Extended Star Clusters: Nature or Nurture?

Mark Gieles (Institute of Astronomy, Cambridge)
Jorge Peñarrubia (Instituto de Astrofísica de Andalucía, Granada)
Florent Renaud (Saclay, Paris)

NAM, Manchester, March 30, 2012

47 Tuc : $M \simeq 10^6\, M_\odot$

$\rho_{\rm h} \simeq 10^4\, M_\odot\, {\rm pc}^{-3}$

NGC 7492 : $M \simeq 10^4\, M_\odot$

$\rho_{\rm h} \simeq 1\, M_\odot\, {\rm pc}^{-3}$

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“Faint fuzzy” and “extended” clusters

Fainter/fuzzier/more extended than ... ?

Scenarios

“Faint fuzzy” and “extended” clusters

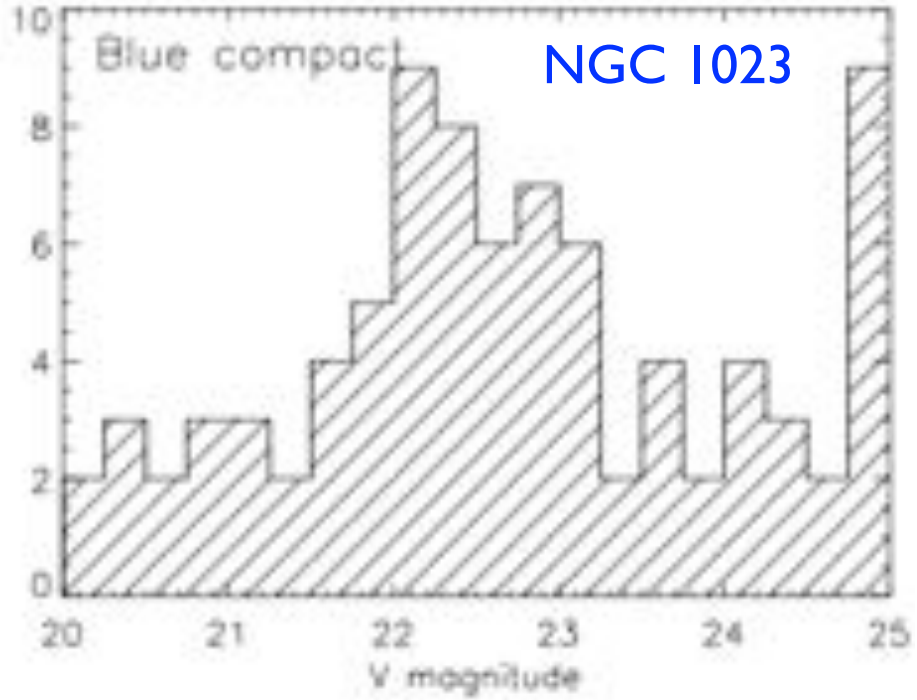
Fainter/fuzzier/more extended than ... ?

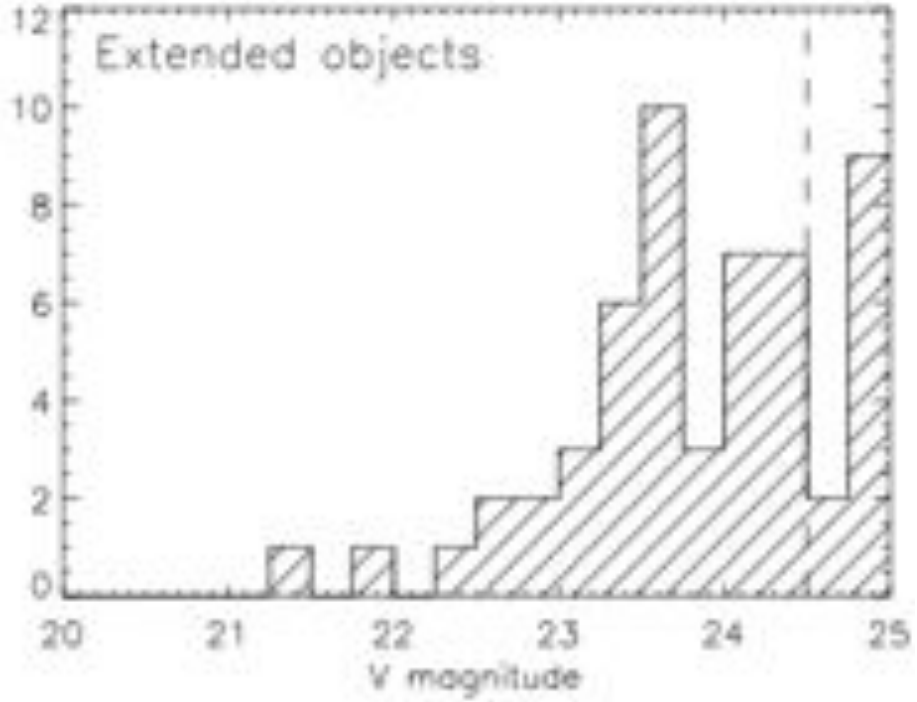
Scenarios

"Faint fuzzy" star clusters

large: $r_{eff} \gtrsim 7$ pc

faint: $M_V \gtrsim -6$



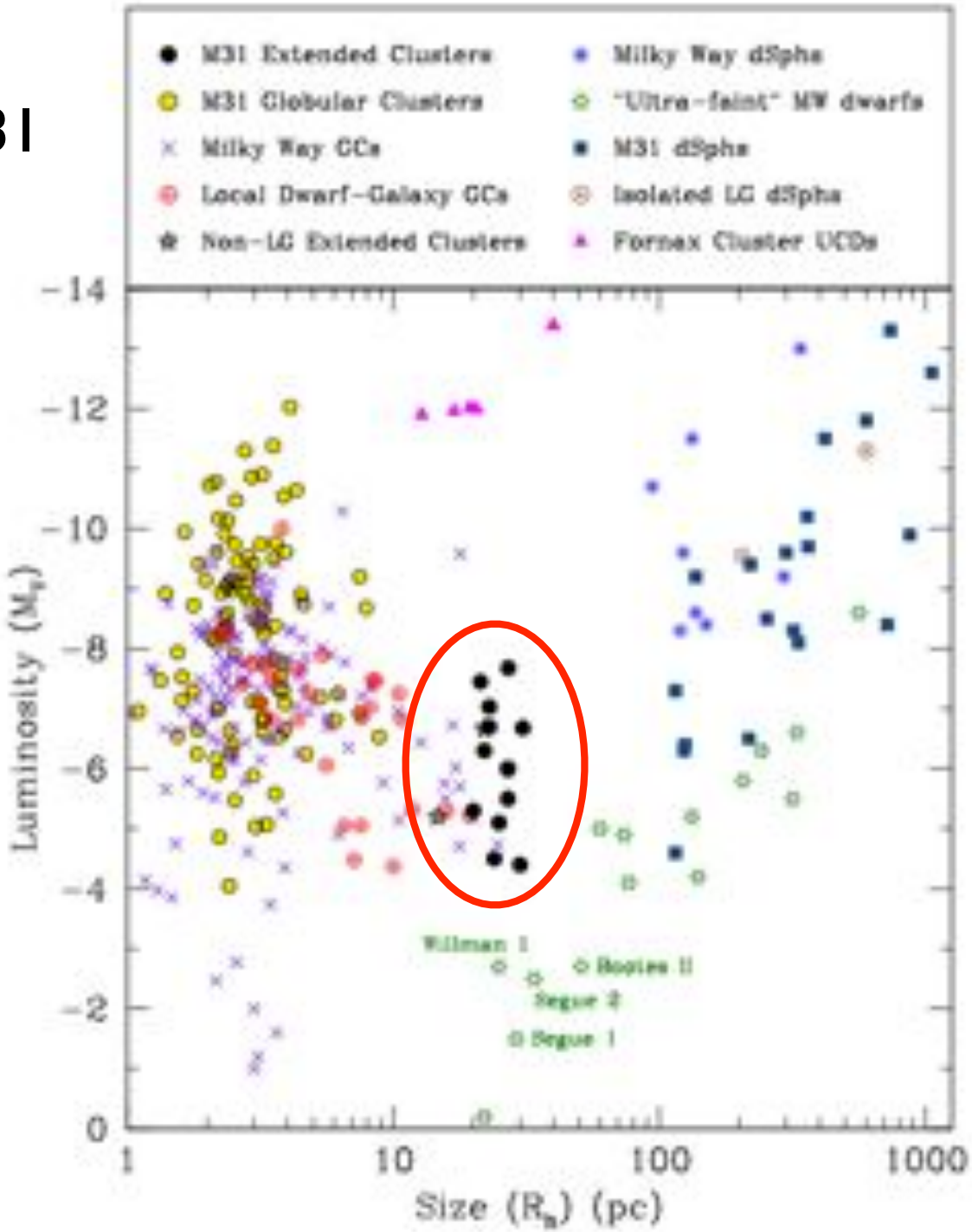


Larsen & Brodie (2000)

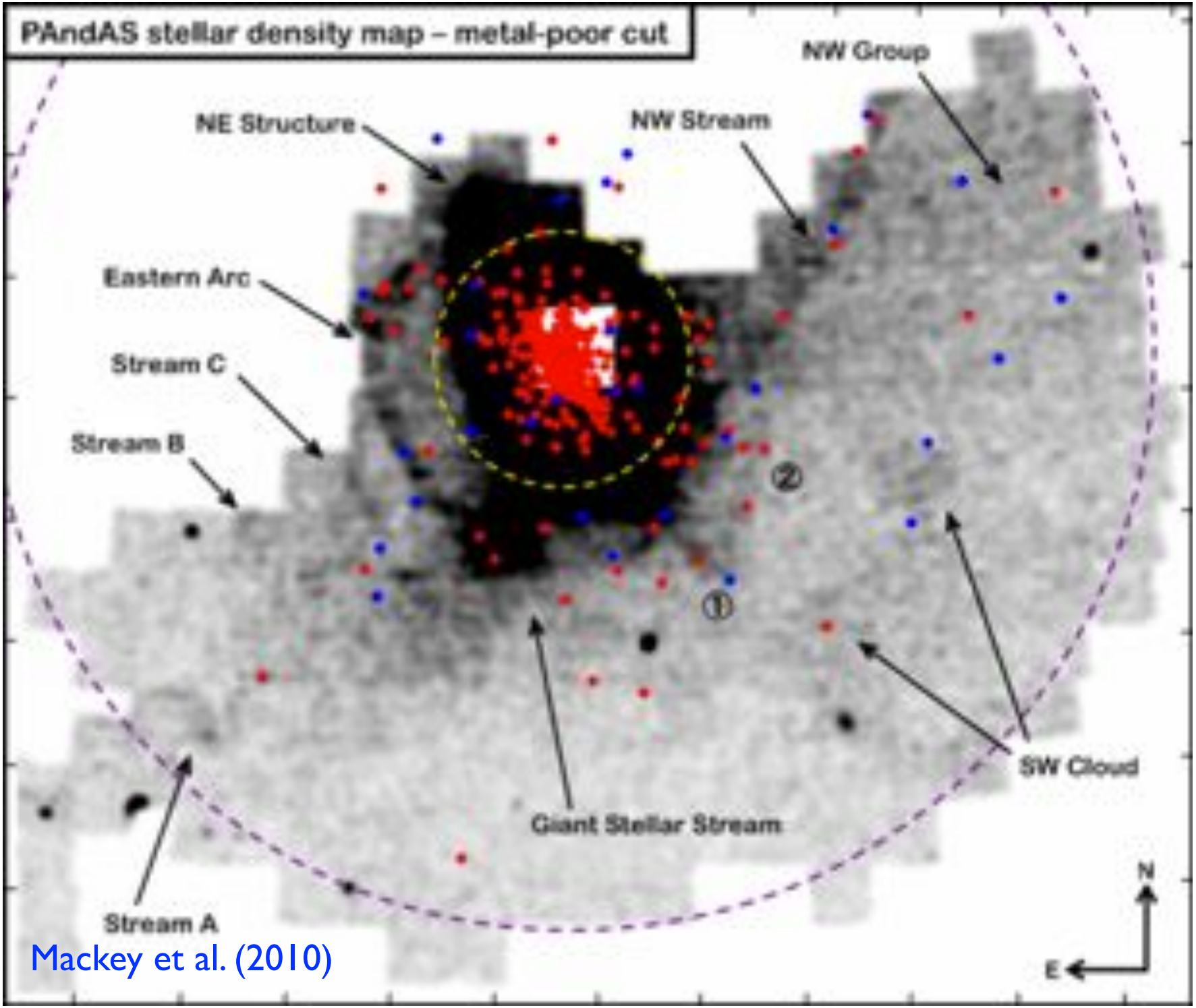
"Extended" clusters in M31

large: $r_{eff} \gtrsim 20$ pc

faint: $M_V \gtrsim -7$



Huxor et al. (2005, 2011)

