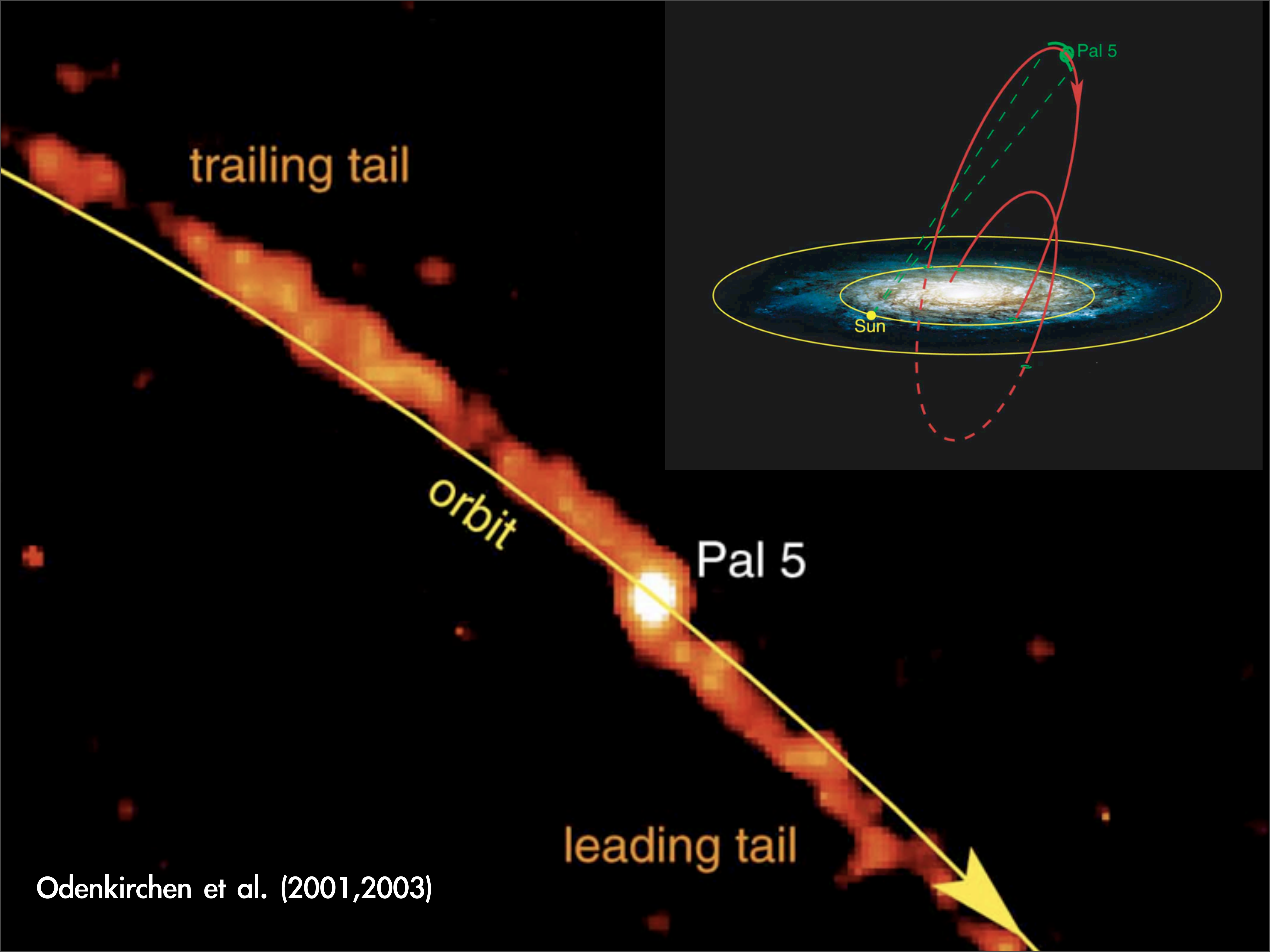
The Universality of the Globular Cluster Mass Function

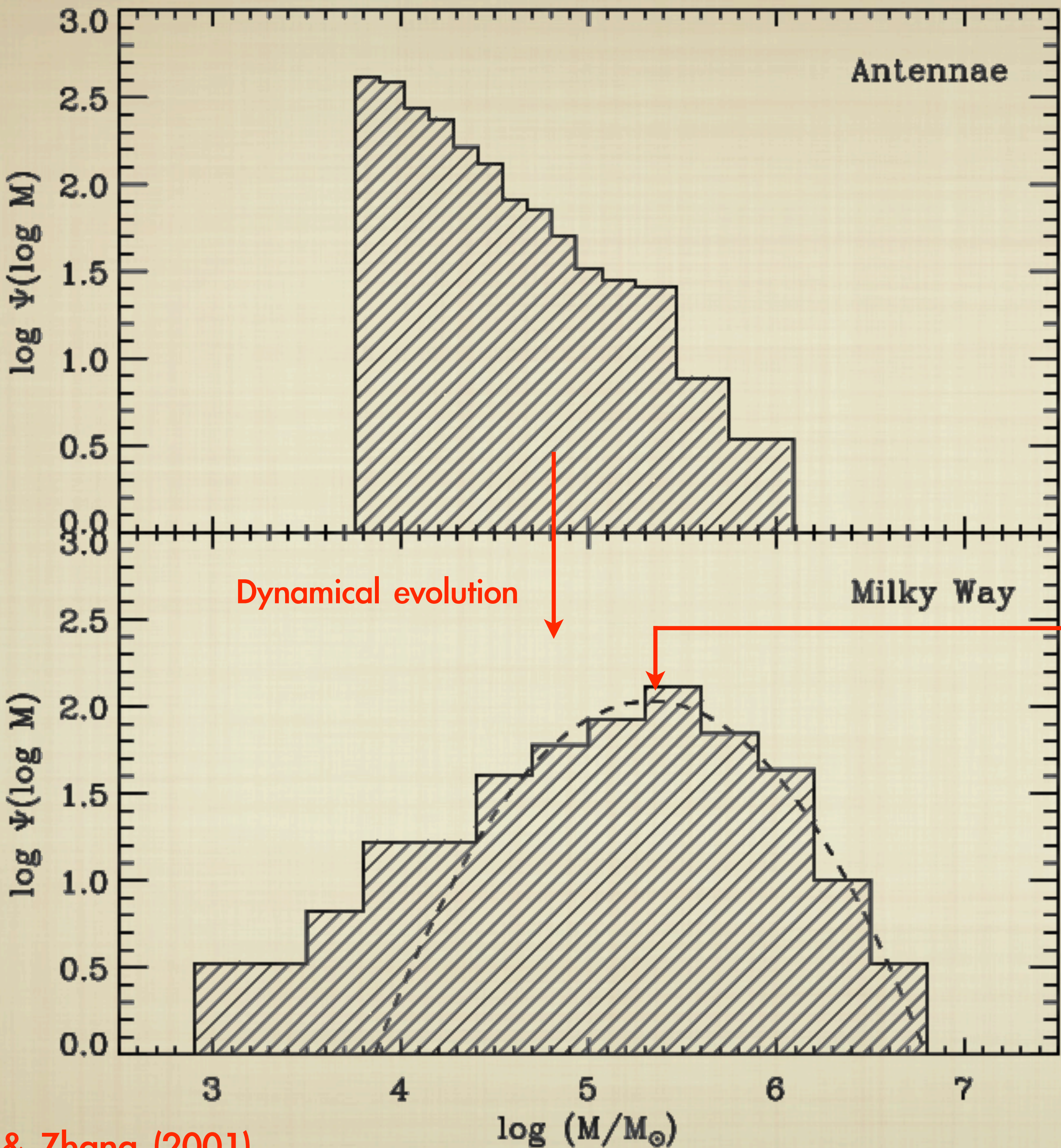
or: the dissolution of clusters in tidal fields

Mark Gieles (ESO)

Gieles & Baumgardt, 2008, MNRAS, 389, L28



Odenkirchen et al. (2001,2003)

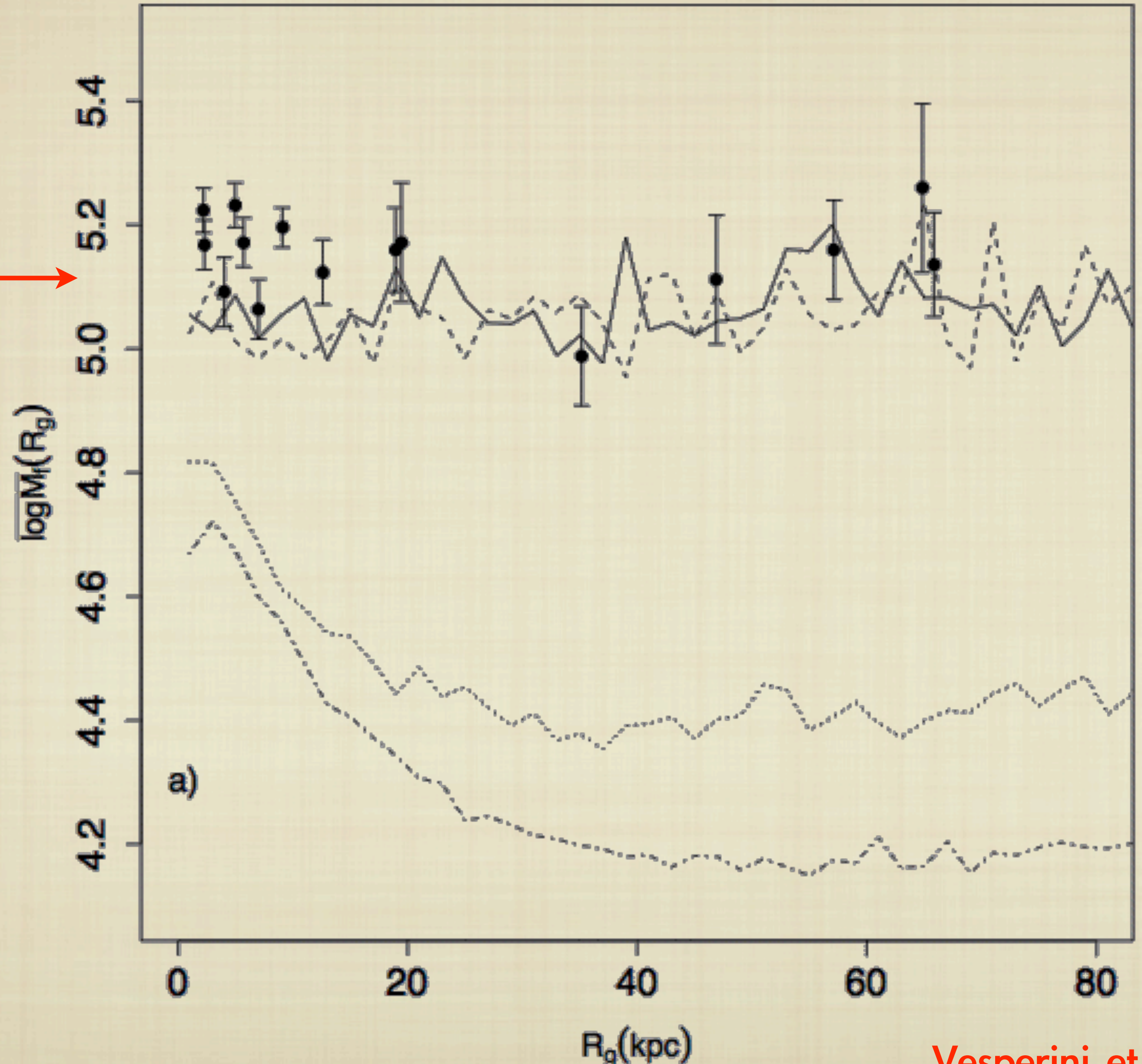


turn-over mass (M_{TO})

Fall & Zhang (2001)

M87

M_{TO} →



Vesperini et al. (2003)
see also Jordán et al. (2007)

$$t_{\rm dis} = \frac{1}{\xi_{\rm e}} t_{\rm rh}$$

ξ_e = escape fraction

Henon (1961); Spitzer (1987)

$$t_{\rm dis} = \frac{1}{\xi_{\rm e}} t_{\rm rh}$$

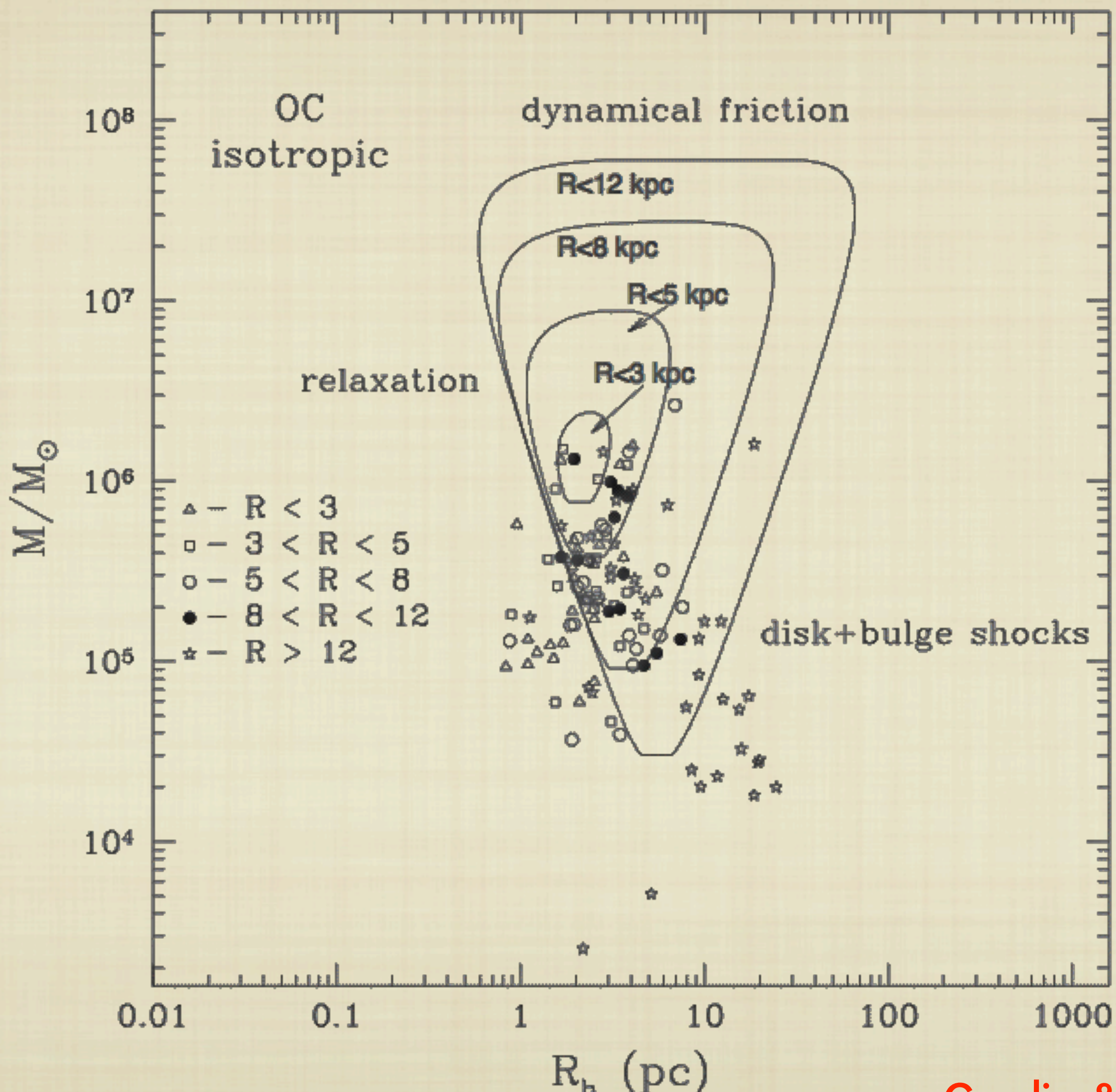
$$\simeq 30\, t_{\rm rh}$$

Assumptions:

★ ξ_e = constant

ξ_e = escape fraction

Henon (1961); Spitzer (1987)

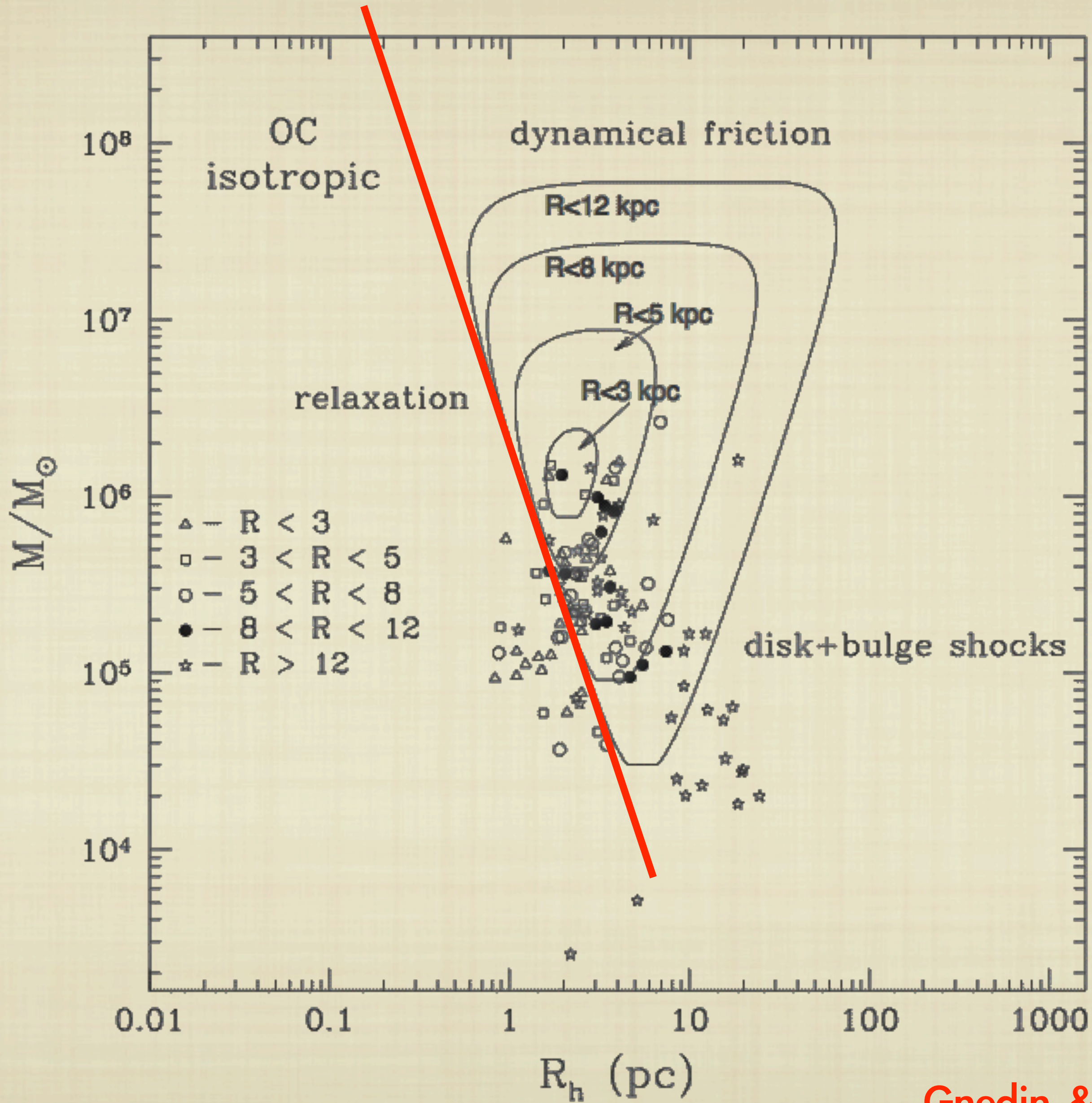


Assumptions:

