Uniformity of Star and Cluster Formation Across Extreme Environments

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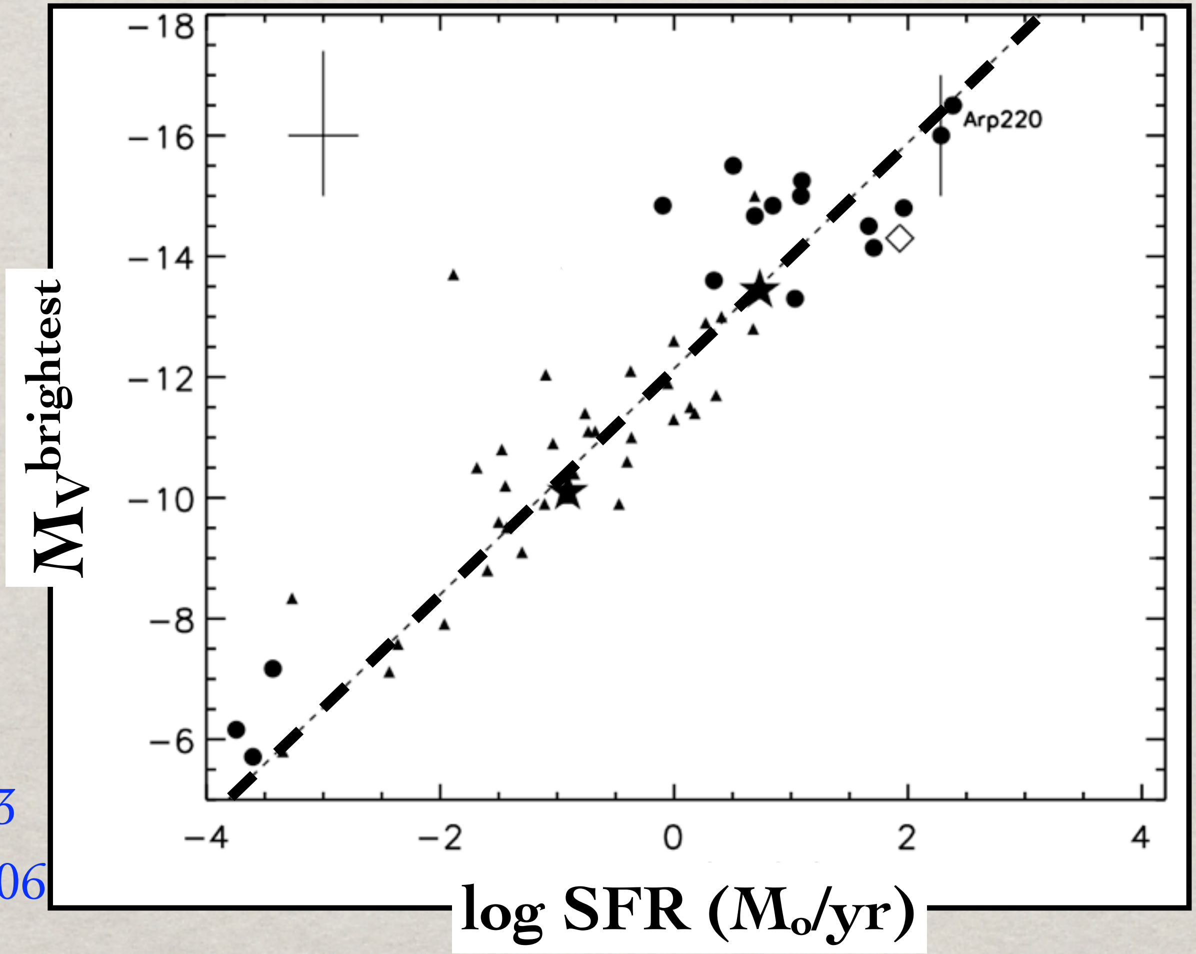
Outline

- Size of sample effects
- Does cluster formation accurately reflect star formation?
- Do all stars form in "clusters"?
- Does star/cluster formation depend on environment?
- Constrain cluster disruption models?