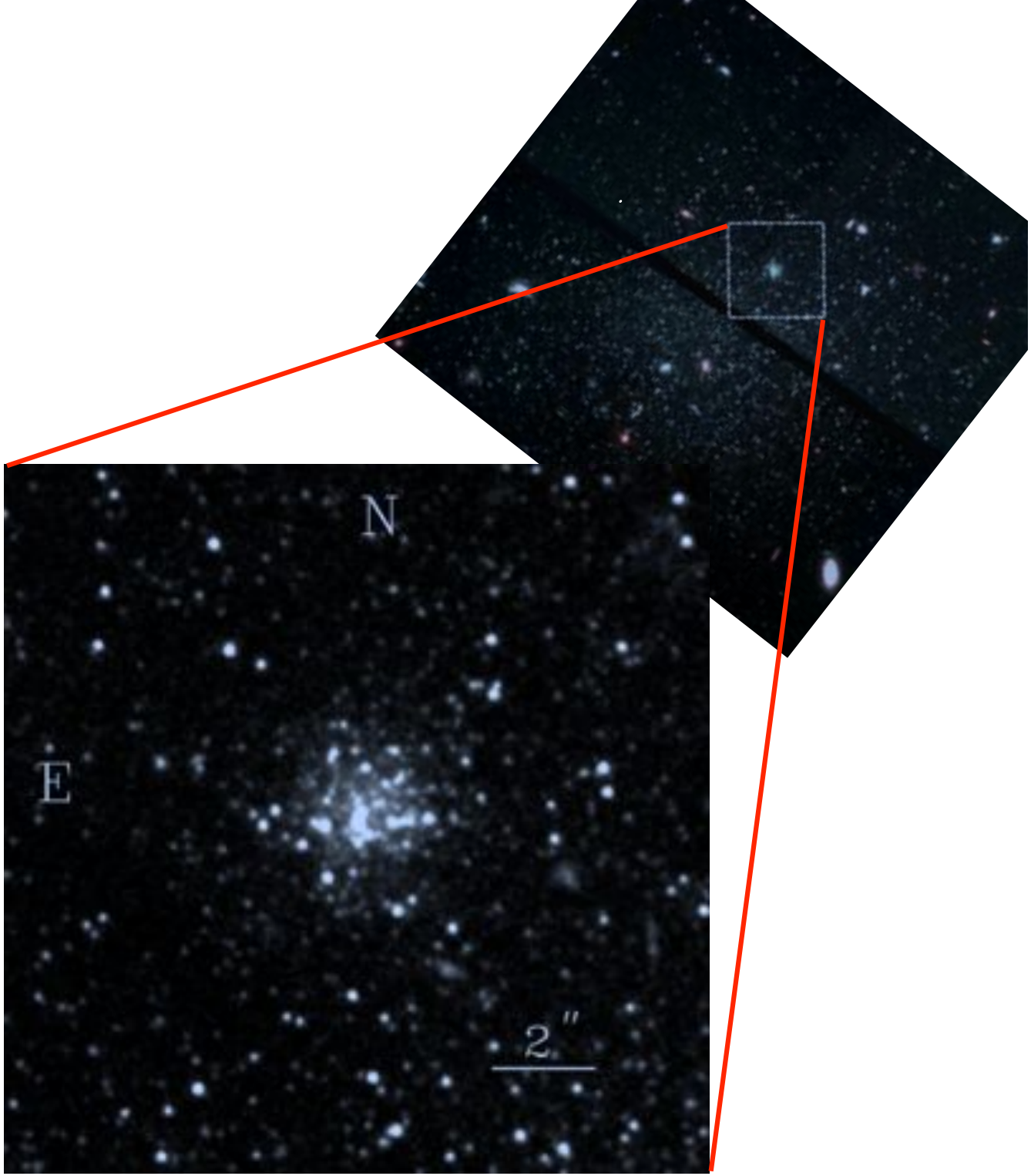


Mackey et al. (2010)

GC1 in Scl-dE1

large: $r_{eff} \simeq 20$ pc

faint: $M_V \simeq -6.7$



Da Costa et al. (2009)

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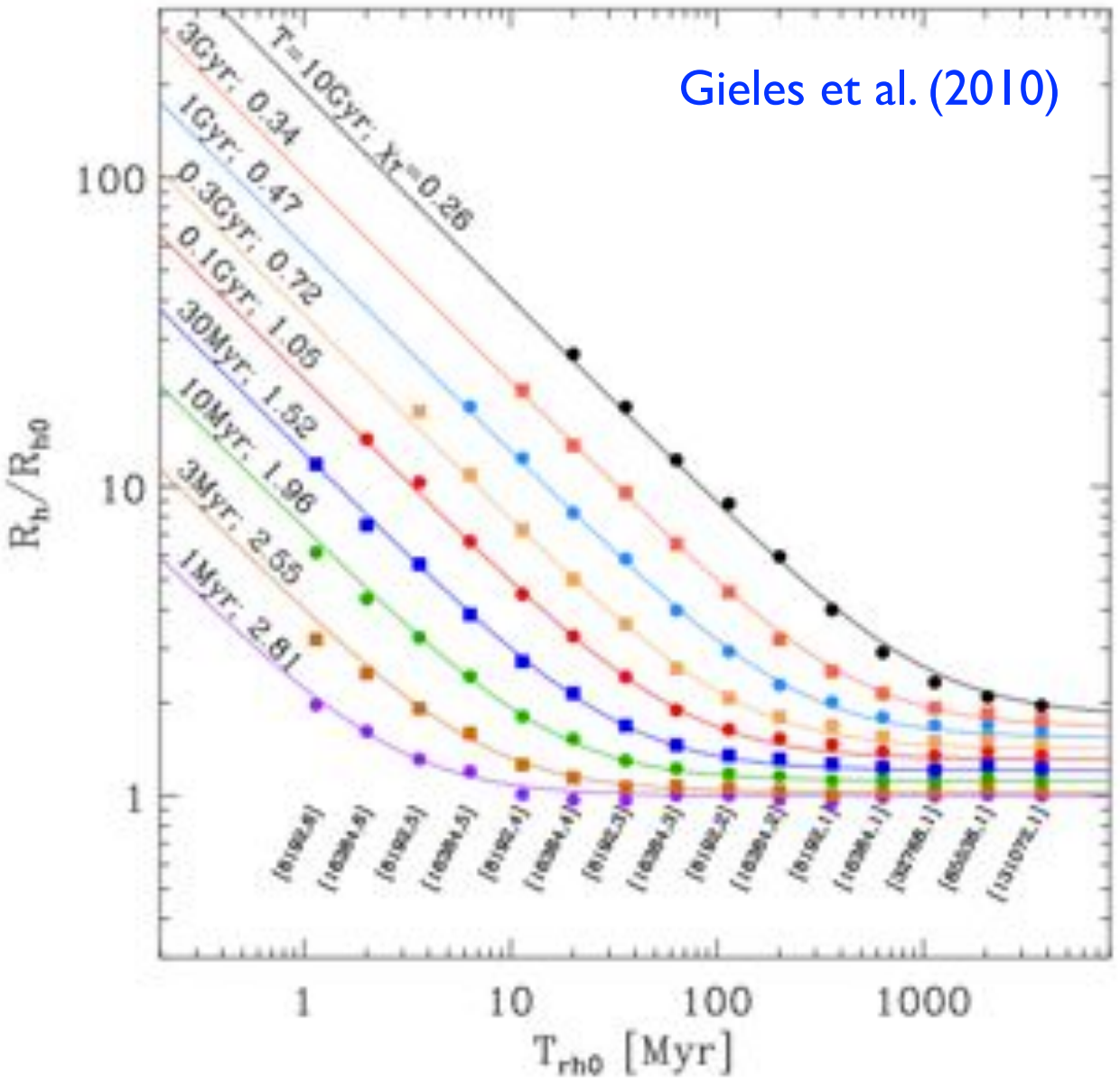
Fainter/fuzzier/more extended than ... ?

Scenarios

Direct *N*-body simulations of expanding clusters (relaxation)