★ ξ_e = constant

Gnedin & Ostriker (1997)
Fall & Rees (1977)

$M^{1/2} r_h^{3/2}$=constant



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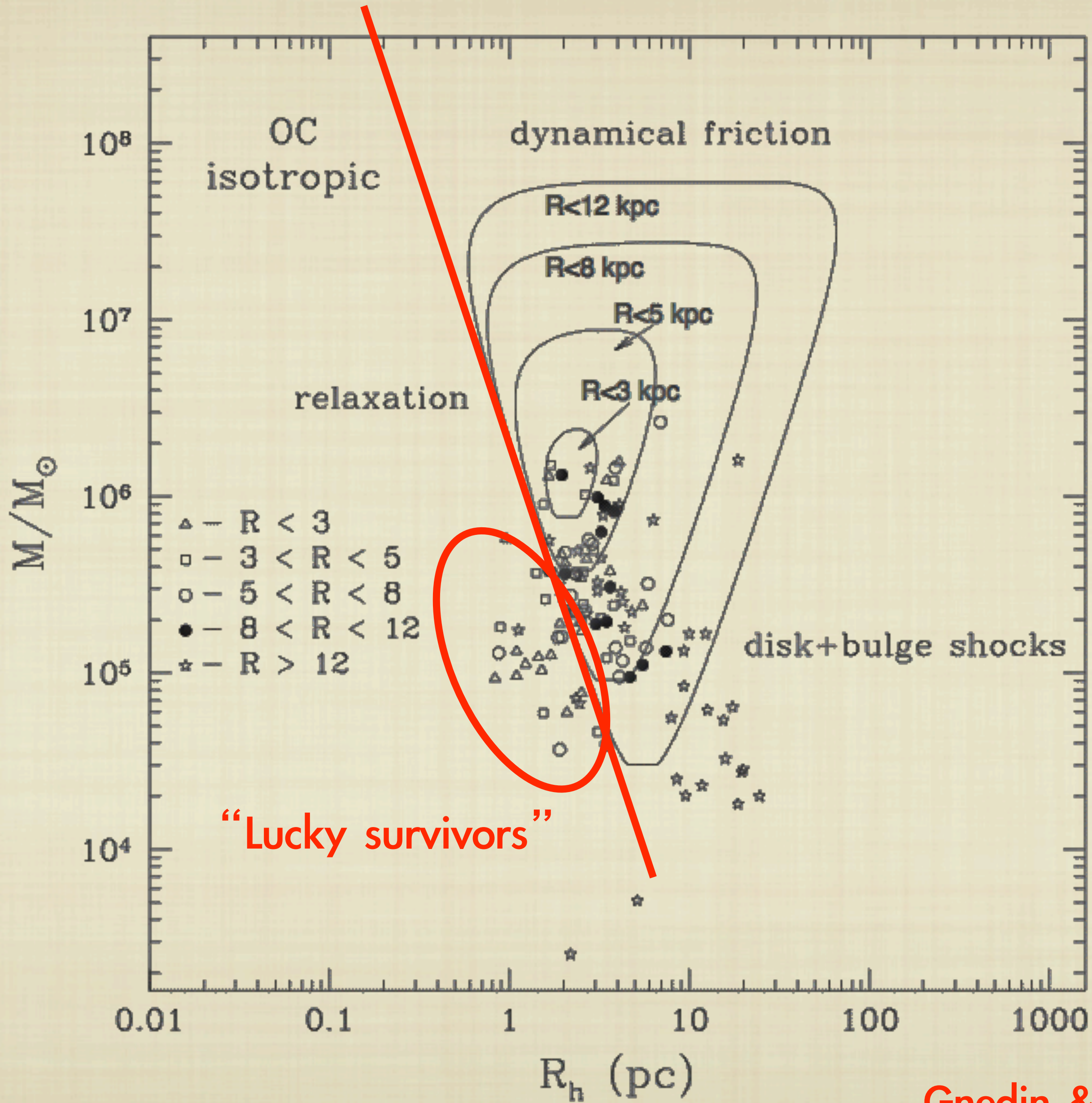

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Fall & Rees (1977)

$$t_{\rm dis} = \frac{1}{\xi_{\rm e}} t_{\rm rh}$$

$$\propto \frac{M}{\omega}$$

<u>Assumptions:</u>

- ⋆ ξ_e = constant
- ⋆ Cluster fills its Roche-lobe

$\omega = V_{\rm G}/R_{\rm G}$ = angular frequency

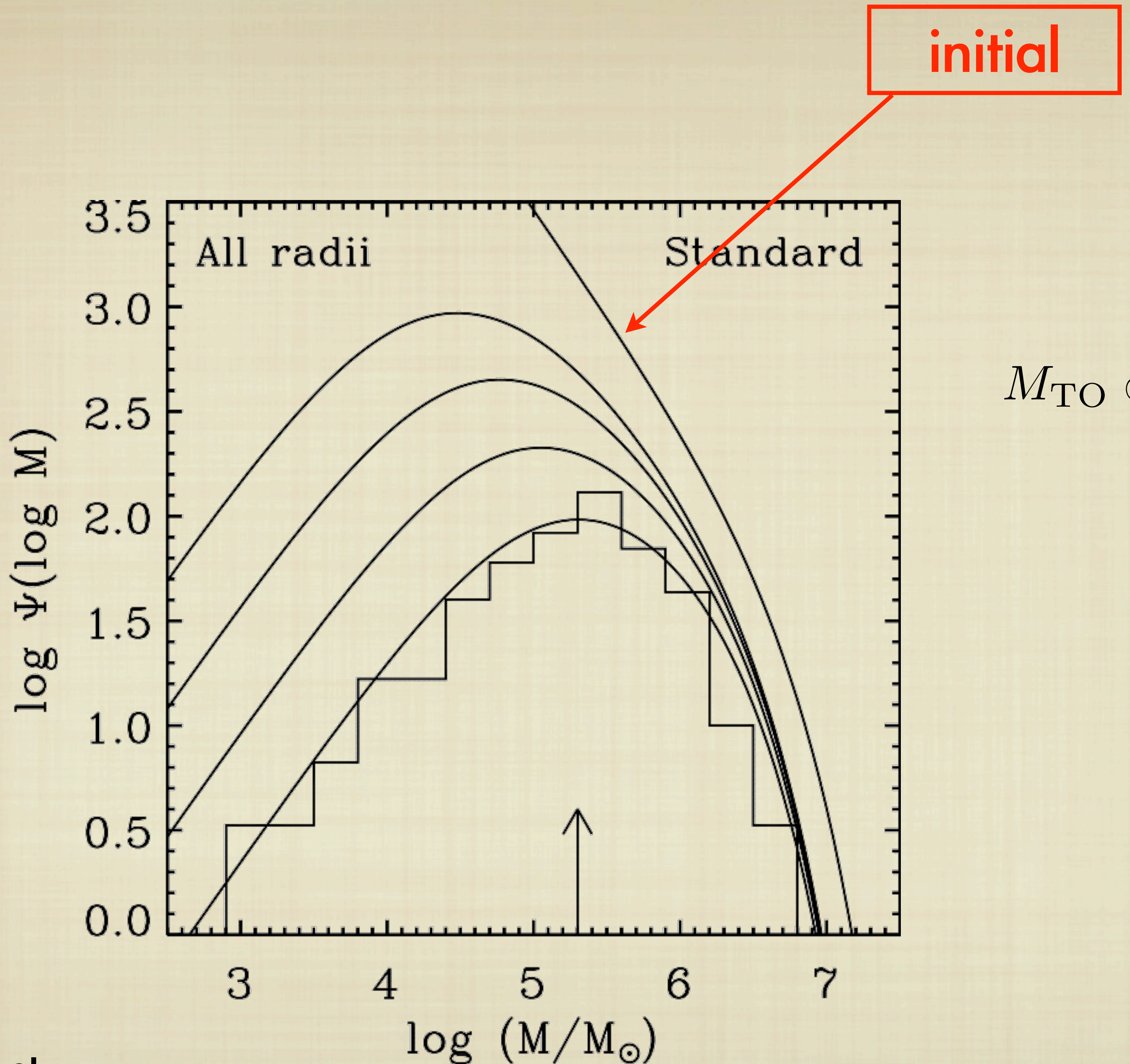
$$t_{\rm dis} = \frac{1}{\xi_{\rm e}} t_{\rm rh}$$

$$\propto \frac{M}{\omega} \sim M R_{\rm G}$$

Assumptions:

- ξ_e = constant
- Cluster fills its Roche-lobe

$\omega = V_{\rm G}/R_{\rm G}$ = angular frequency

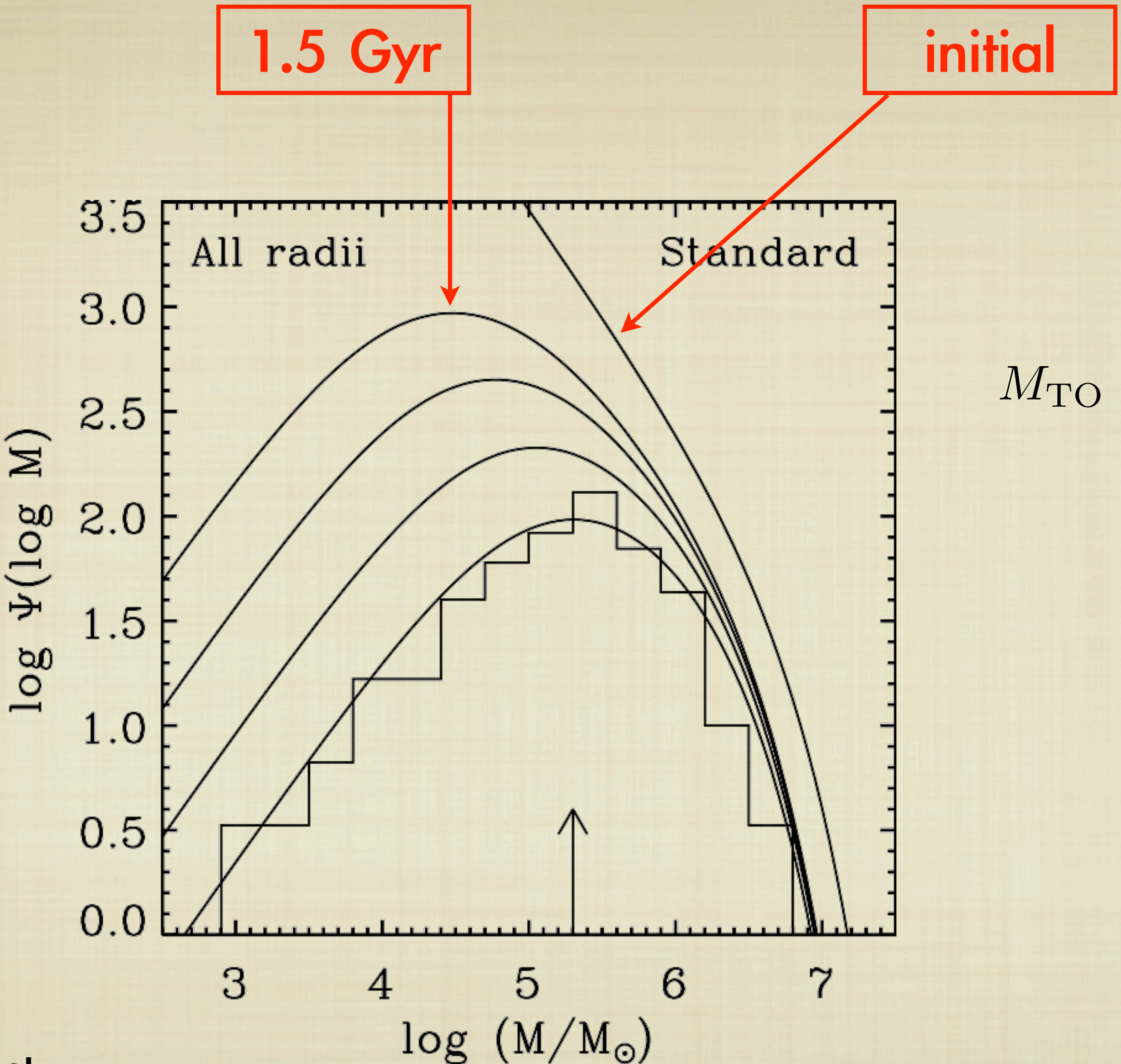


$M_{\rm TO} \propto t R_{\rm G}$

Assumptions:

- ⋆ ξ_e = constant
- ⋆ Cluster fills its Roche-lobe

Fall & Zhang (2001)



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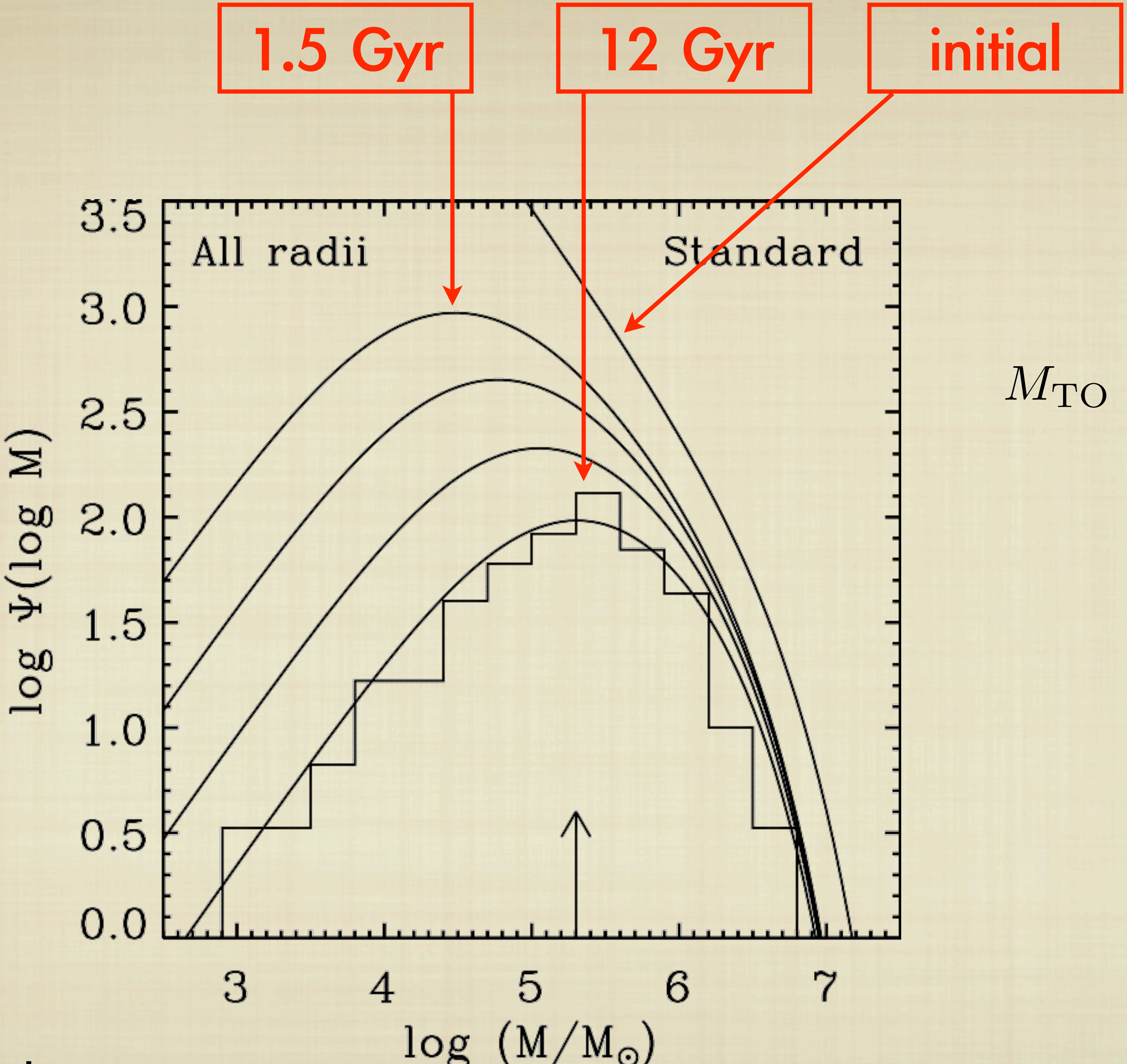

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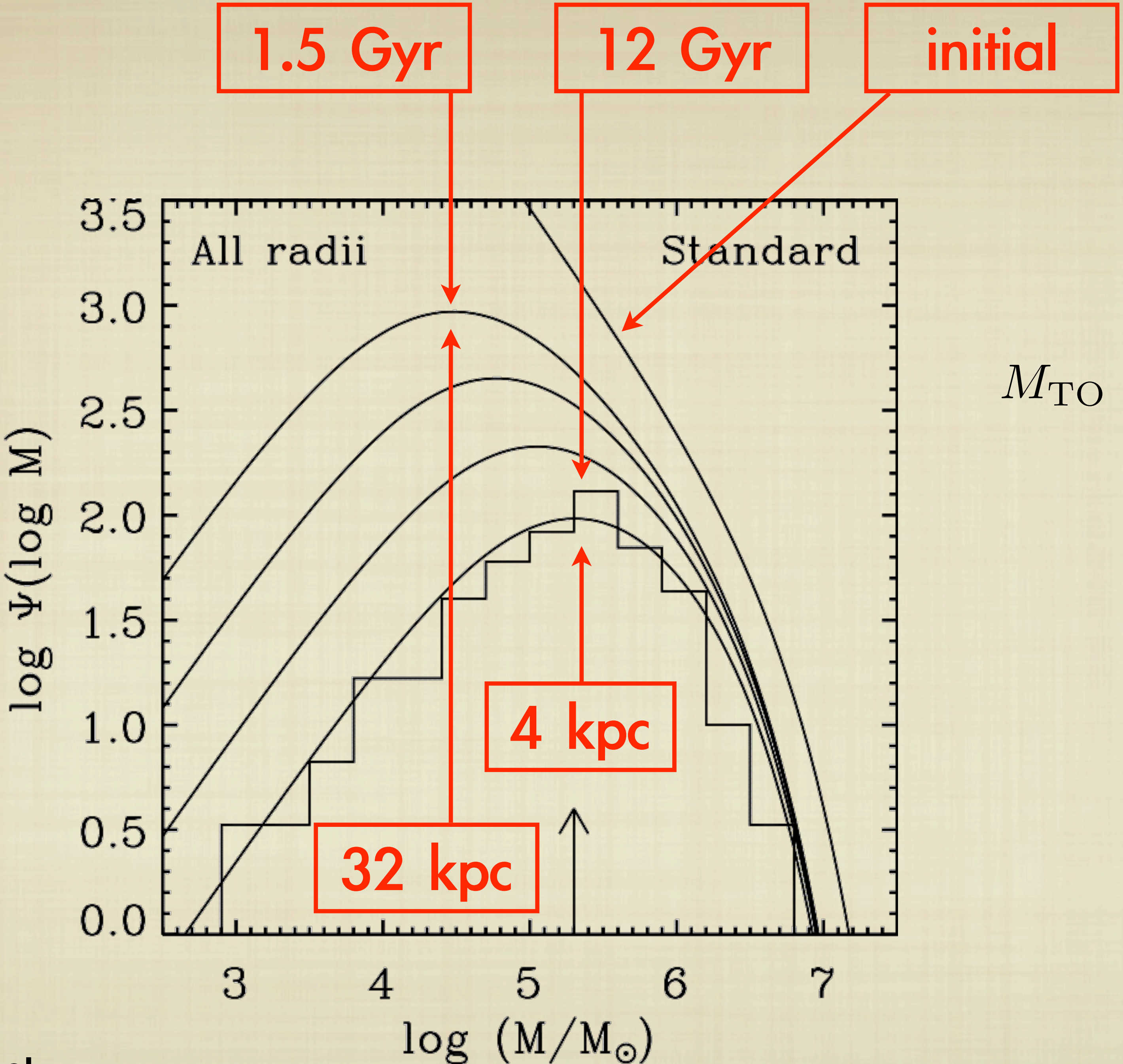