Cluster/Star formation Relation



Larsen 2002

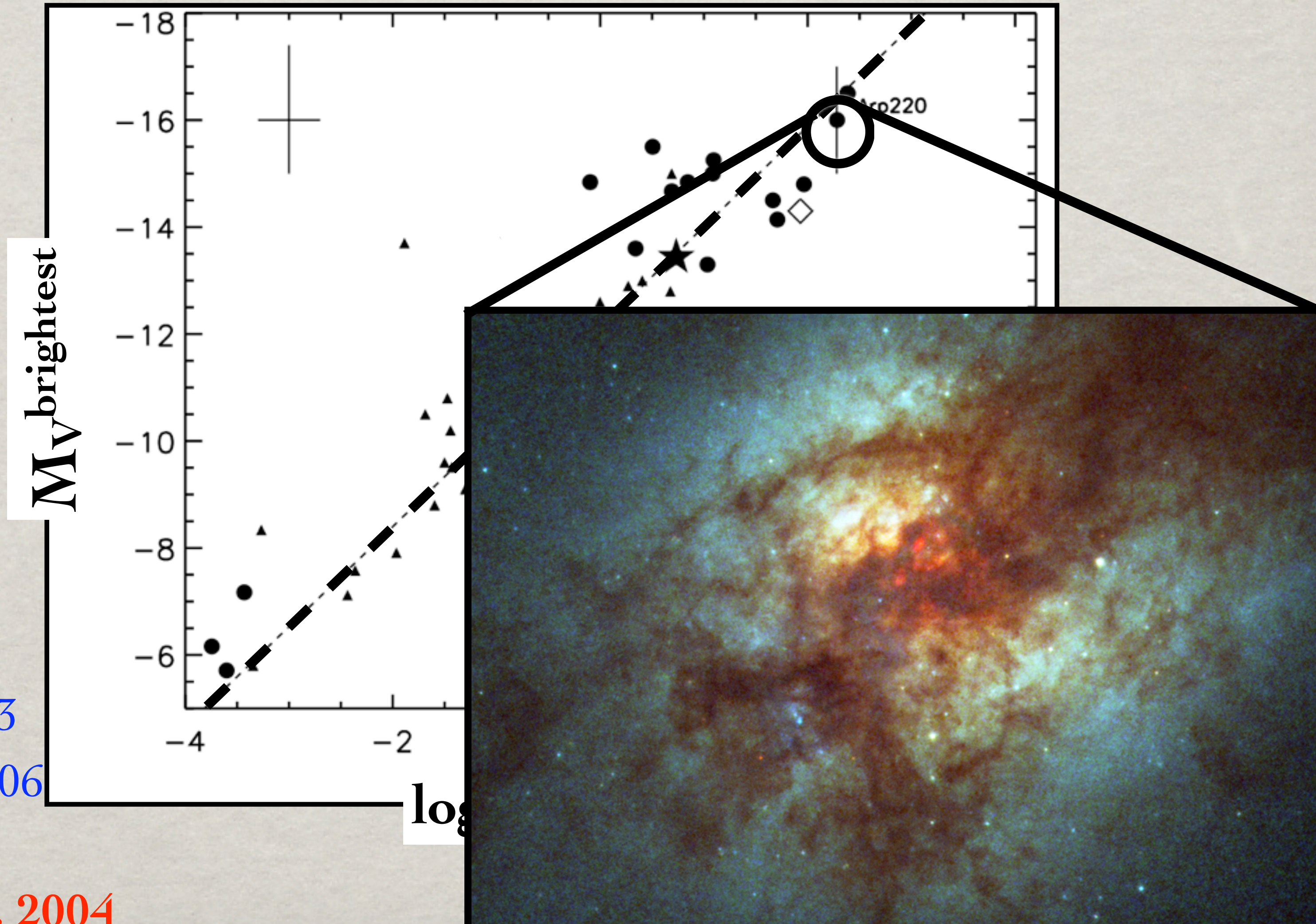
Whitmore 2003

Gieles et al. 2006

Bastian 2008

Weidner et al. 2004

Cluster/Star formation Relation



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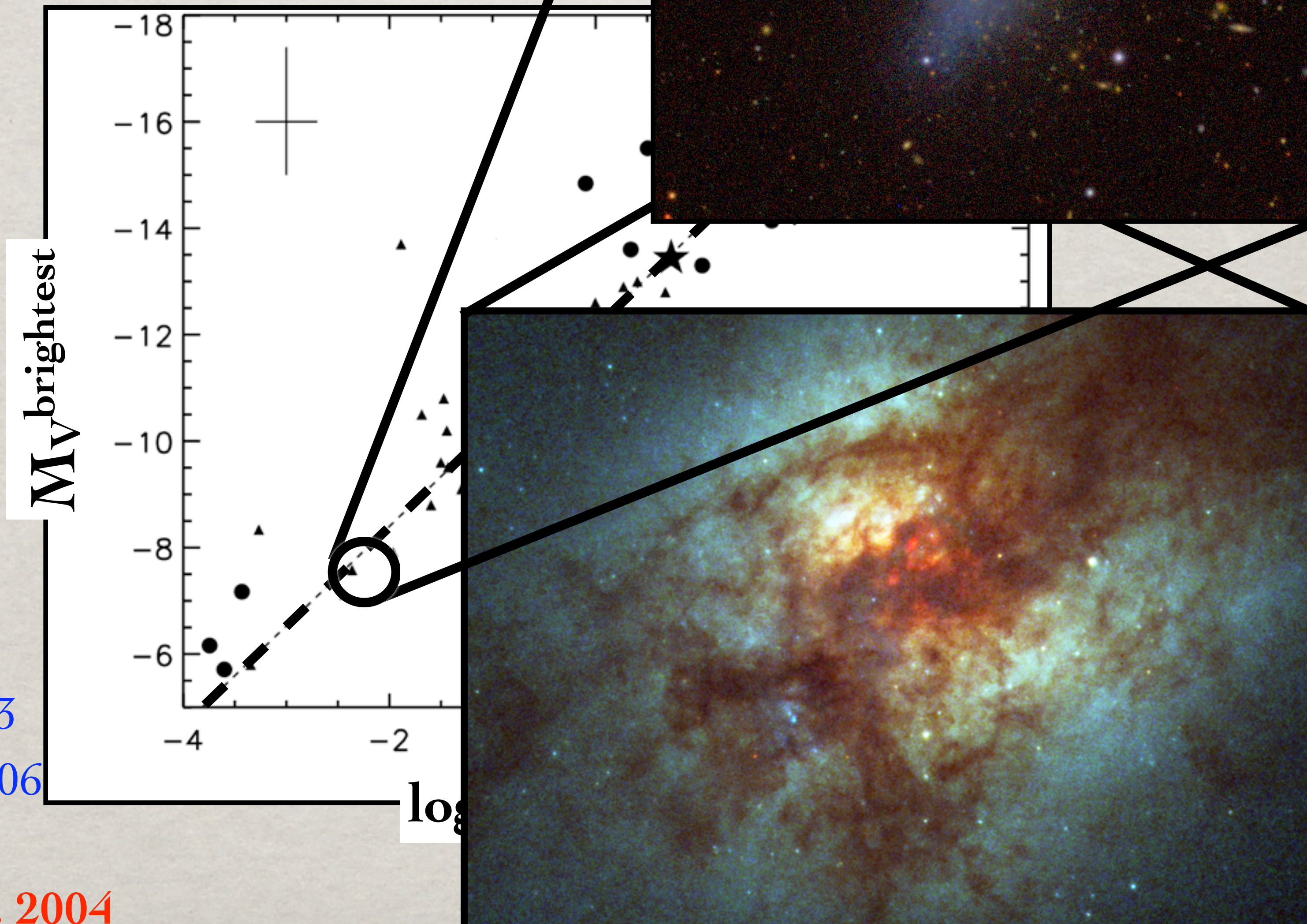
Wilson et al. 2006

CLUSTER/STAR F
RELATIO



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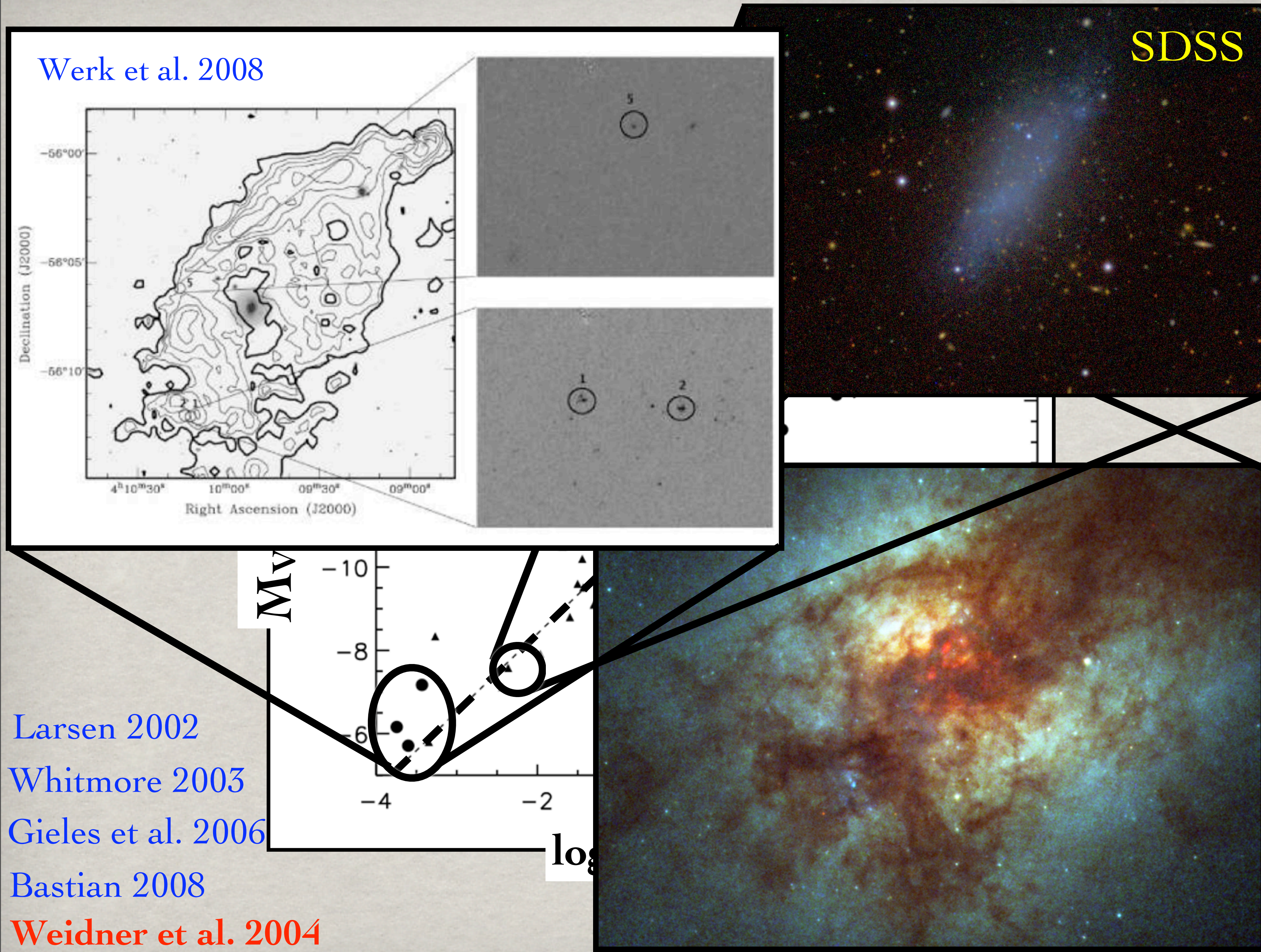
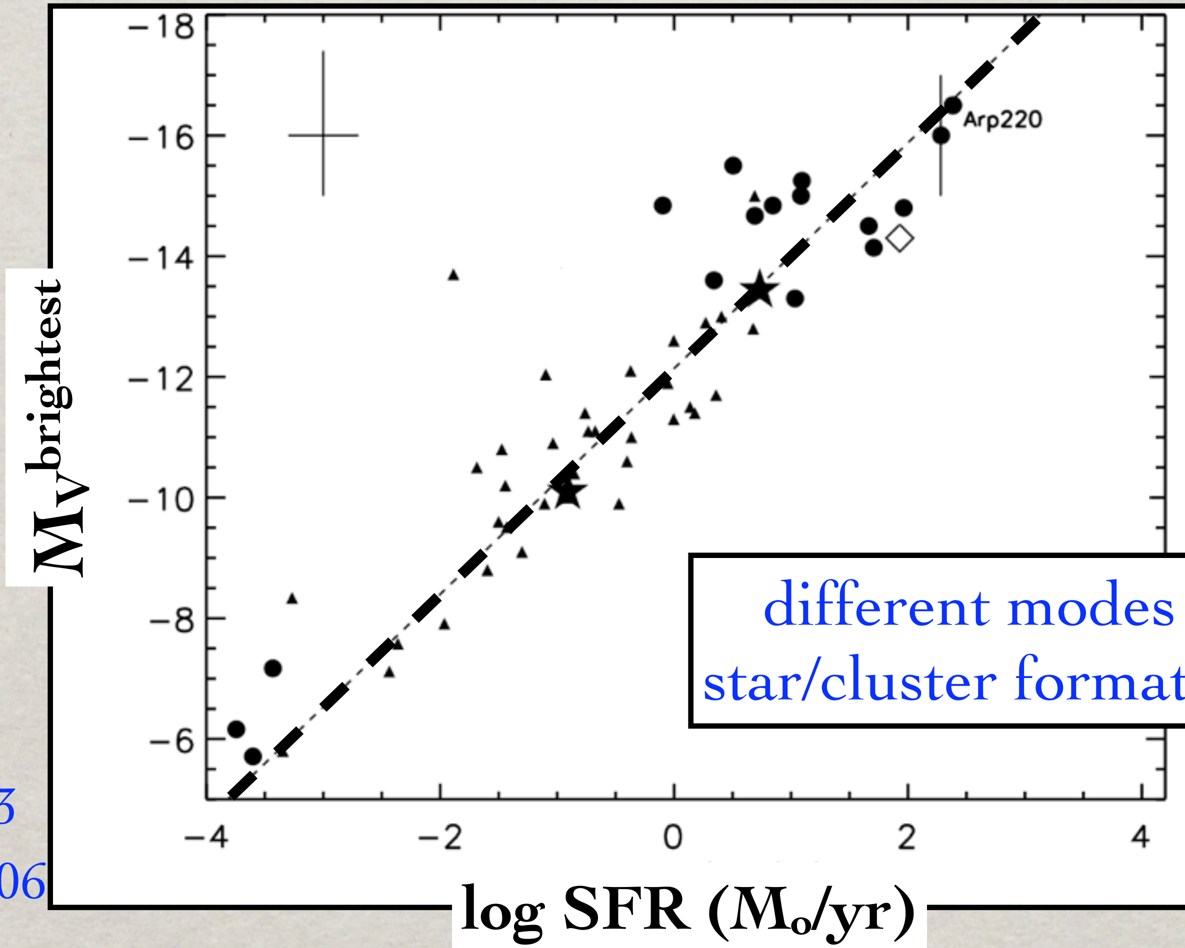

