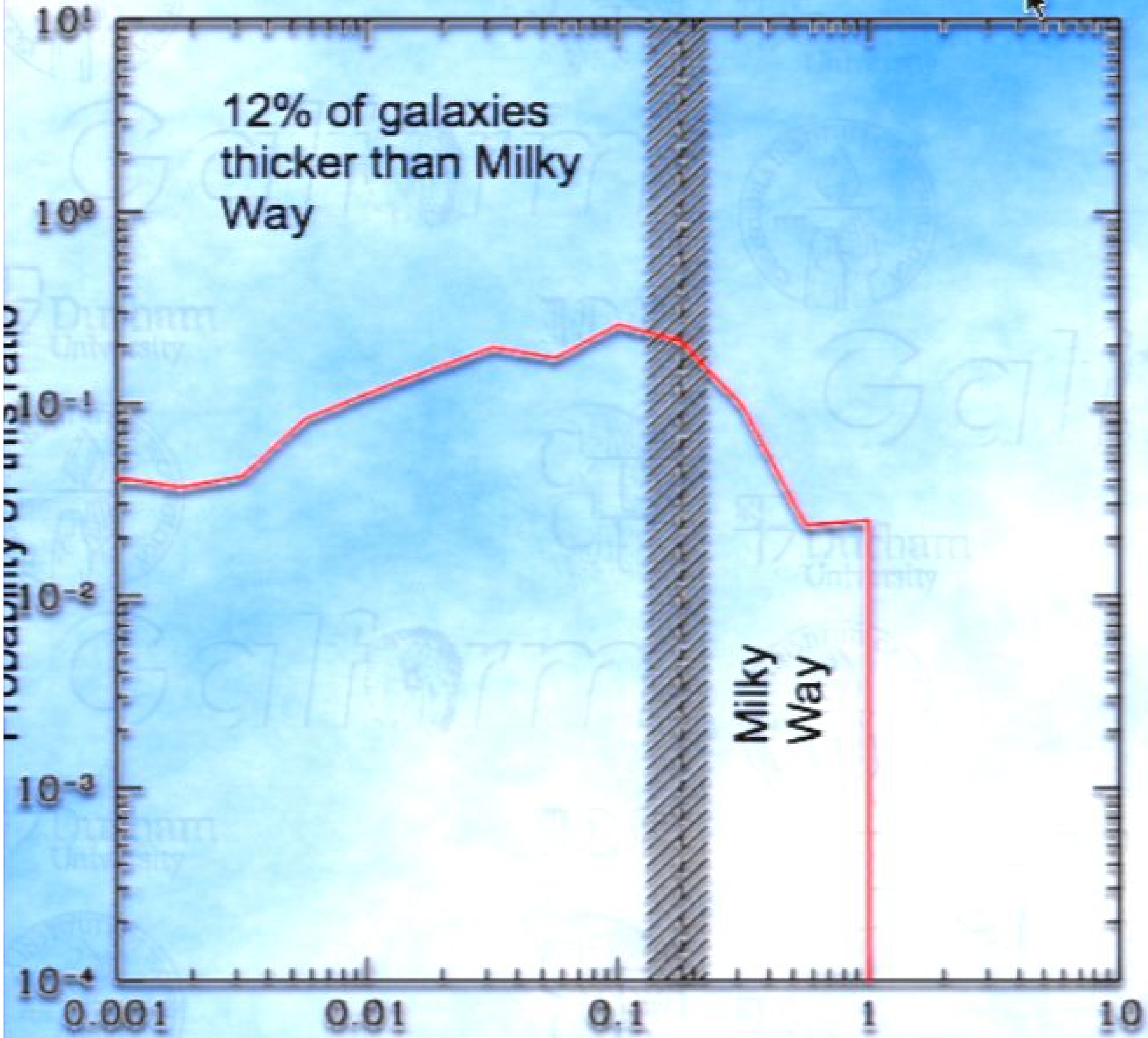
- Milky Way thin disk has:

  $h(=z_0/r_0) \approx 0.18$

Application: Disk Scale Heights

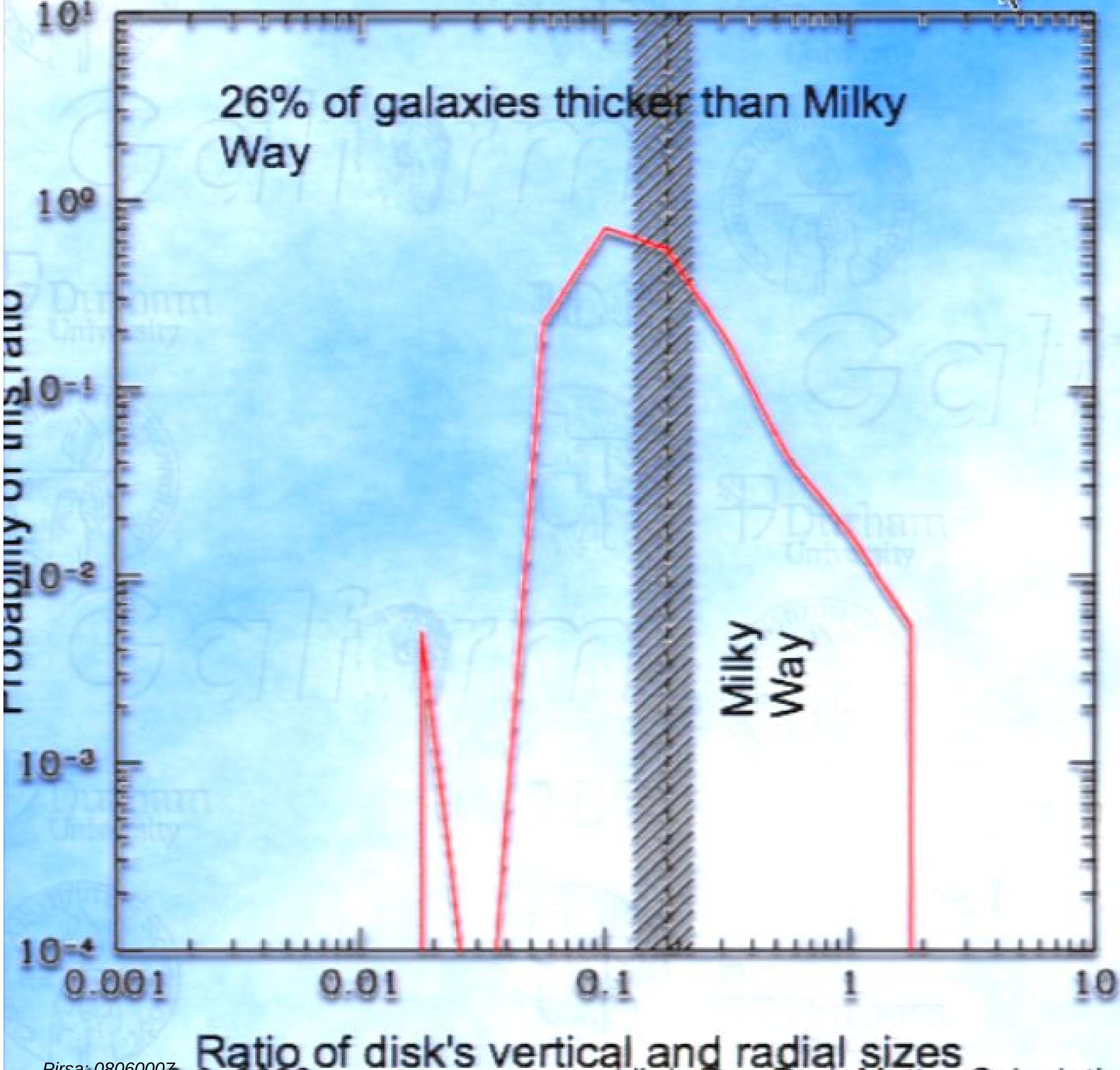


- Performed the calculation in a ΛCD cosmology
- Milky Way thin disk has:

  $h(=z_0/r_0)\approx 0.18$

- L_* and brighter galaxies peak near h=0.1

Application: Disk Scale Heights



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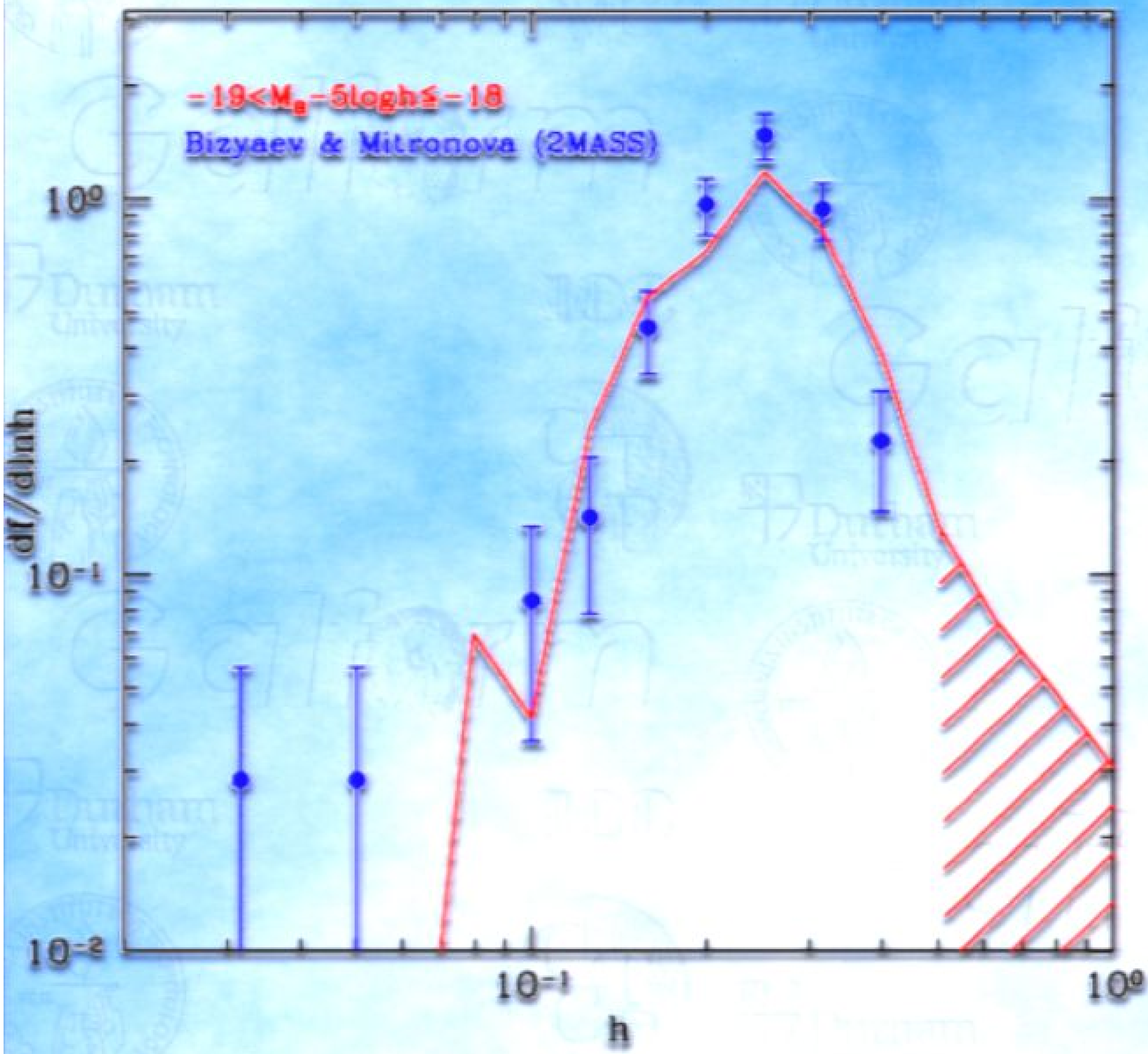
Application: Disk Scale Heights



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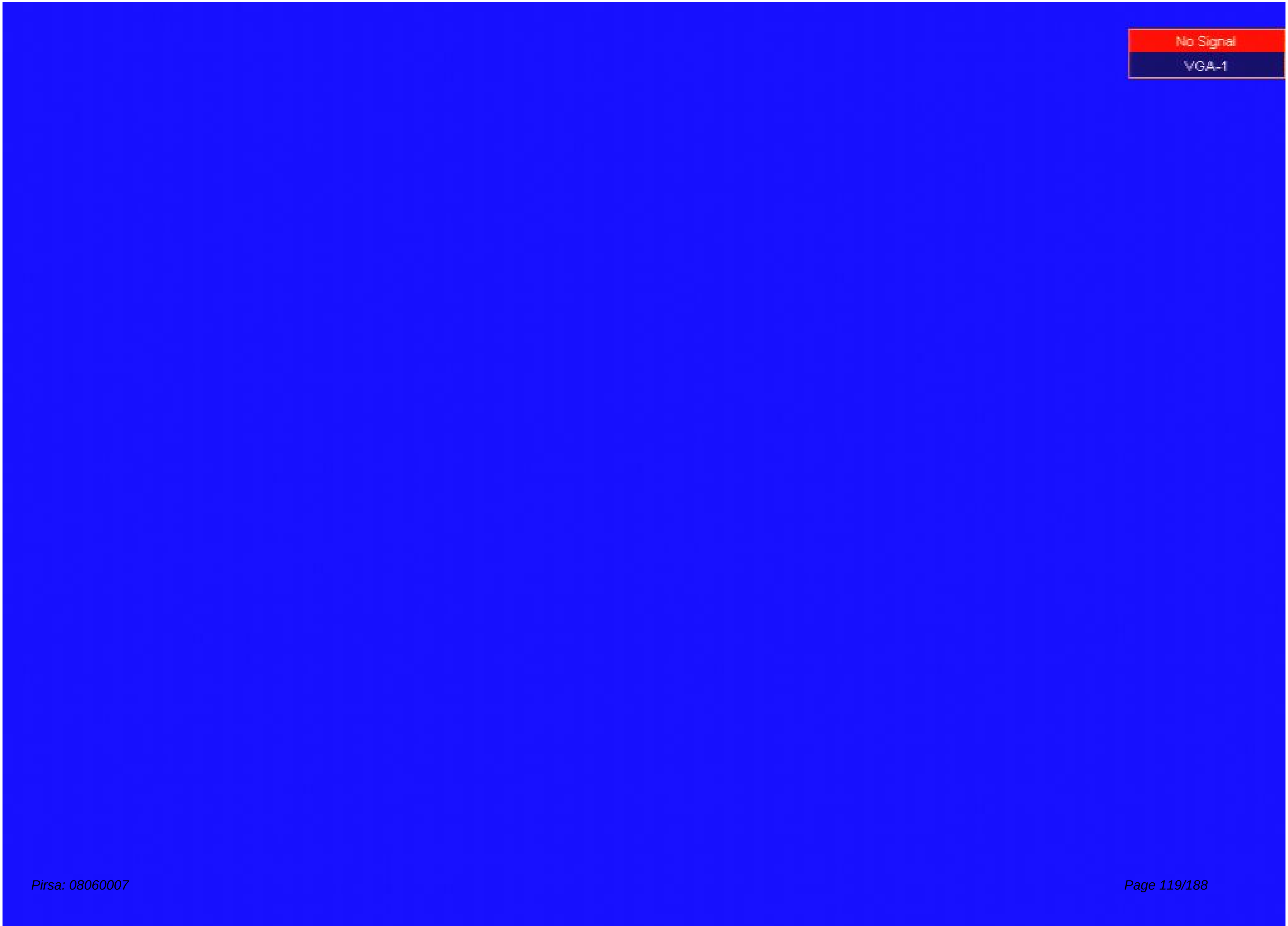
No Signal