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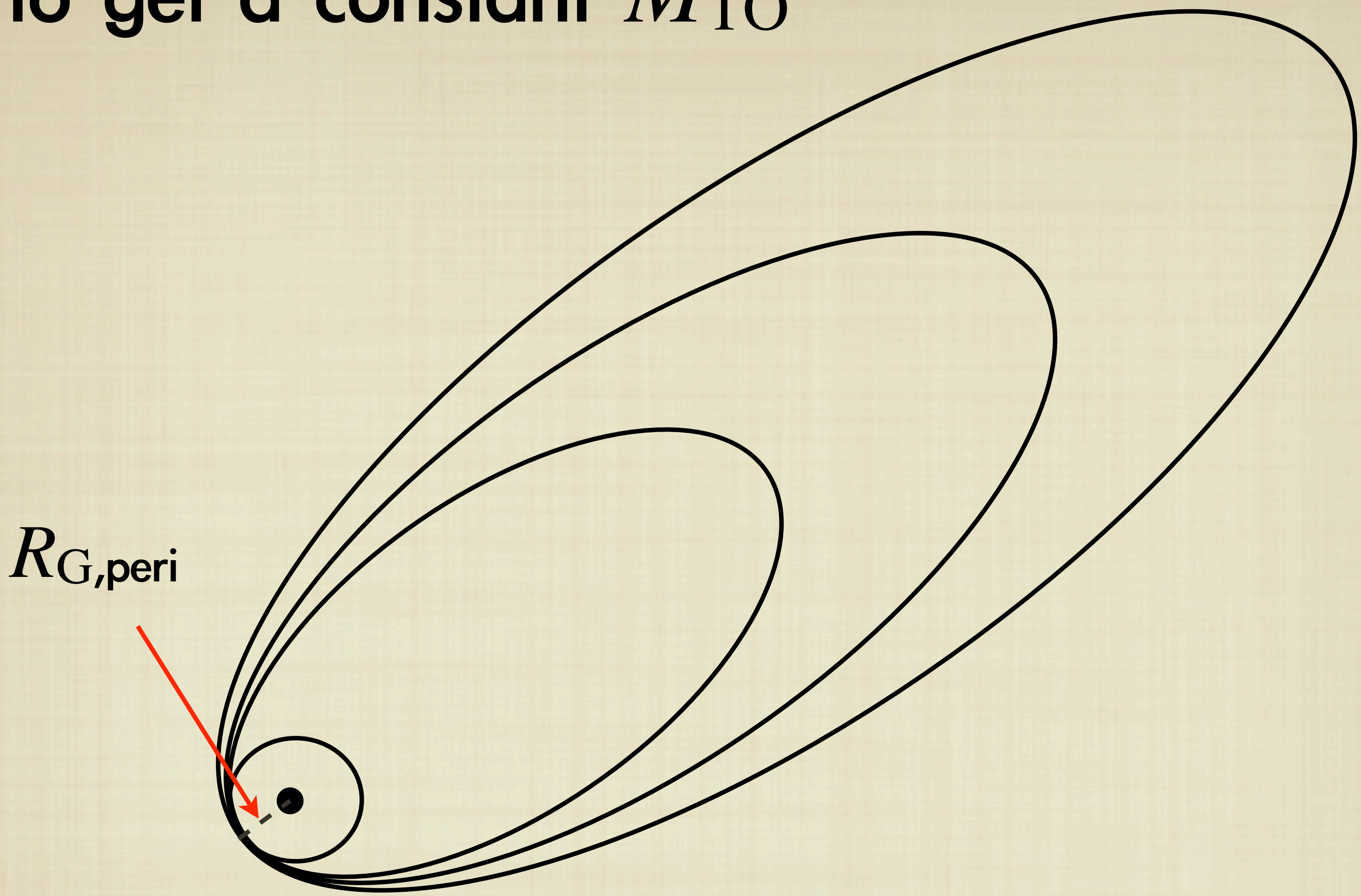
- ⋆ Cluster fills its Roche-lobe

Fall & Zhang (2001)

How to get a constant M_{TO}



Assumptions:

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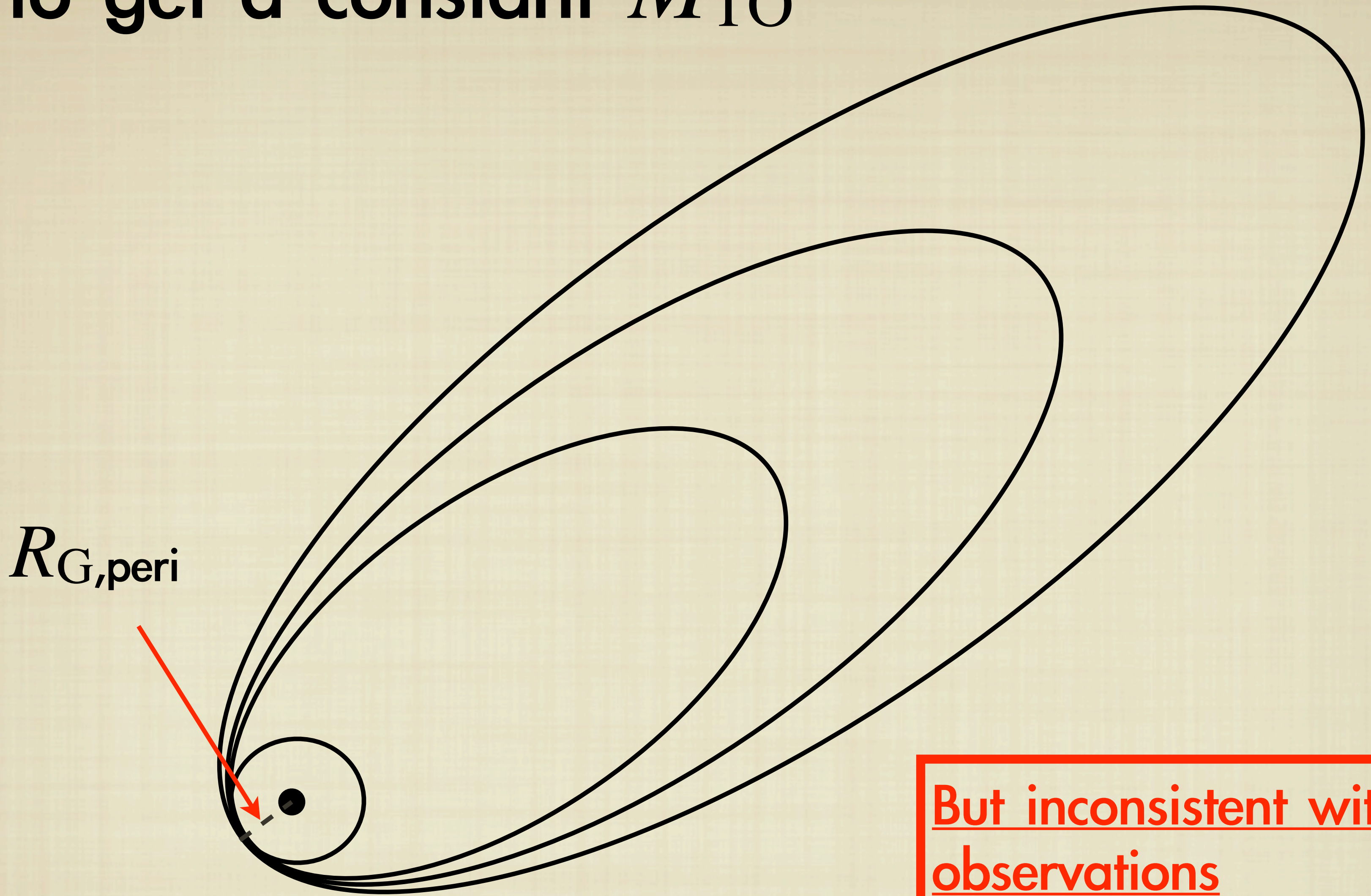
- ⋆ Cluster fills its Roche-lobe
- ⋆ $R_{\mathrm{G,peri}}$ = constant

Fall & Zhang (2001)

How to get a constant M_{TO}



But inconsistent with observations
(Vesperini et al. 2003; Côté et al. 2001)

Assumptions:
- ⋆ ξ_e = constant
- ⋆ Cluster fills its Roche-lobe
- ⋆ $R_{\mathrm{G,peri}}$ = constant

Fall & Zhang (2001)

$$\dot{M} = \xi_{\rm e} \frac{M}{t_{\rm rh}}$$

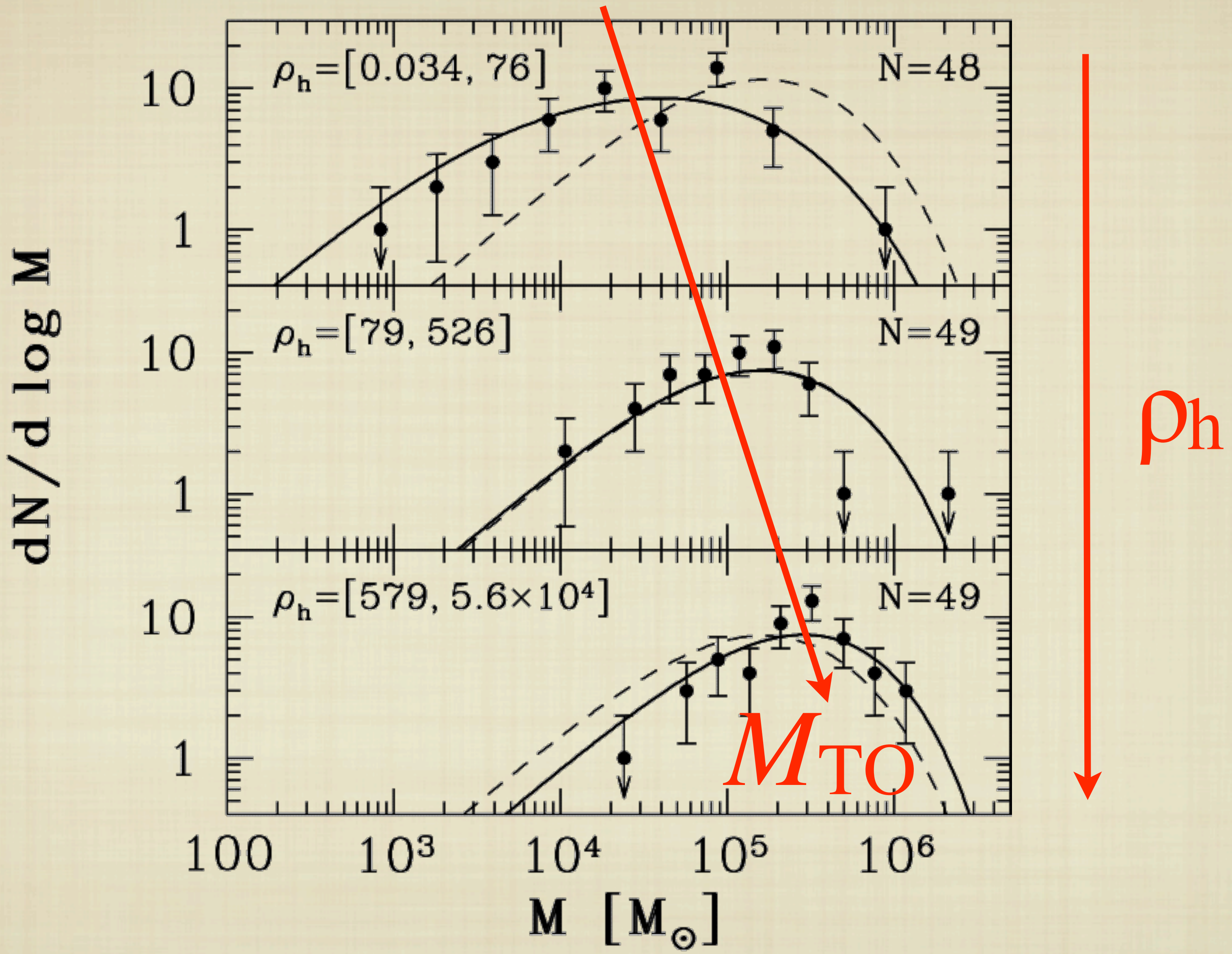
$$\propto \rho_{\rm h}^{1/2}$$

Assumptions:

- ★ $\xi_{\rm e}$ = constant
- ★ ~~Cluster fills its Roche-lobe~~
- ★ ~~$R_{\rm G,peri}$ = constant~~

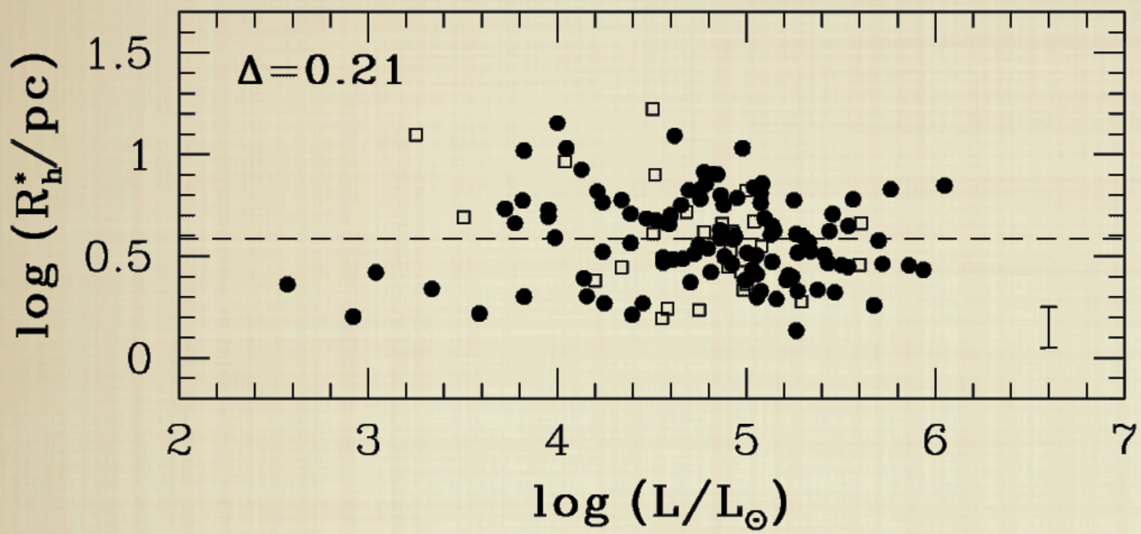
McLaughlin & Fall (2008)

GCMF not universal?

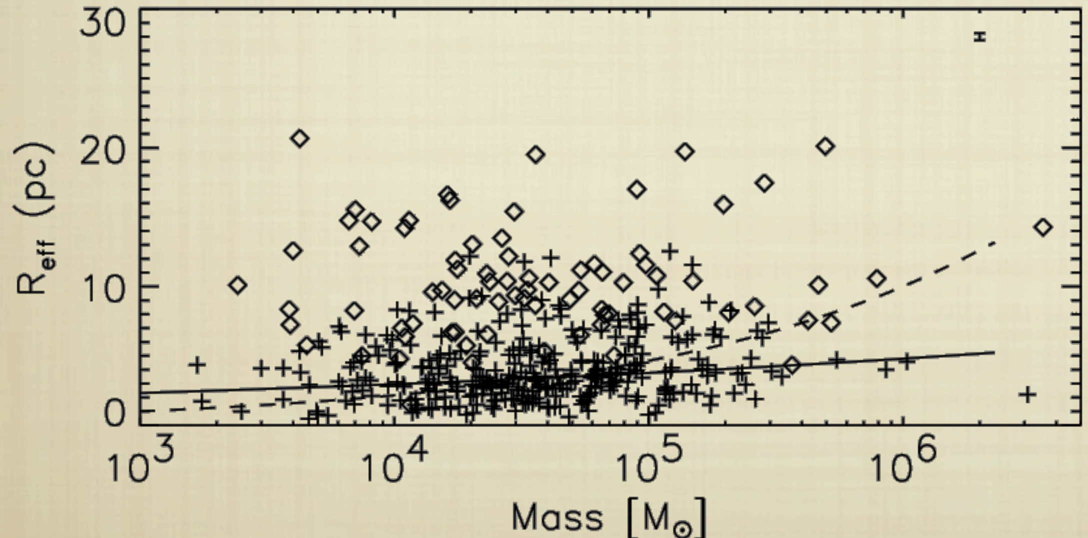


McLaughlin & Fall (2008)

Mass-density relation intrinsic?