Werk et al. 2008
Declination (J2000)
-56°00'
-56°05'
-56°10'
4h10m30s
10m00s
09m30s
09m00s
Right Ascension (J2000)
5
1
2
SDSS
Mv
−10
−8
−6
−4
−2
log
Larsen 2002
Whitmore 2003
Gieles et al. 2006
Bastian 2008
Weidner et al. 2004
Wilson et al. 2006

Cluster/Star formation

usually attributed to size-of-sample effects



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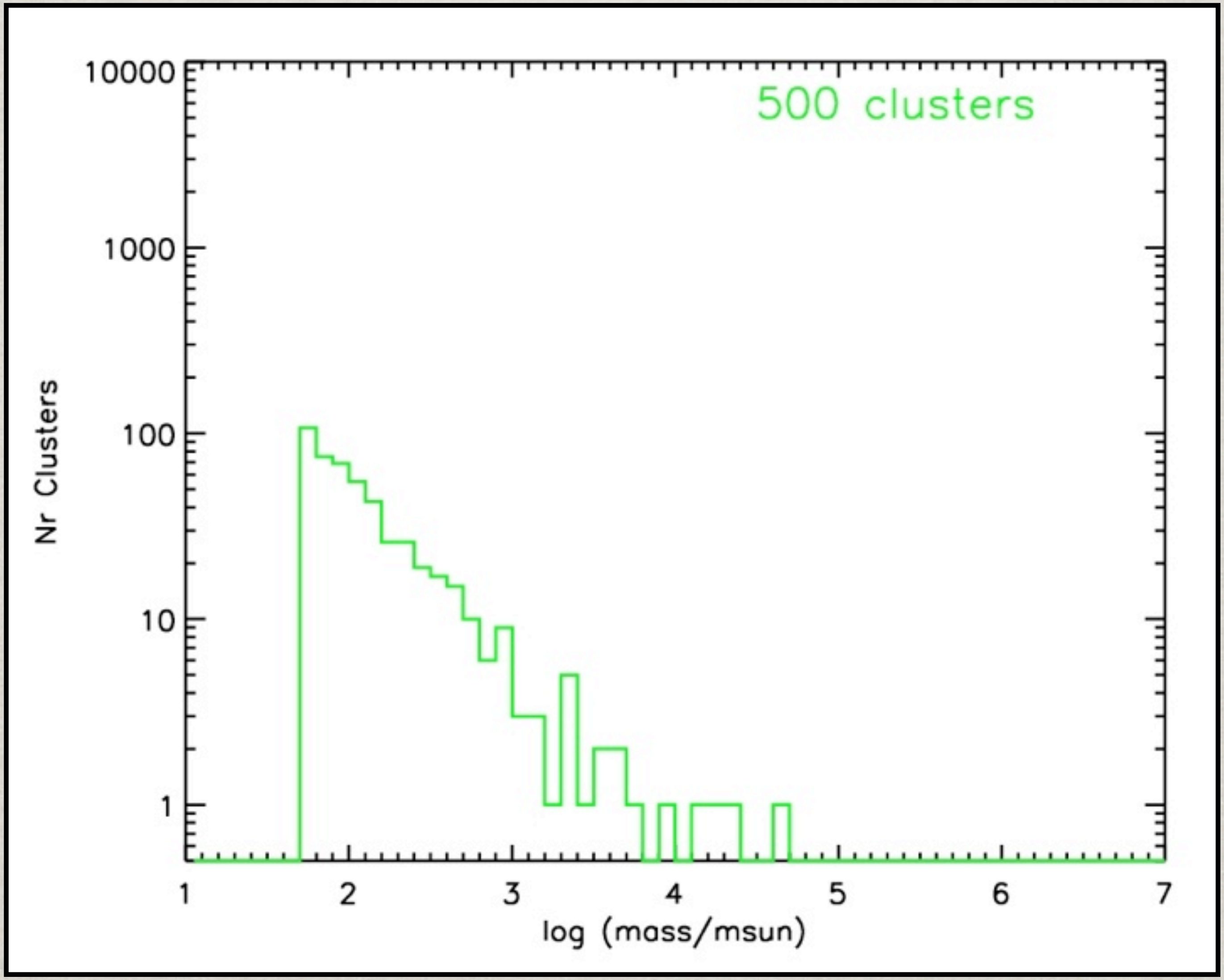
Size-of-Sample Effects