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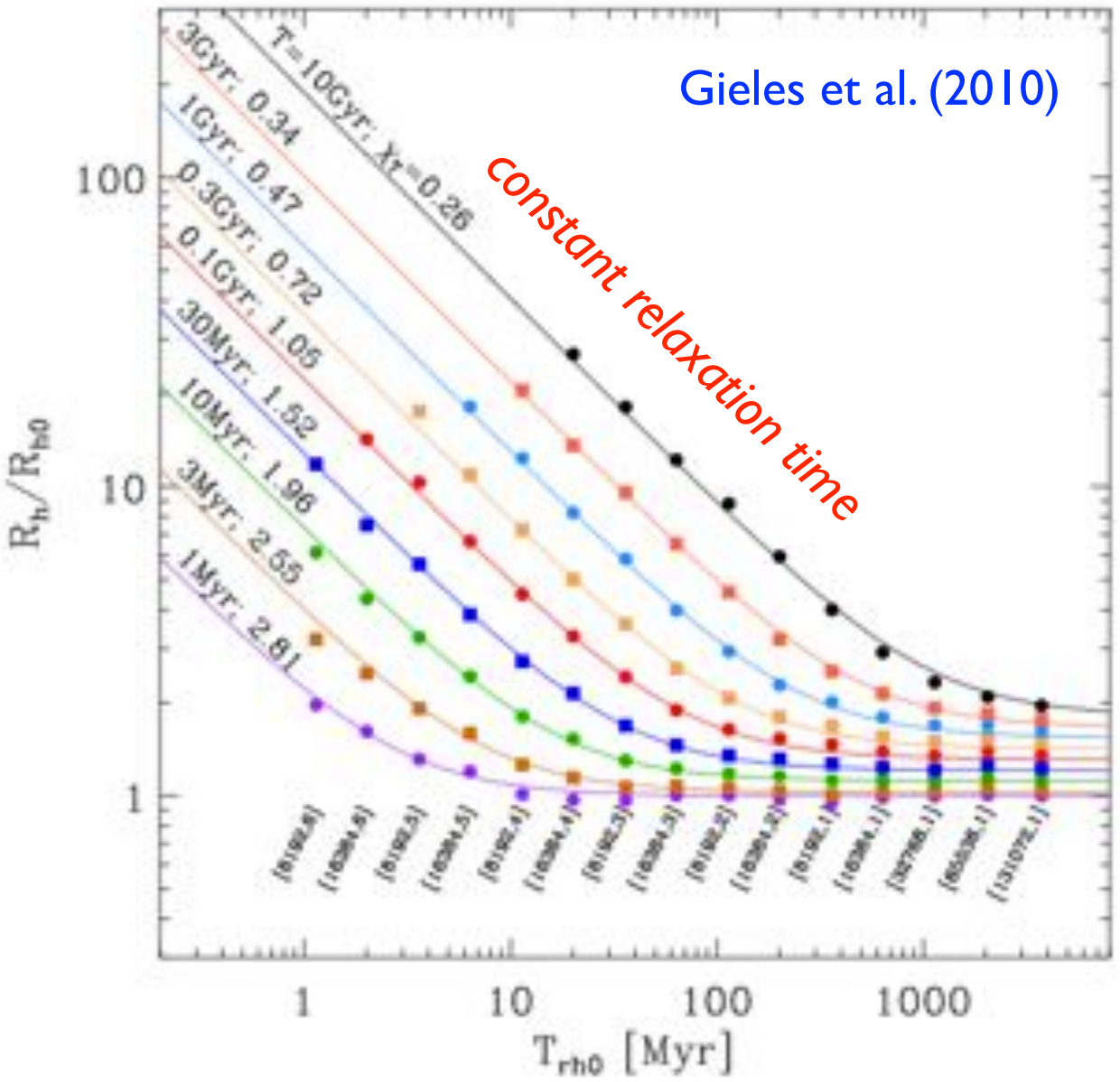
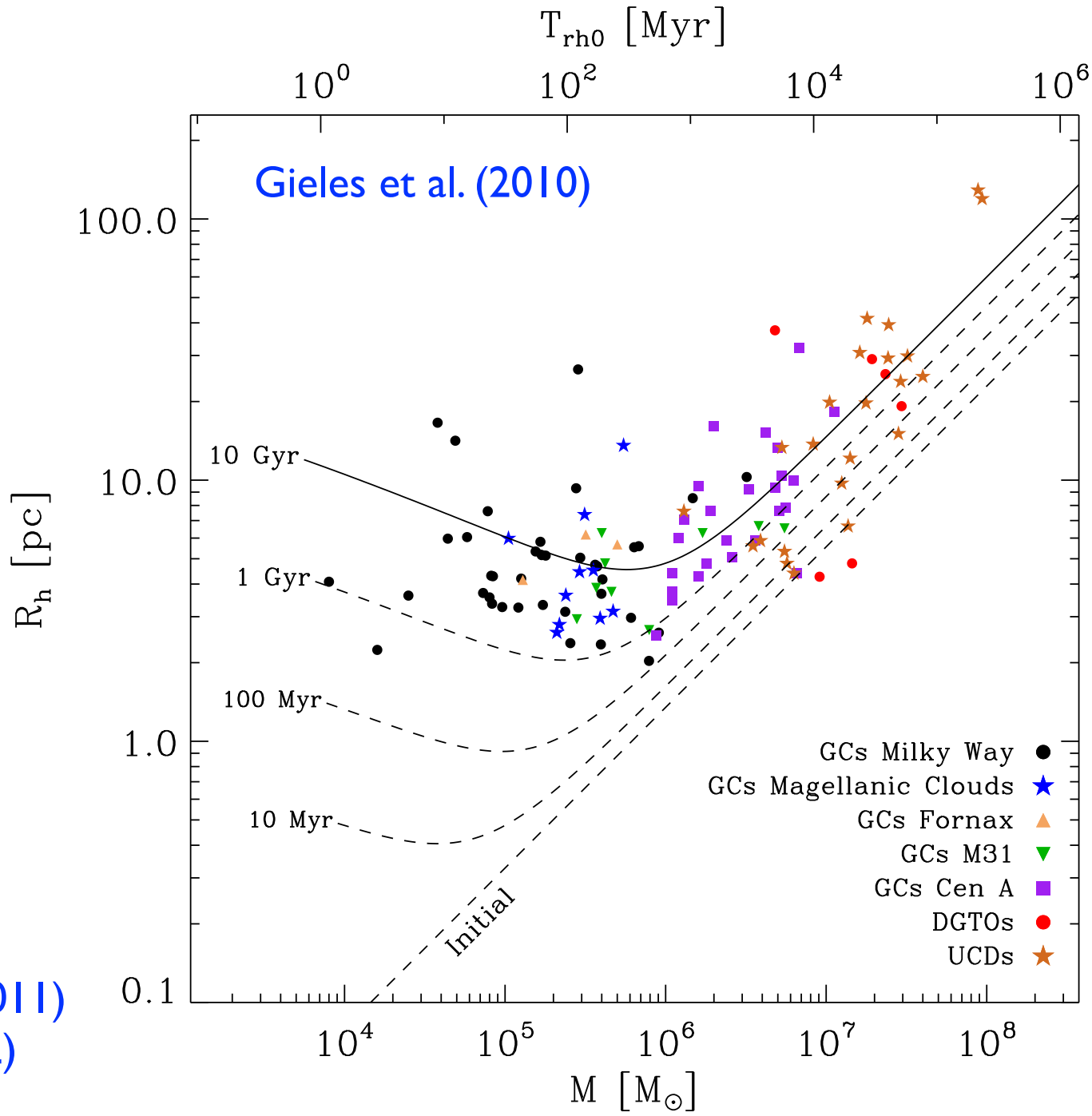
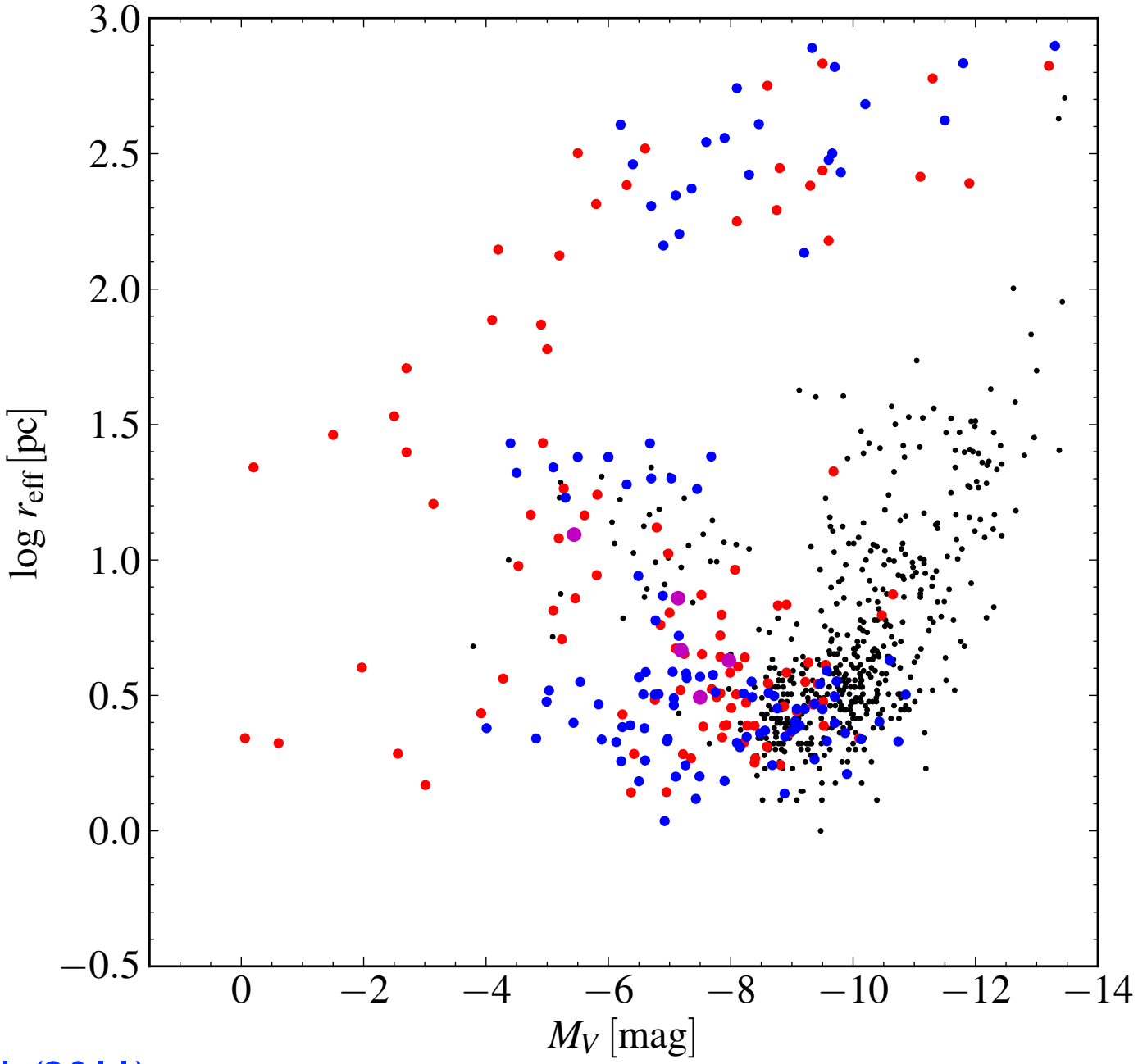
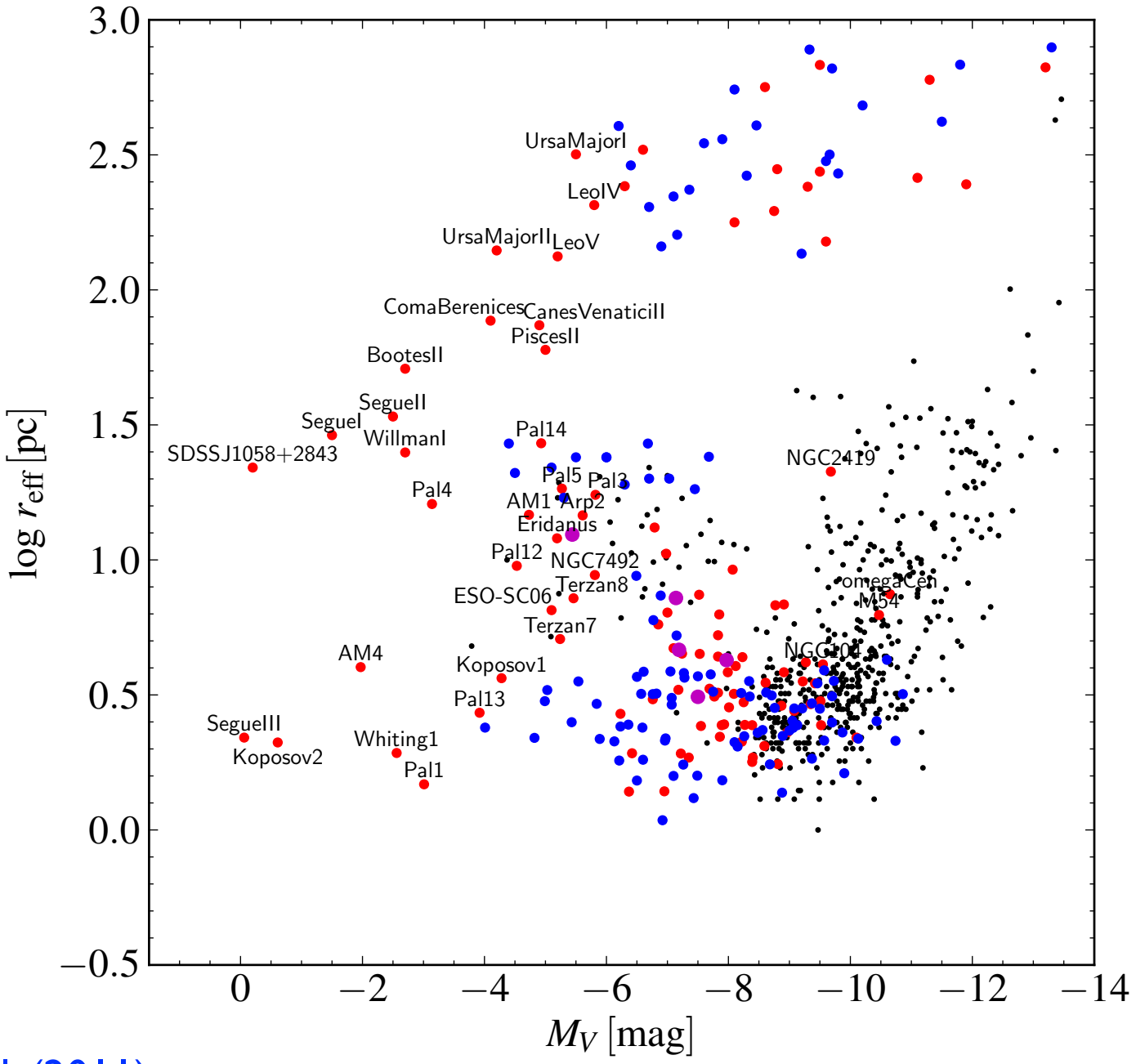