Galactic globular clusters
(McLaughlin 2000)



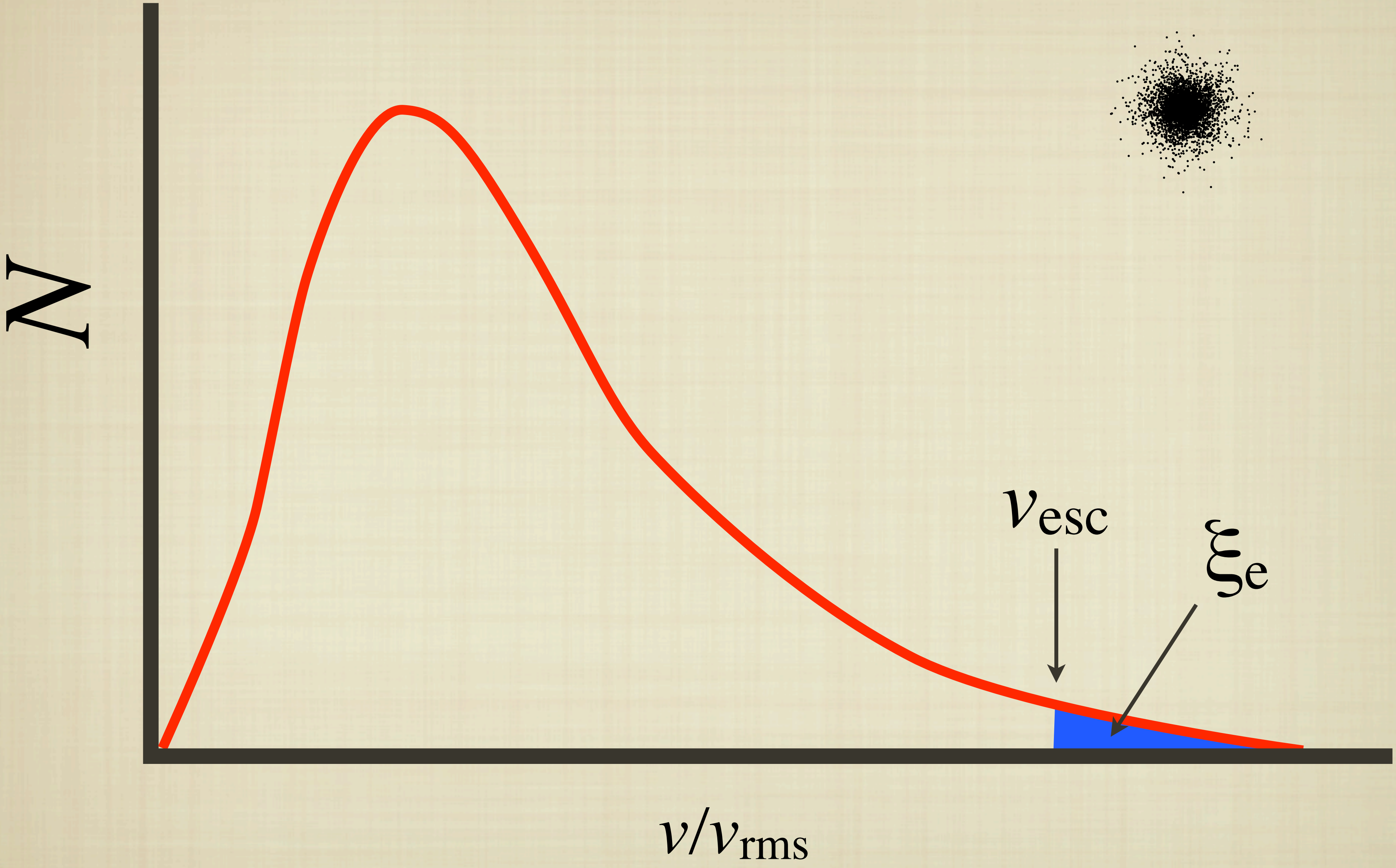
Young clusters
(Larsen 2004)

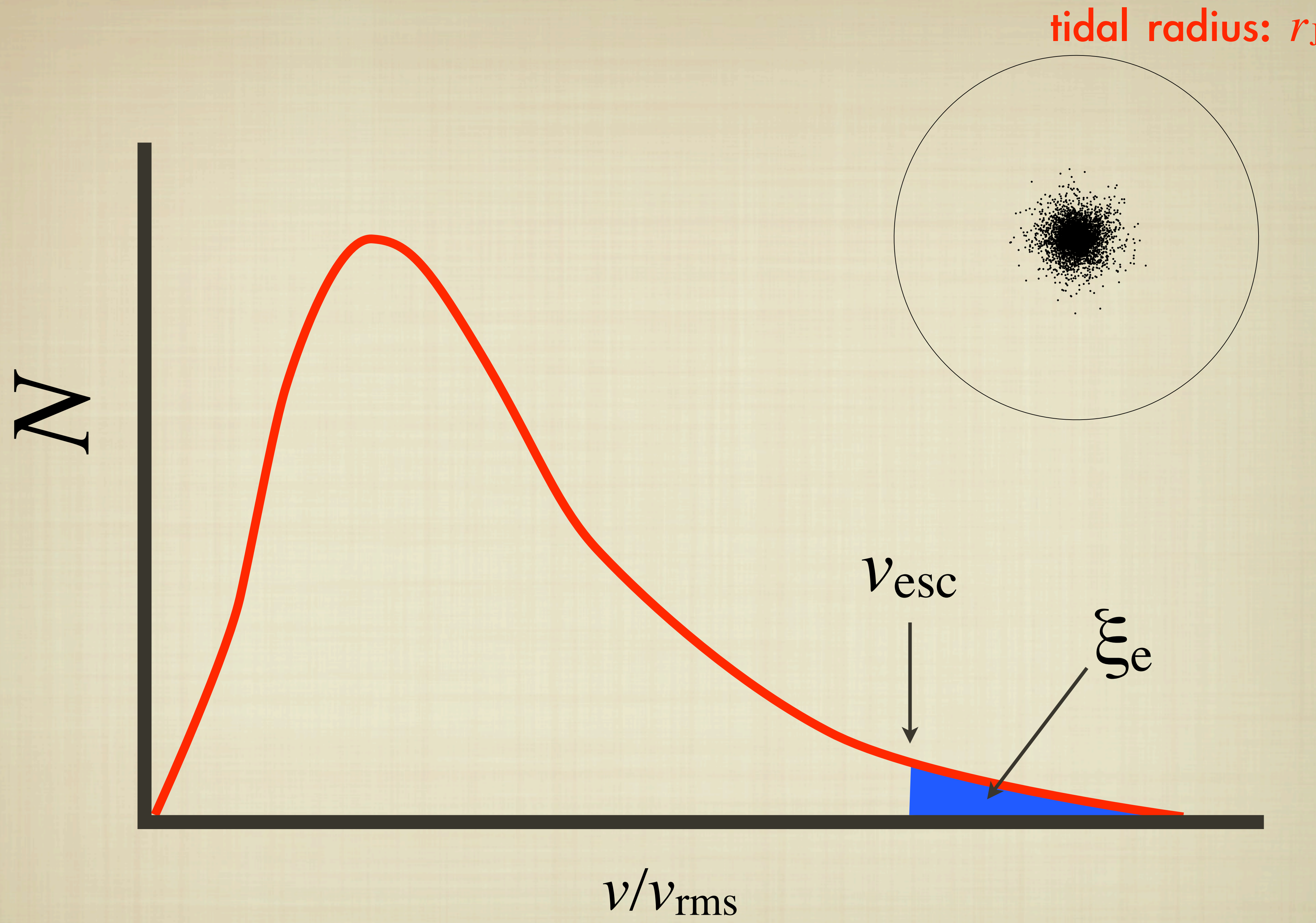
ξ_e = constant?

ξ_e = constant?

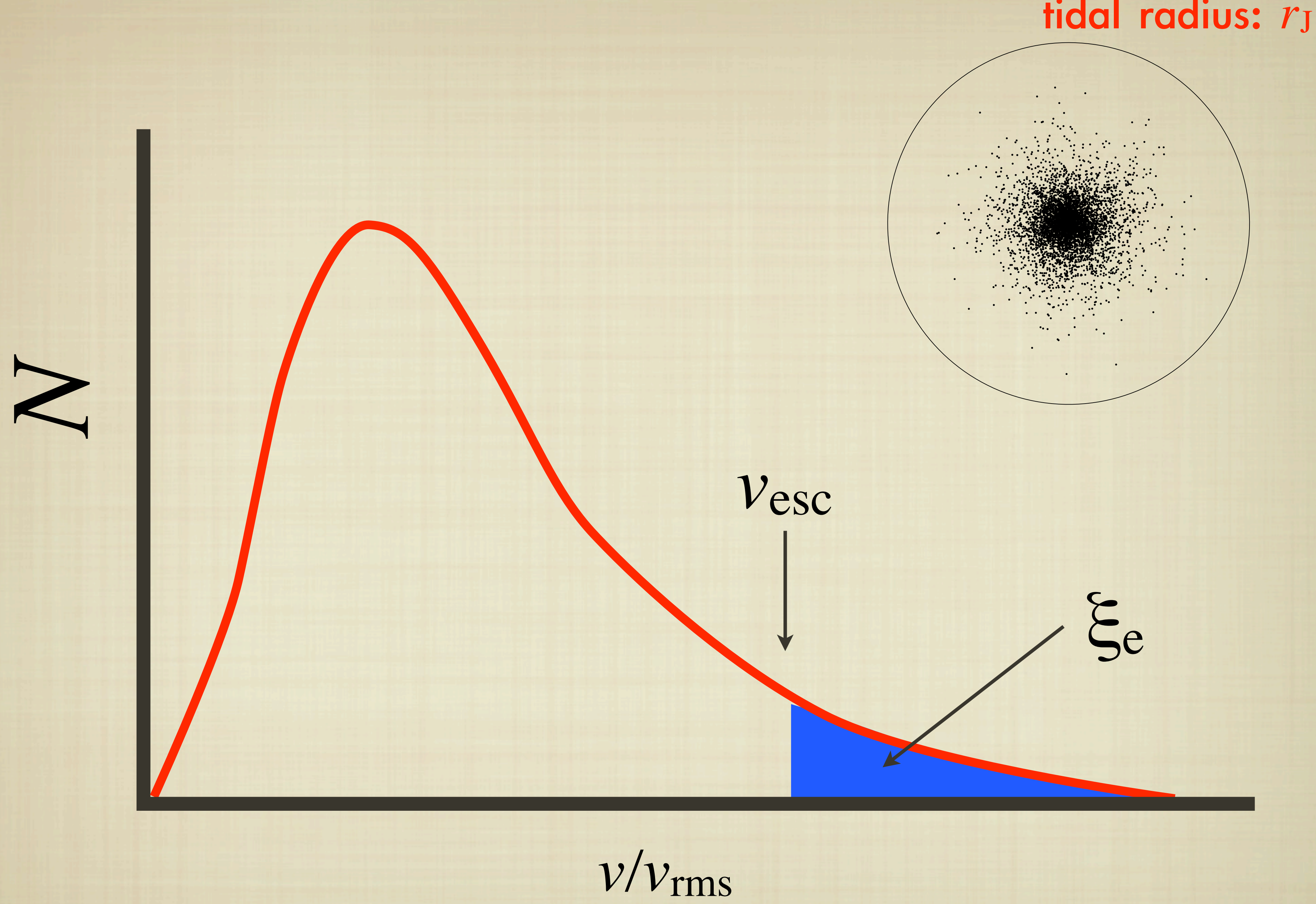
or, do clusters with smaller radii live shorter?

isolated





tidal radius: r_J
N
v_{esc}
ξ_e
v/v_{rms}



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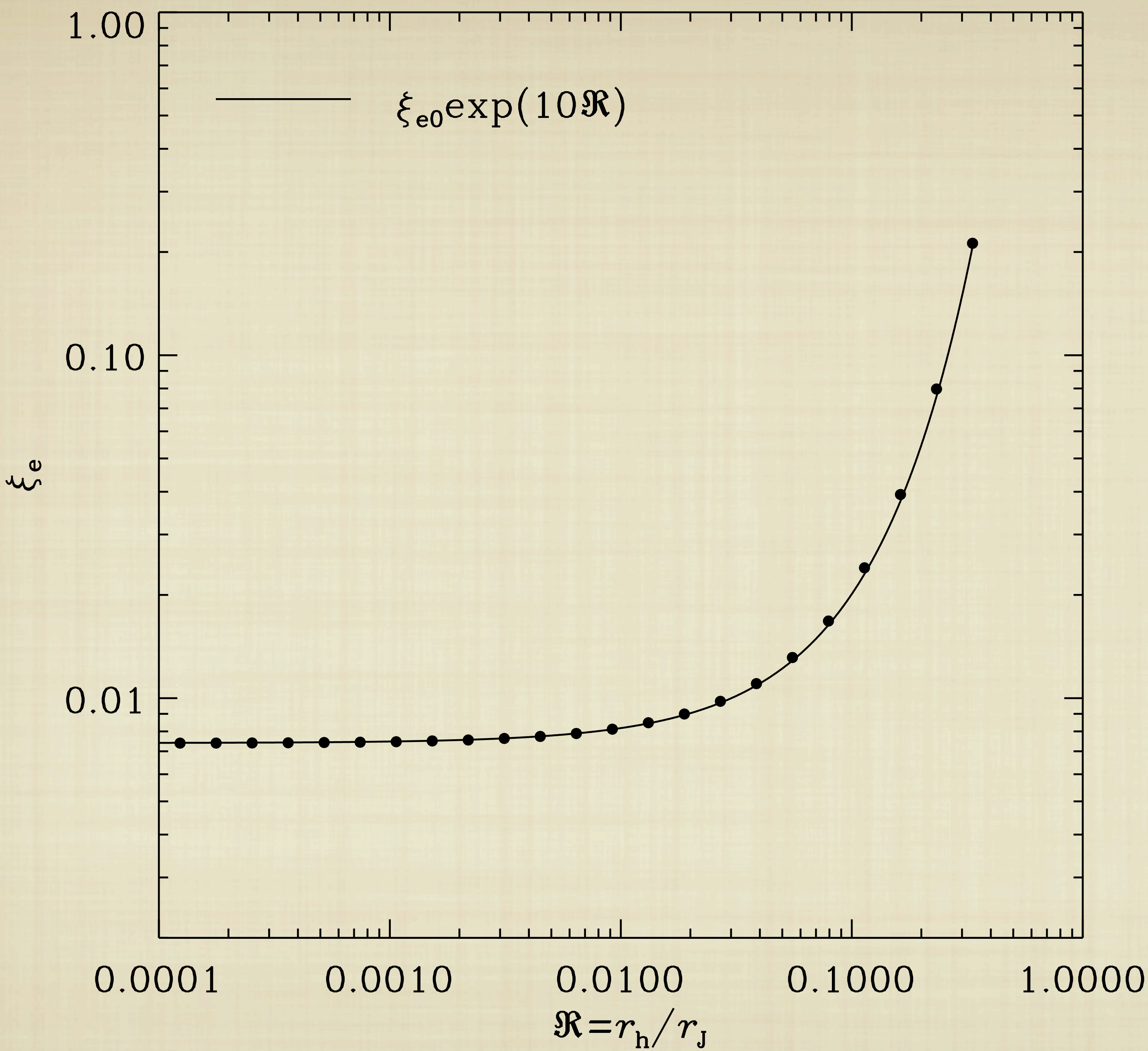
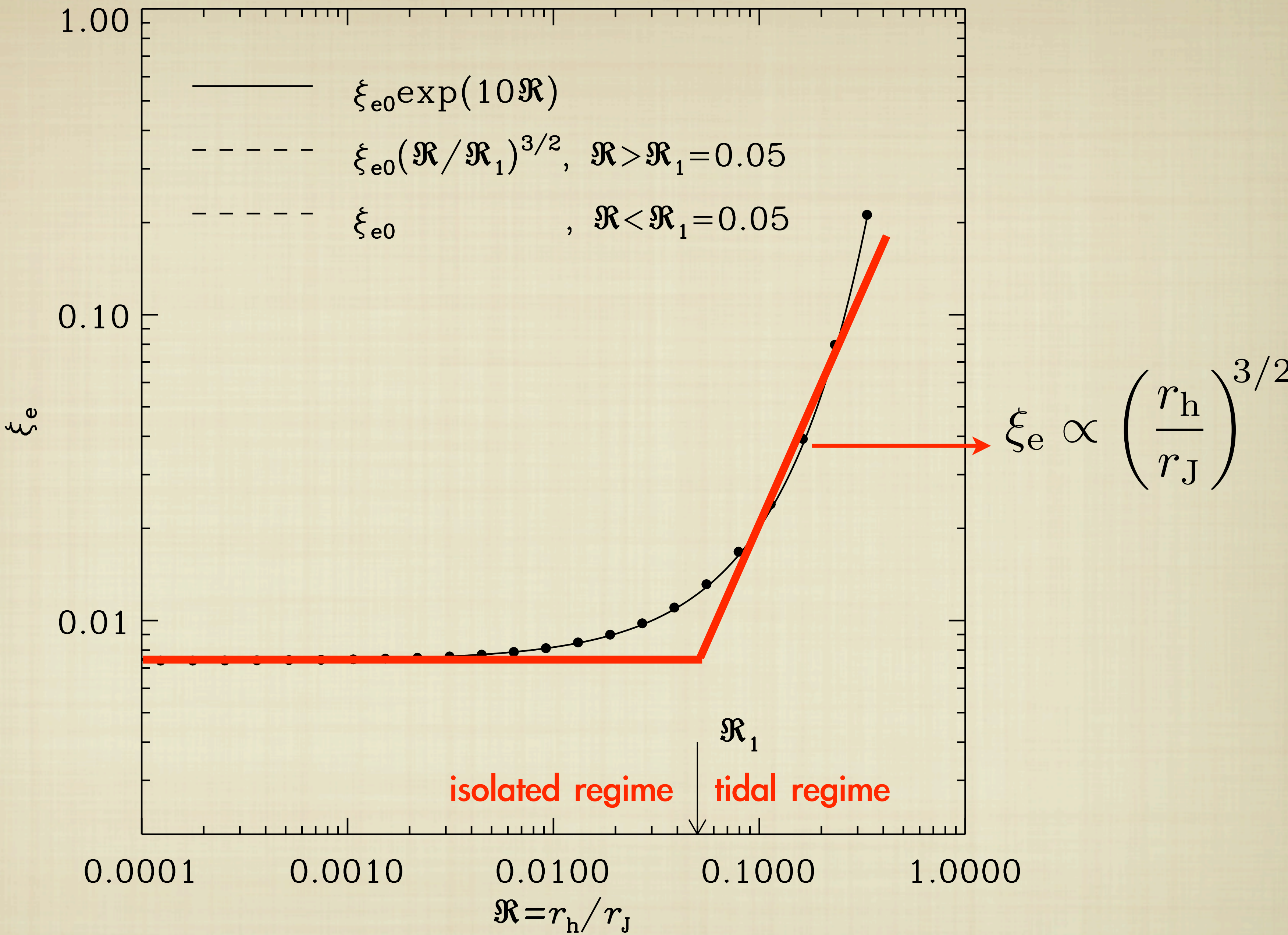


Gieles & Baumgardt (2008)



Gieles & Baumgardt (2008)

$$t_{\rm dis} = \frac{1}{\xi_{\rm e}} t_{\rm rh}$$

<u>Assumptions:</u>

- ★ ~~$\xi_{\rm e}$ = constant~~
- ★ ~~Cluster fills its Roche-lobe~~
- ★ ~~$R_{\rm G,peri}$ = constant~~

$$t_{\mathrm{dis}} = \frac{1}{\xi_{\mathrm{e}}} t_{\mathrm{rh}}$$

$$\propto \frac{M}{\omega} \sim M R_{\mathrm{G}}$$

Assumptions:

★ ~~ξ_e = constant~~

★ ~~Cluster fills its Roche-lobe~~

★ ~~$R_{G,peri}$ = constant~~

Same as for the Roche-lobe filling case!

$$t_{\rm dis} = \frac{1}{\xi_{\rm e}} t_{\rm rh}$$

$$\propto \frac{M}{\omega} \sim M R_{\rm G}$$

Assumptions:

- ★ ~~$\xi_{\rm e}$ = constant~~
- ★ ~~Cluster fills its Roche-lobe~~
- ★ ~~$R_{\rm G,peri}$ = constant~~

$$\dot{M} = \xi_{\rm e} \frac{M}{t_{\rm rh}}$$

$$\propto \rho_{\rm J}^{1/2}$$

<u>Assumptions:</u>

- ⋆ ~~$\xi_{\rm e}$ = constant~~
- ⋆ ~~Cluster fills its Roche-lobe~~
- ⋆ ~~$R_{\rm G,peri}$ = constant~~

$$\dot{M} = \xi_{\mathrm{e}} \frac{M}{t_{\mathrm{rh}}}$$

$$\propto \rho_{\mathrm{h}}^{1/2} \left(\frac{\rho_{\mathrm{J}}}{\rho_{\mathrm{h}}} \right)^{1/2}$$