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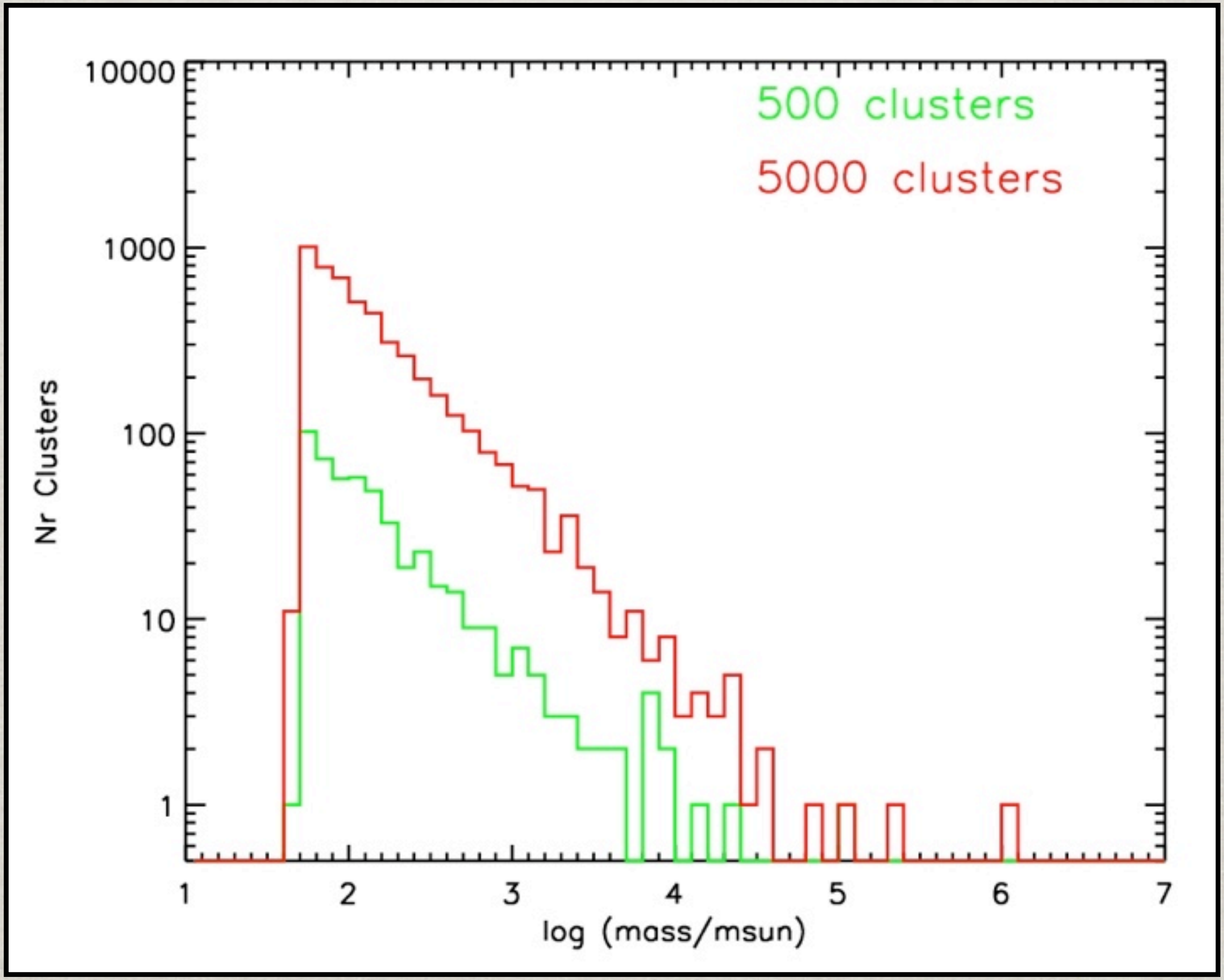

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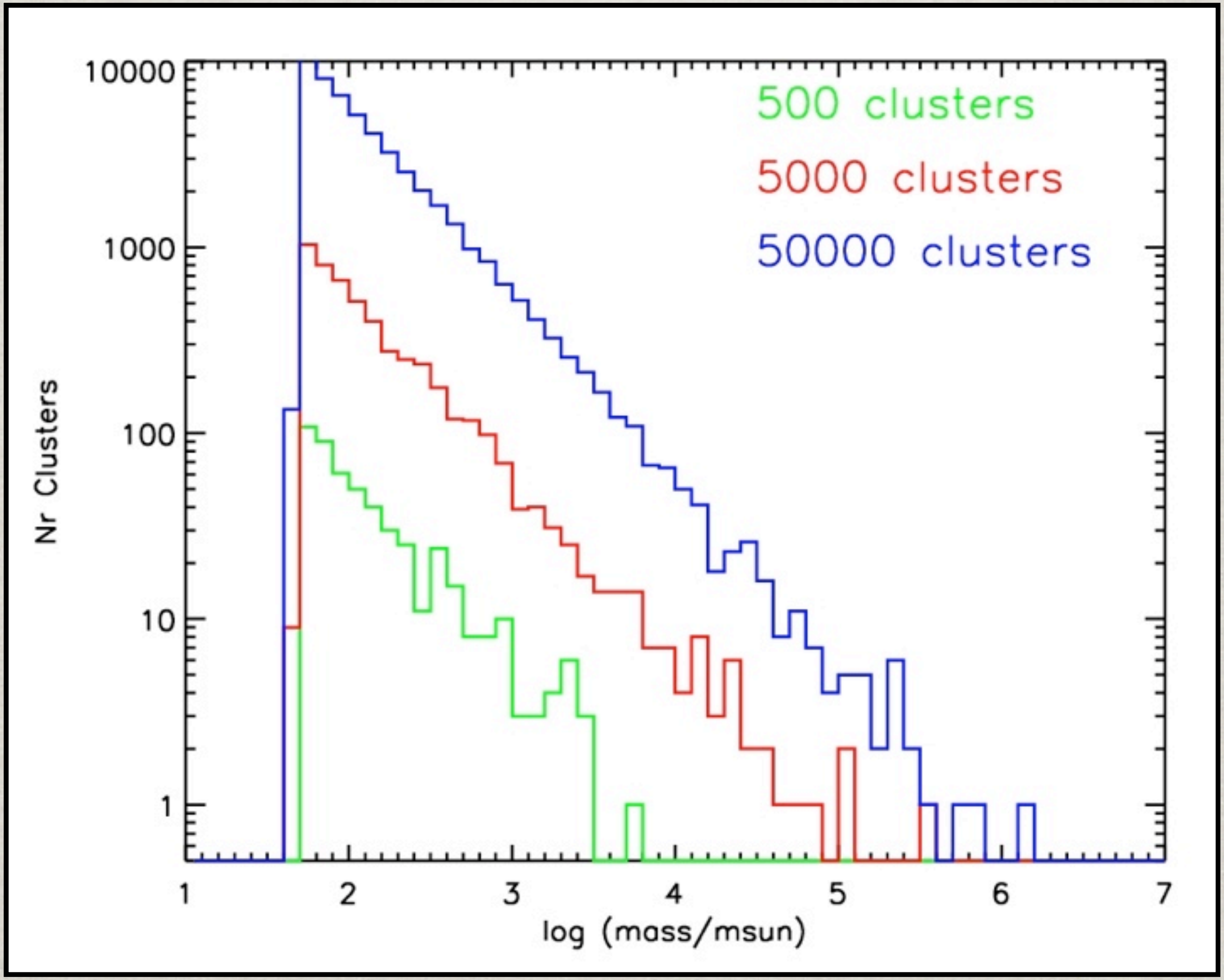
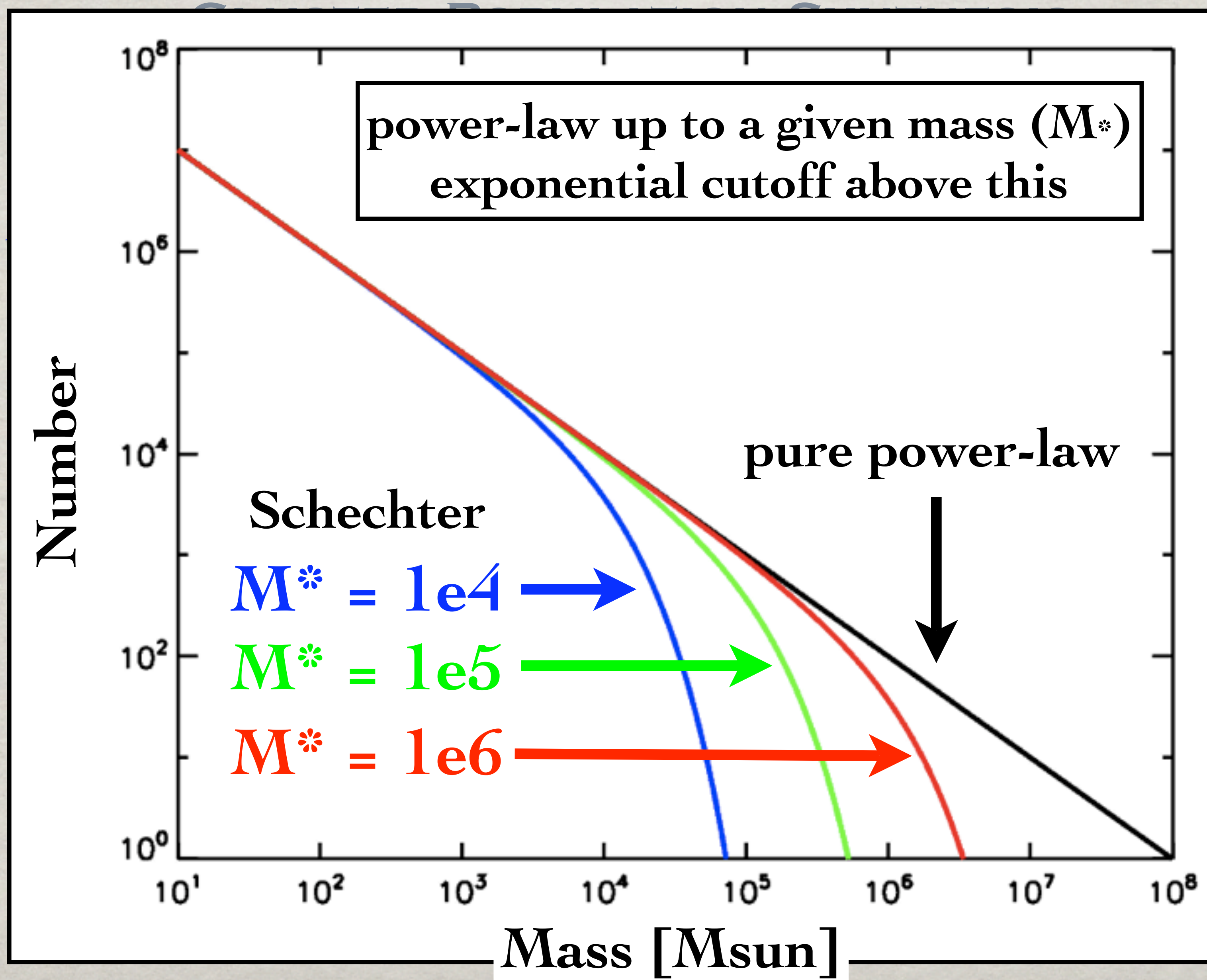