VGA-1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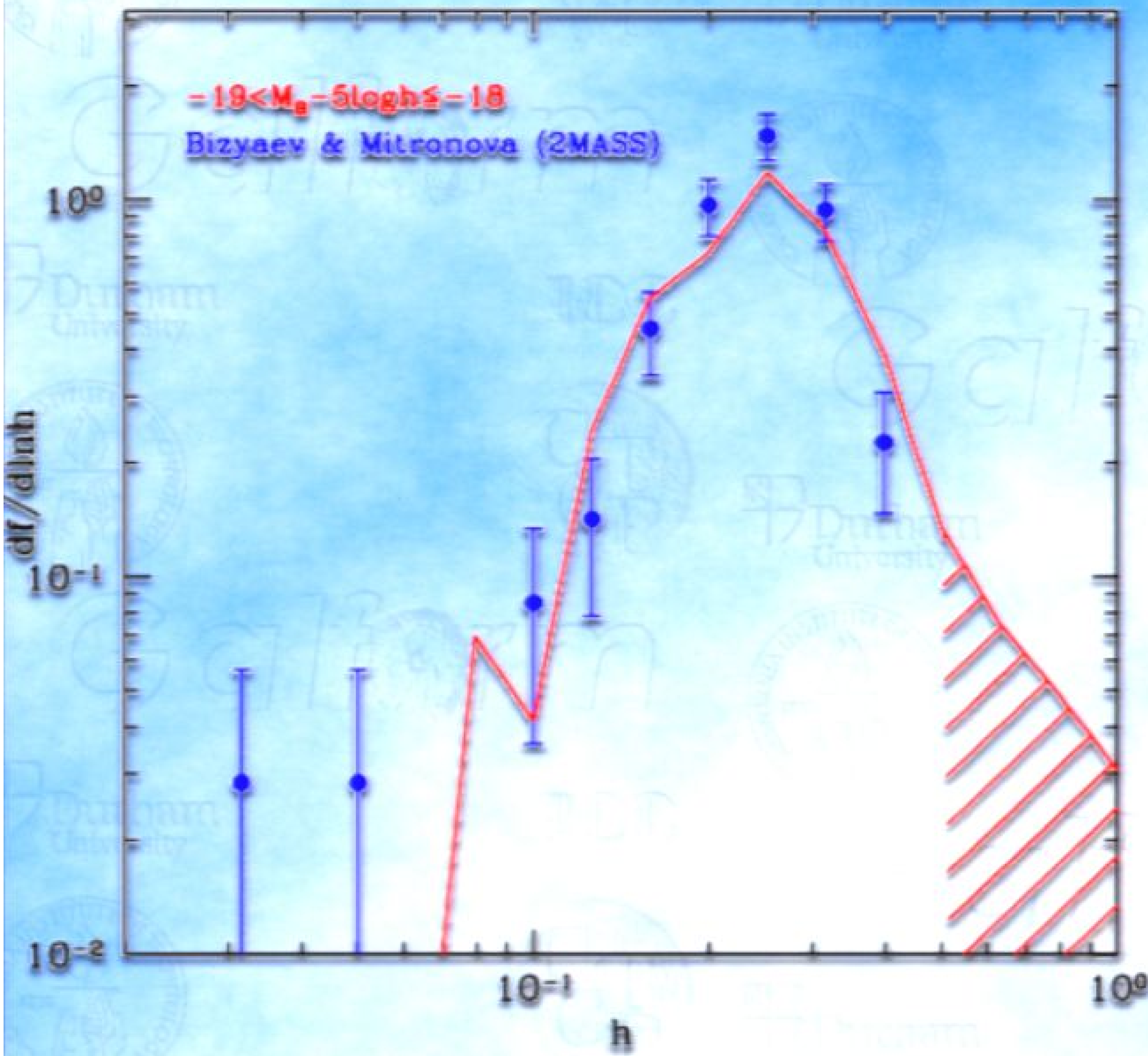
Application: Disk Scale Heights



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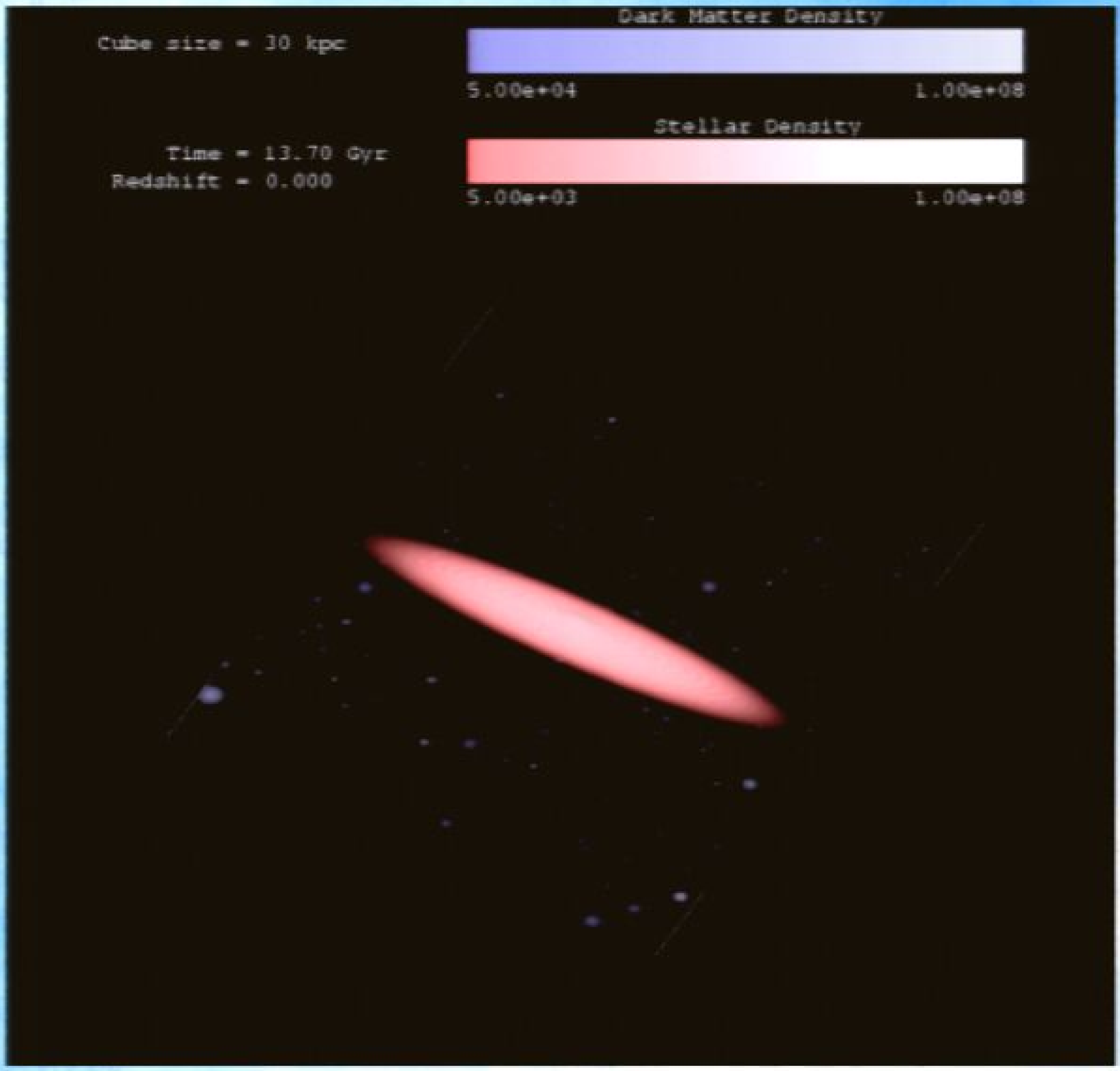
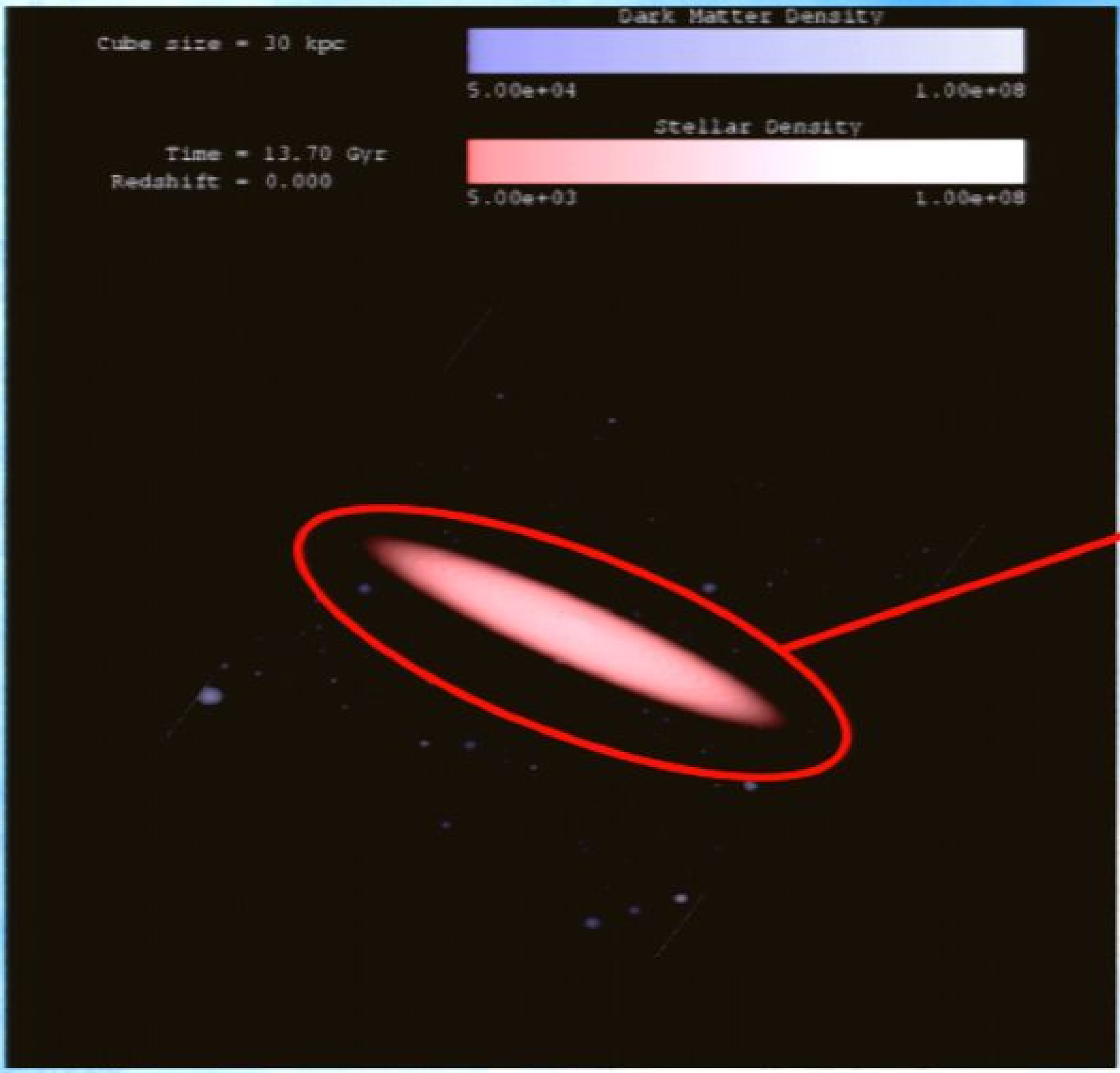
Formation of a Galaxy in GALFORM

Formation of a Galaxy in GALFORM



- Model predicts full dynamics of forming galaxy as a function of time
- Need a movie!
- *Stars*

Formation of a Galaxy in GALFORM



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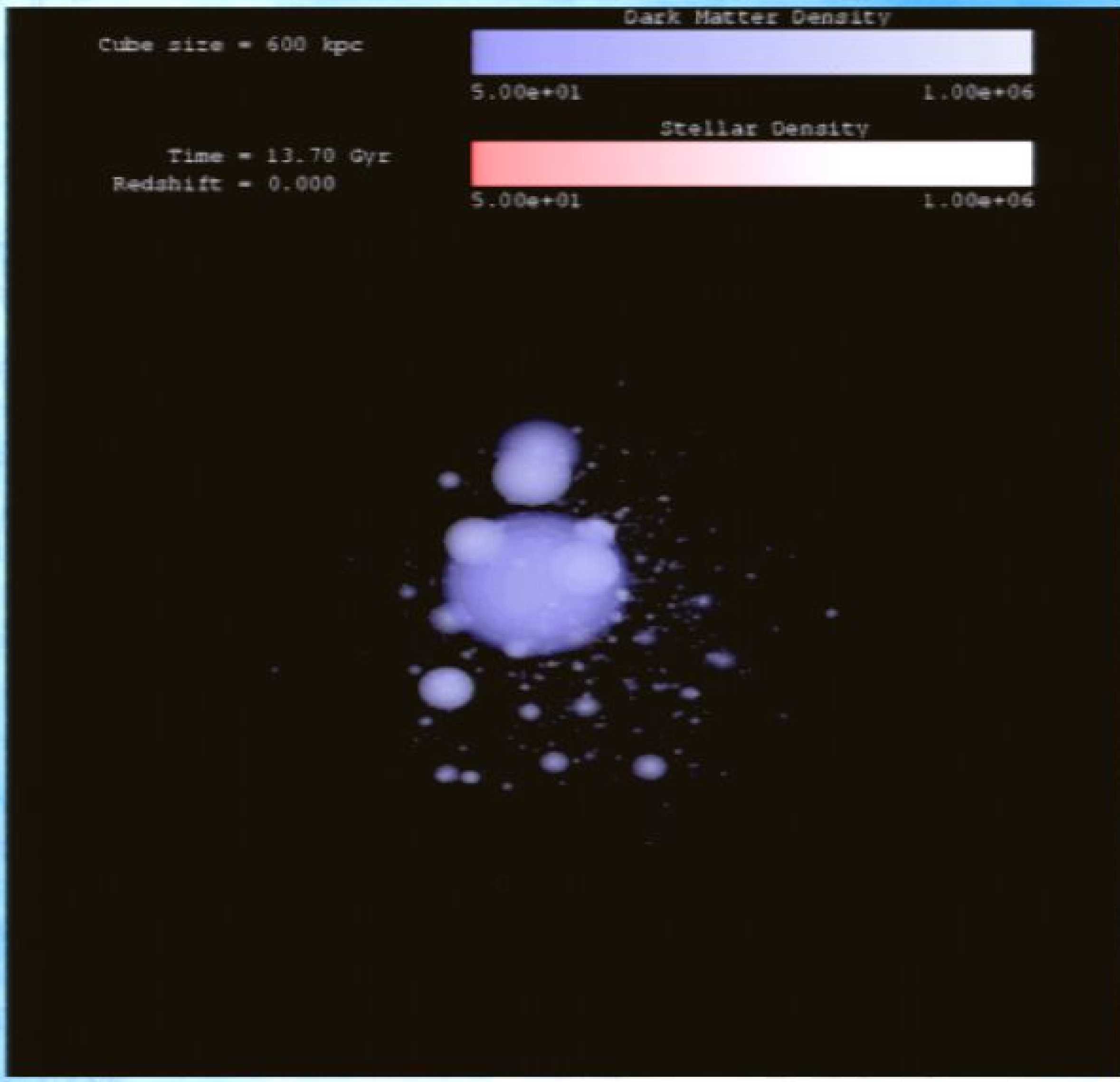
Formation of a Galaxy in GALFORM