McLaughlin 12/01/2009 18:00

$$\dot{M} = \xi_{\rm e} \frac{M}{t_{\rm rh}}$$

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~constant

McLaughlin 12/01/2009 18:00

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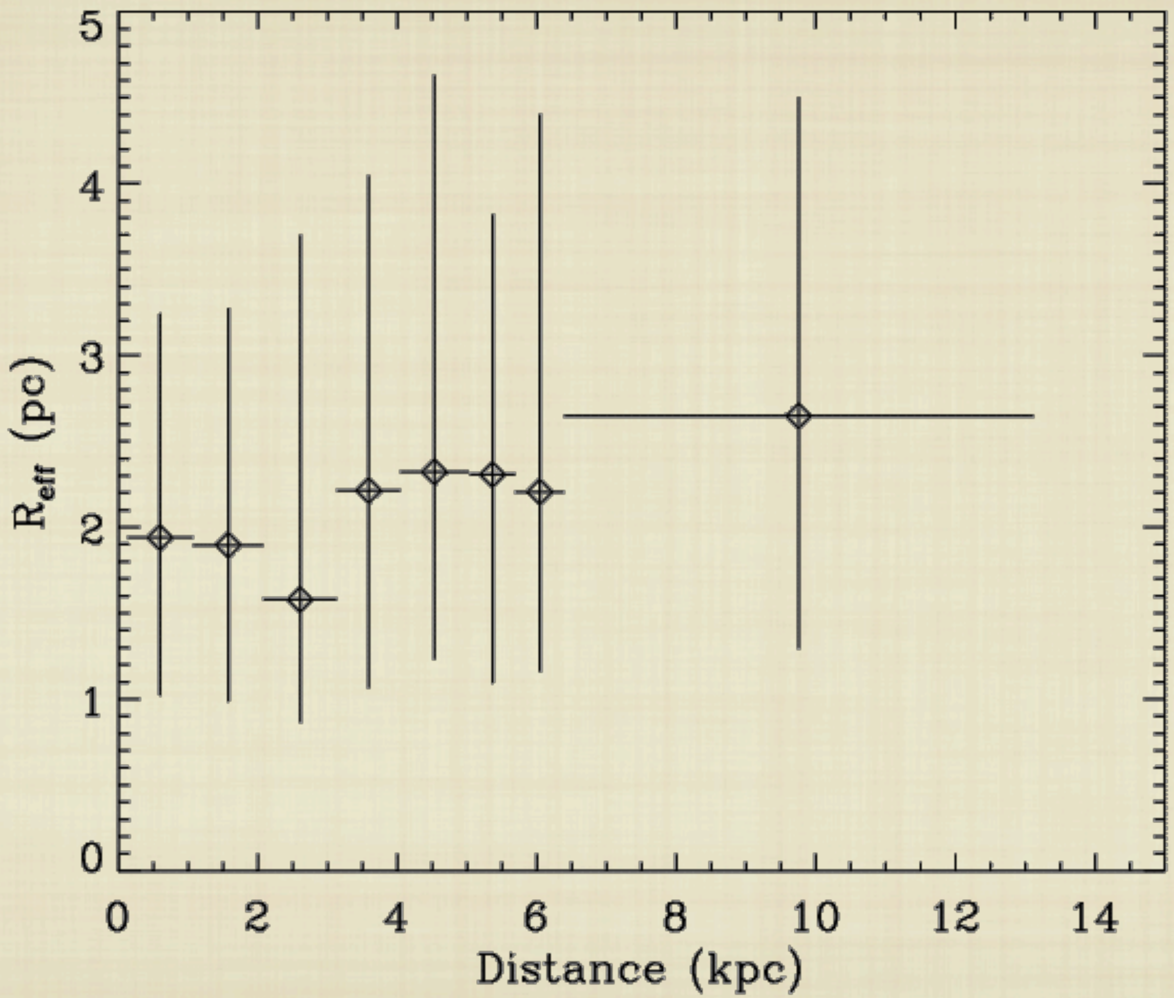
~constant

McLaughlin 12/01/2009 18:00

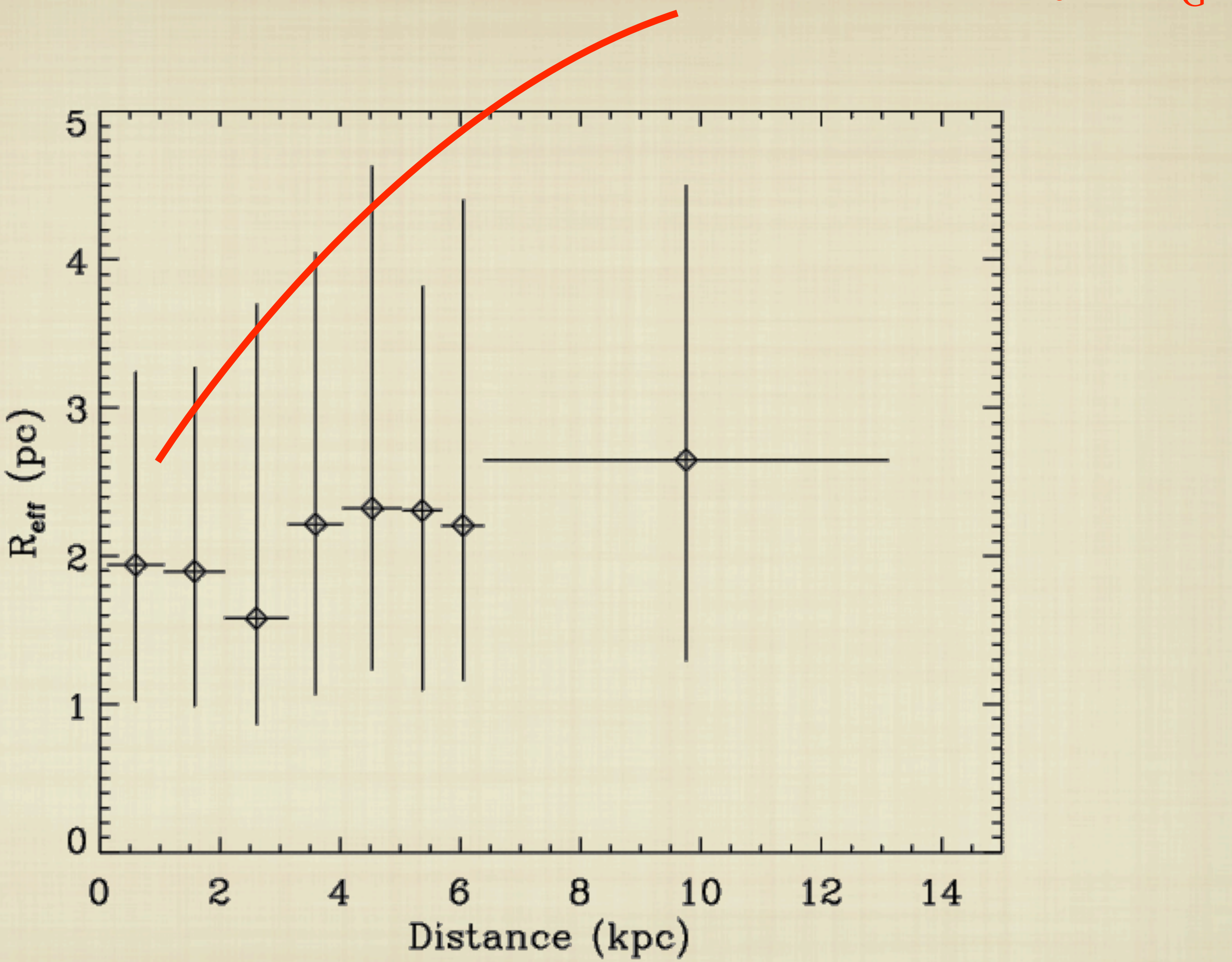
McLaughlin 12/01/2009 18:10: “we are both right, but you are wrong by saying we are wrong”

M51



Scheepmaker et al. (2007)

M51



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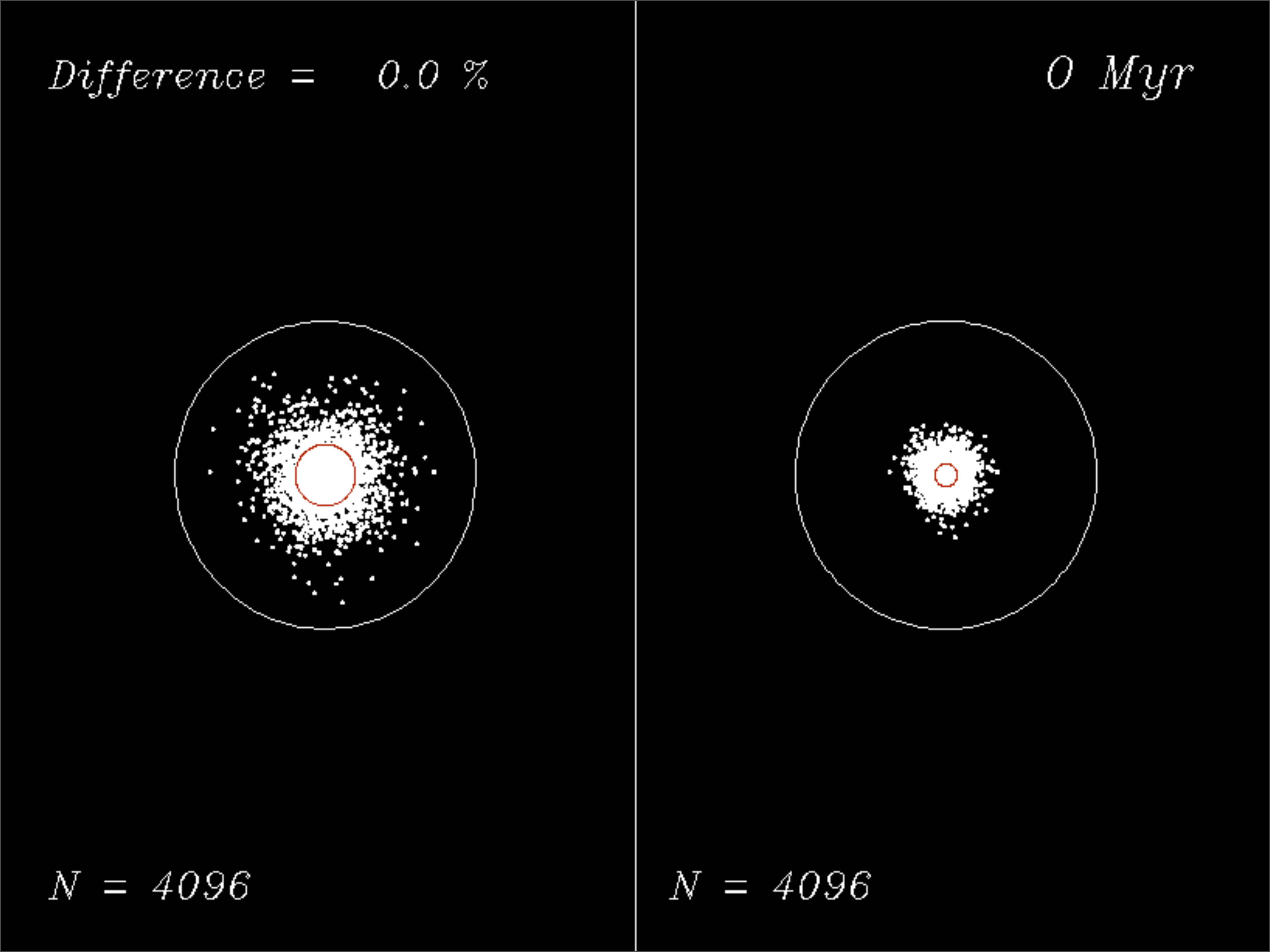
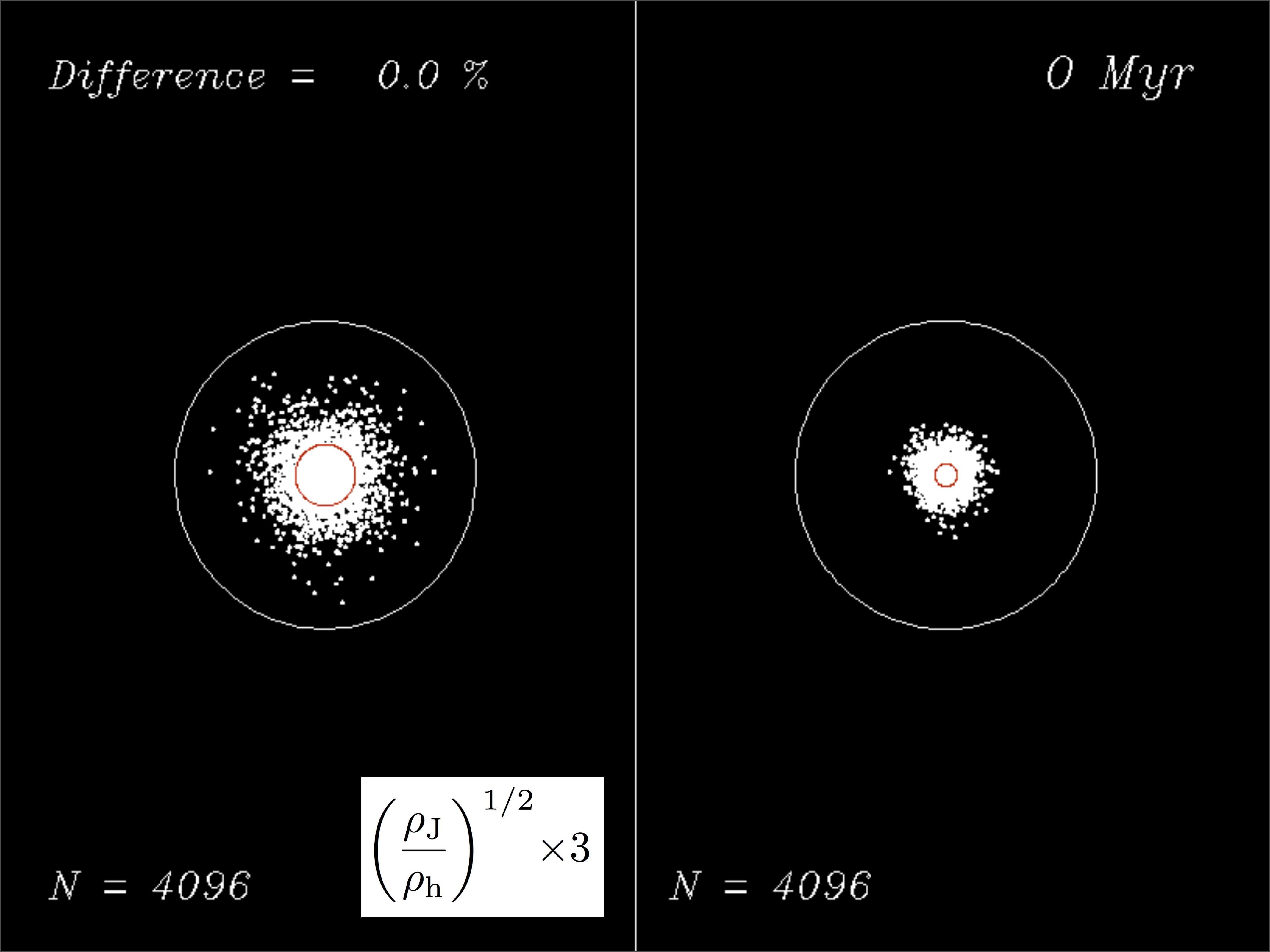
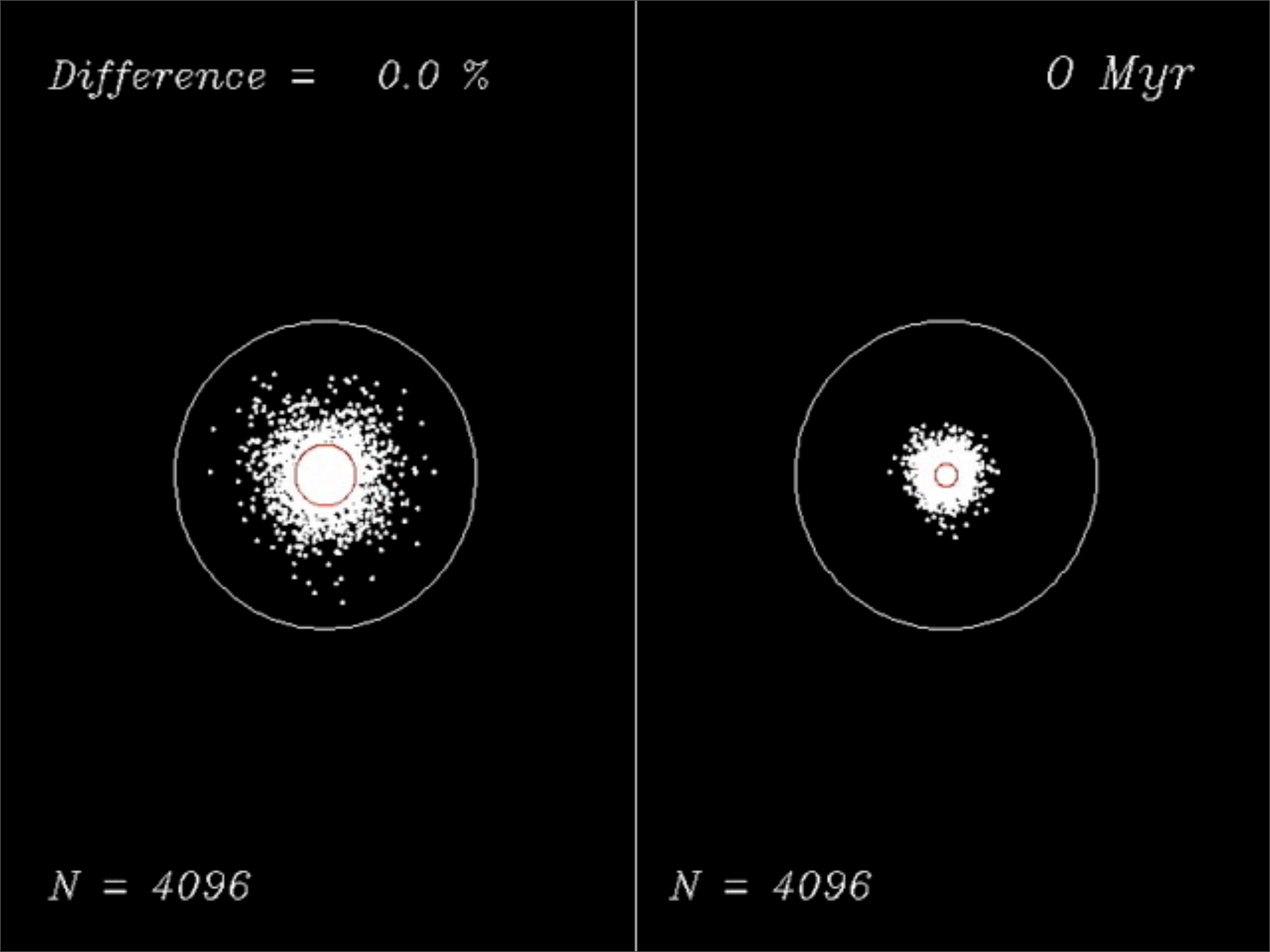


Difference = 0.0 %
0 Myr
N = 4096
N = 4096



Difference = 0.0 %
0 Myr
N = 4096
$\left(\frac{\rho_J}{\rho_h}\right)^{1/2} \times 3$
N = 4096