Building a Cluster Population
Cluster Population Synthesis

- Mass Function: $NdM \sim M^{-2}dM$ or Schechter function

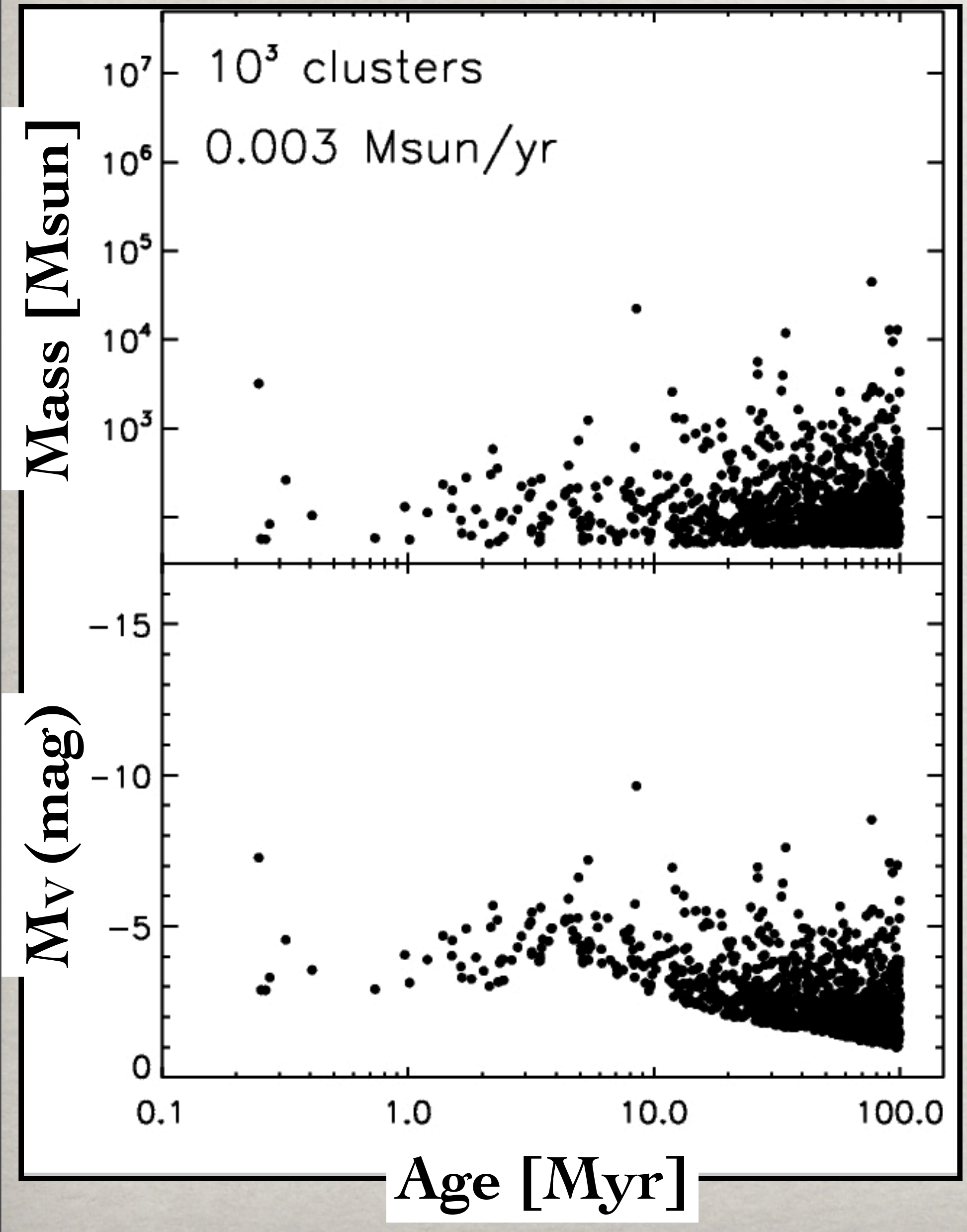
Building a Cluster Population



Building a Cluster Population
Cluster Population Synthesis

- ❖ Mass Function: $NdM \sim M^{-2}dM$ or Schechter function
- ❖ Constant Cluster Formation History (~100 Myr)
- ❖ Combine ages and masses to get M_V (e.g. Bruzual+Charlot)
- ❖ Find brightest cluster (and age of that cluster)
- ❖ Cluster formation rate (CFR) =
  total mass in clusters / duration of experiment (100 Myr)

Building a Cluster Population



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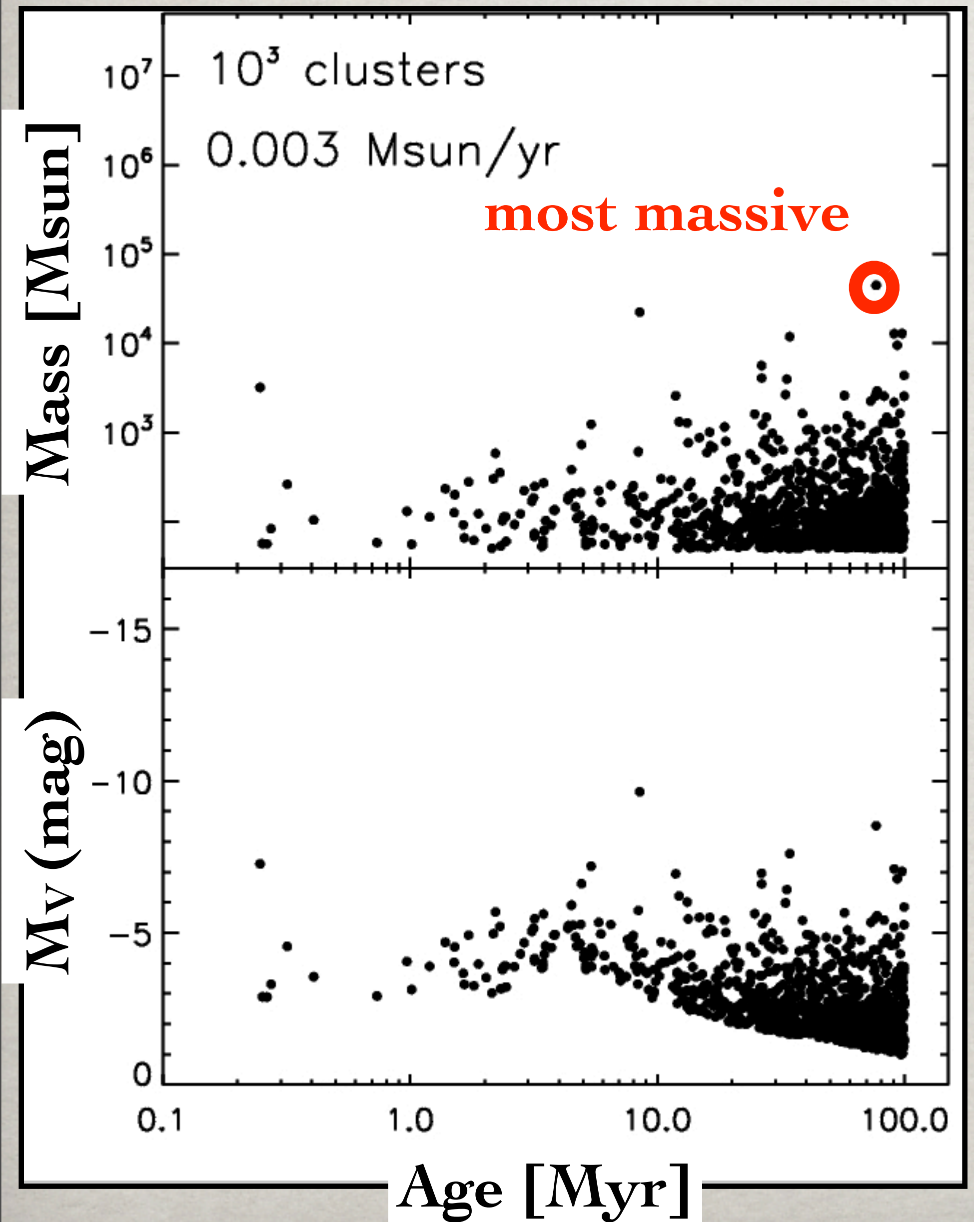