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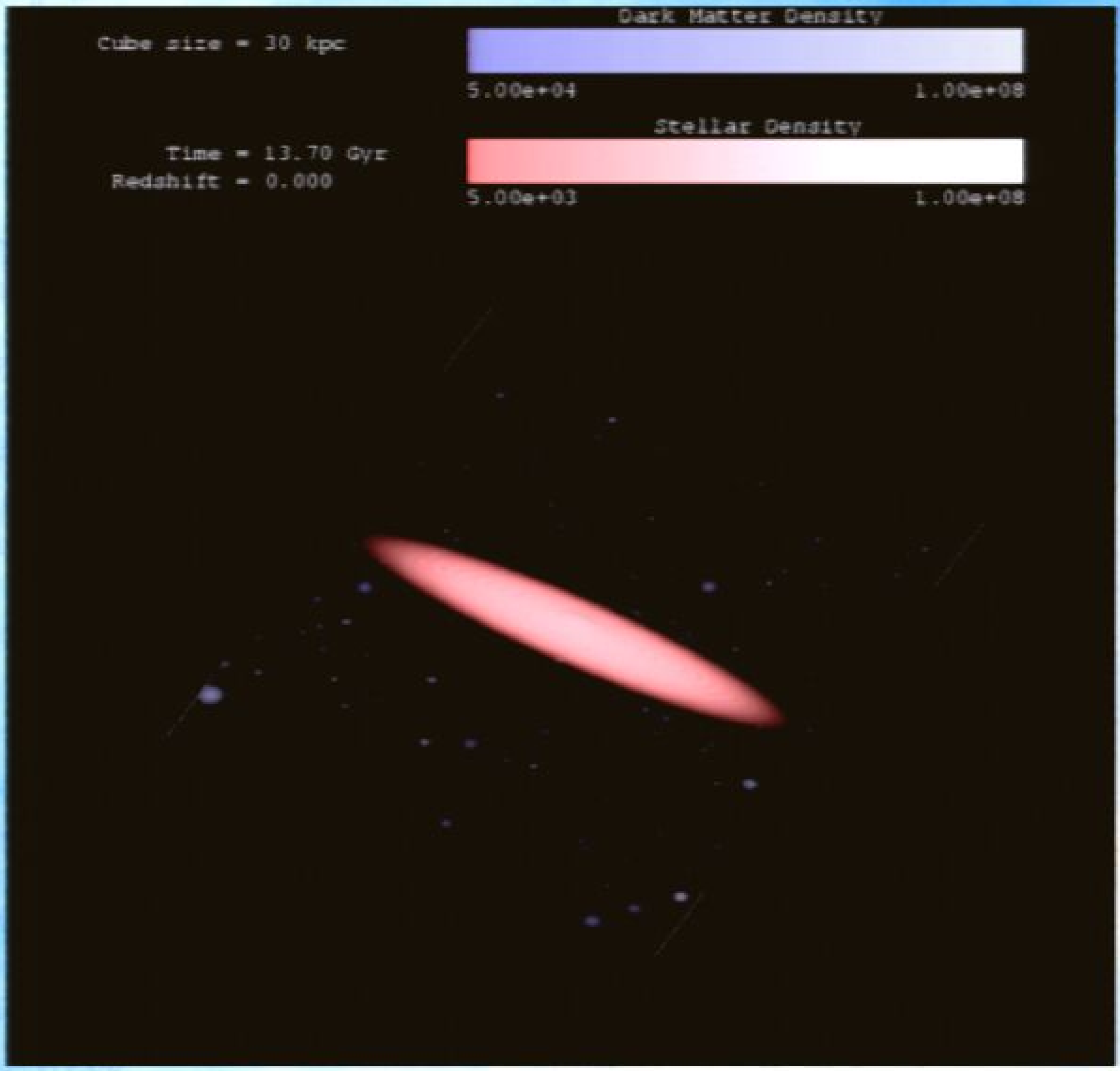
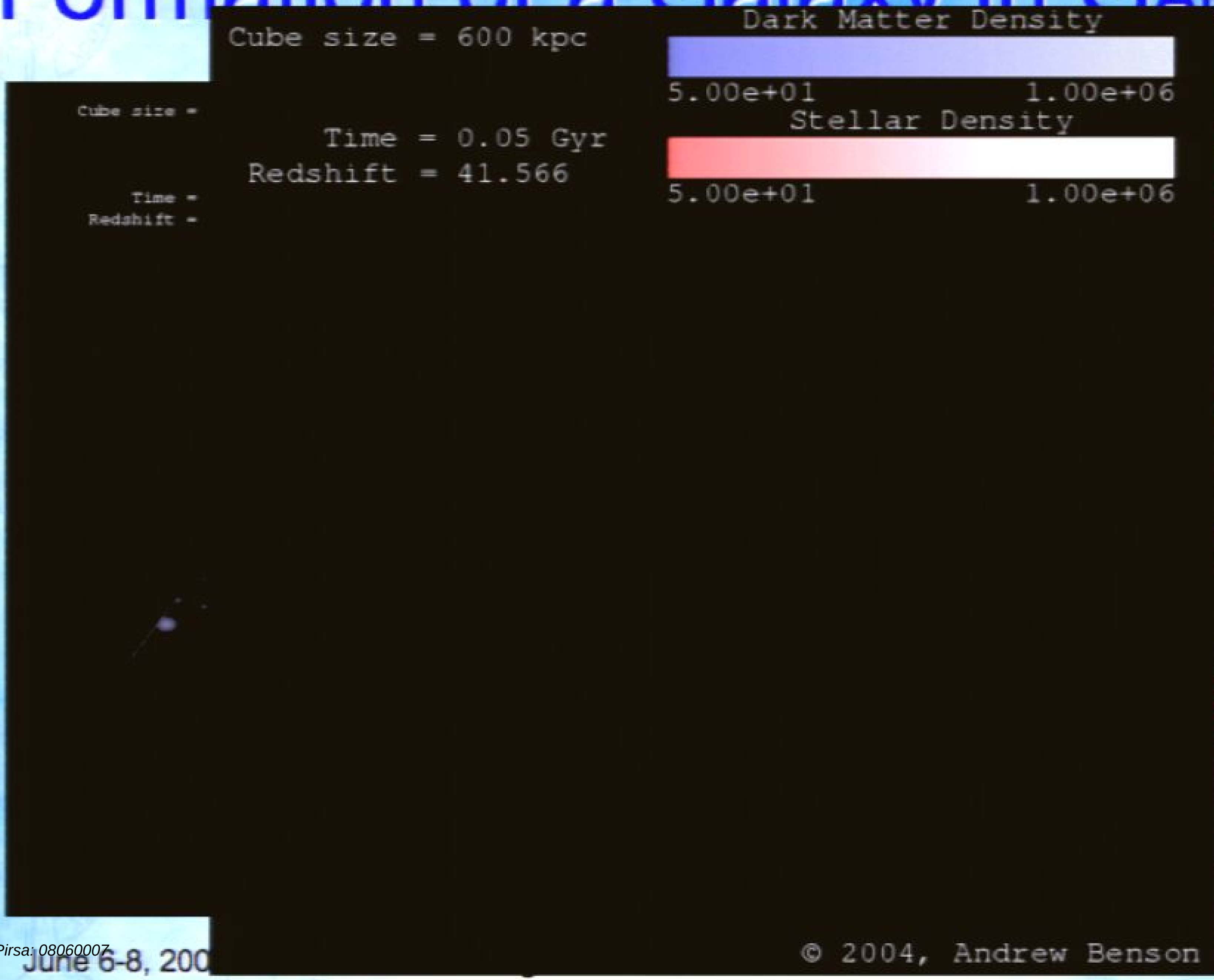
- Full halo

Formation of a Galaxy in GALFORM



- Model predicts full dynamics of forming galaxy as a function of time
- Need a movie!
- *Stars*
- *Dark matter*
- Full halo
- Zoomed region
- Watch for growth of the galaxy

Formation of a Galaxy in GALFORM



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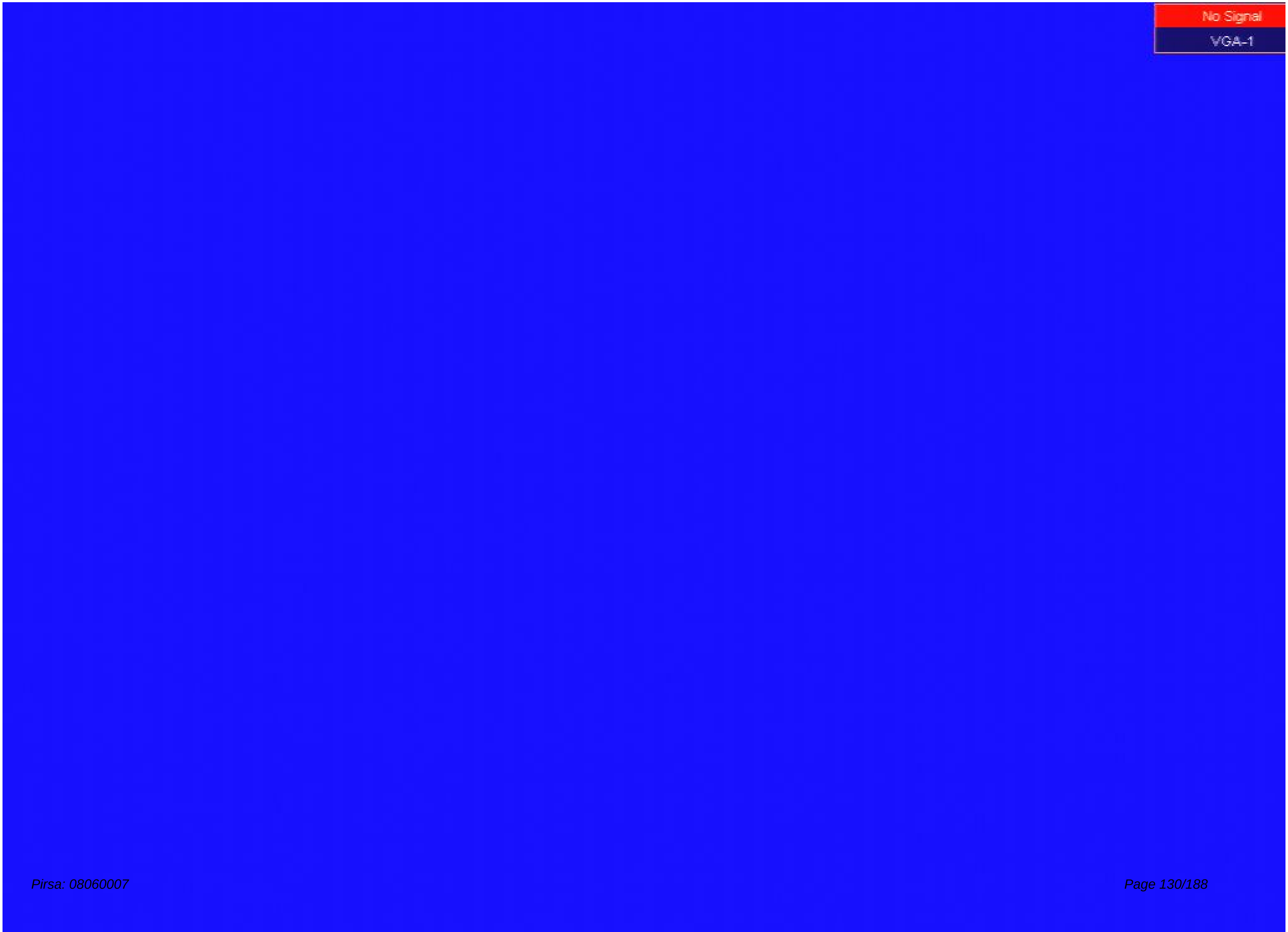
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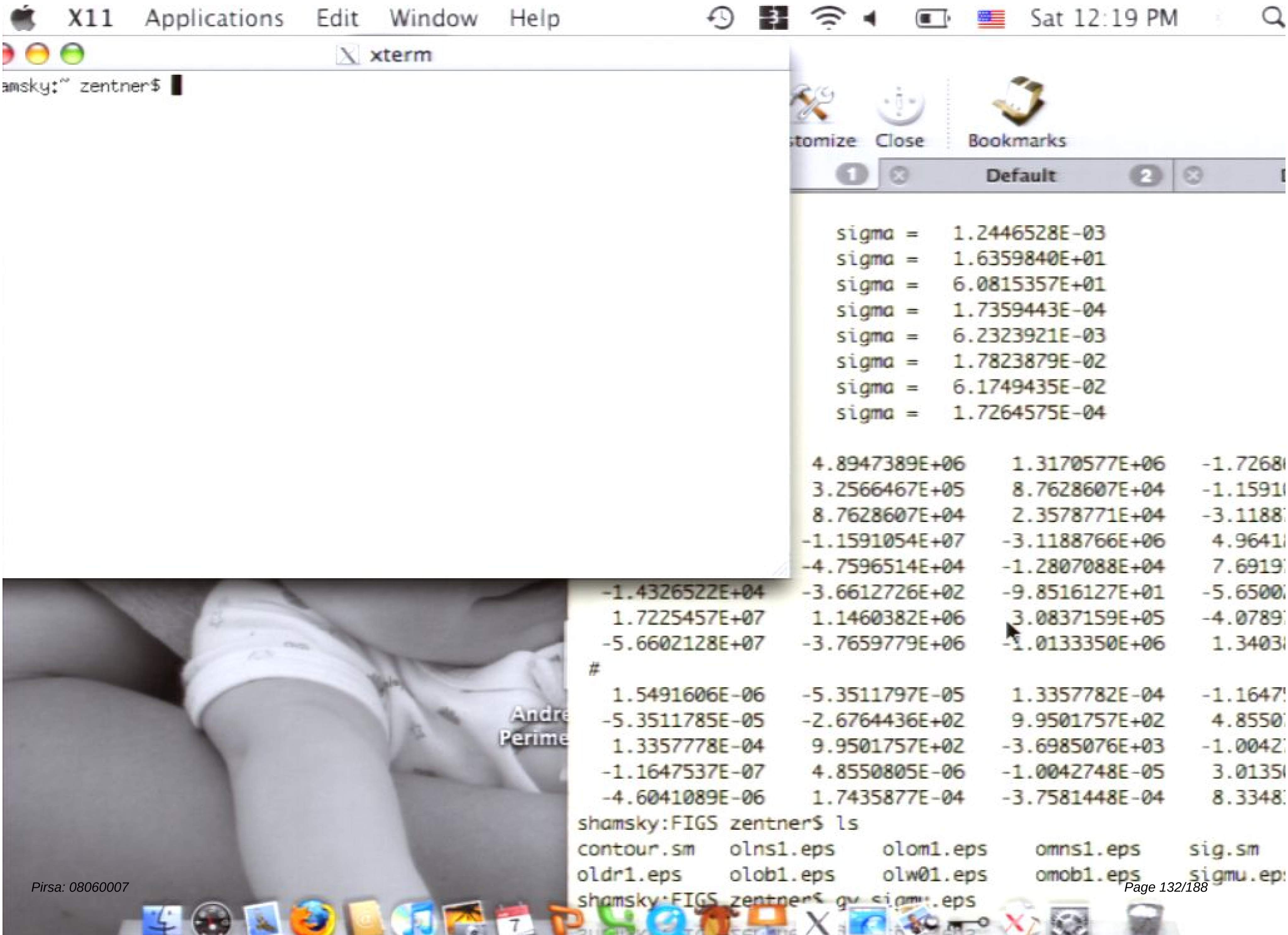
X11 Applications Edit Window Help
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Close
Bookmarks
Default
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sigma = 6.0815357E+01
sigma = 1.7359443E-04
sigma = 6.2323921E-03
sigma = 1.7823879E-02
sigma = 6.1749435E-02
sigma = 1.7264575E-04
4.8947389E+06 1.3170577E+06
3.2566467E+05 8.7628607E+04
8.7628607E+04 2.3578771E+04
-1.1591054E+07 -3.1188766E+06
-4.7596514E+04 -1.2807088E+04
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1.7225457E+07 1.1460382E+06 3.0837159E+05
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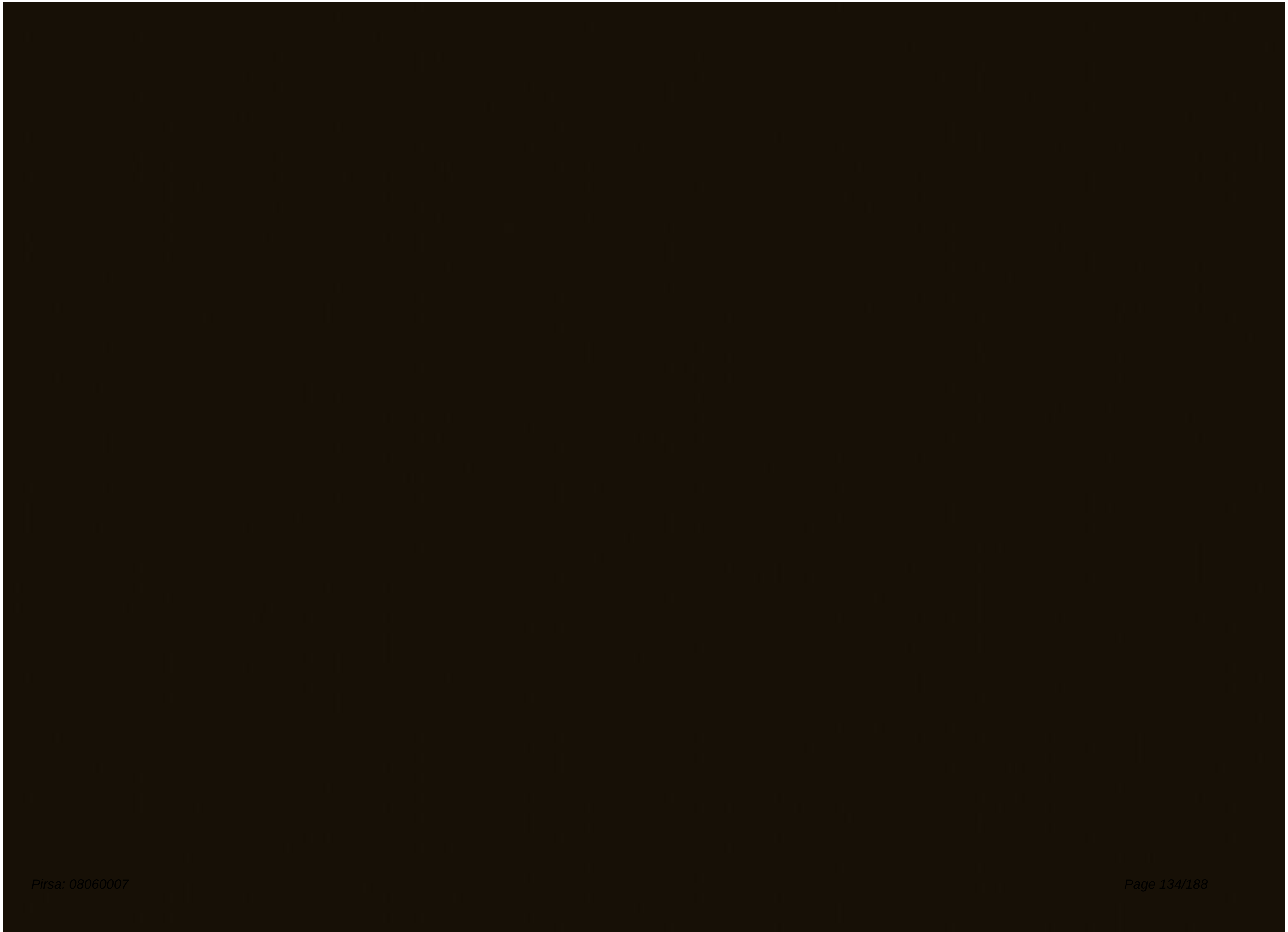