Difference = 0.0 %
0 Myr
N = 4096
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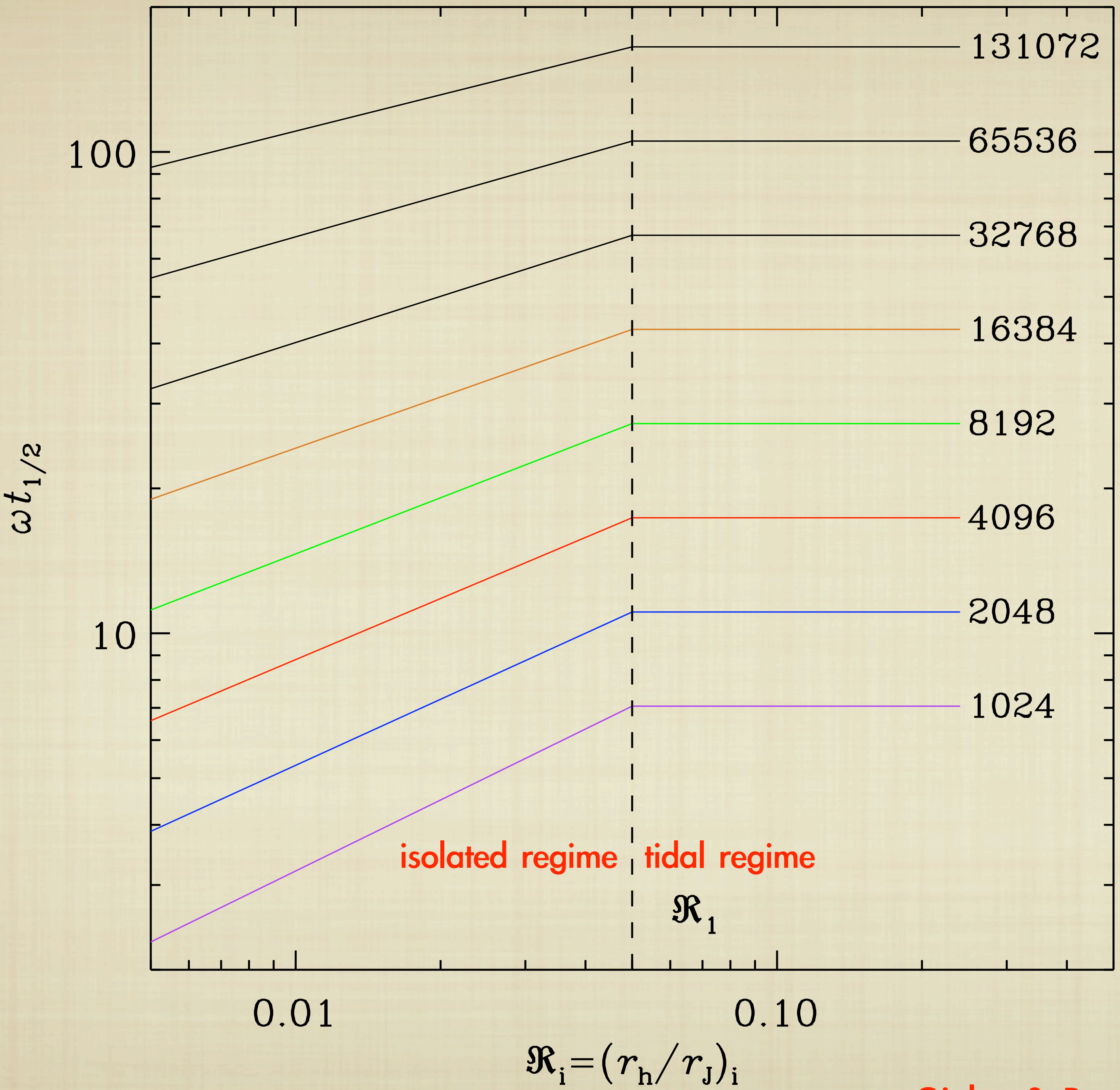
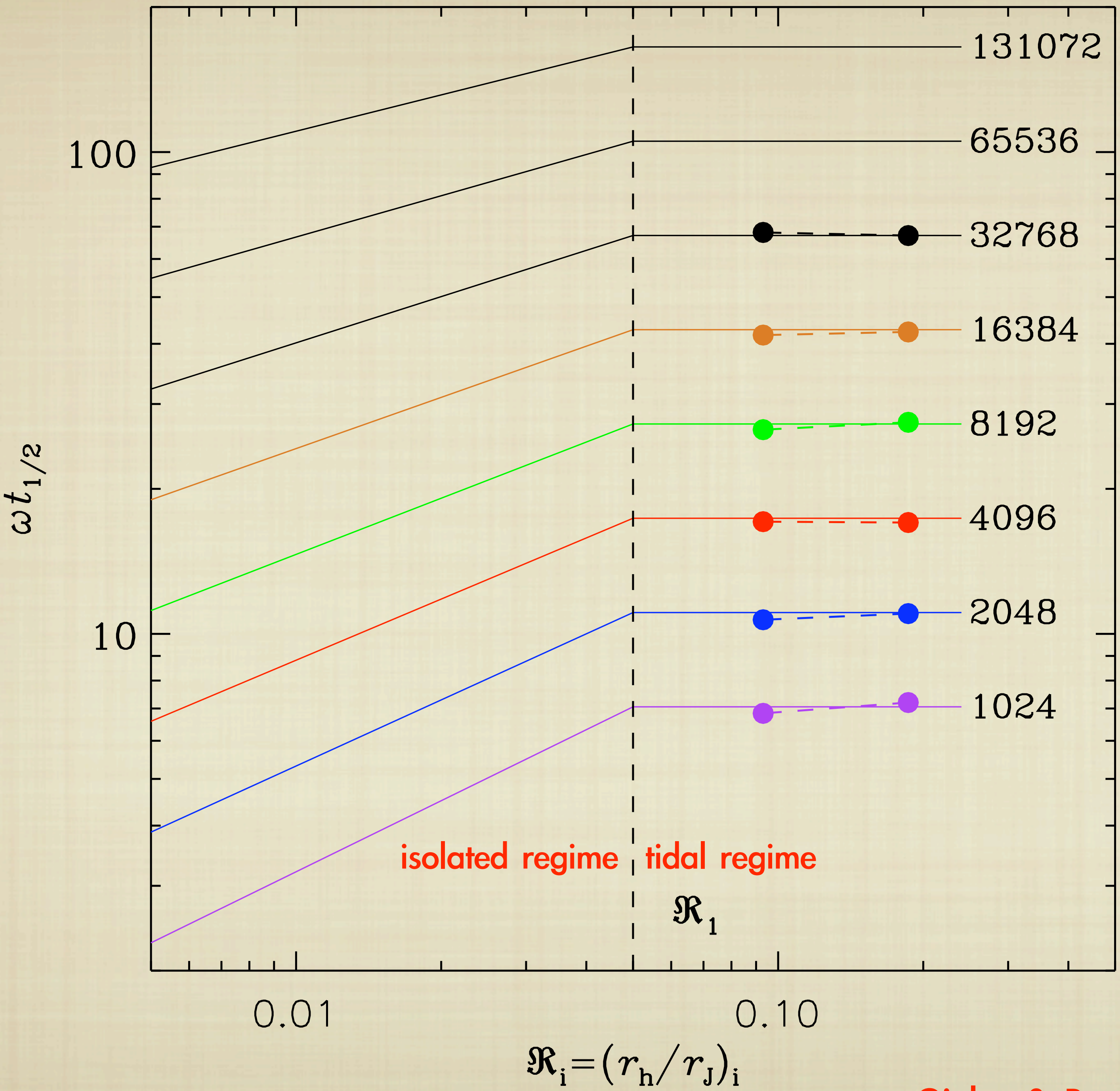


Gieles & Baumgardt (2008)



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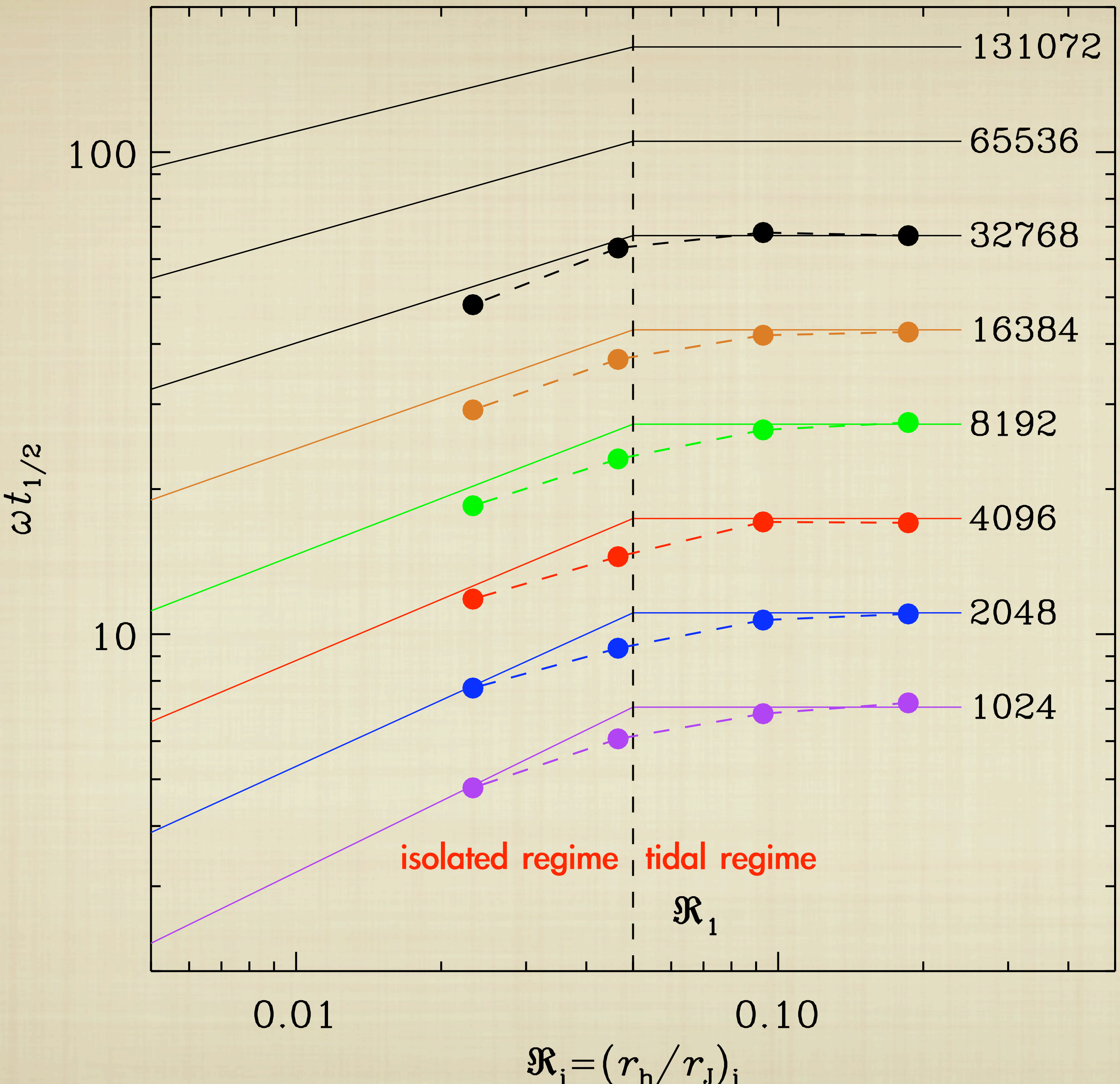
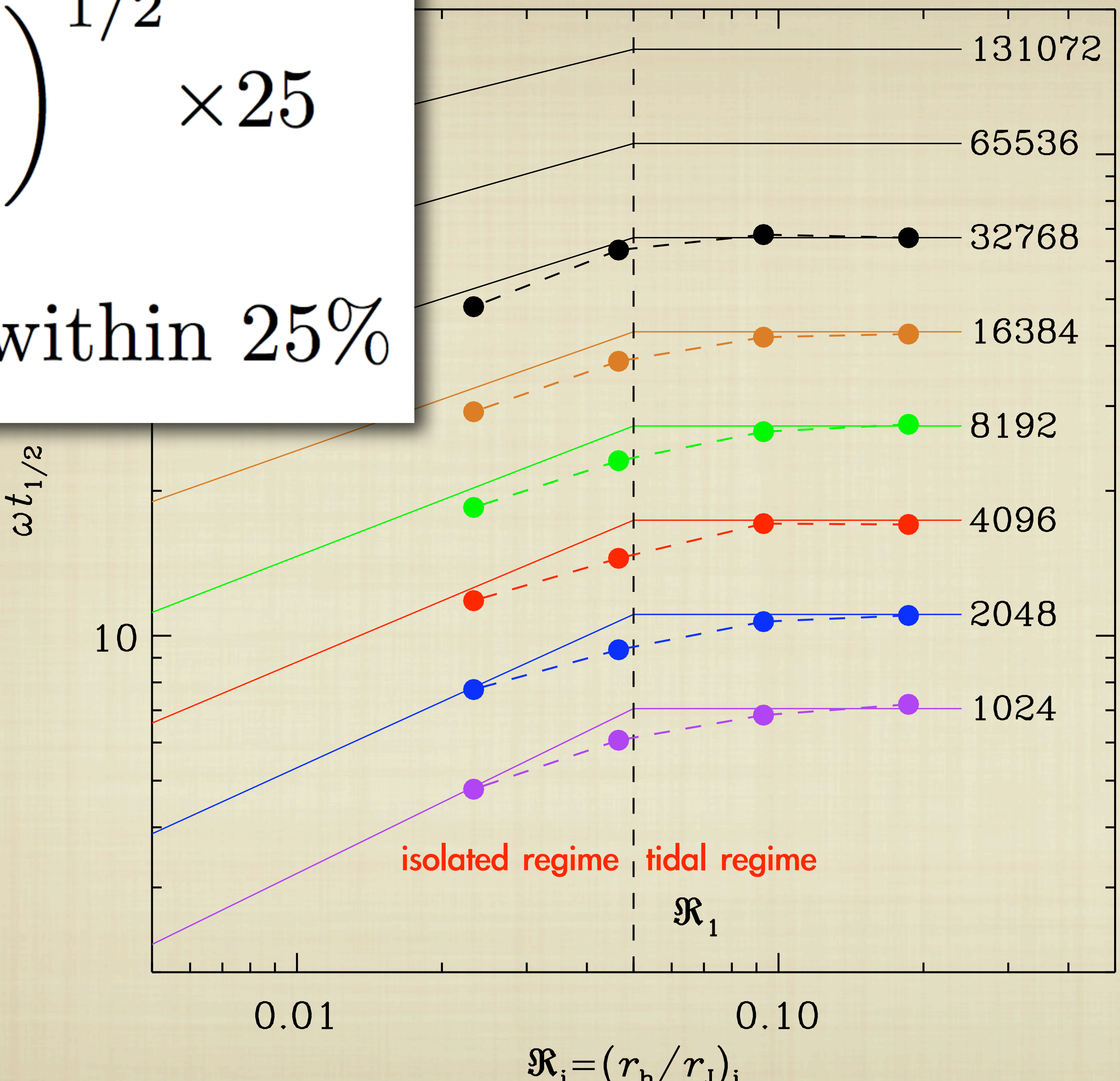


Gieles & Baumgardt (2008)

$$\left(\frac{\rho_{\rm J}}{\rho_{\rm h}}\right)^{1/2} \times 25$$

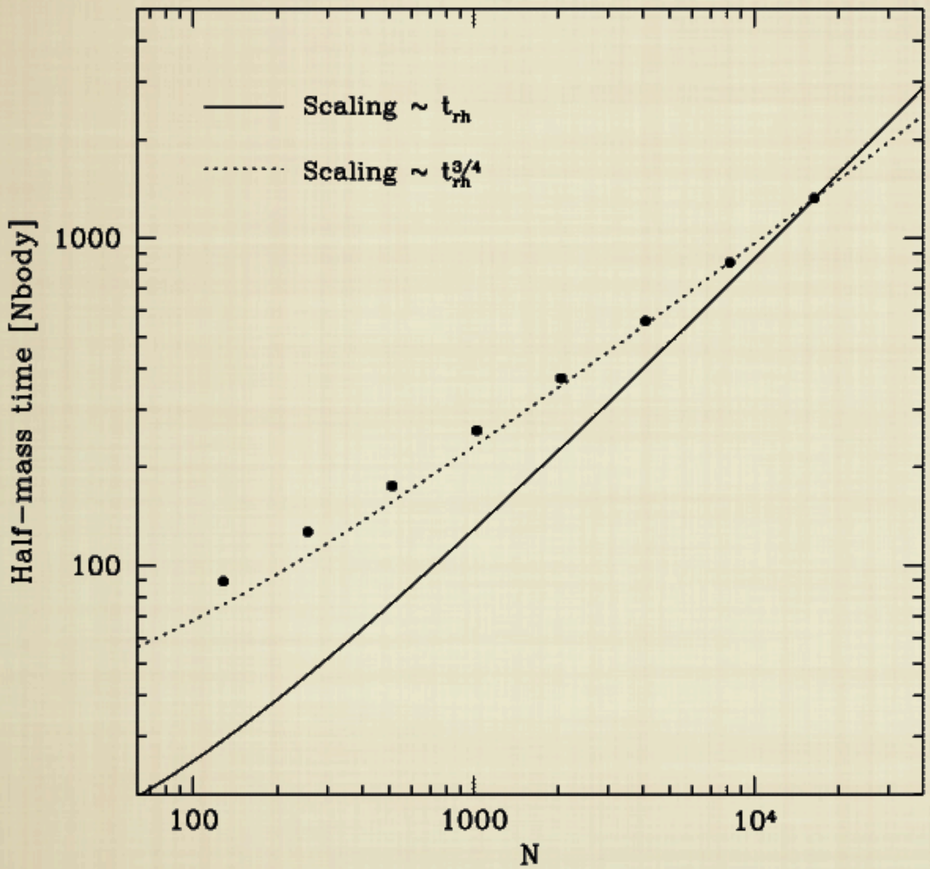
$t_{\rm dis}$ within 25%

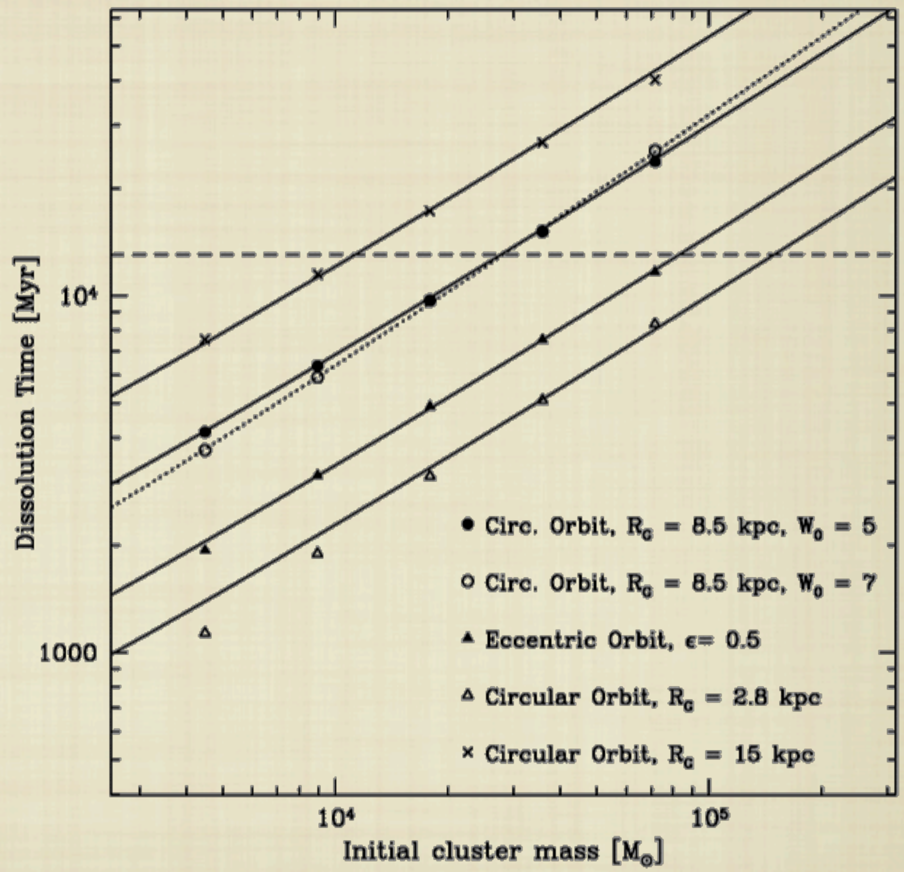


Gieles & Baumgardt (2008)

The importance of the escape time of stars

Fukushige & Heggie (2000)