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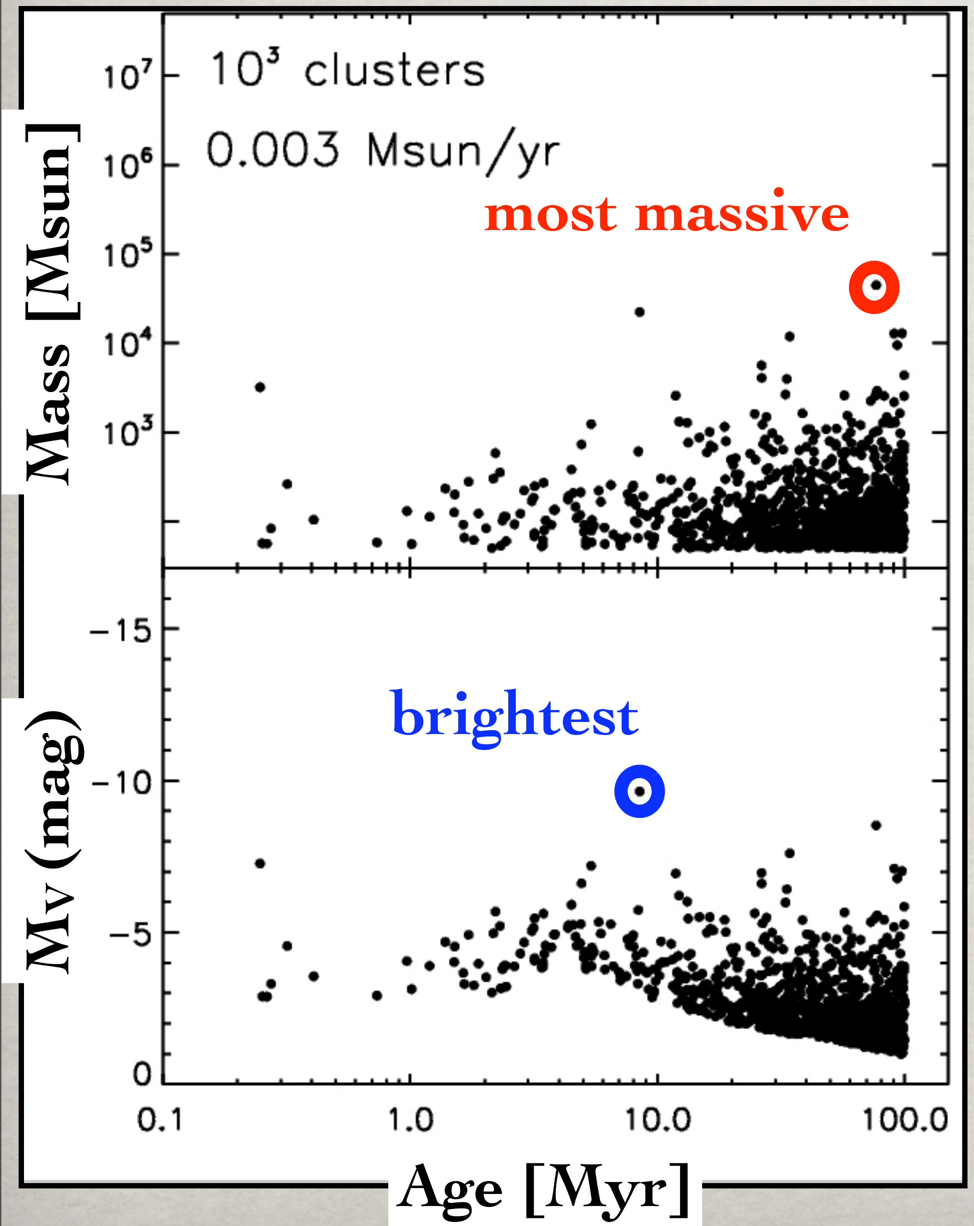

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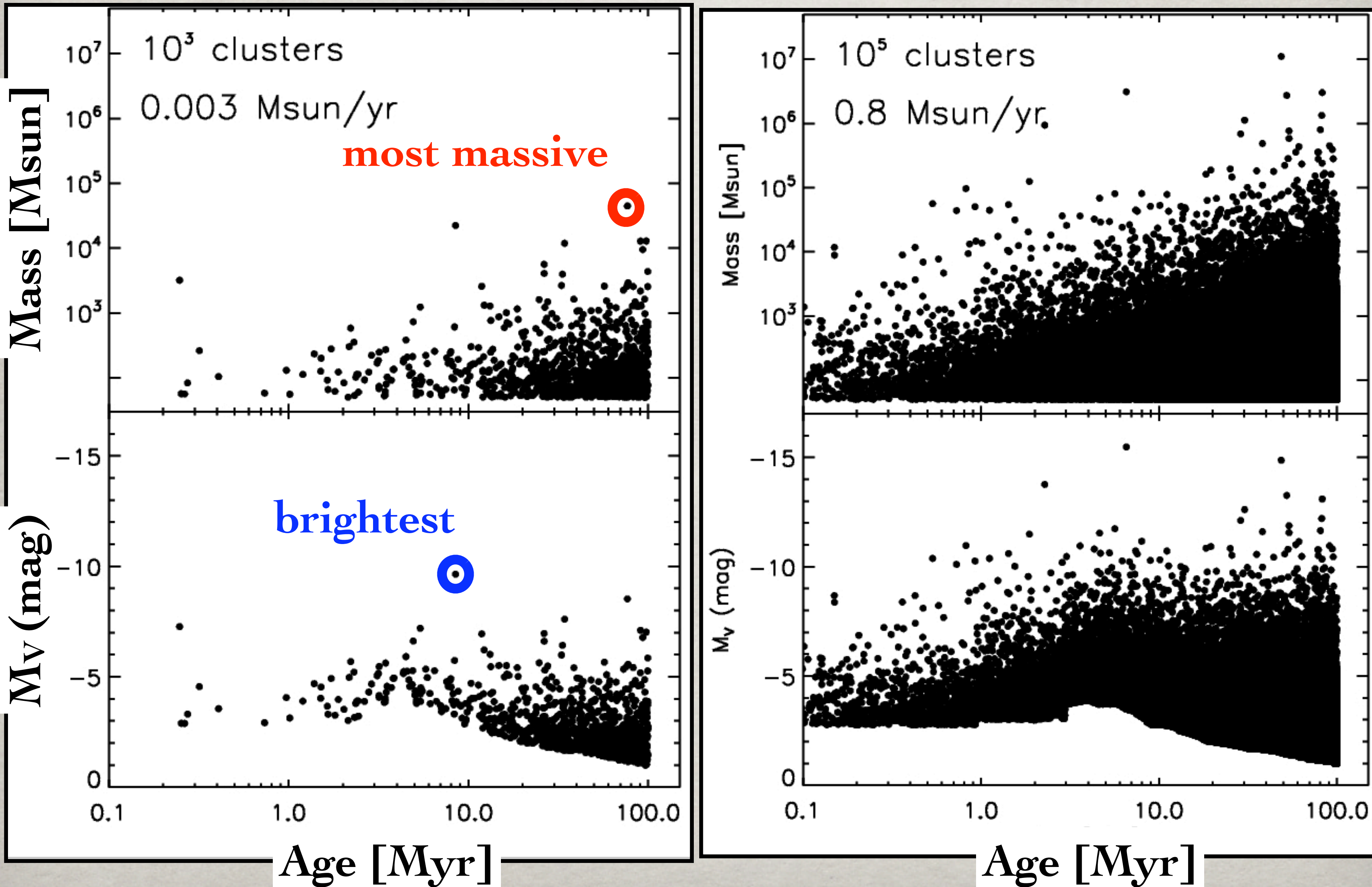