xterm

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shamsky:FIGS zentner$ gv w0wa1.eps
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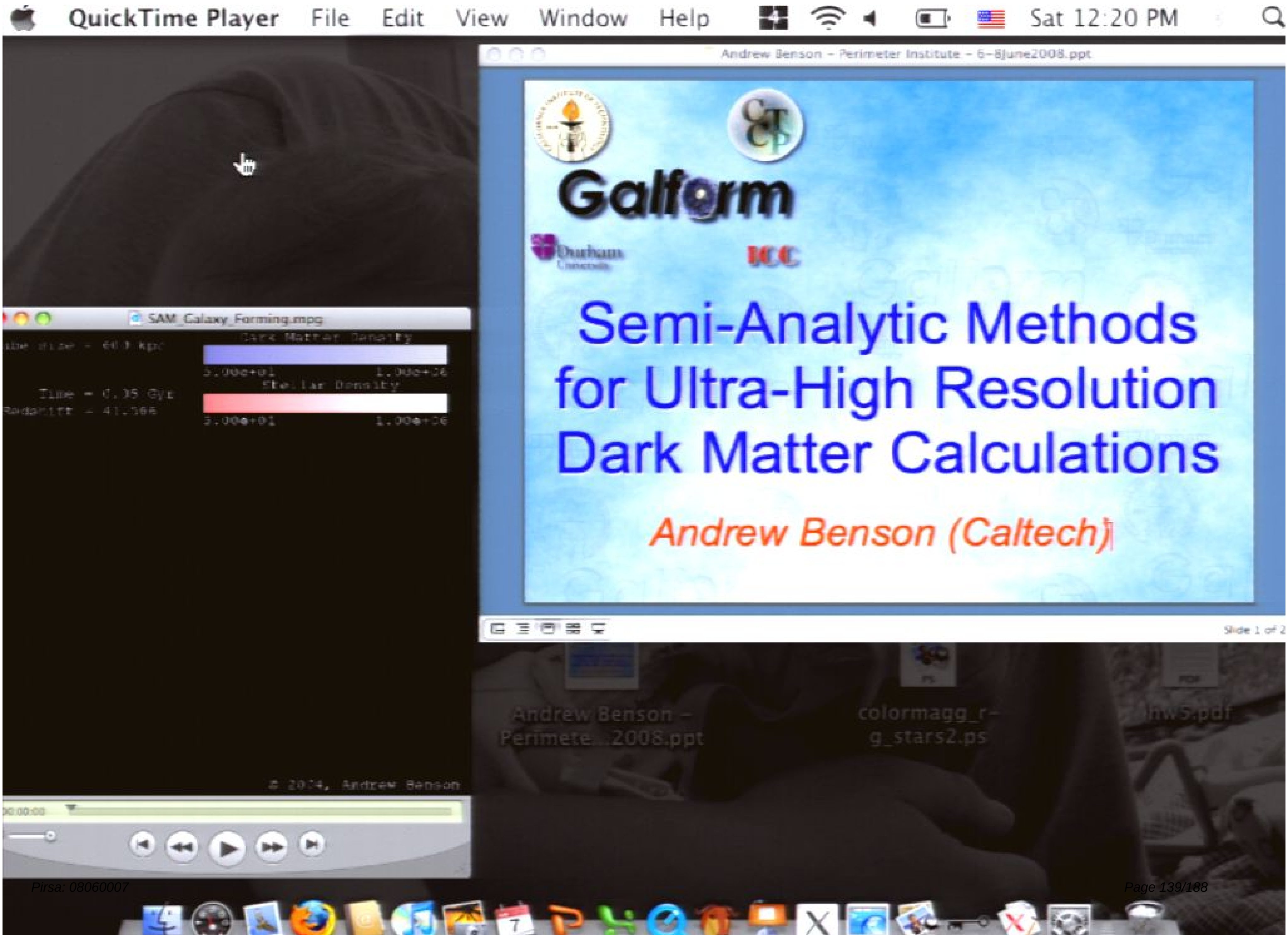
Semi-Analytic Methods for Ultra-High Resolution Dark Matter Calculations

Andrew Benson (Caltech)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Galform
Durham University
ICC
Semi-Analytic Methods for Ultra-High Resolution Dark Matter Calculations
Andrew Benson (Caltech)
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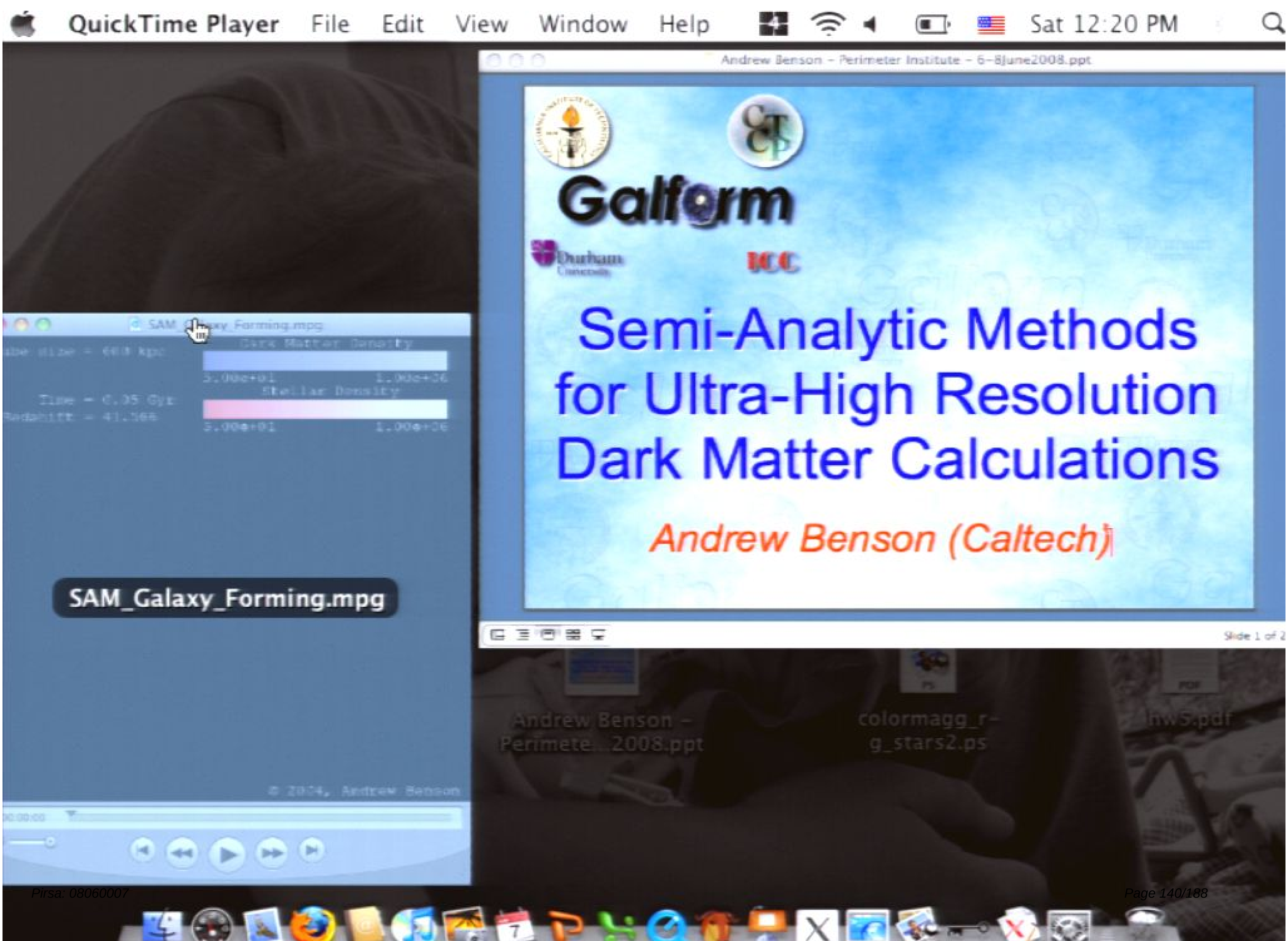
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Andrew Benson (Caltech)
SAM_Galaxy_Forming.mpg
Dark Matter Density
Stellar Density
© 2004, Andrew Benson
SAM_Galaxy_Forming.mpg
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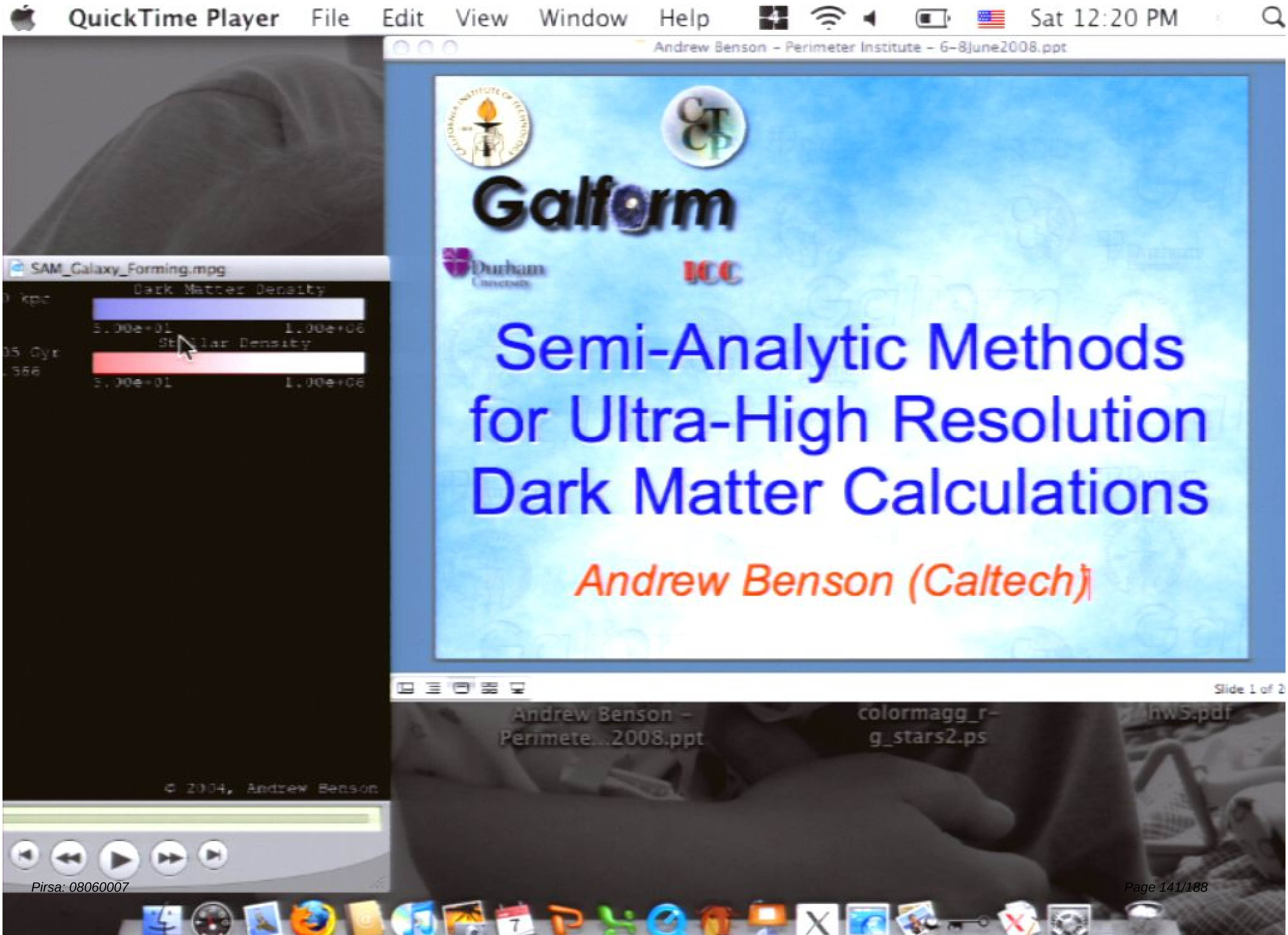
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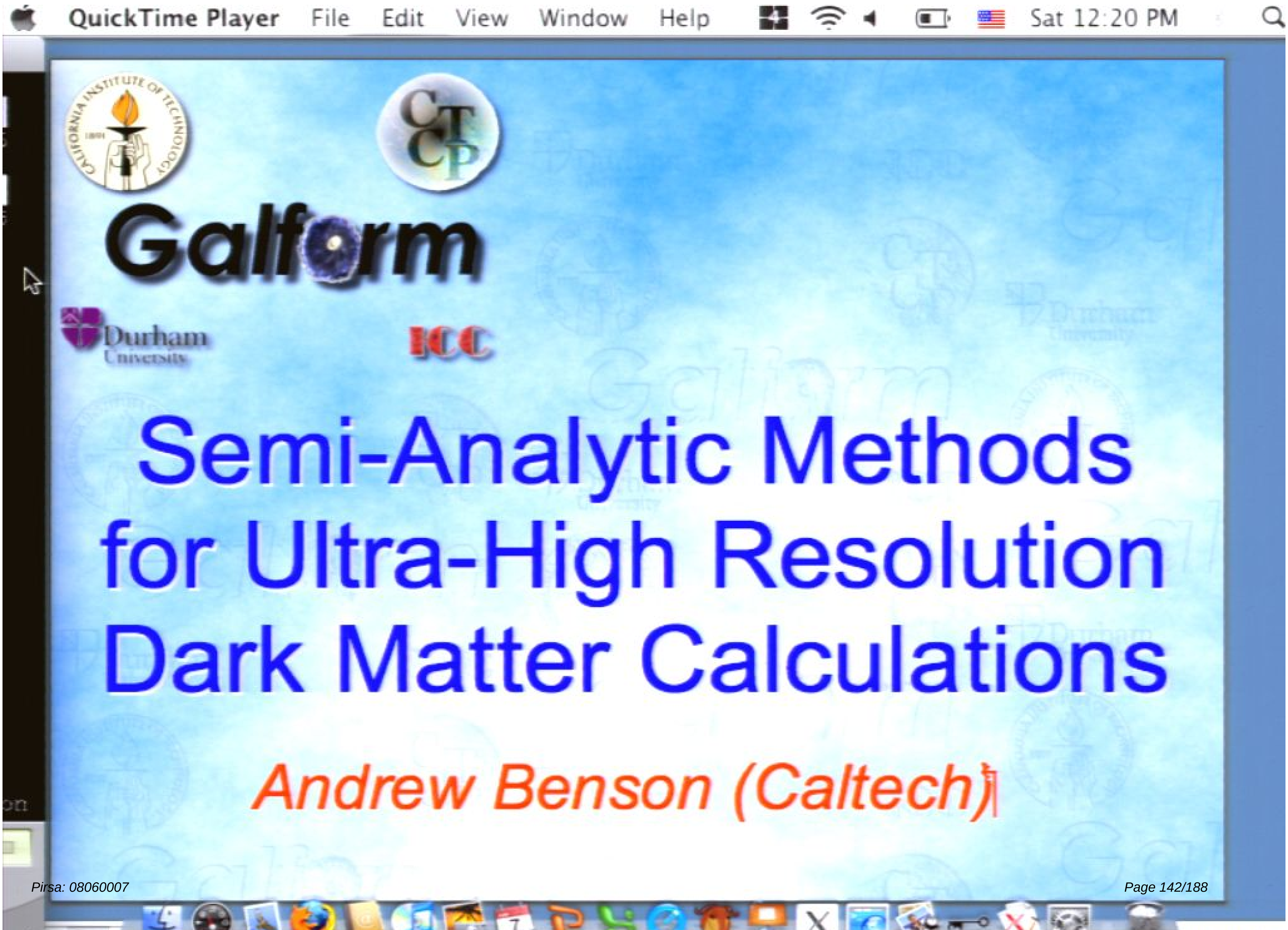
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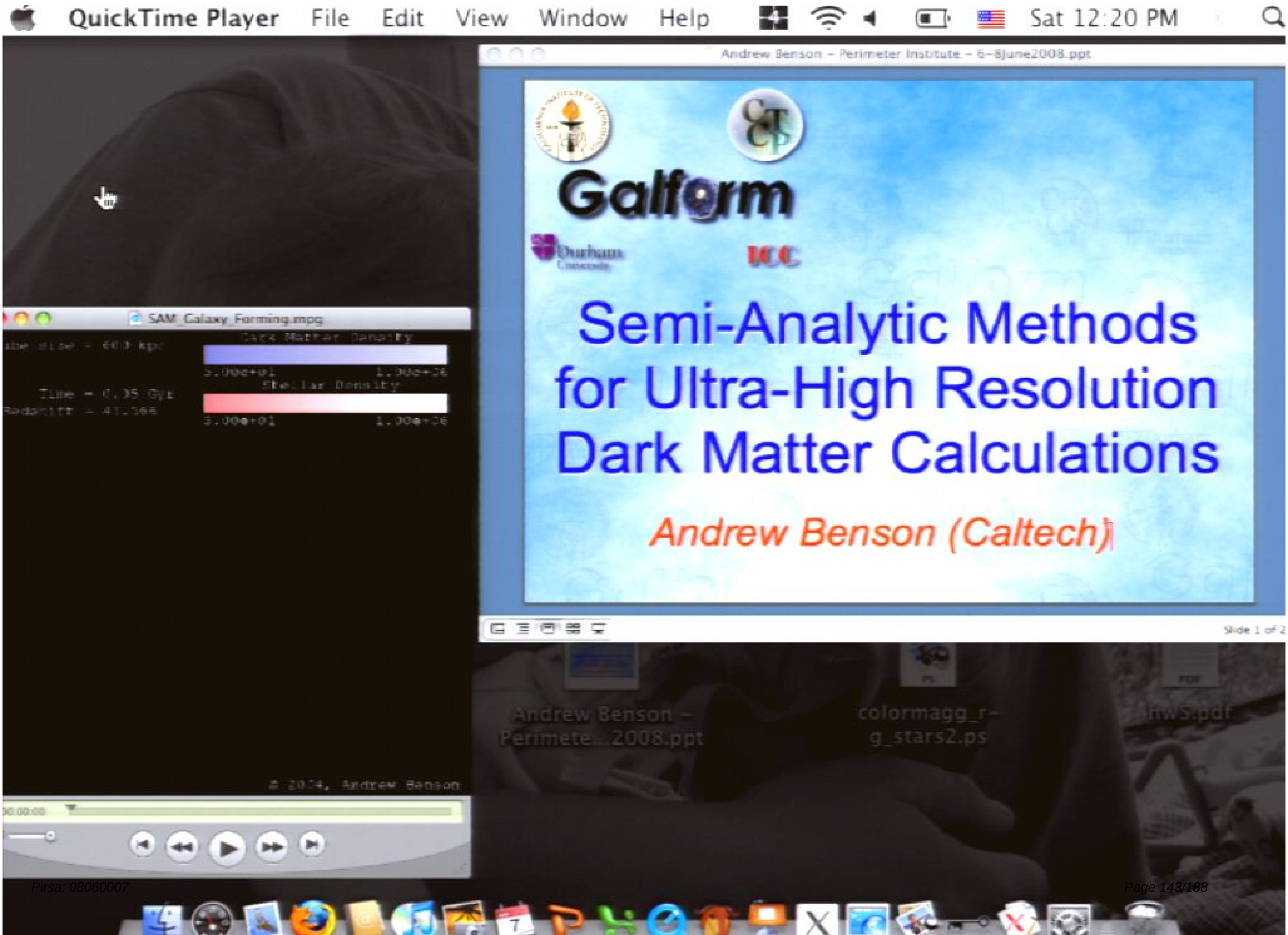
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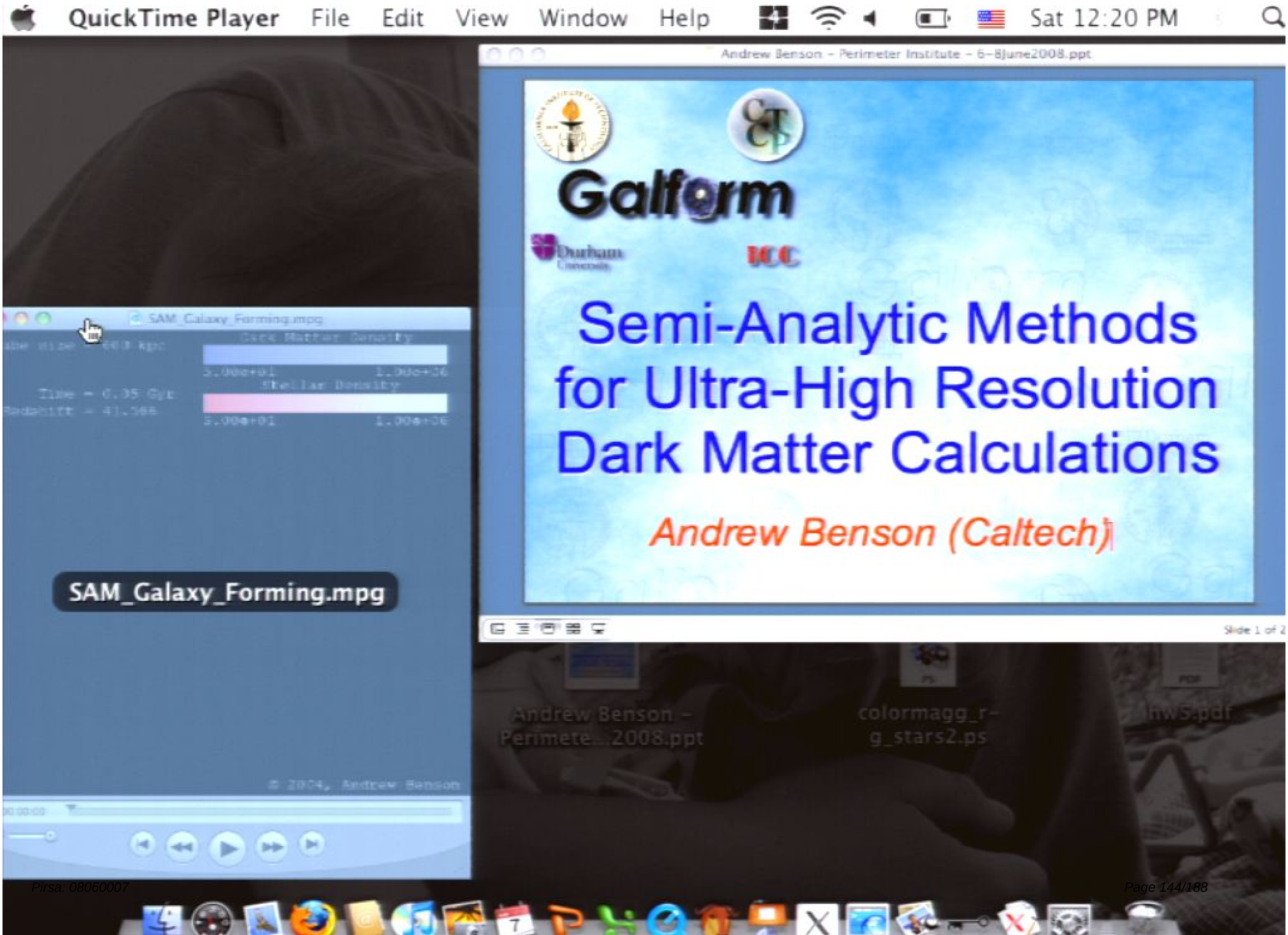
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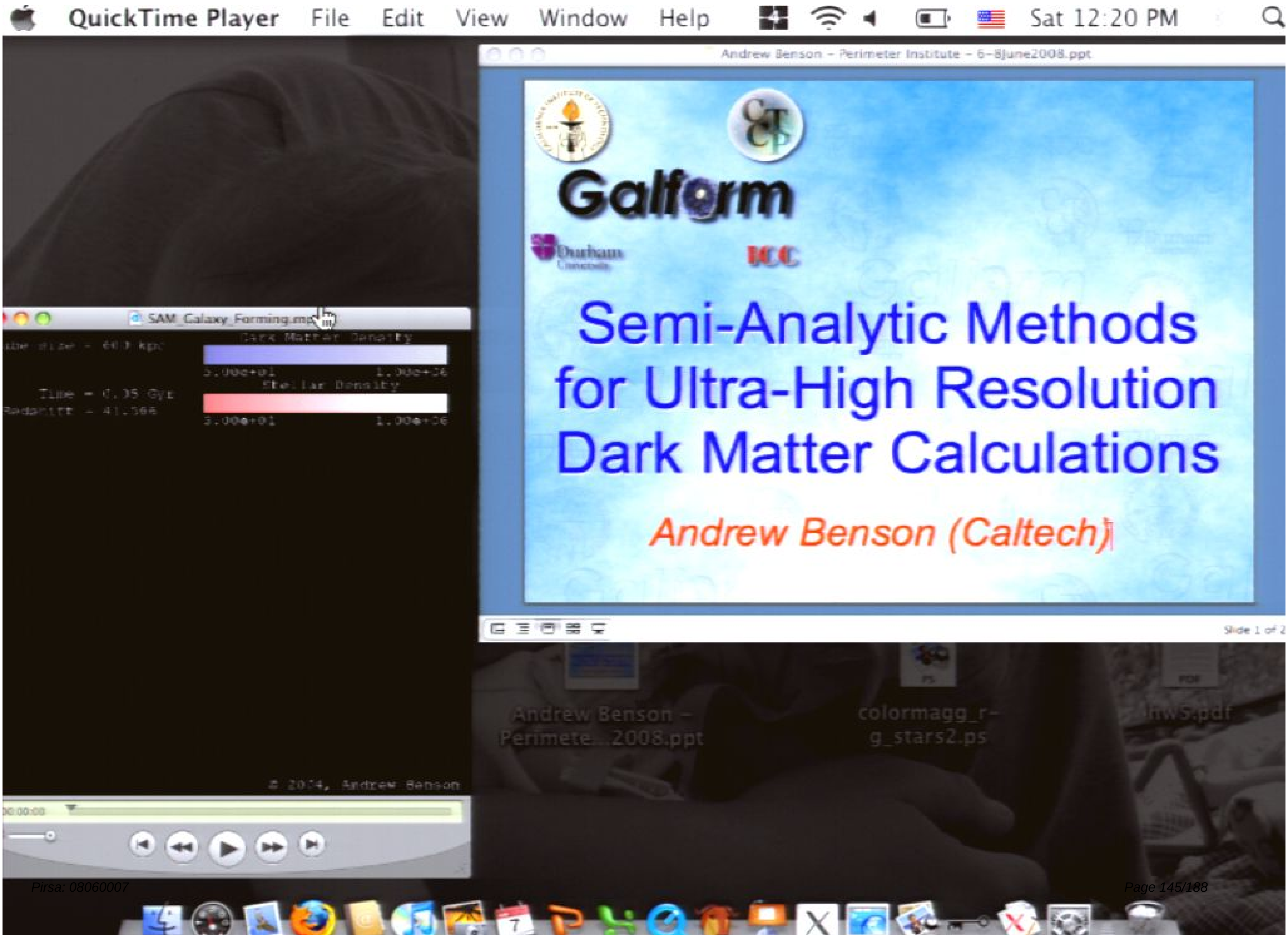