Models with tides:
Gieles, Heggie & Zhao (2011)
Alexander & Gieles (2012)



data from Brodie et al. (2011)



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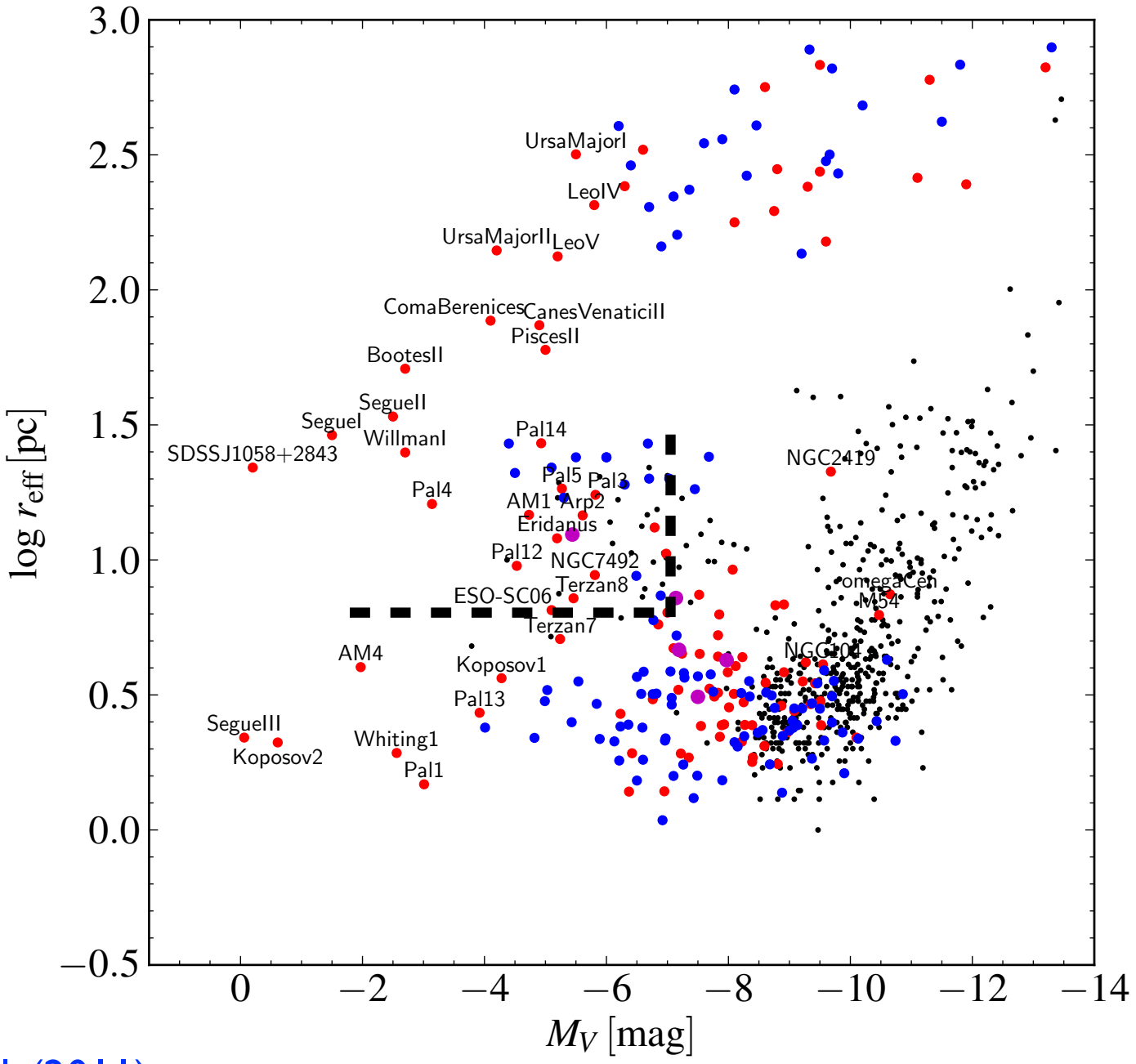

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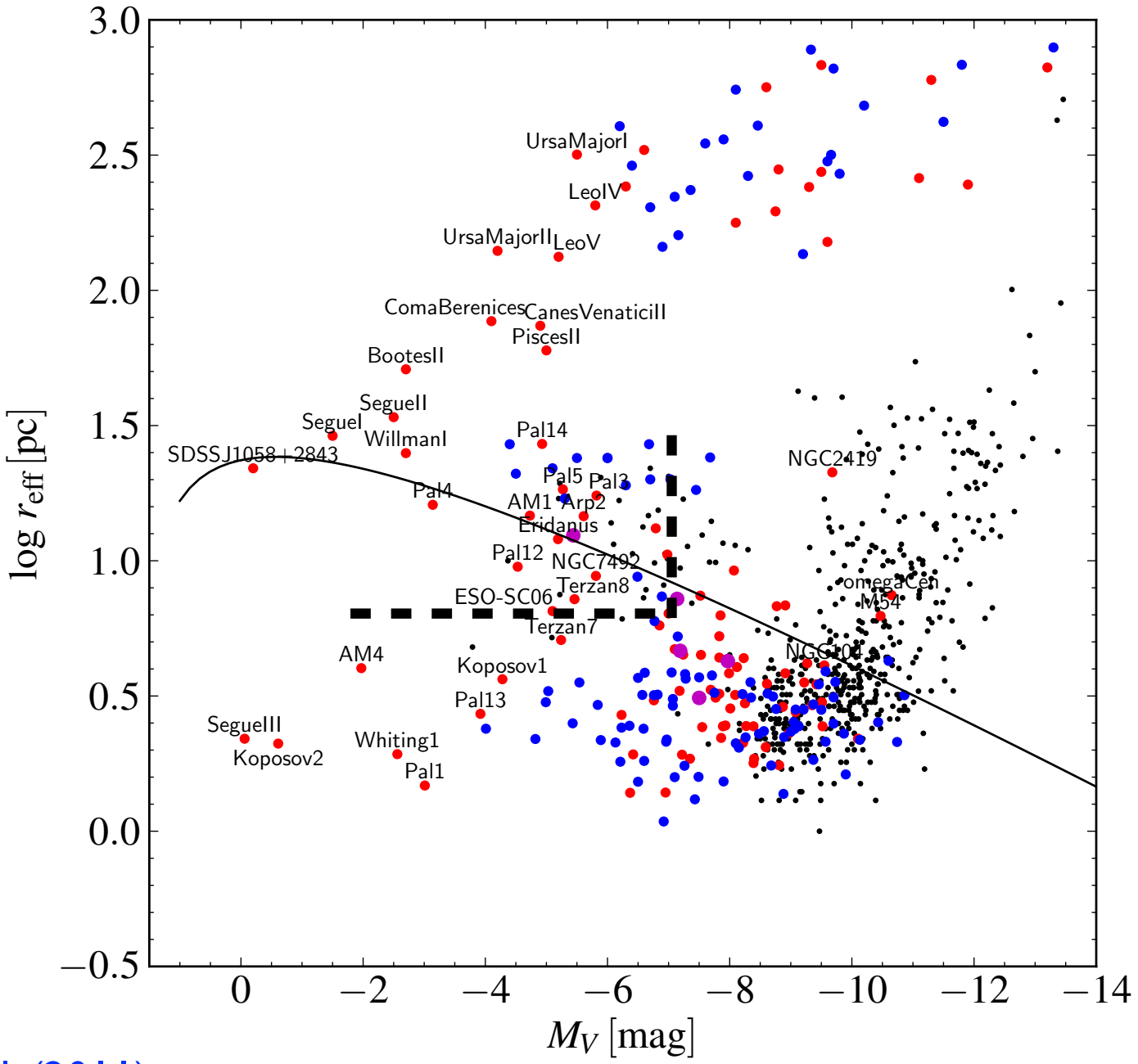