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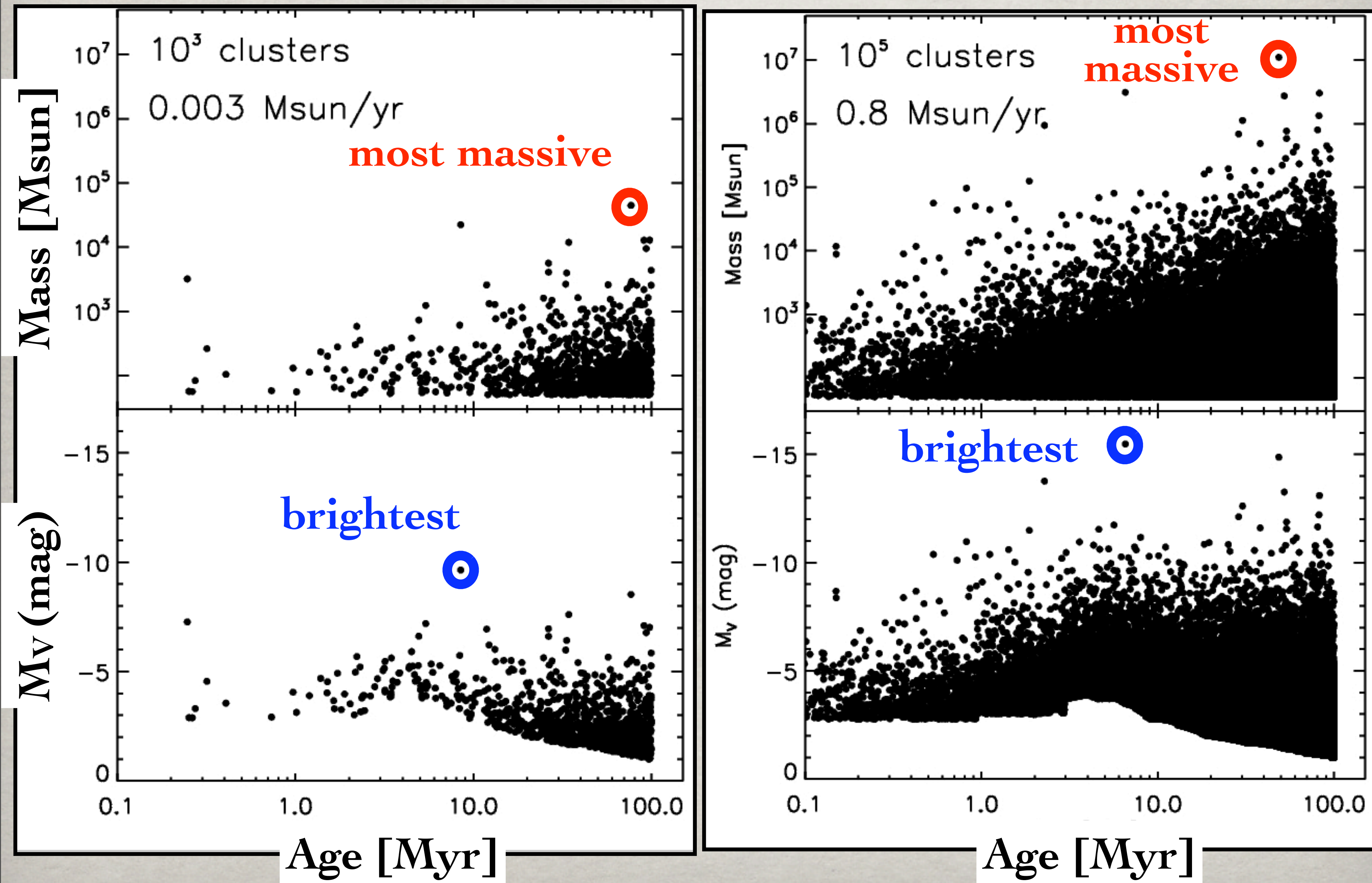