Equal mass clusters

Baumgardt (2001)

Mass function + SEV

Baumgardt & Makino (2003)

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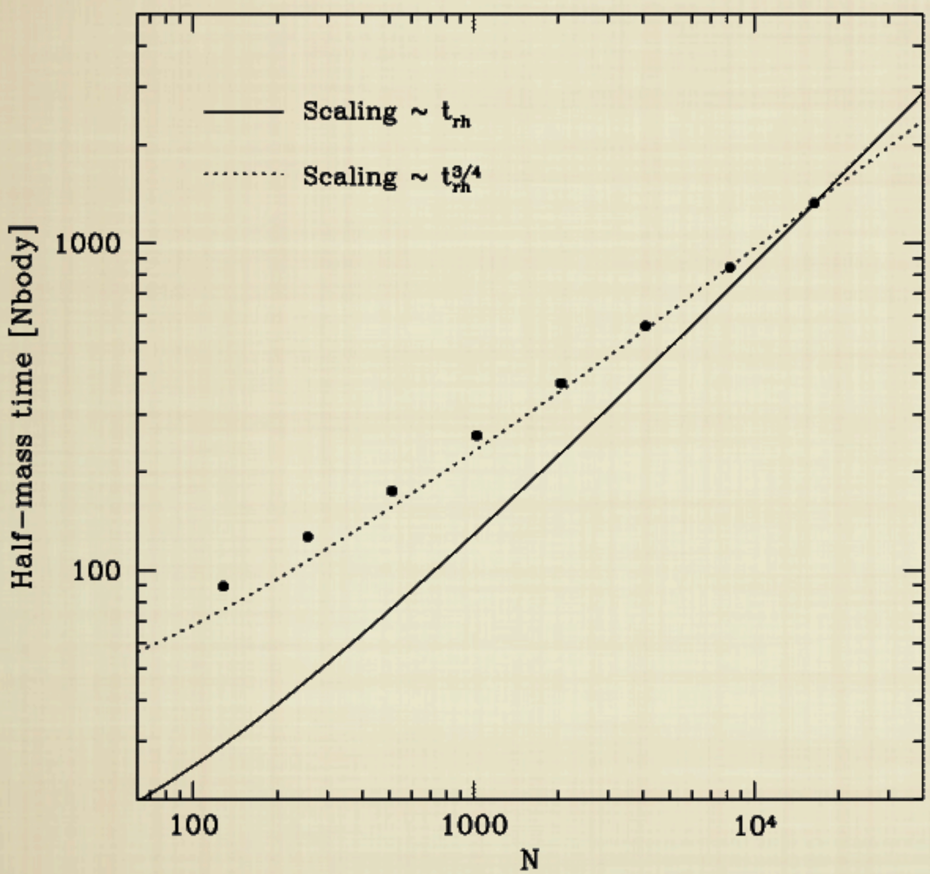

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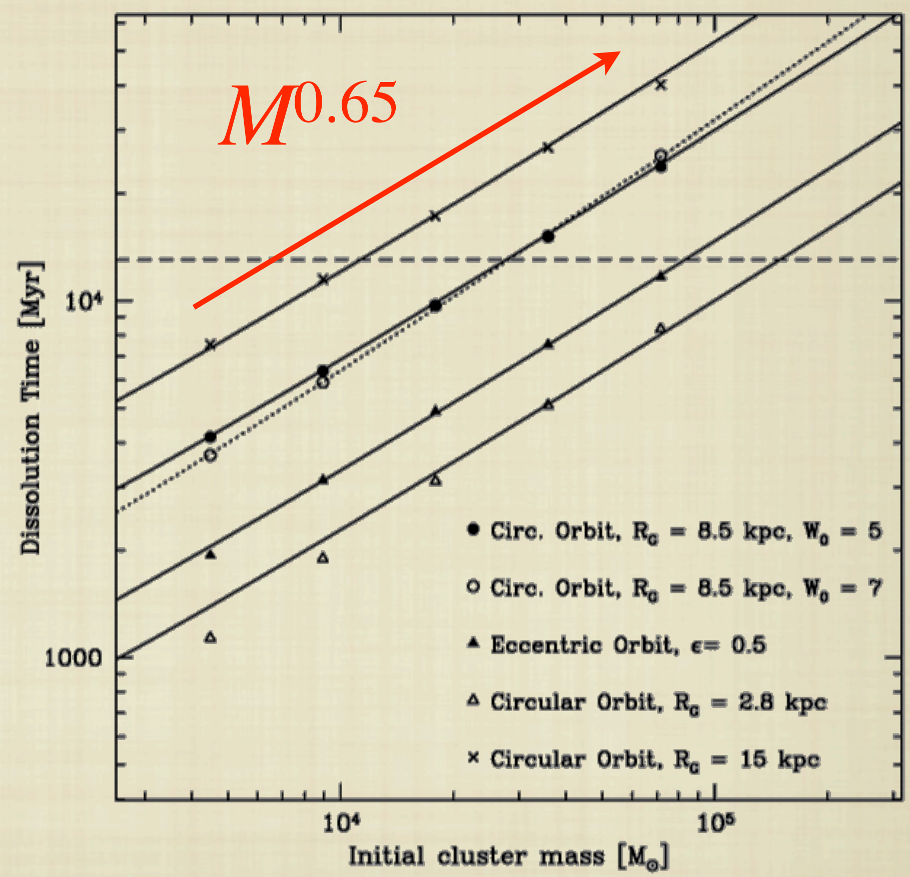

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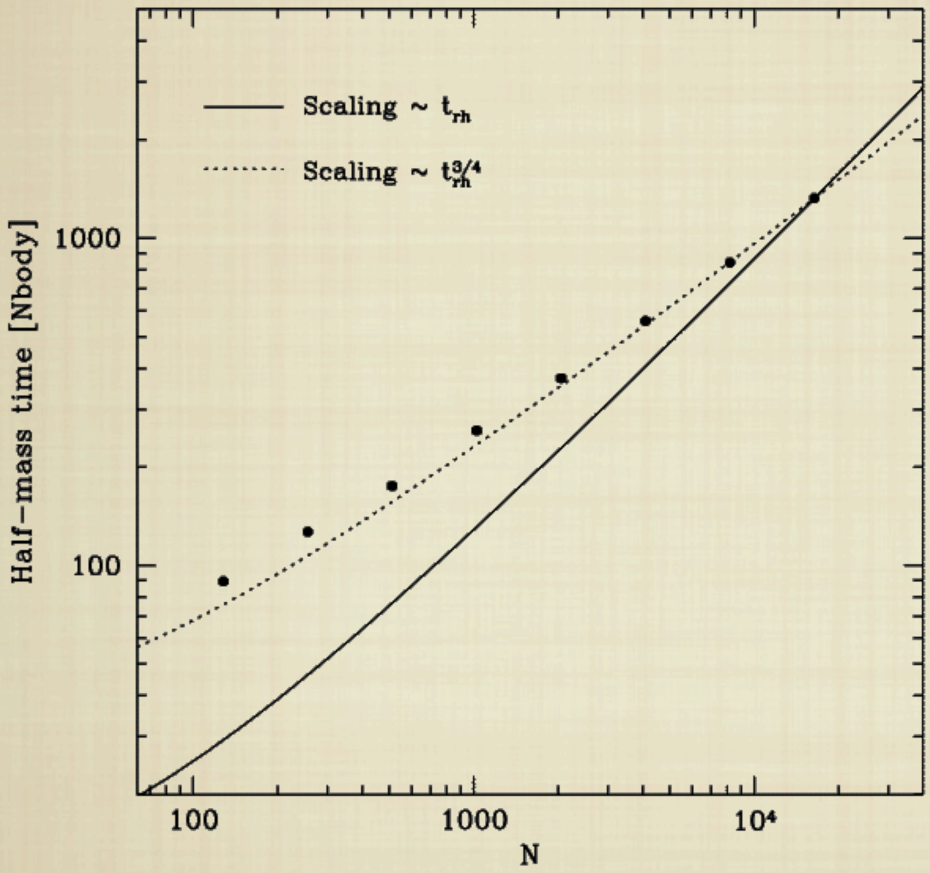

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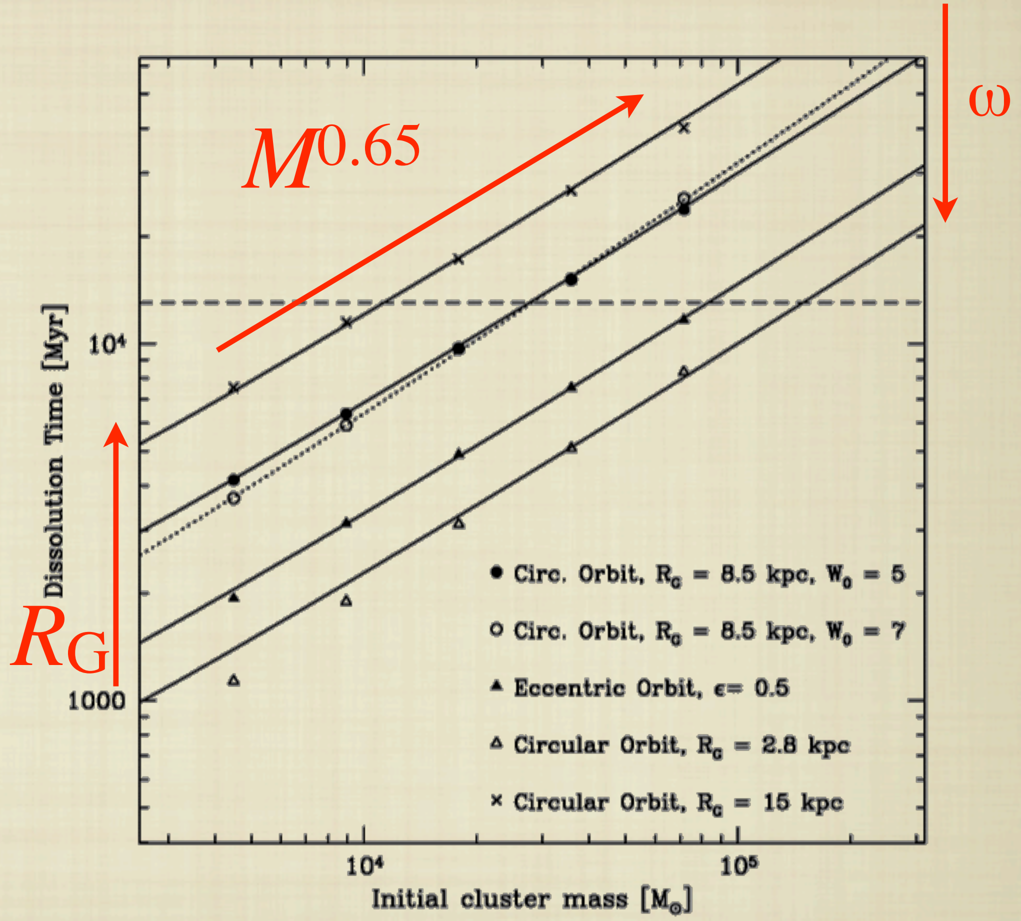


Mass function + SEV

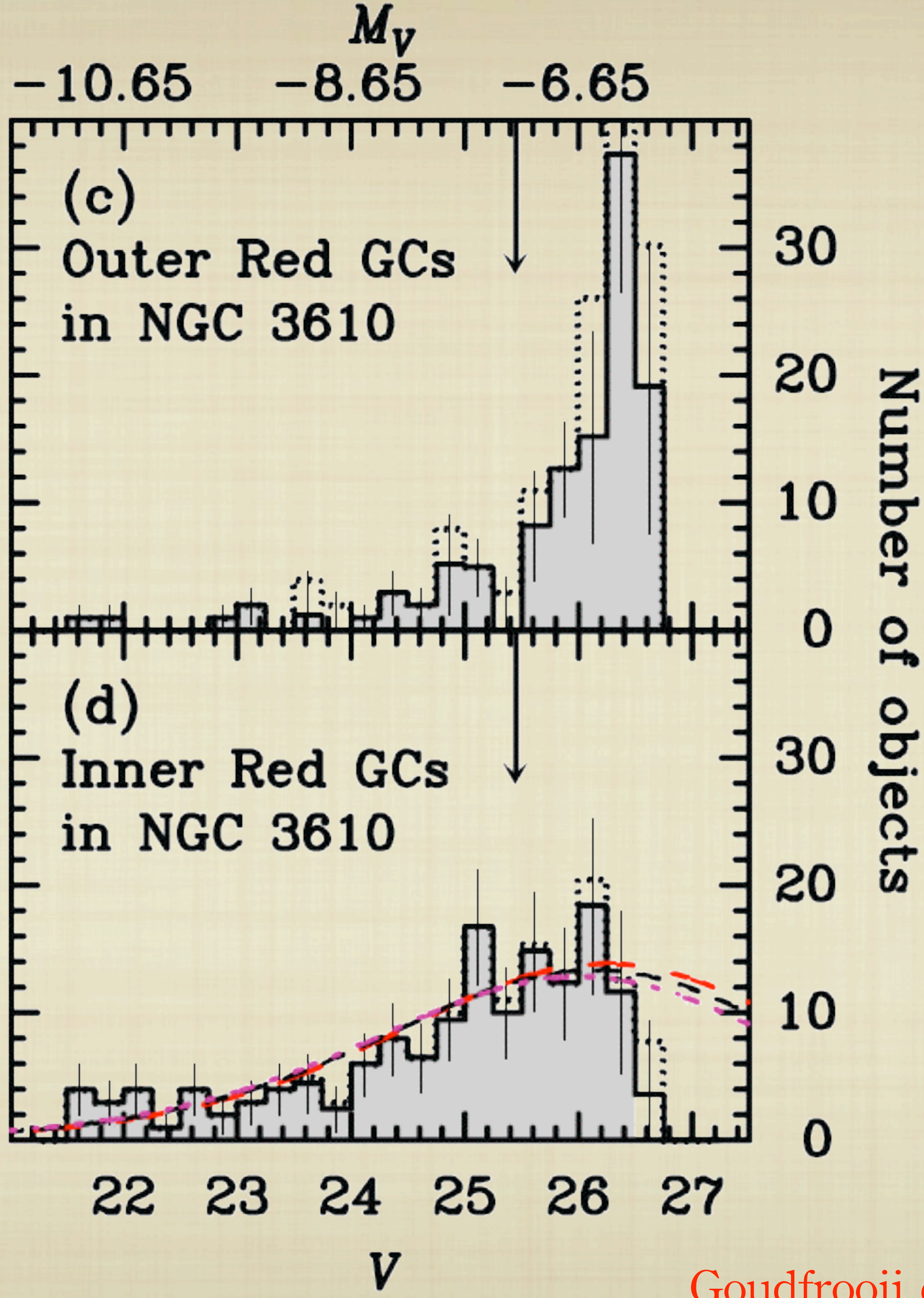
Baumgardt & Makino (2003)

Dissolution in tidal regime

$$t_{\rm dis} \propto \frac{M^{0.65}}{\omega}$$

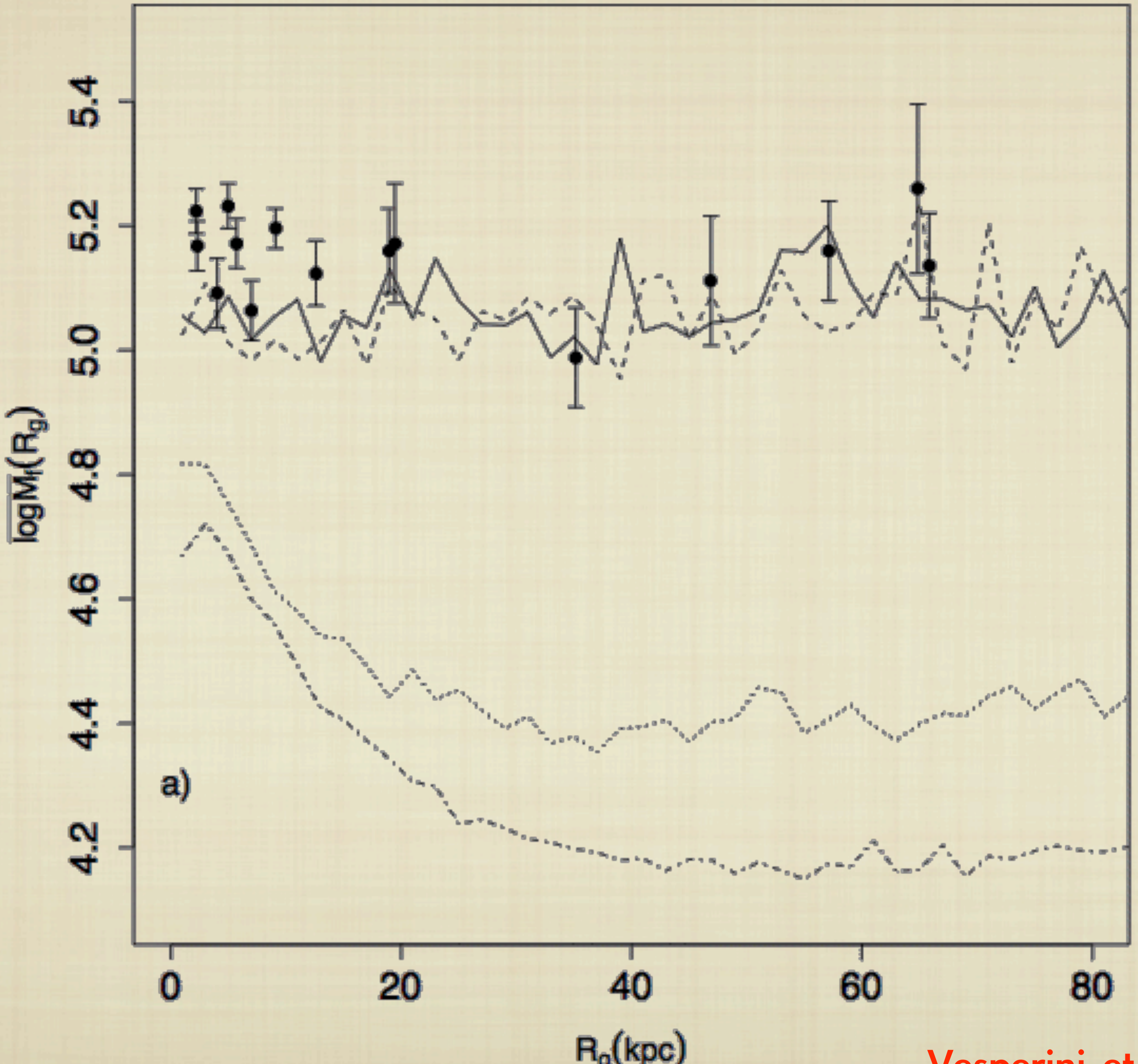
Gieles & Baumgardt (2008)

few Gyr population in NGC 3610



Goudfrooij et al. (2007)

Near constant M_{TO} is a problem with this dissolution law



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see also Jordán et al. (2007)