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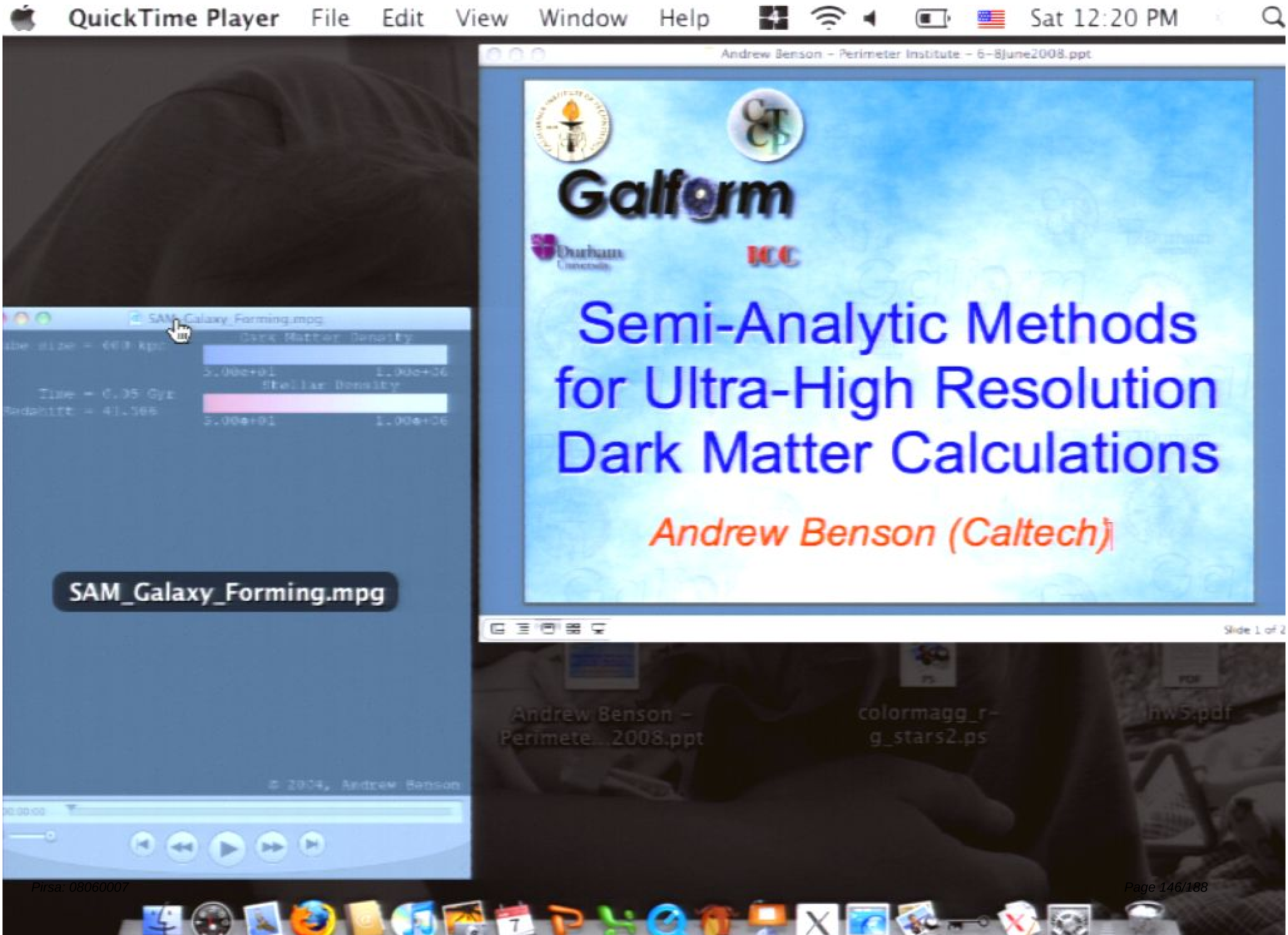
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Durham University

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Semi-Analytic Methods for Ultra-High Resolution Dark Matter Calculations

Andrew Benson (Caltech)

No Signal
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X11 Applications Edit Window Help Sat 12:21 PM

xterm

amsky:~ zentner$

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				+06
				+08
				+05
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07	-1.6749568E+05	-1.2884291E+03	4.0332563E+06	-1.3252495E+07
08	5.5040487E+05	4.2338863E+03	-1.3252495E+07	1.0000262E+07

07	-4.6041089E-06	2.2657216E-06	-2.9924451E-06	-3.9103991E-14
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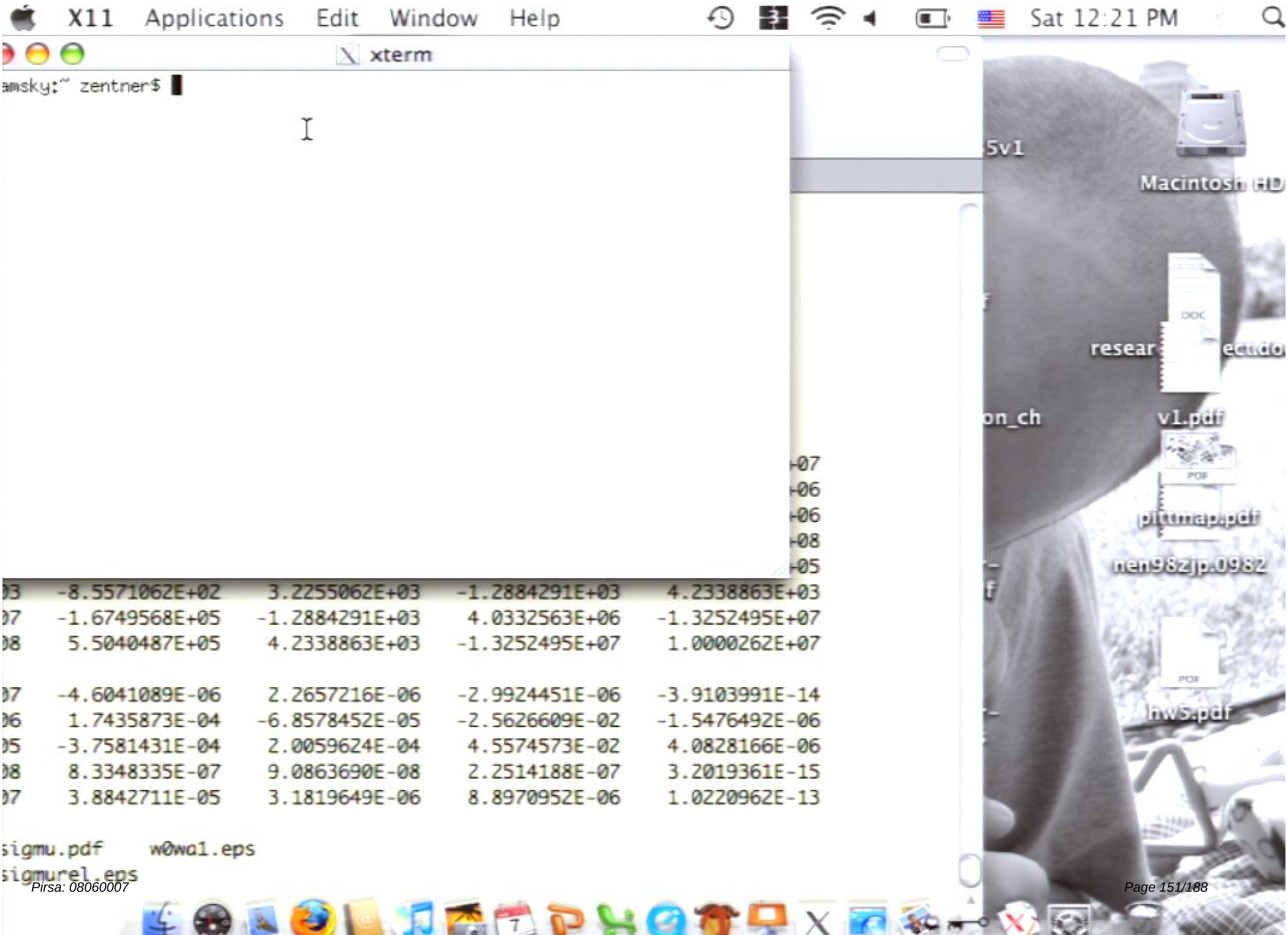
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Sat 12:21 PM
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Default (146,30)