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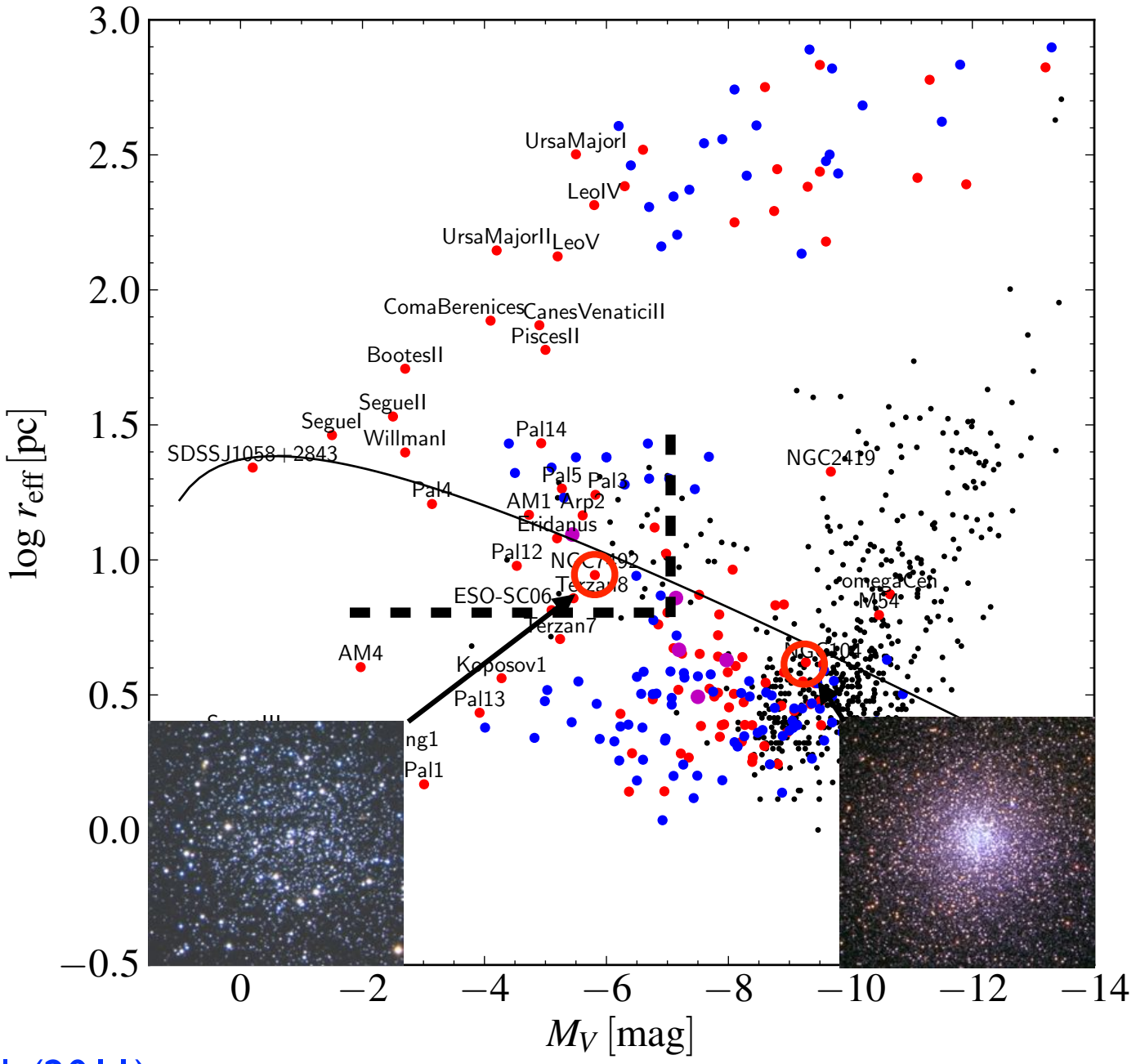

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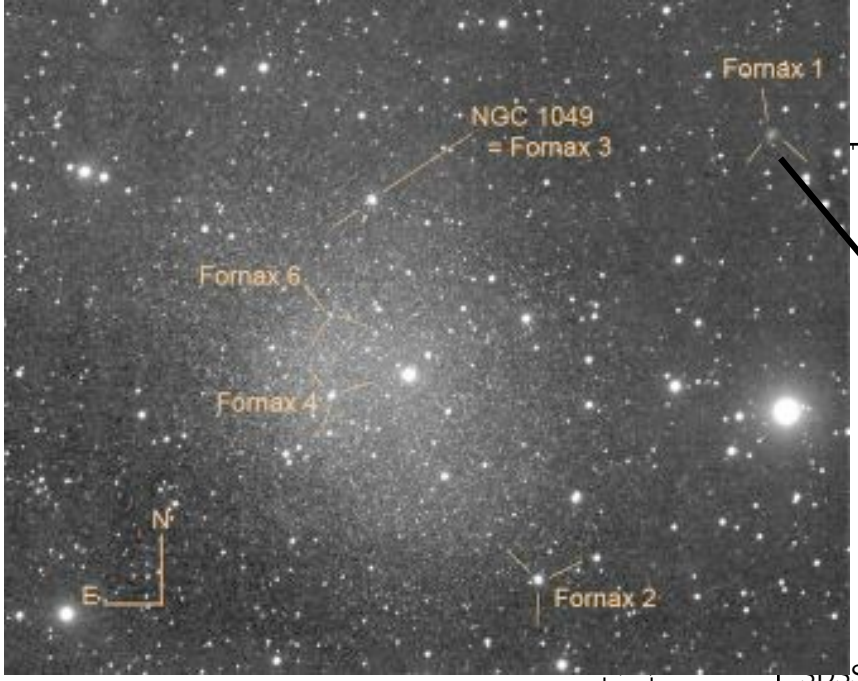

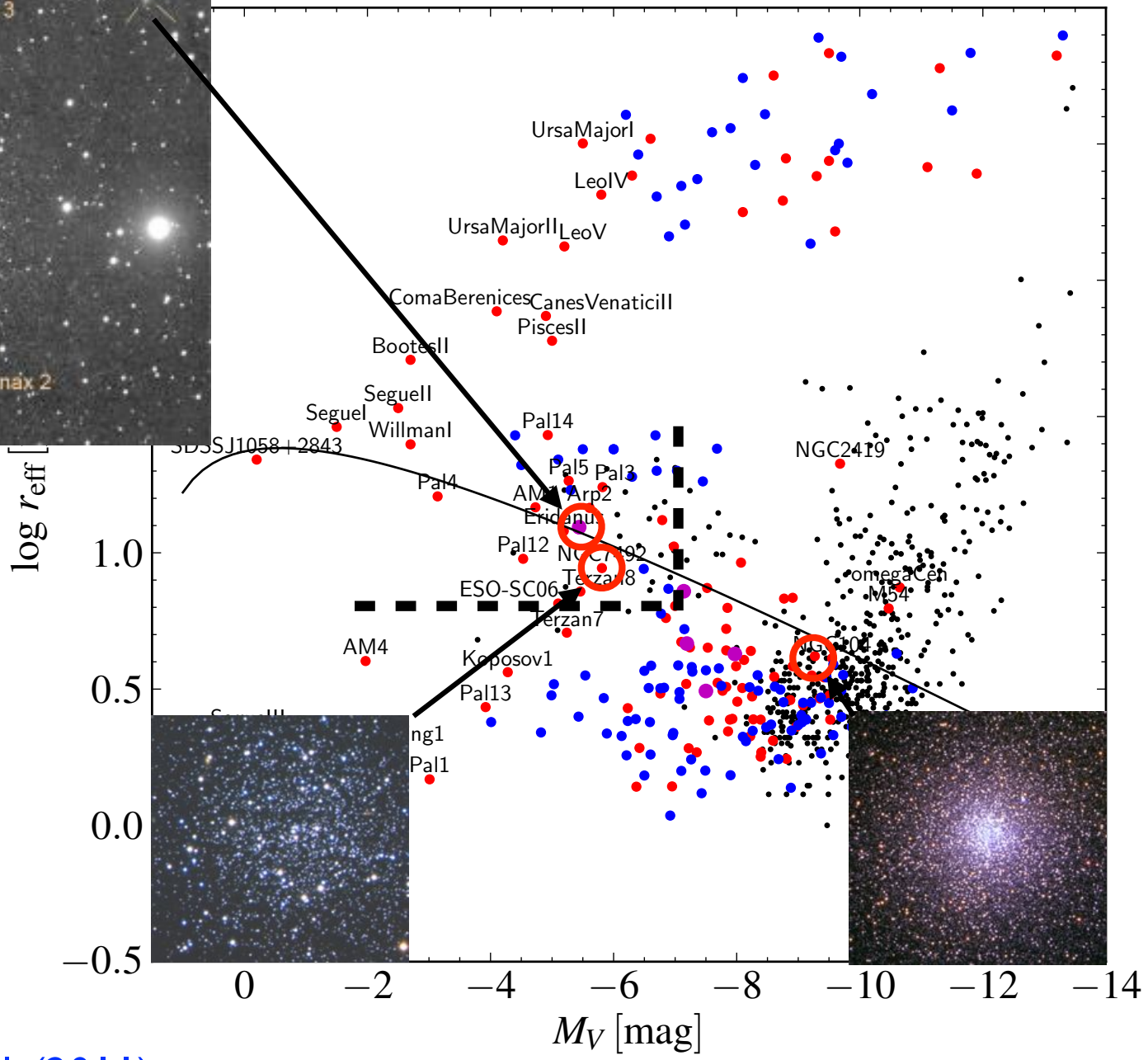

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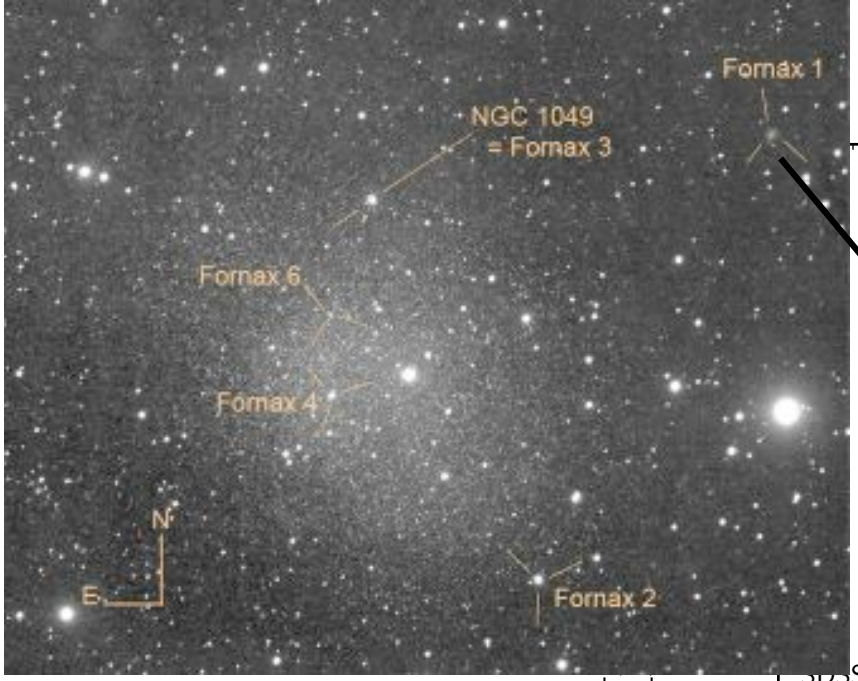