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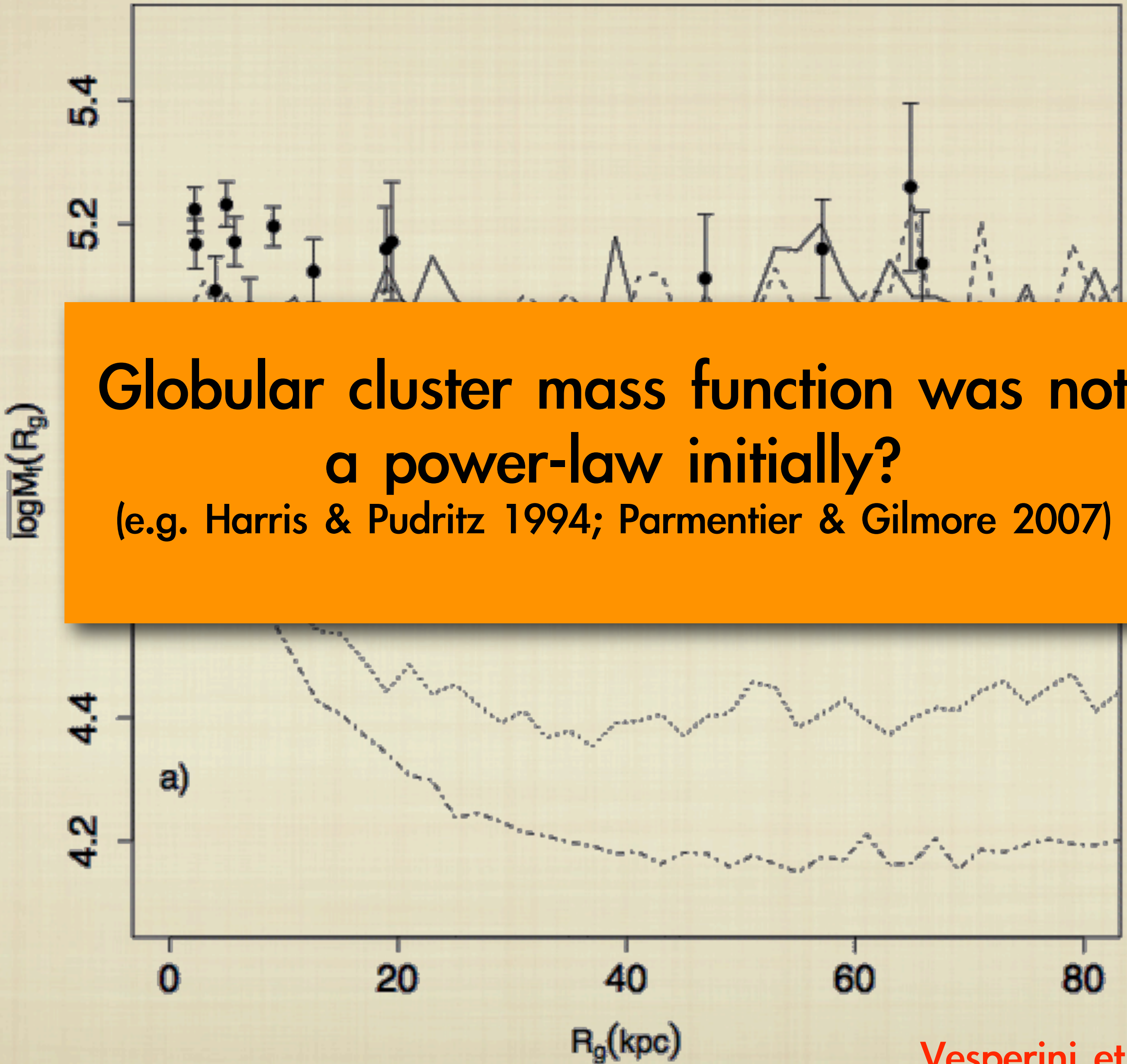
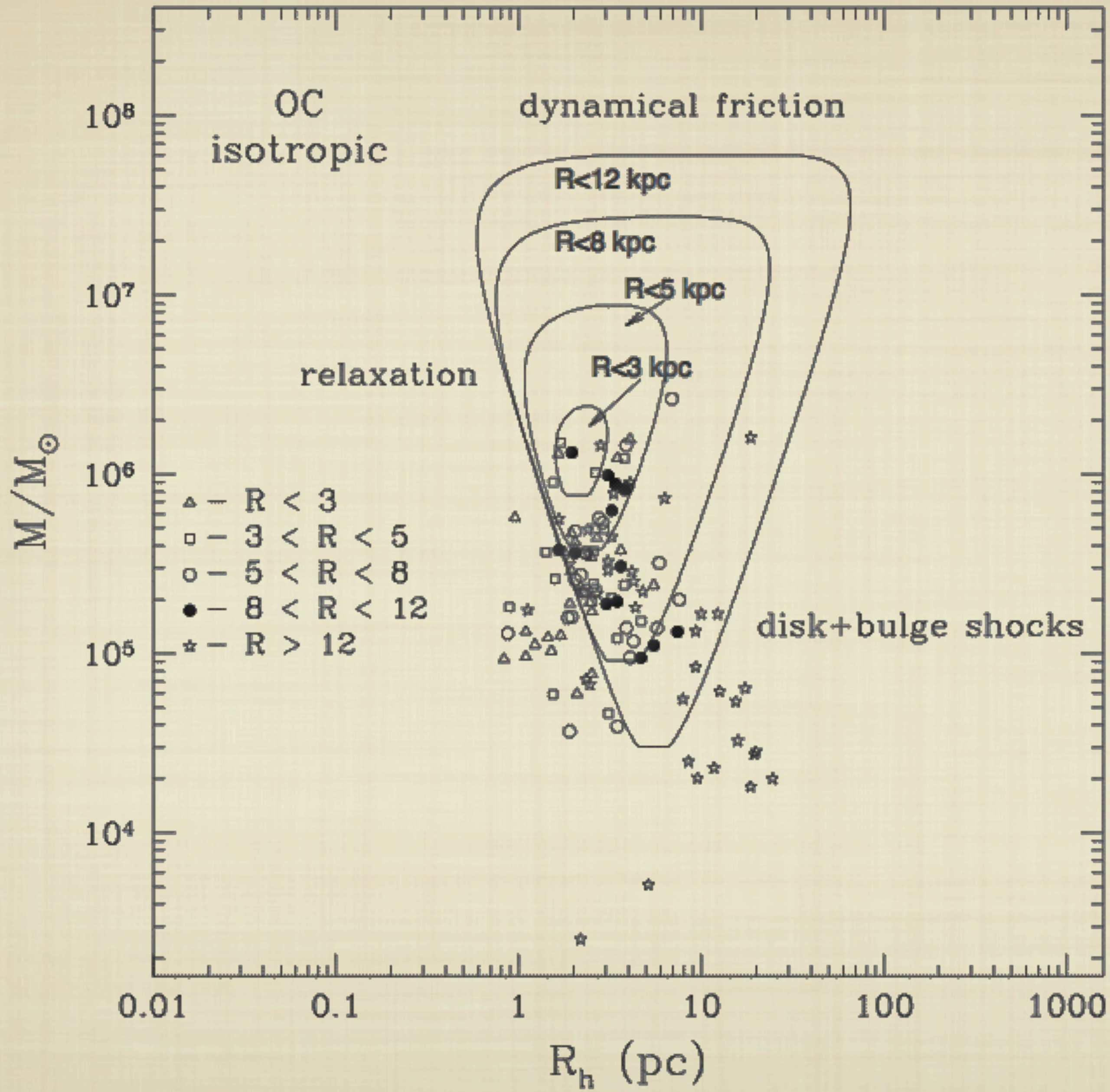


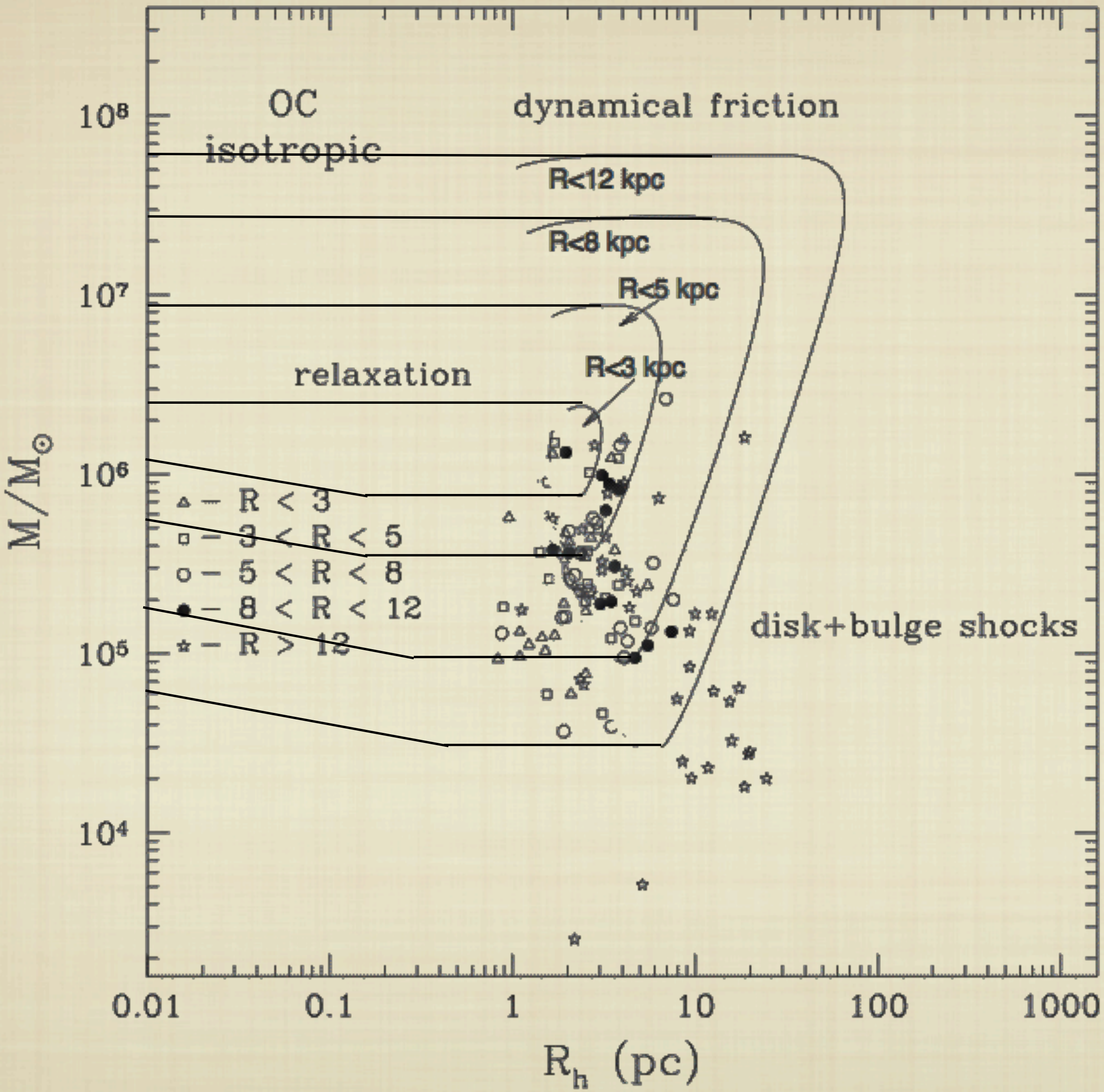
Globular cluster mass function was not a power-law initially?

(e.g. Harris & Pudritz 1994; Parmentier & Gilmore 2007)

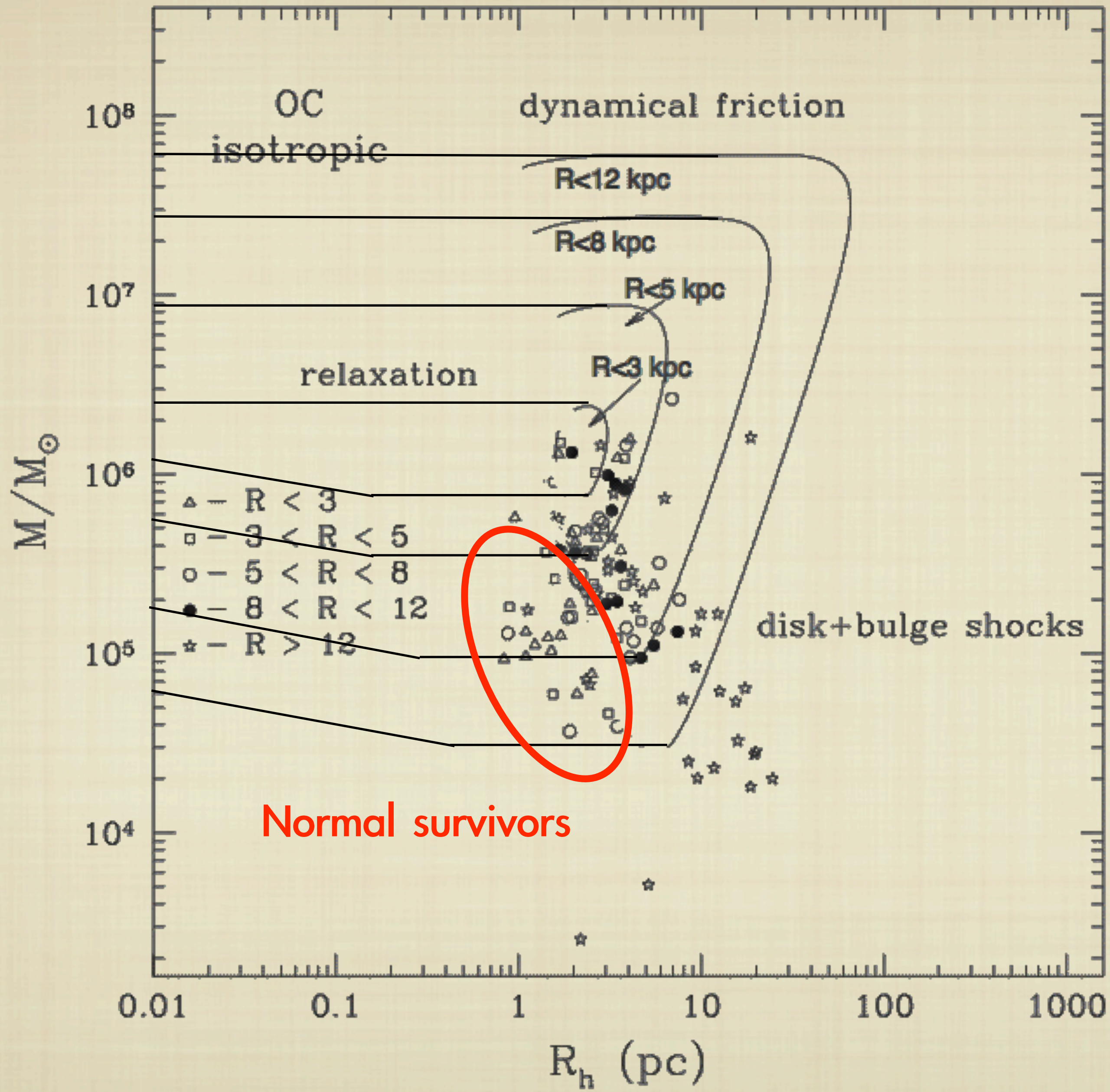
Vesperini et al. (2003)
see also Jordán et al. (2007)



Gnedin & Ostriker (1997)



OC
isotropic
dynamical friction
R<12 kpc
R<8 kpc
R<5 kpc
R<3 kpc
relaxation
disk+bulge shocks
– R < 3
– 3 < R < 5
– 5 < R < 8
– 8 < R < 12
– R > 12
10^8
10^7
10^6
10^5
10^4
$M/M_\odot$
0.01
0.1
1
10
100
1000
R_h (pc)



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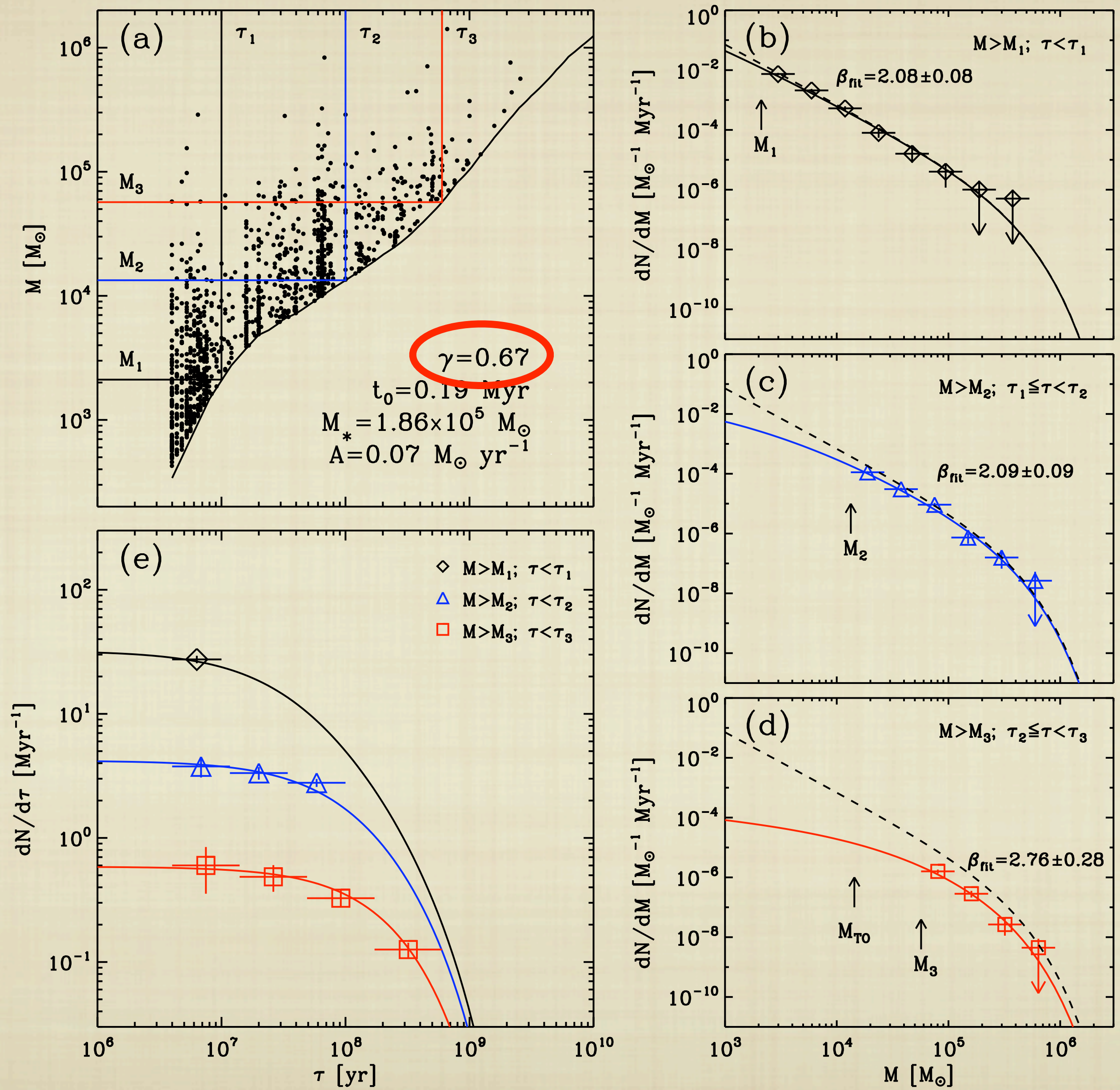
disk+bulge shocks
Normal survivors
10^8
10^7
10^6
10^5
10^4
$M/M_\odot$
0.01
0.1
1
10
100
1000
R_h (pc)

Application to young clusters: see my poster



Gieles 2009, MNRAS, ArXiv:0901.0830

So....

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- Results for Roche-lobe filling clusters apply to clusters of other (smaller) radii as well ($\xi_e \neq$ constant)
- $t_{\rm dis} \propto M^{0.65}/\omega$
- $\dot{M} \not\propto \rho_h^{1/2}$; $t_{\rm dis} \neq 30\, t_{\rm rh}$
- The problem of getting a "universal" $M_{\rm TO}$ from a power-law CIMF at all $R_{\rm G}$ still stands