Default

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06	-1.2807088E+04	-9.8516127E+01	3.0837159E+05	-1.0133350E+06
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08	5.5040487E+05	4.2338863E+03	-1.3252495E+07	1.0000262E+07
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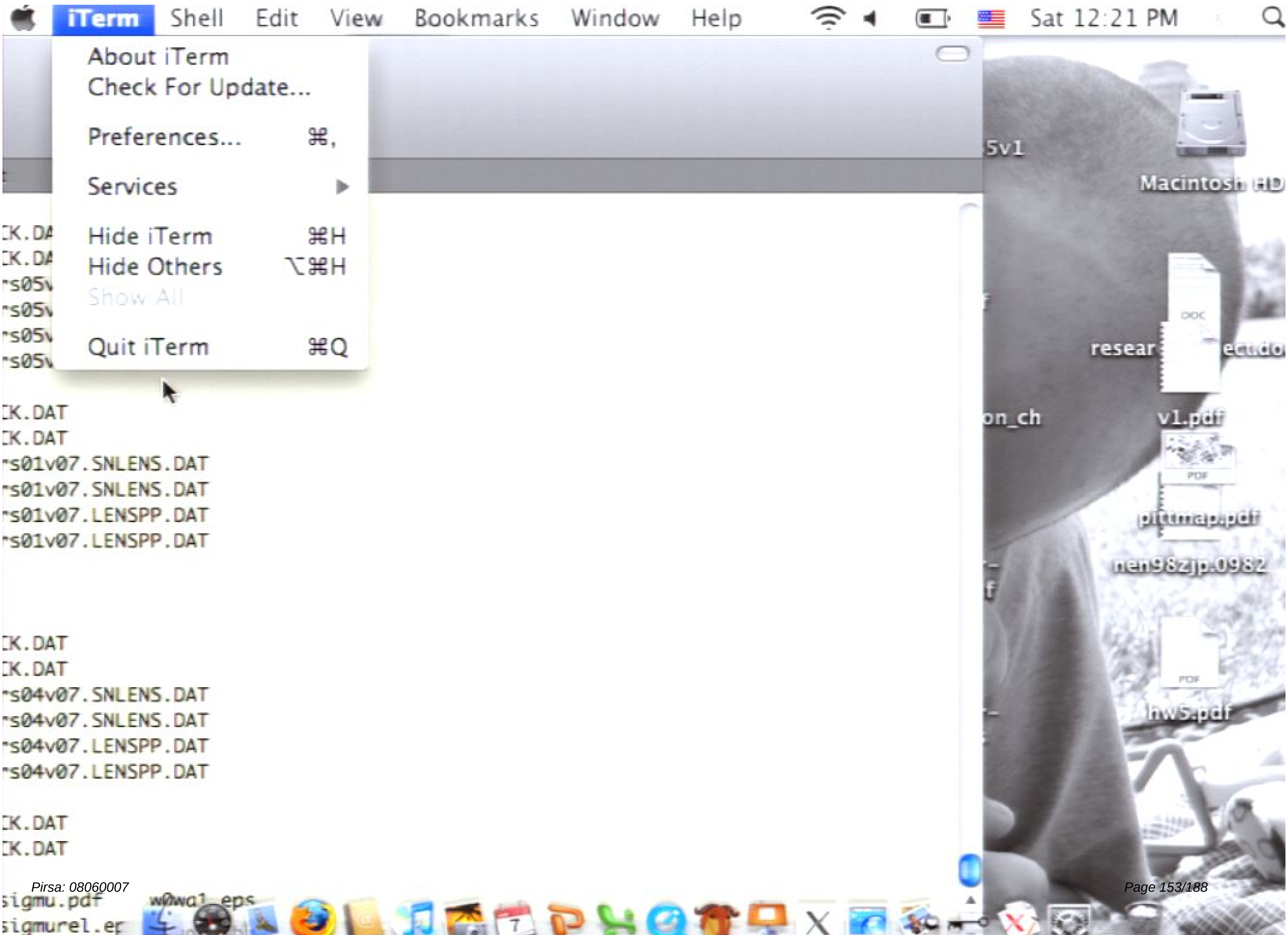
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Check For Update...
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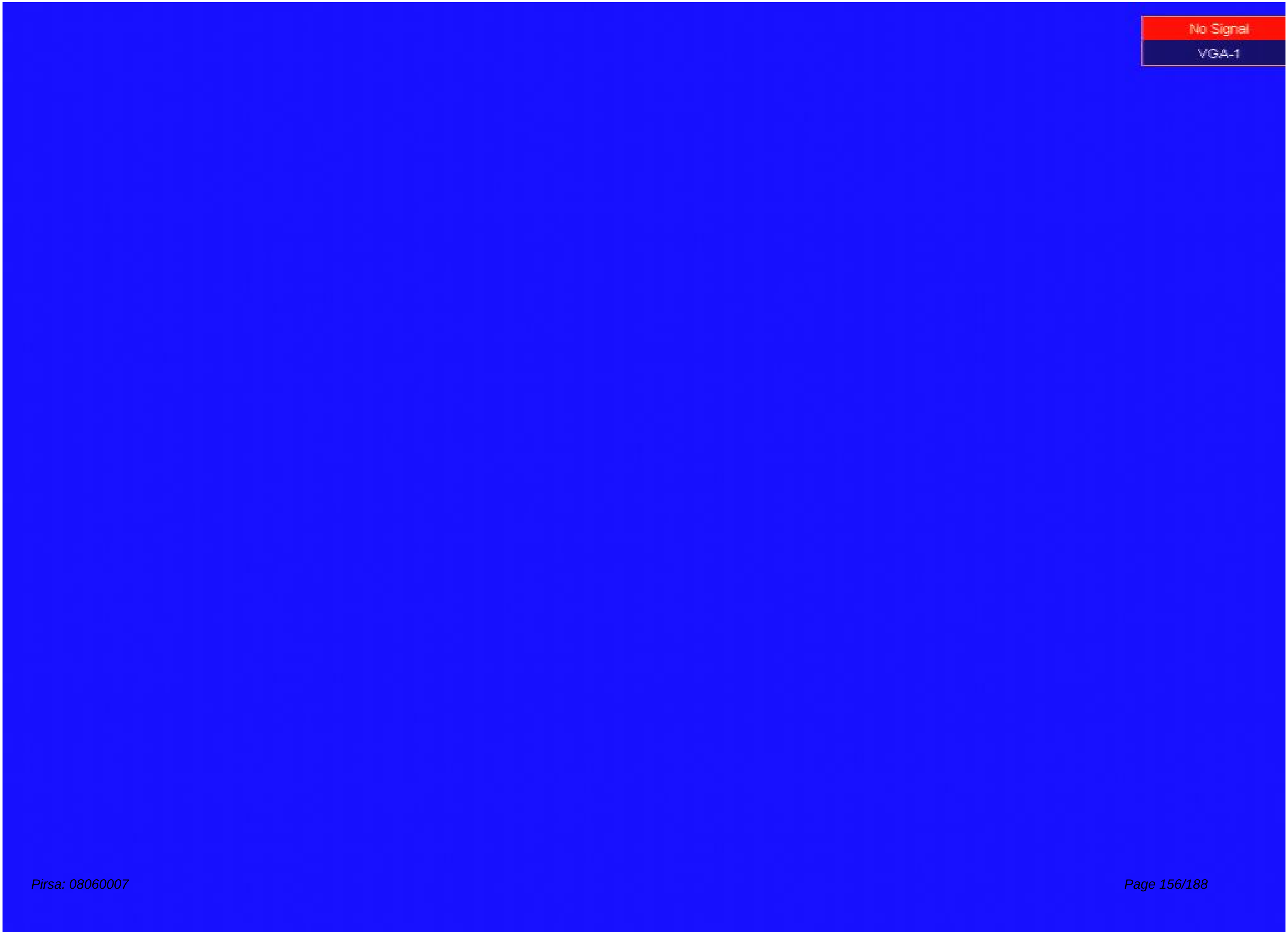
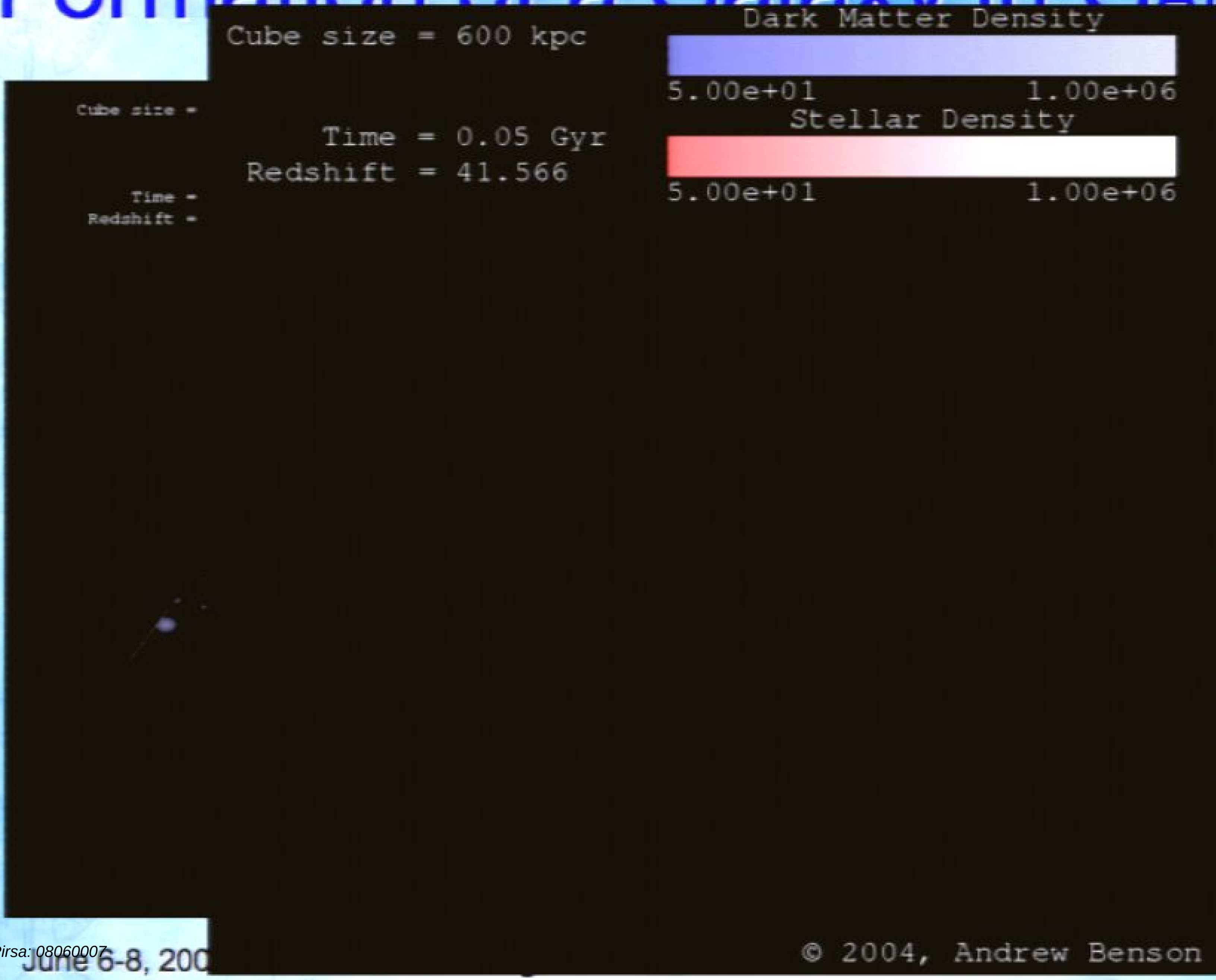
No Signal
VGA-1


No Signal
VGA-1

Formation of a Galaxy in GALFORM



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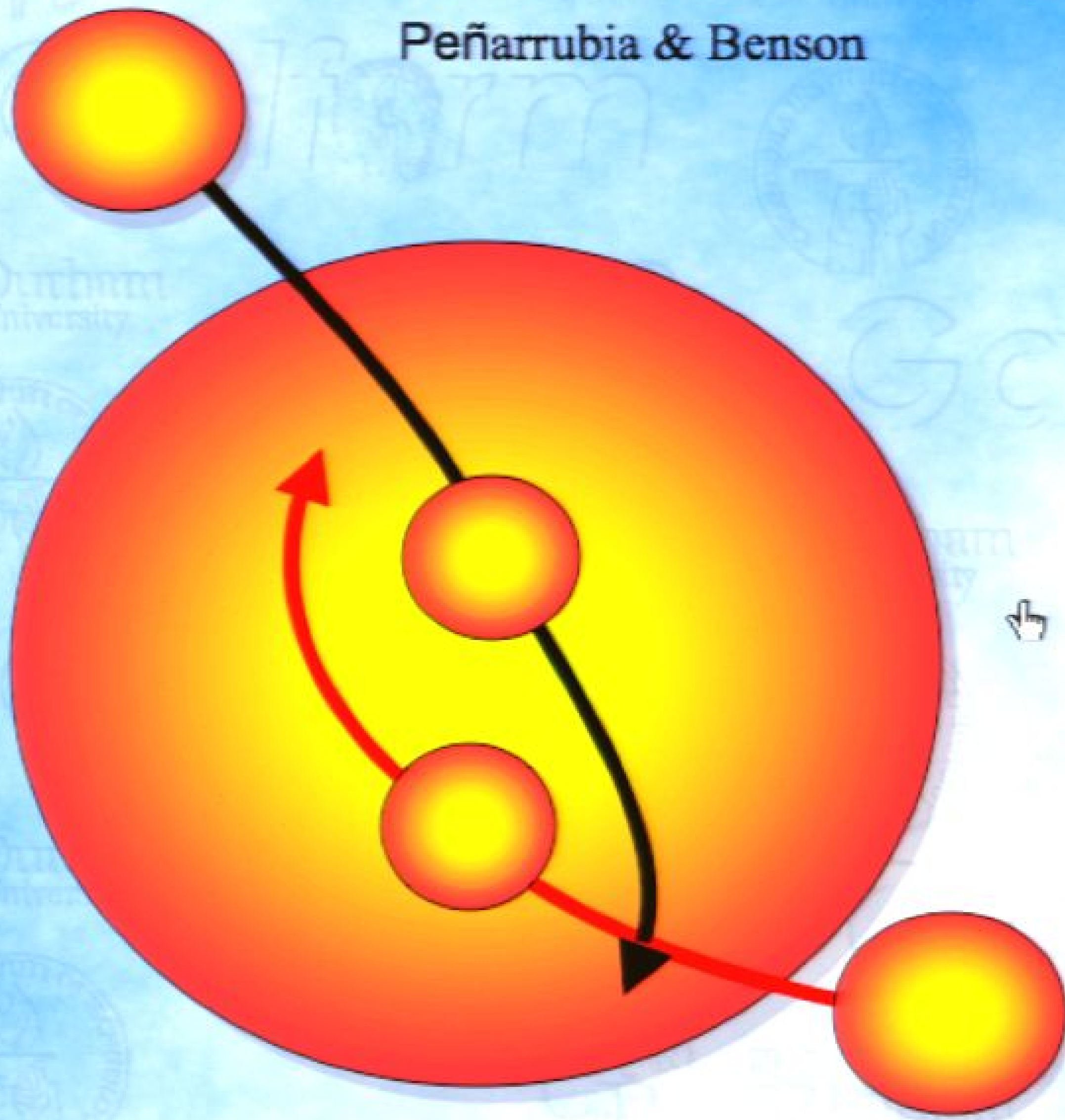
Two-body Scattering of Substructure