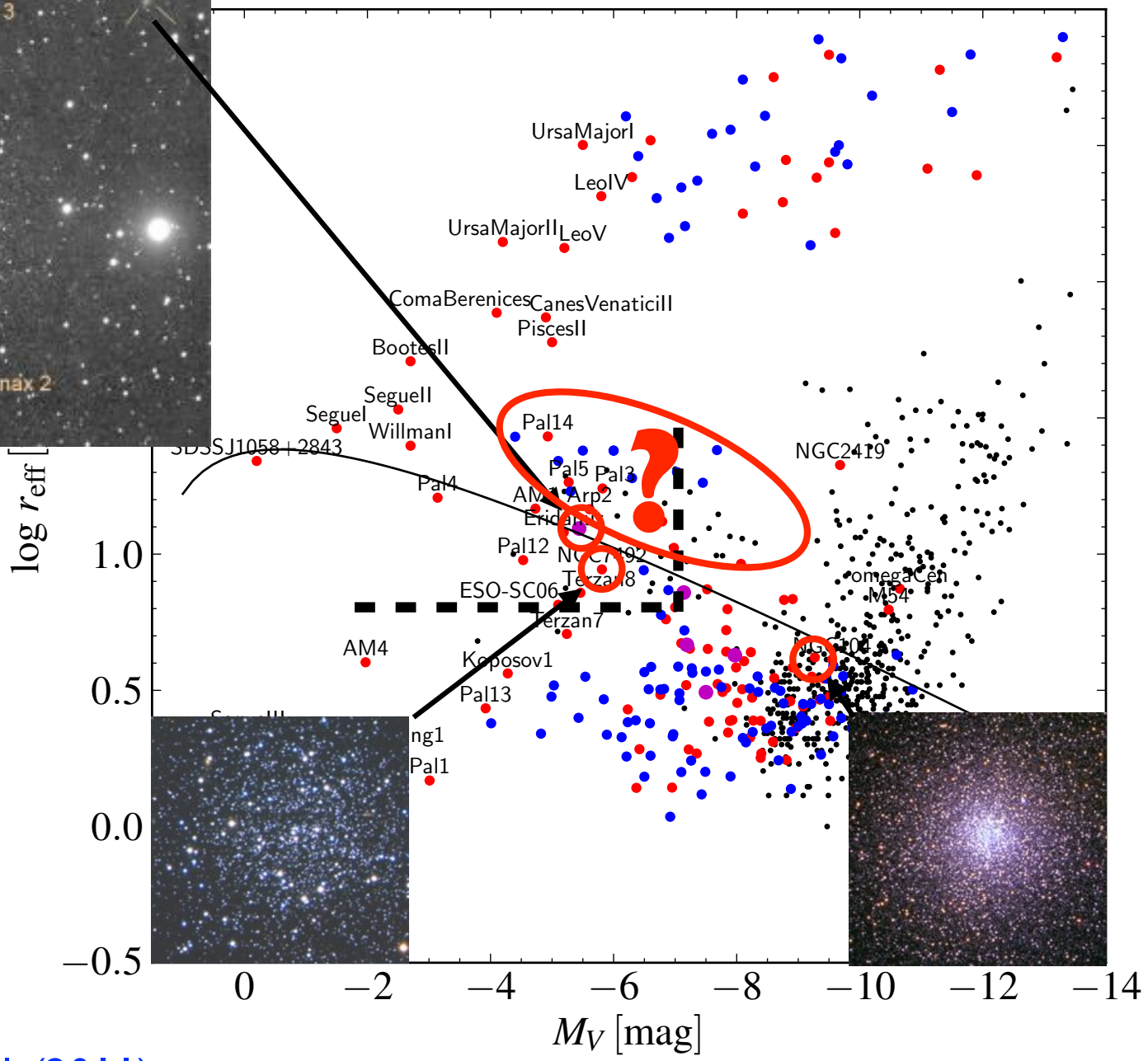

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“Faint fuzzy” and “extended” clusters

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Scenarios

Nature

Form in collisional ring galaxies (Cartwheel like interactions) (Burkert, Brodie & Larsen 2005)

Natural outcome of star formation at high pressure/Mach number (Elmegreen 2008)

Nurture

Star cluster mergers (Fellhauer & Kroupa 2005; Assman et al. 2011)

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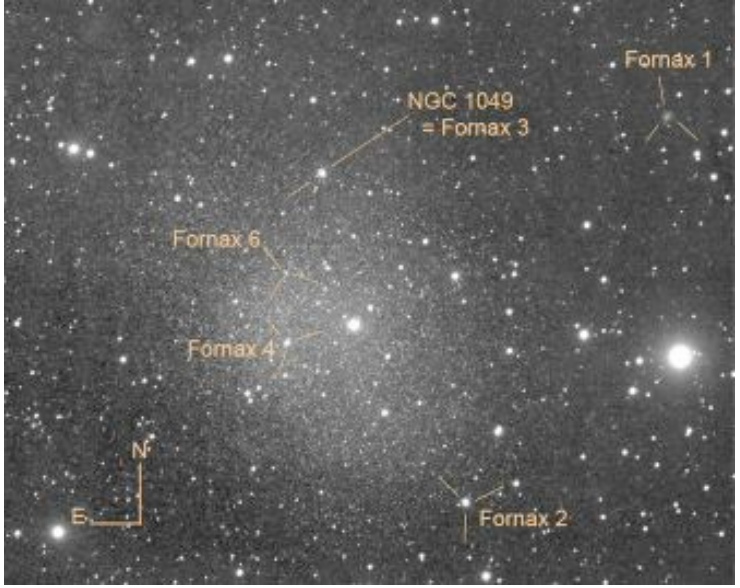
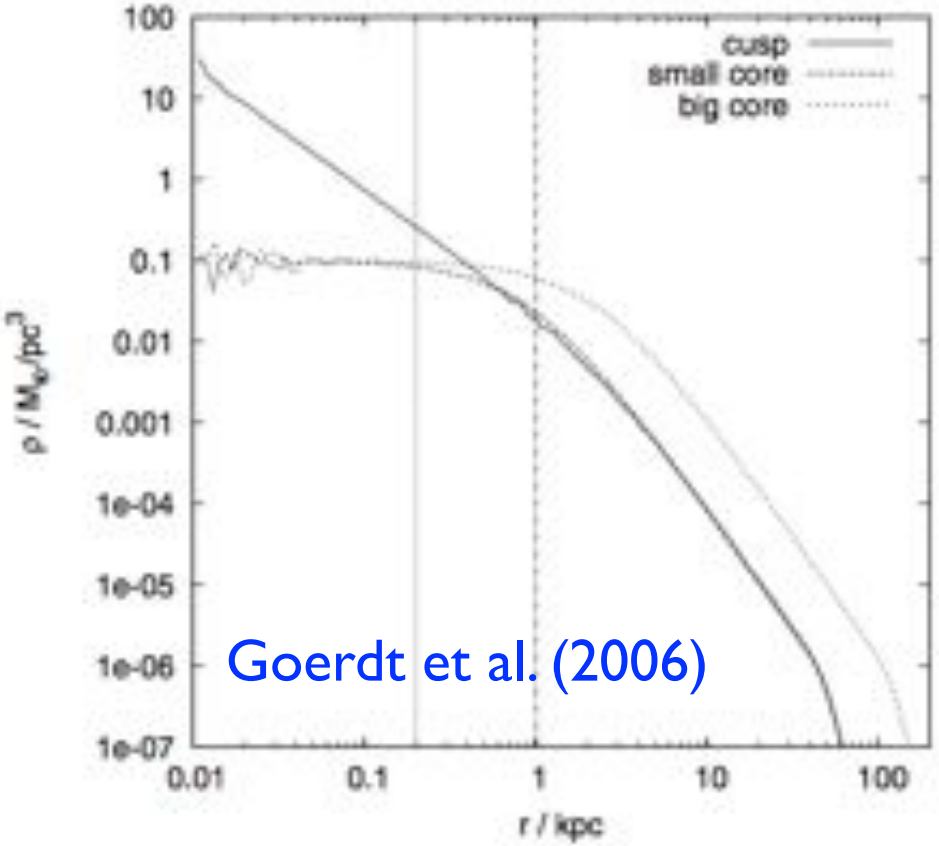
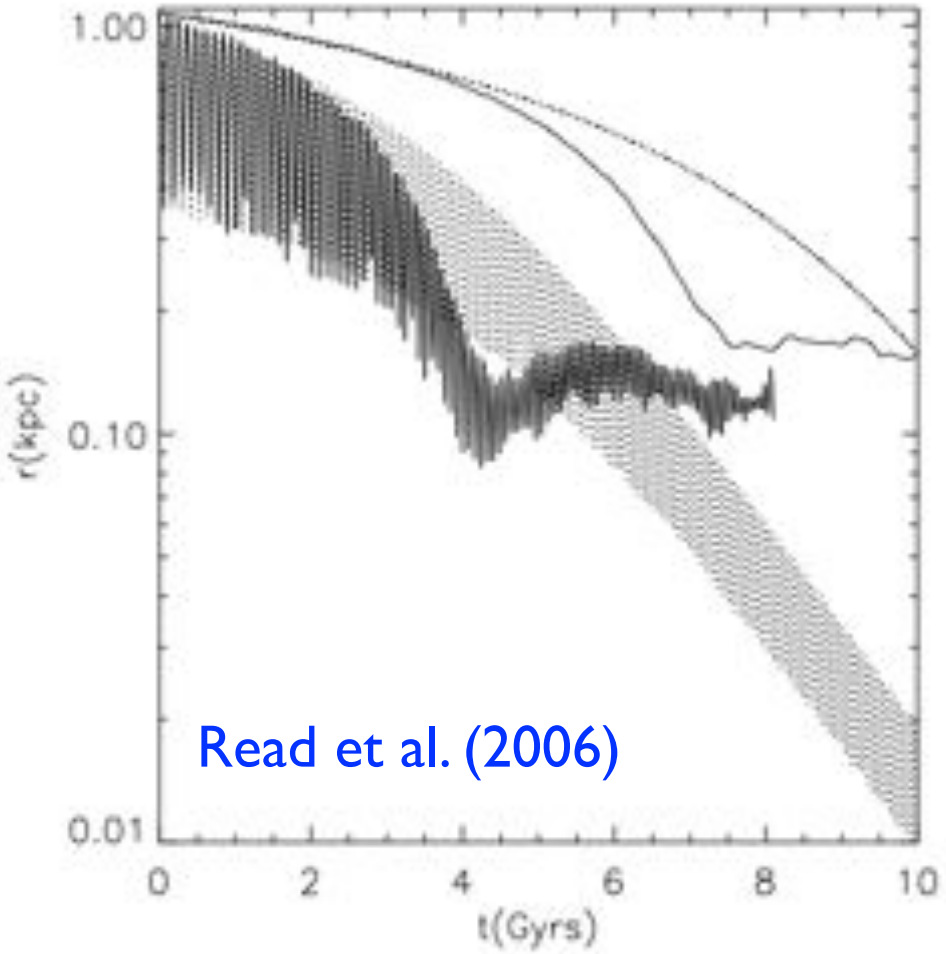
Are mergers between clusters expected?

How does the merger remnant evolve?