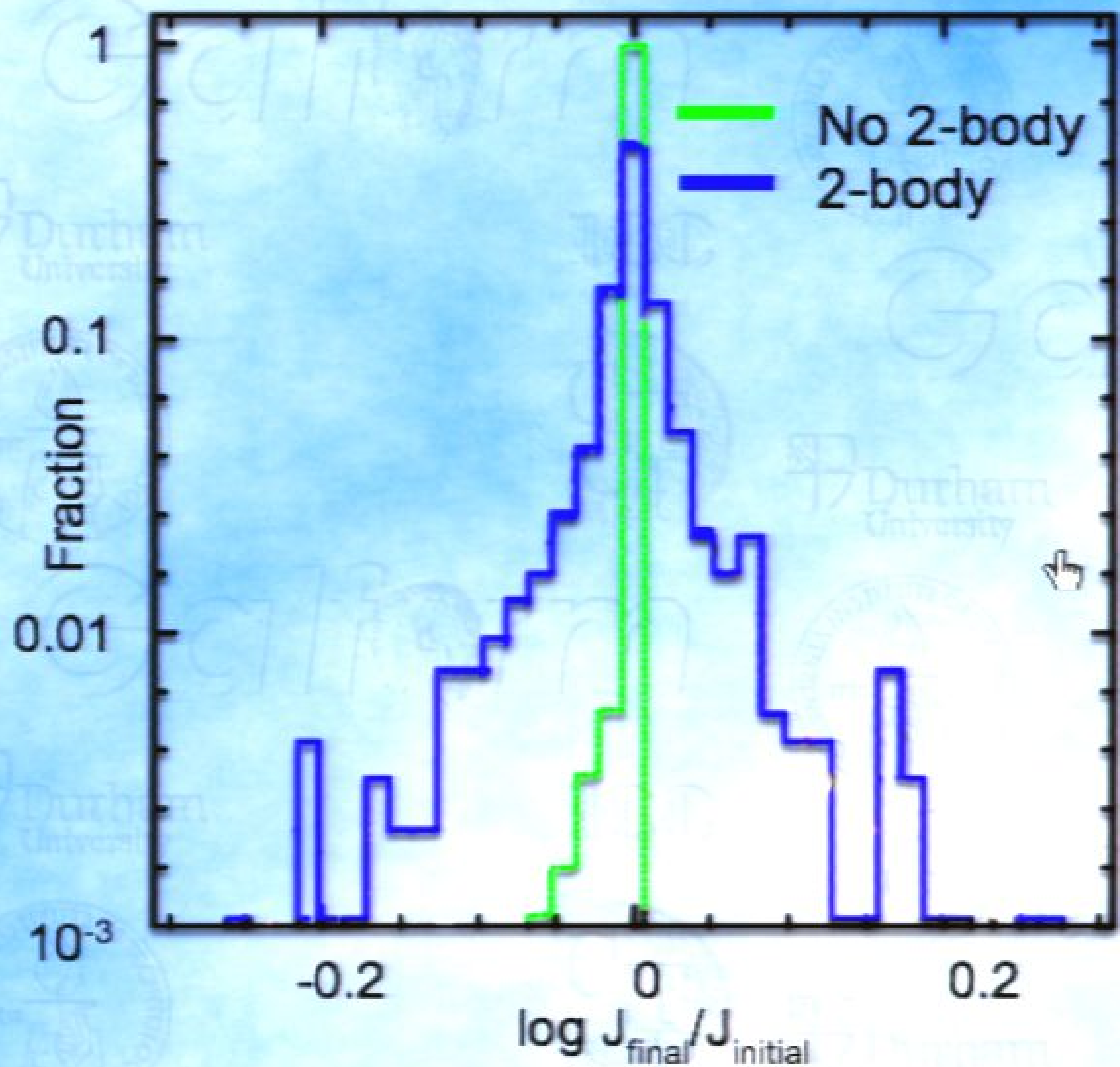
Two-body Scattering of Substructure



Peñarrubia & Benson

- Current modeling ignores two-body scattering of subhalos
- Is it important?
- Can include in model as direct N^2 sum over all pairs

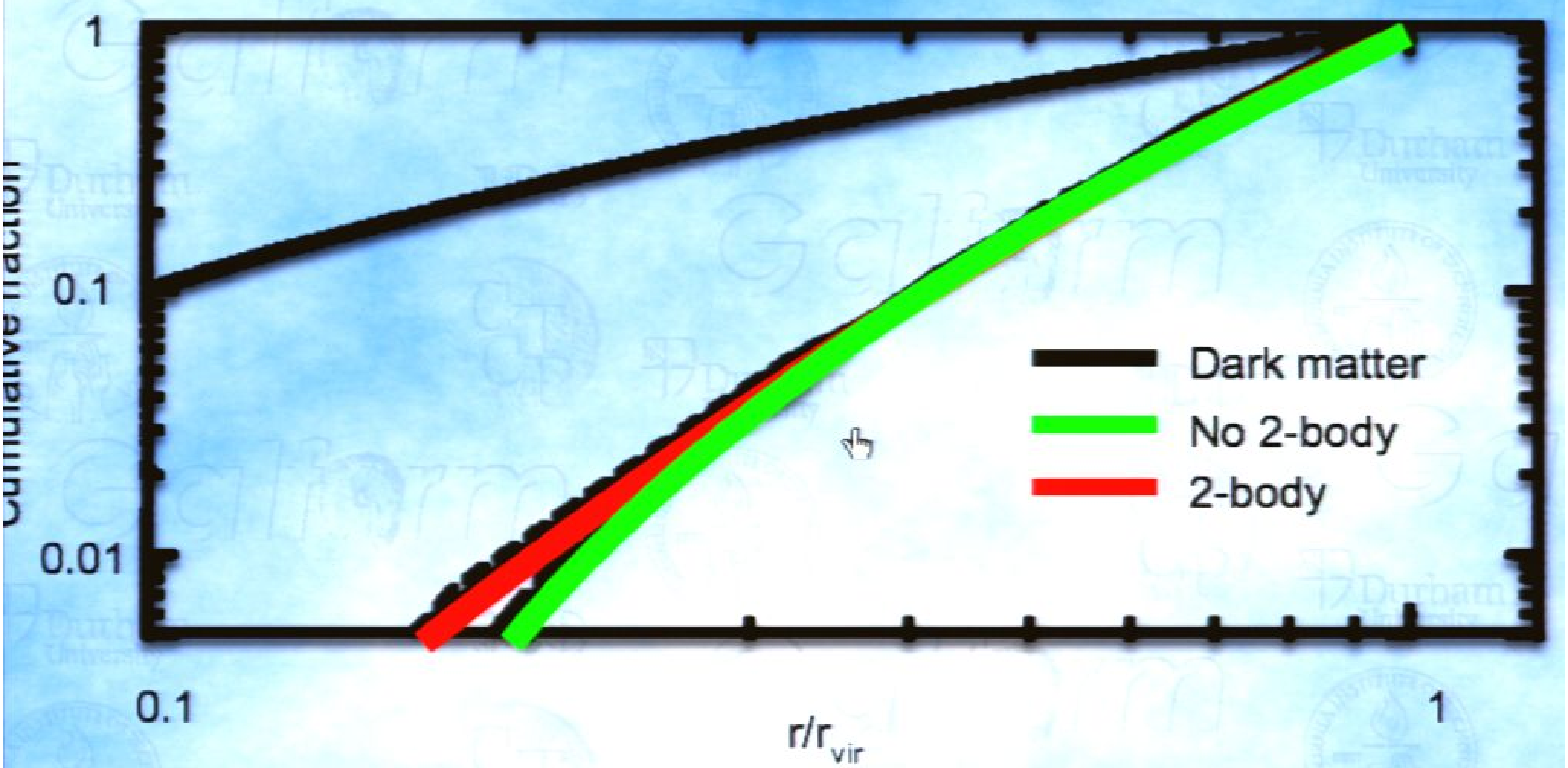
Change in Angular Momentum



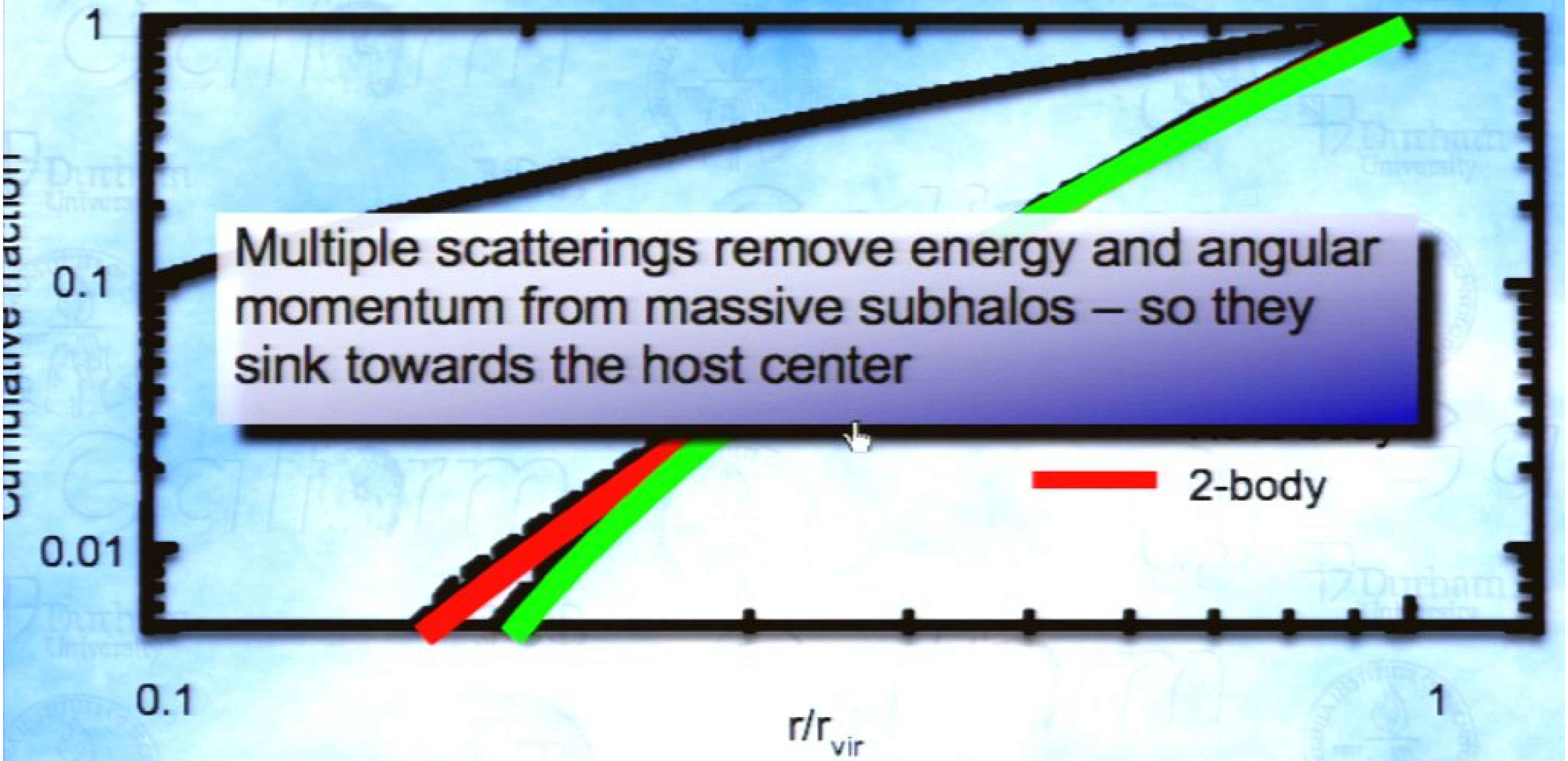
- With no 2-body scattering AM decreases....
- ....due to dynamical friction

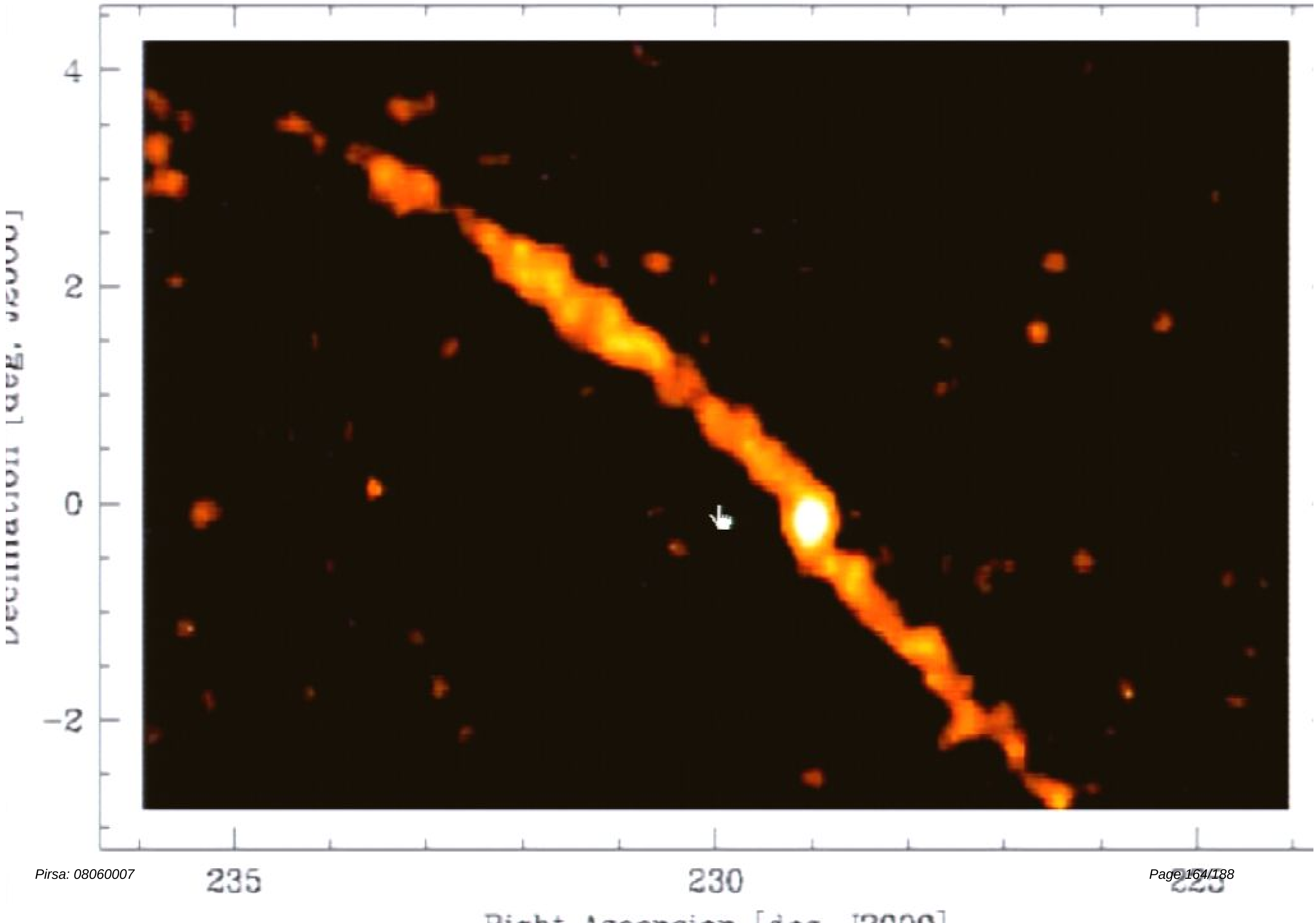
Change in Spatial Distribution

Change in Spatial Distribution



Change in Spatial Distribution

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225

Tidal Mass Loss: Improved Model

Kampakoglou & Benson

- Substructure halos experience tidal forces from host

Tidal Mass Loss: Improved Model

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Tidal Mass Loss: Improved Model

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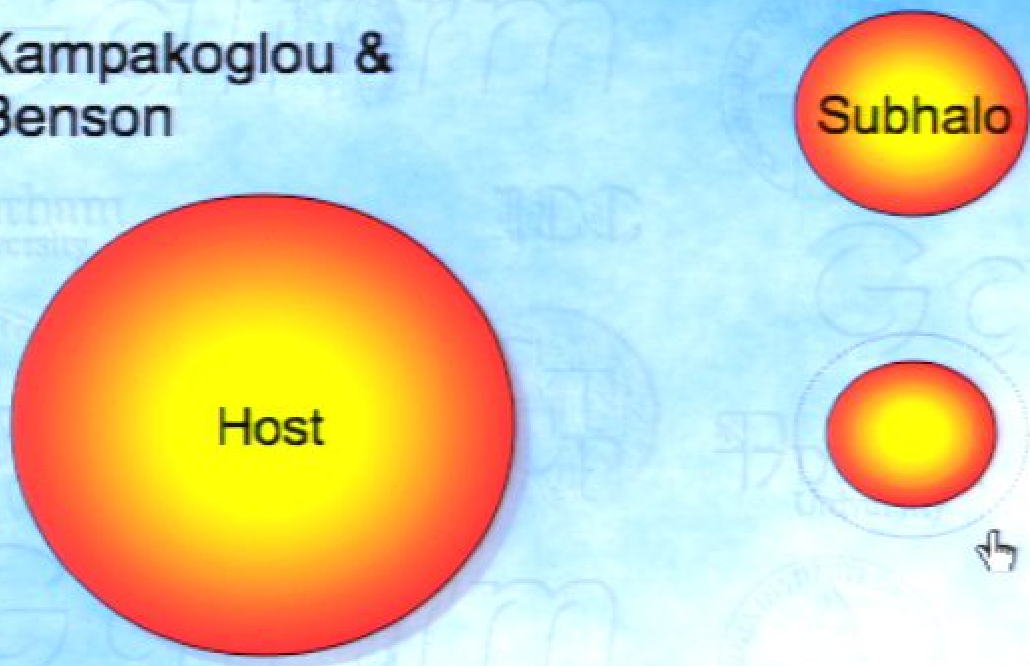


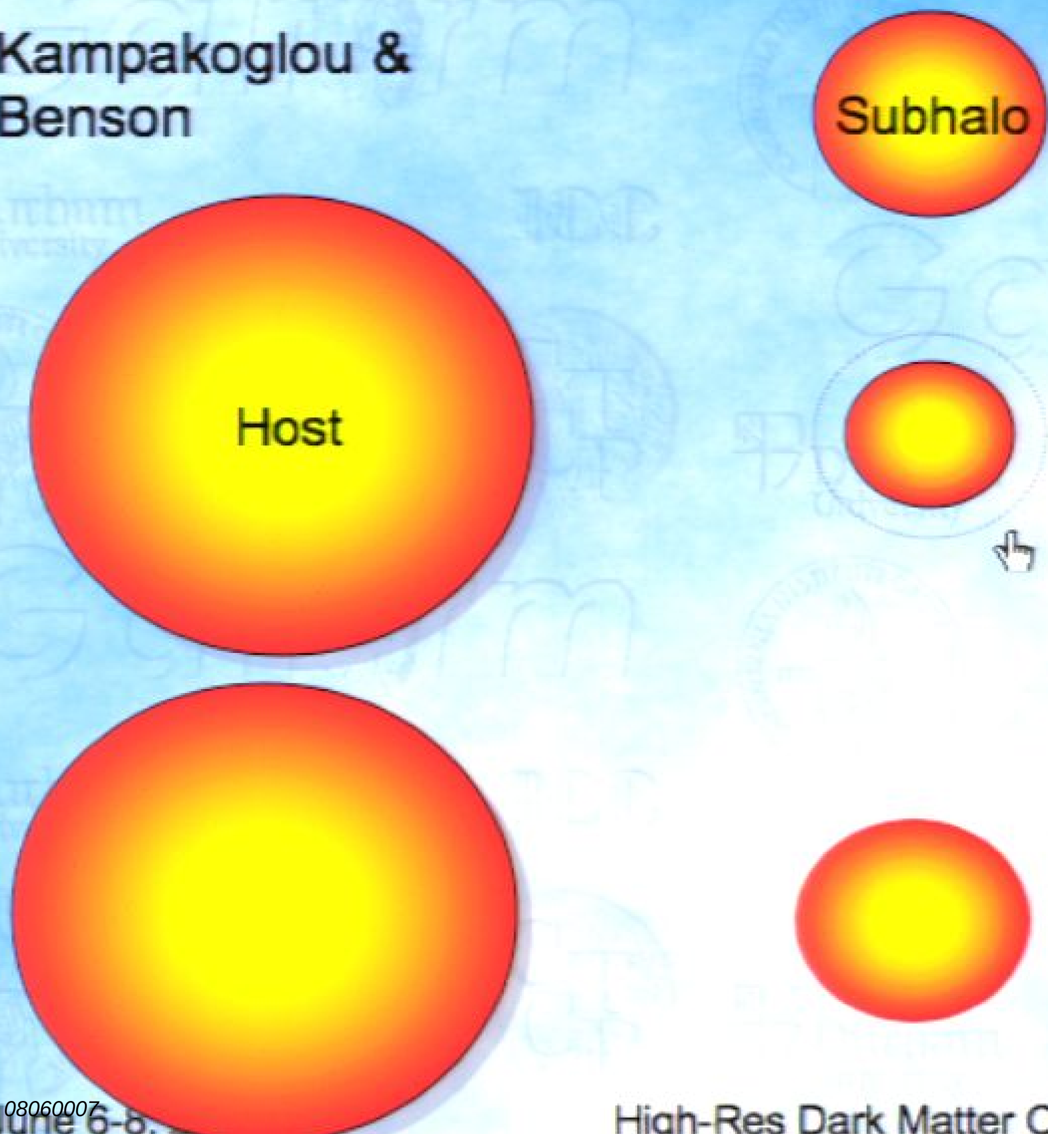
- Substructure halos experience tidal forces from host
- Causes mass loss
- Simple model: truncate subhalo where forces balance

$$F_{sub} = F_{tidal}$$

$$\frac{GM(<r)}{r^2} = r\frac{d}{dr}\frac{GM(<R)}{R^2}$$

Tidal Mass Loss: Improved Model

Kampakoglou & Benson



- Substructure halos experience tidal forces from host
- Causes mass loss
- Simple model: truncate subhalo where forces balance
- Not very realistic!
- Better model accounts for phase space structure of subhalo

Improved Model of Tidal Mass Loss

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$$W_{\max} = \frac{r_{\max}^2}{2} \frac{d}{dR} \frac{GM(<R)}{R^2}$$

- Consider each particle in the subhalo
- Find work done by tidal force....
- ....does this unbind the particle (e.g. $W_{\max}+E>0$?)

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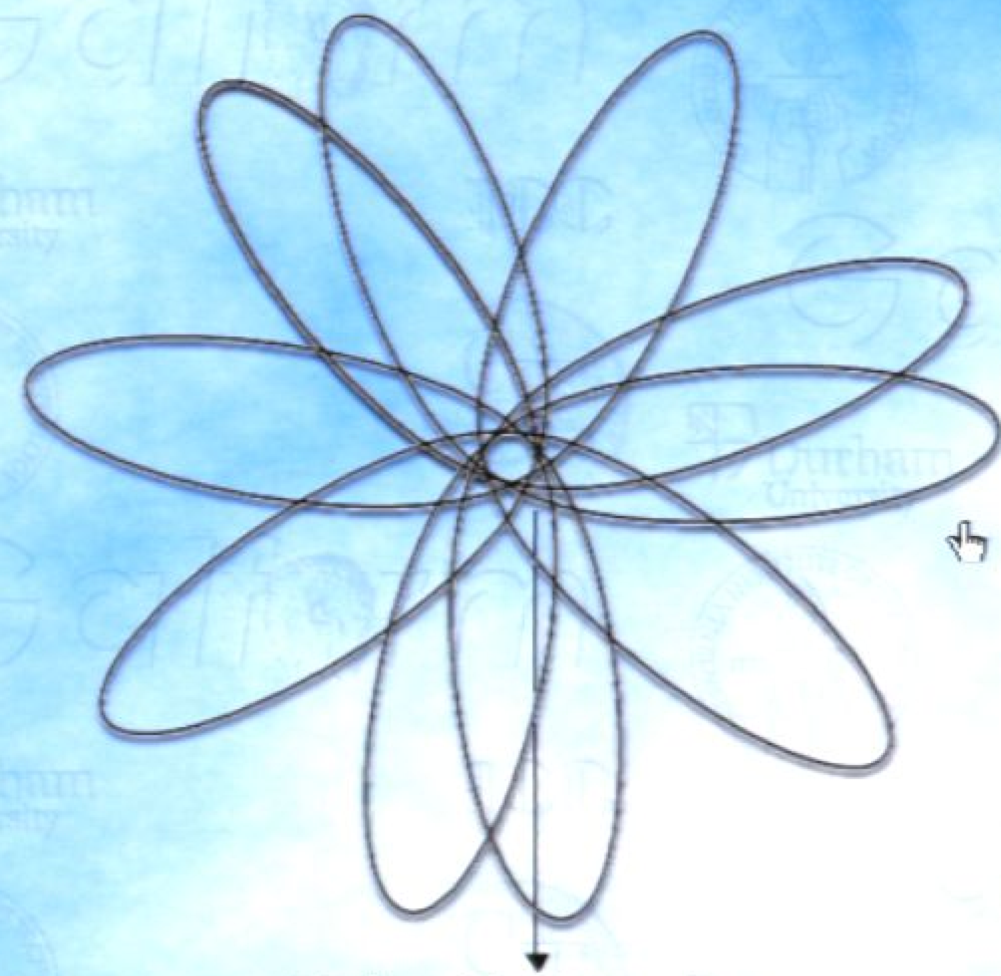

- Consider each particle in the subhalo
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- ....does this unbind the particle (e.g. $W_{max}+E>0$?)
- If so, particle is lost
- Only 5 integrals due to precession

...and the Tidal Debris?

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...and the Tidal Debris?

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- Assumes *mechanical similarity*

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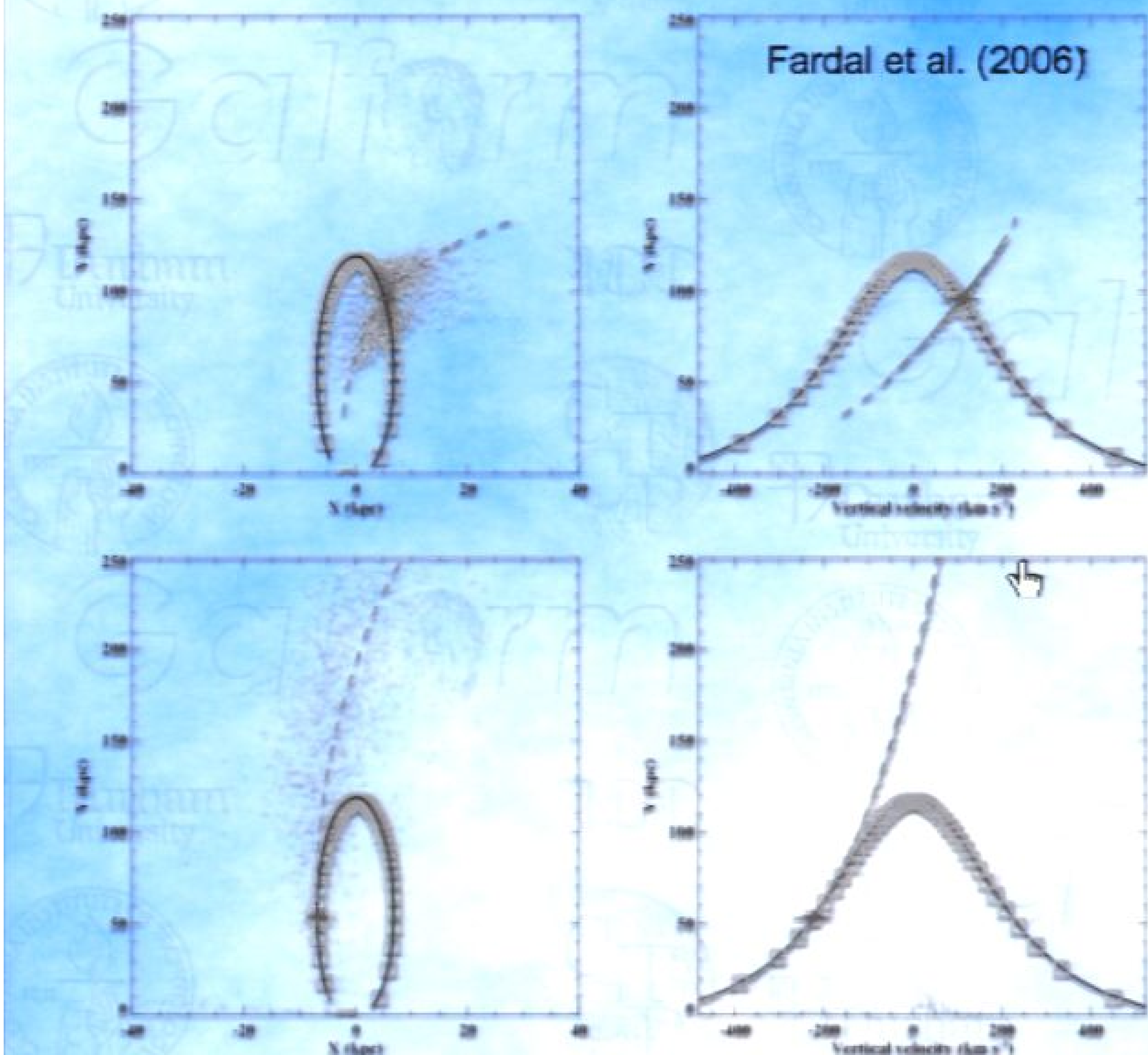

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- Orbits have similar shape with different time and length scales
- Agrees quite well with N-body simulation

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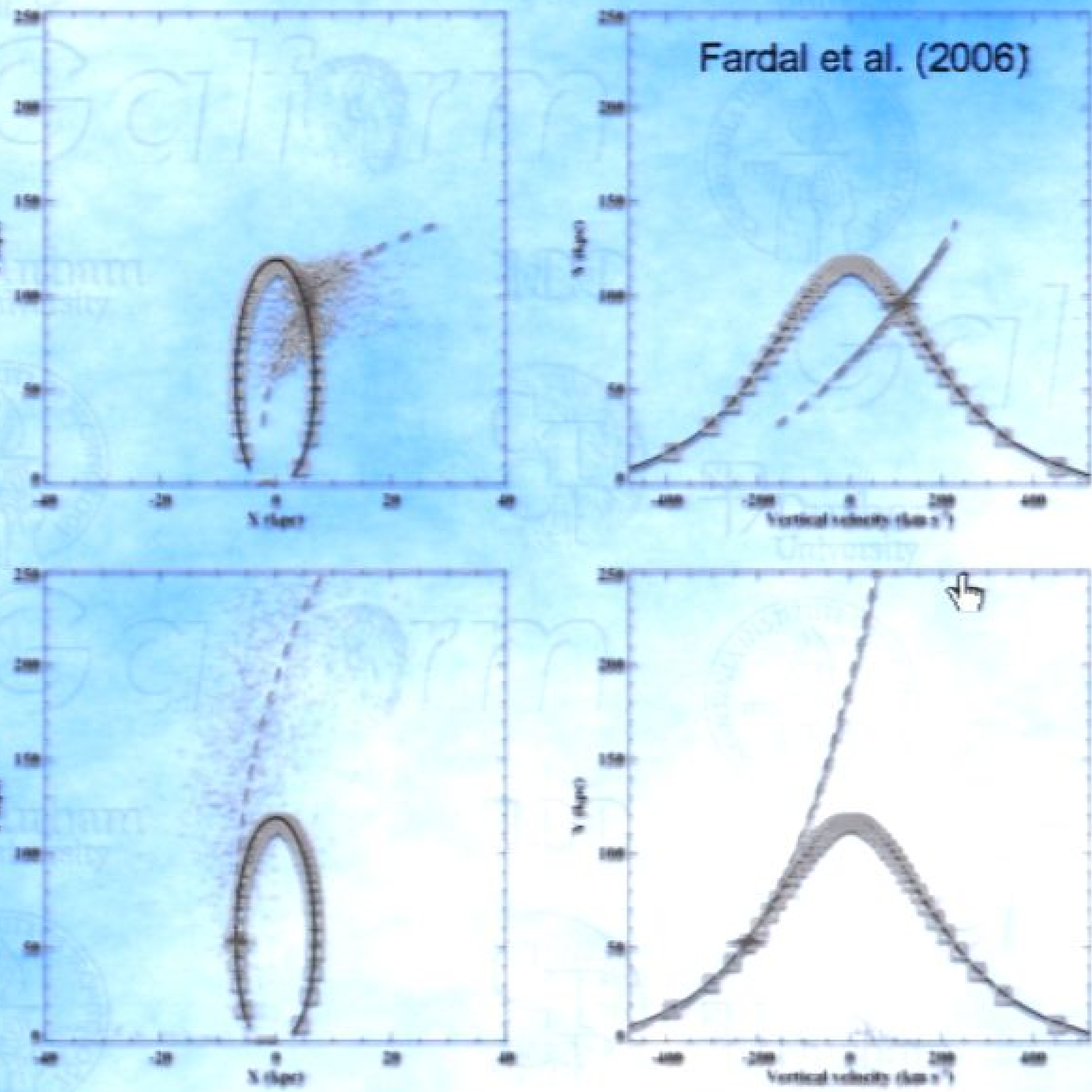

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- Assumes *mechanical similarity*
- Orbits have similar shape with different time and length scales
- Agrees quite well with N-body simulation
- Spread in energy gives stream length

Prospects & Outlook

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  - *High resolution*

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  - *Precision?*

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- What do we get?