(No) dynamical friction in constant density cores of galaxies



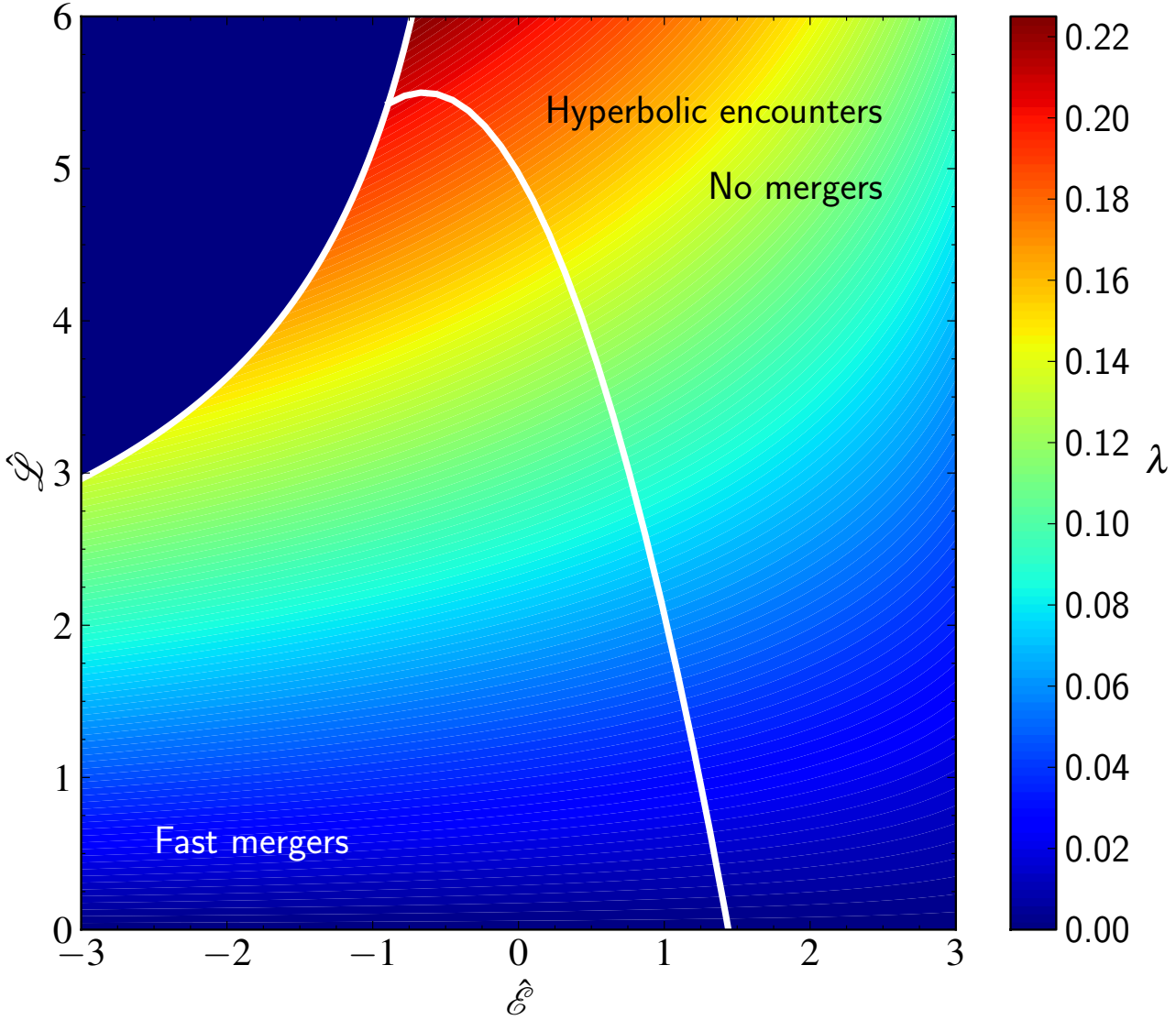


(Detection of cored mass profiles by Walker & Peñarrubia 2011)

Conditions for merging

$$\hat{\mathcal{L}} \equiv \frac{L_{\rm orb}}{r_{\rm h}\sigma}$$

$$\hat{\mathcal{E}} \equiv \frac{E_{\rm orb}}{0.5\sigma^2}$$



Gieles, Peñarrubia & Renaud (2012, in prep)

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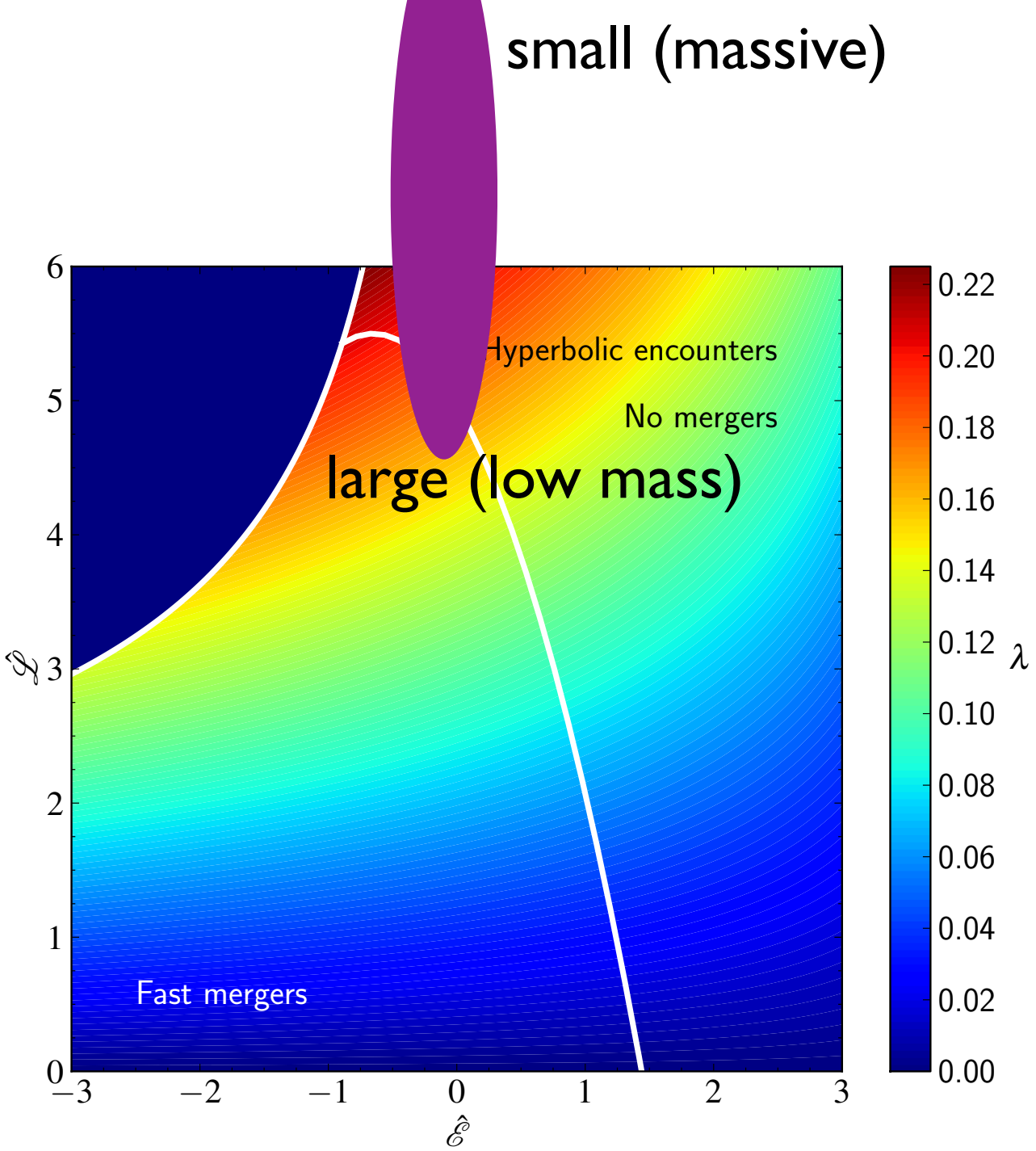


Gieles, Peñarrubia & Renaud (2012, in prep)

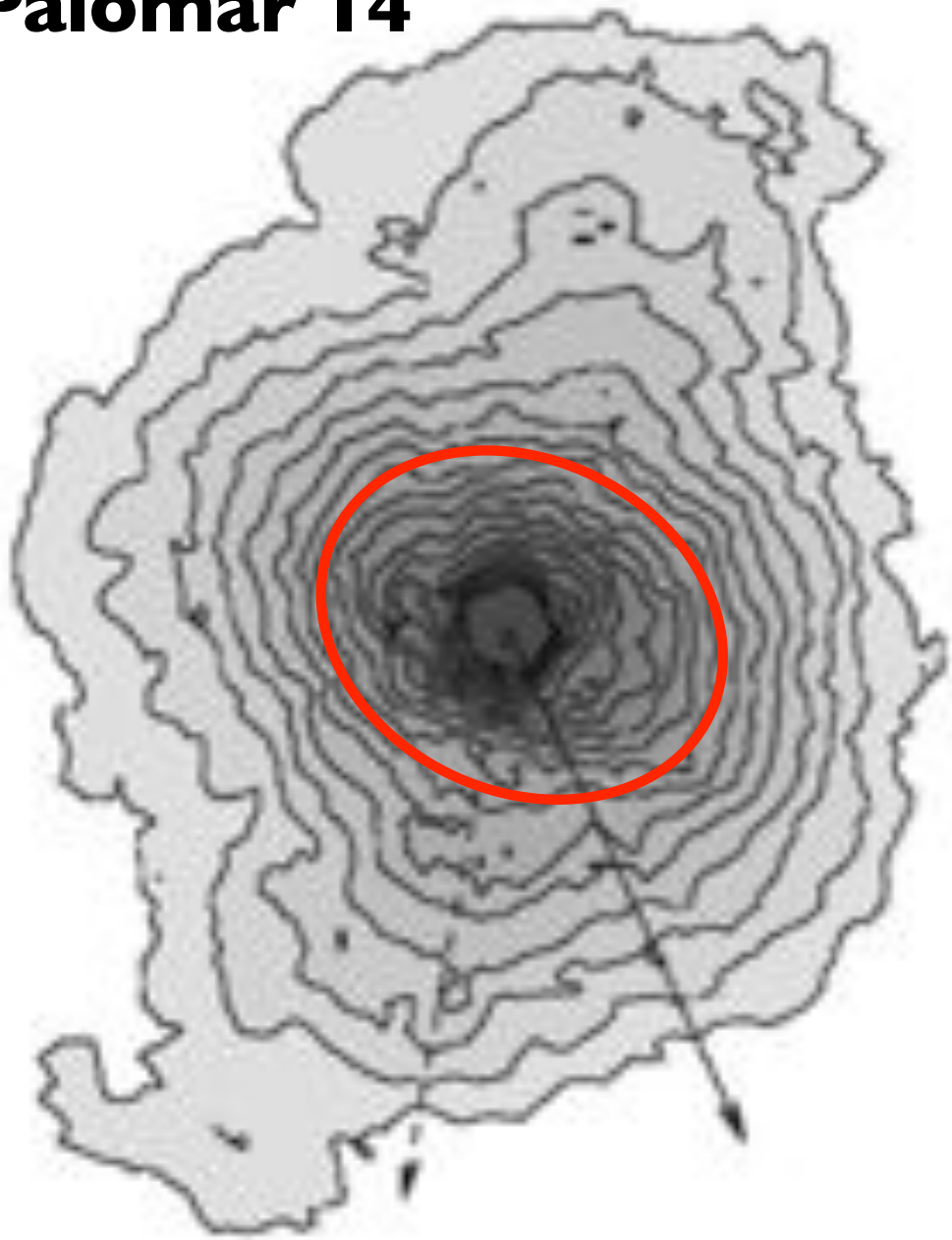
Palomar 14

Condition:

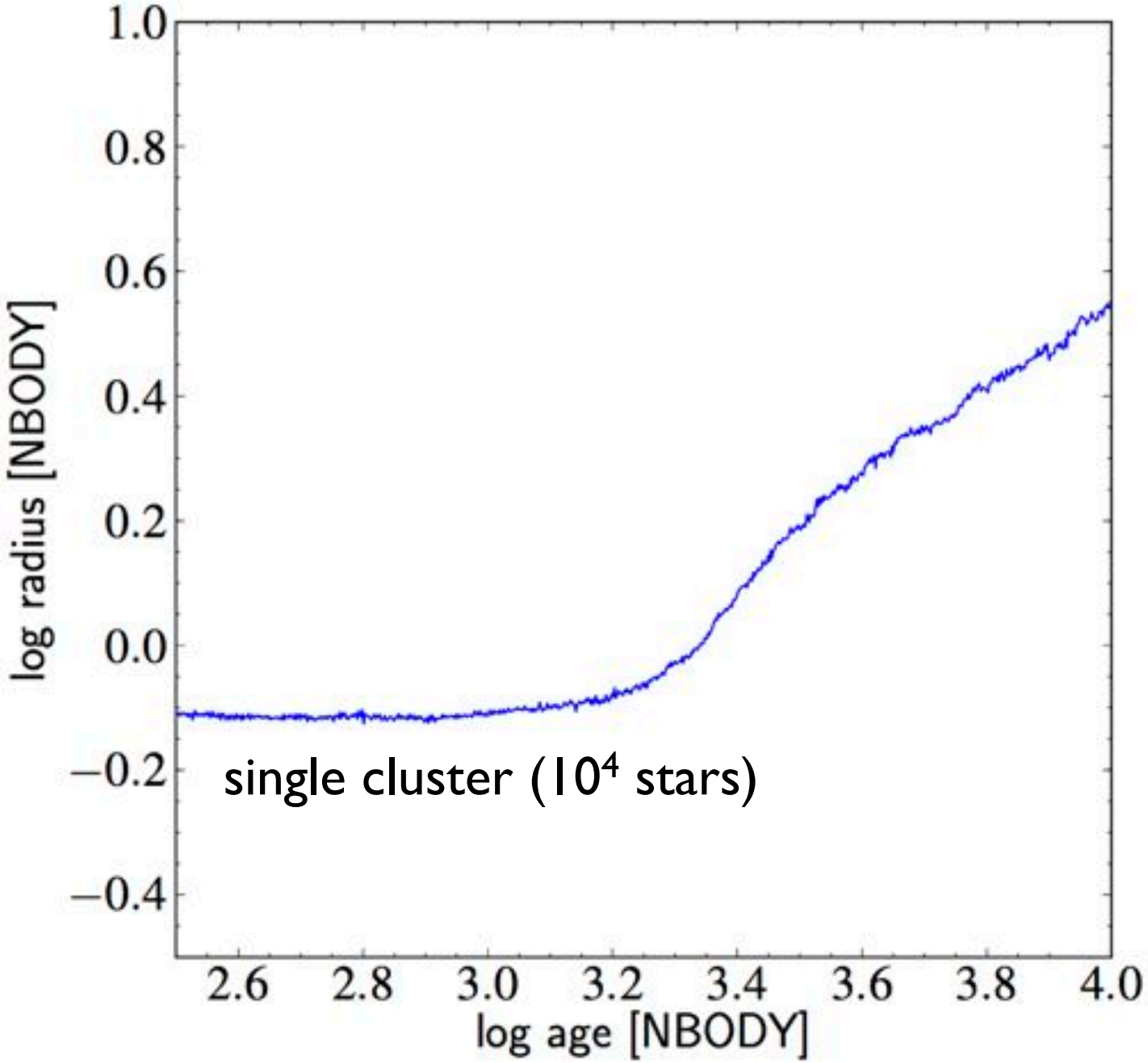
2 clusters in cored dwarf
massive enough to reach core by DF
large enough to absorb AM

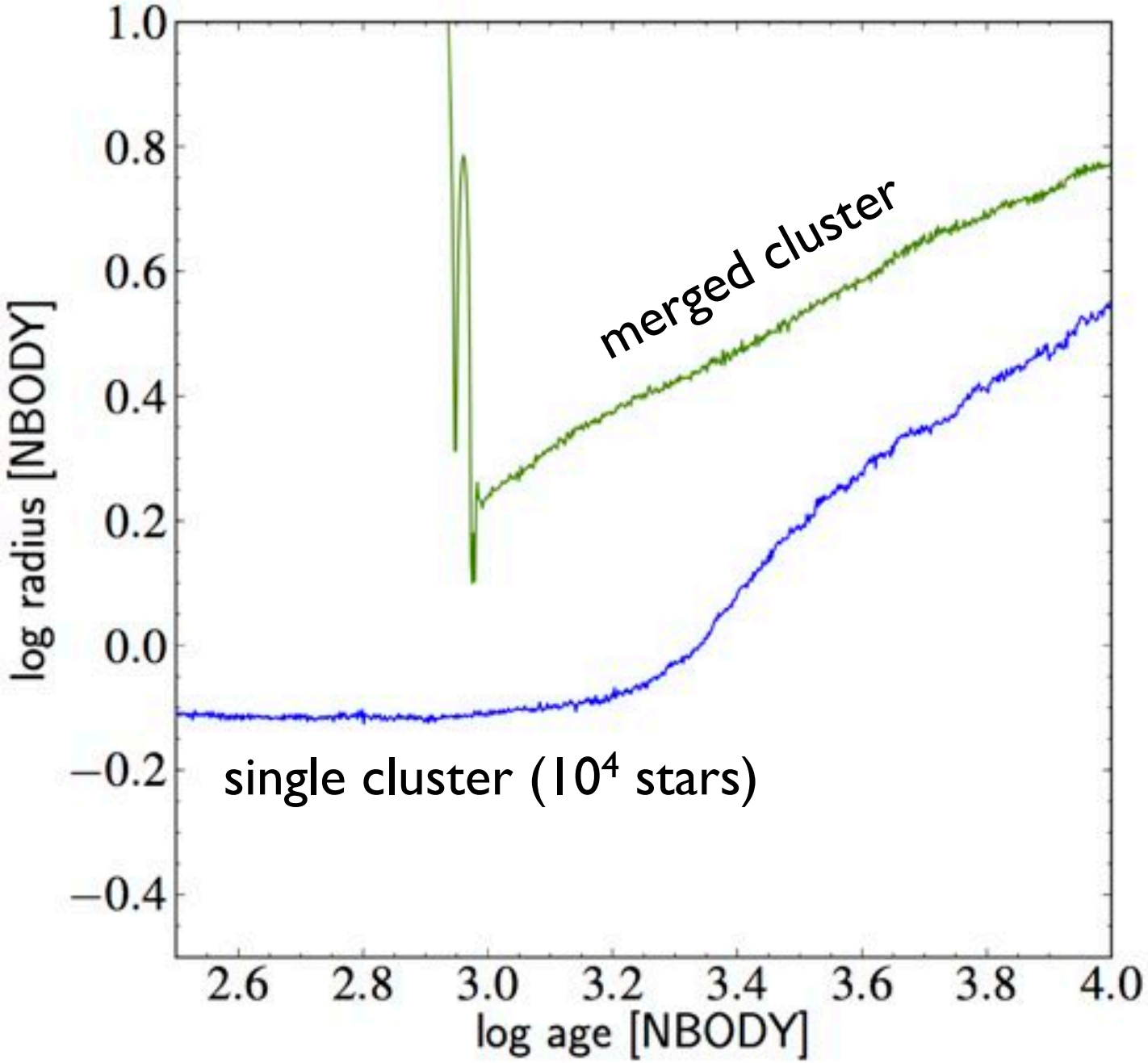
Prediction:

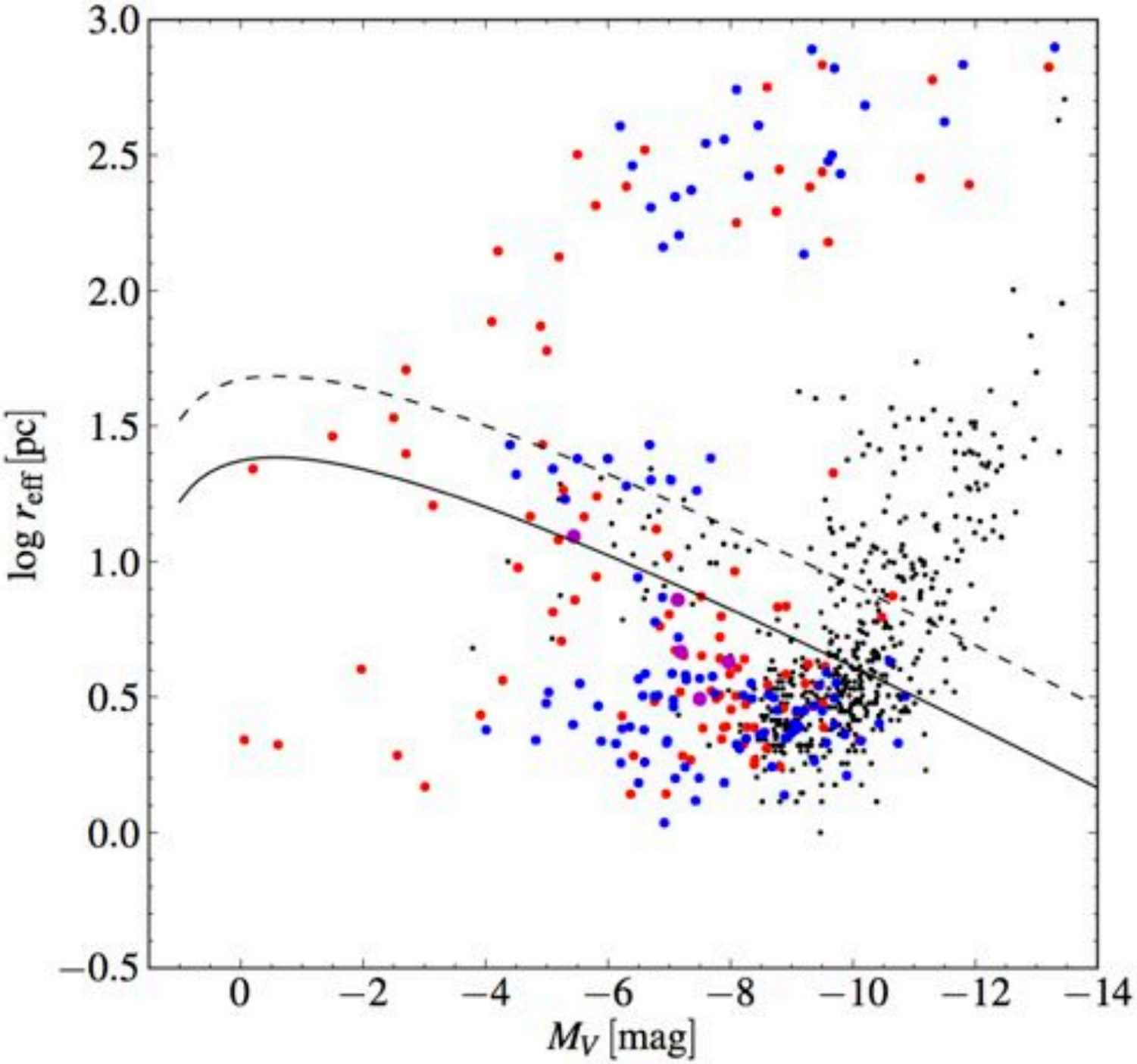
Rotation and flattening



(Sollima et al. 2011)


1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
log radius [NBODY]
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
log age [NBODY]
single cluster (10^4 stars)


1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
log radius [NBODY]
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
log age [NBODY]
merged cluster
single cluster (10^4 stars)


3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
log $r_{\rm eff}$ [pc]
0
−2
−4
−6
−8
−10
−12
−14
M_V [mag]

"Faint fuzzy"/"extended" when fainter/fuzzier or more extended than: $\left(\frac{M}{10^5\,M_\odot}\right)\left(\frac{r_{\rm eff}}{7\,{\rm pc}}\right)^3 \gtrsim 1$

Mergers in (**cored**) dwarf galaxies can account for an additional factor of 2 in size

Look at structure: flattening (rotation=hard!)