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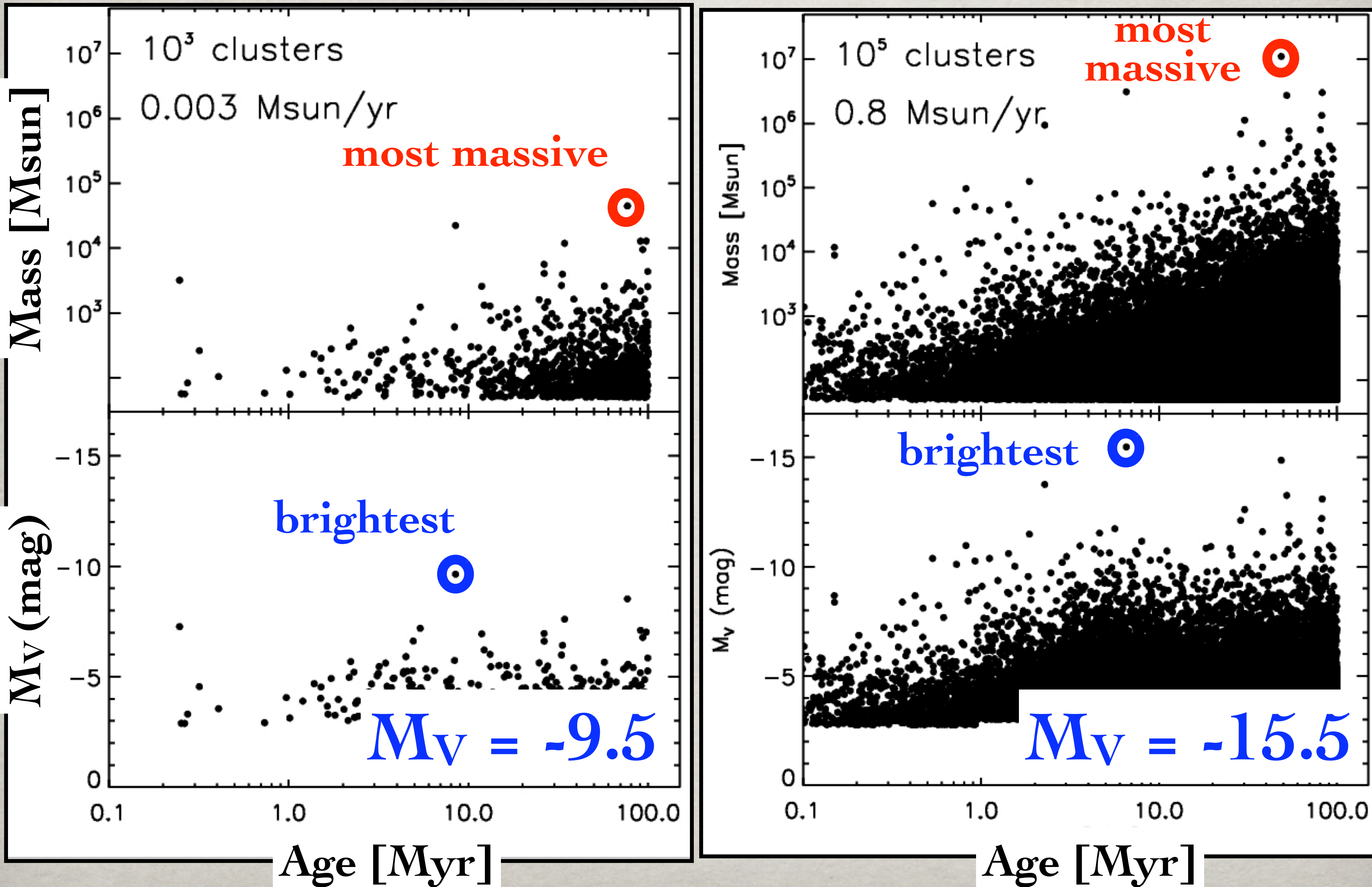
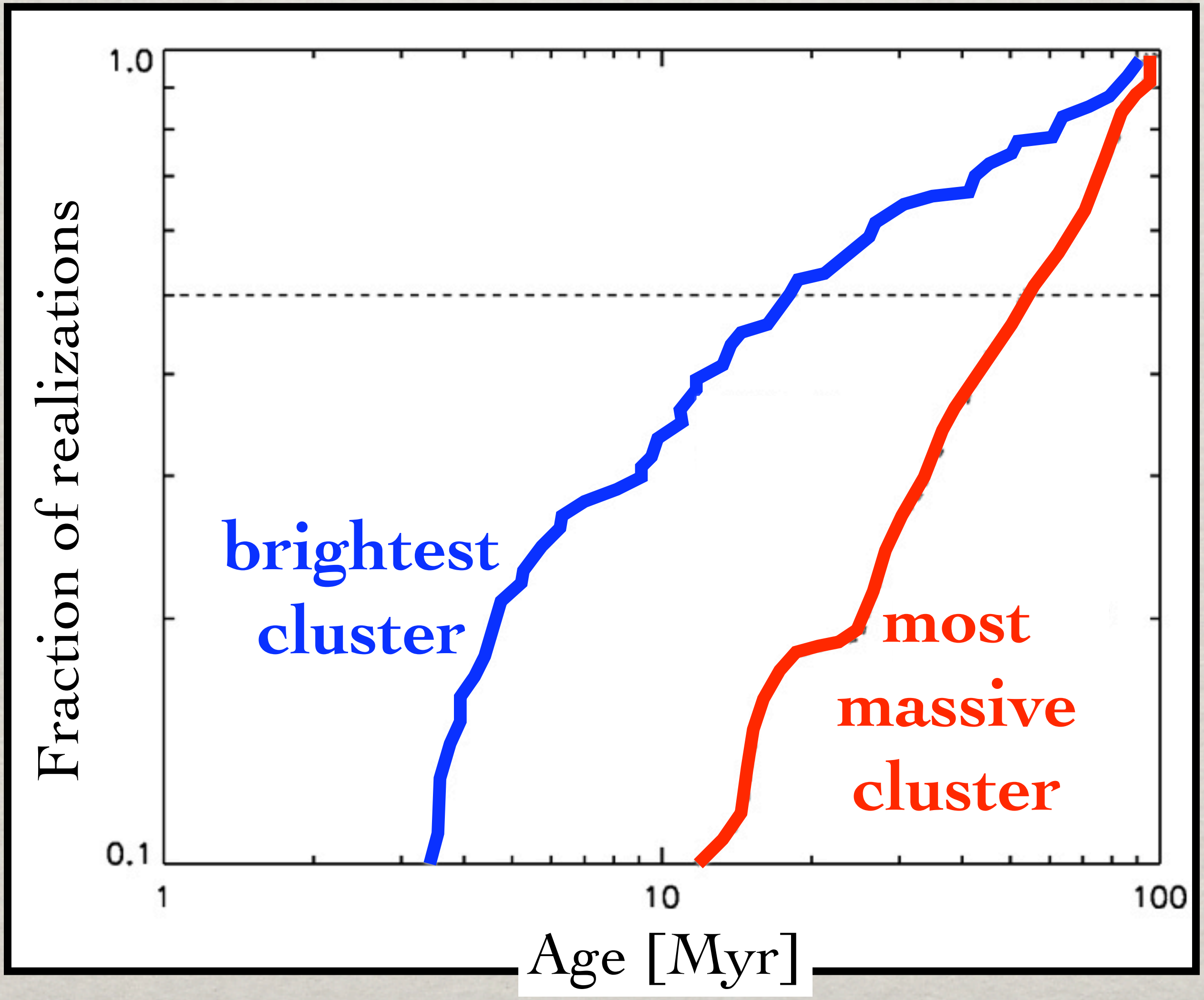
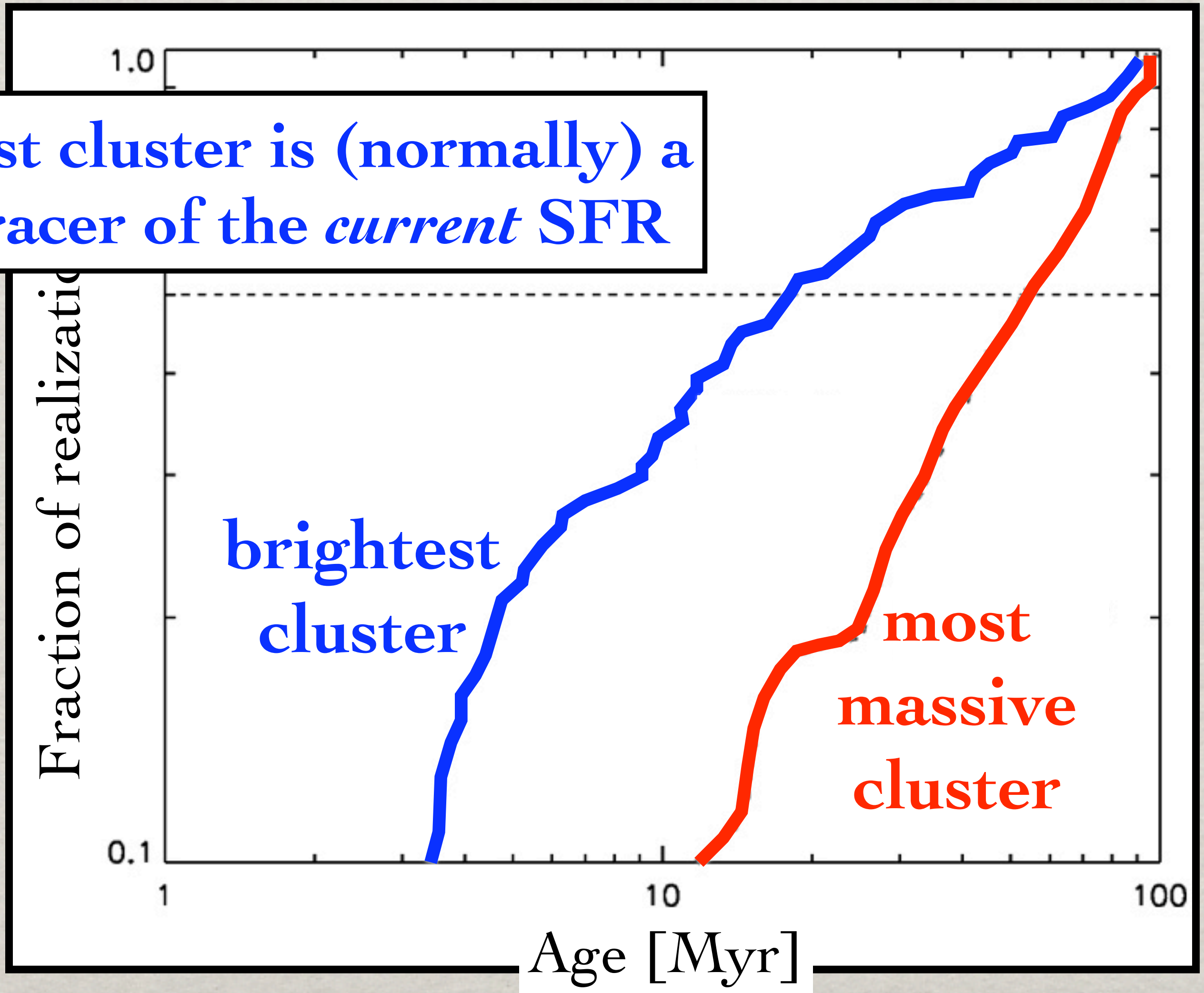


Brightest cluster tends to be young



Brightest cluster tends to be young

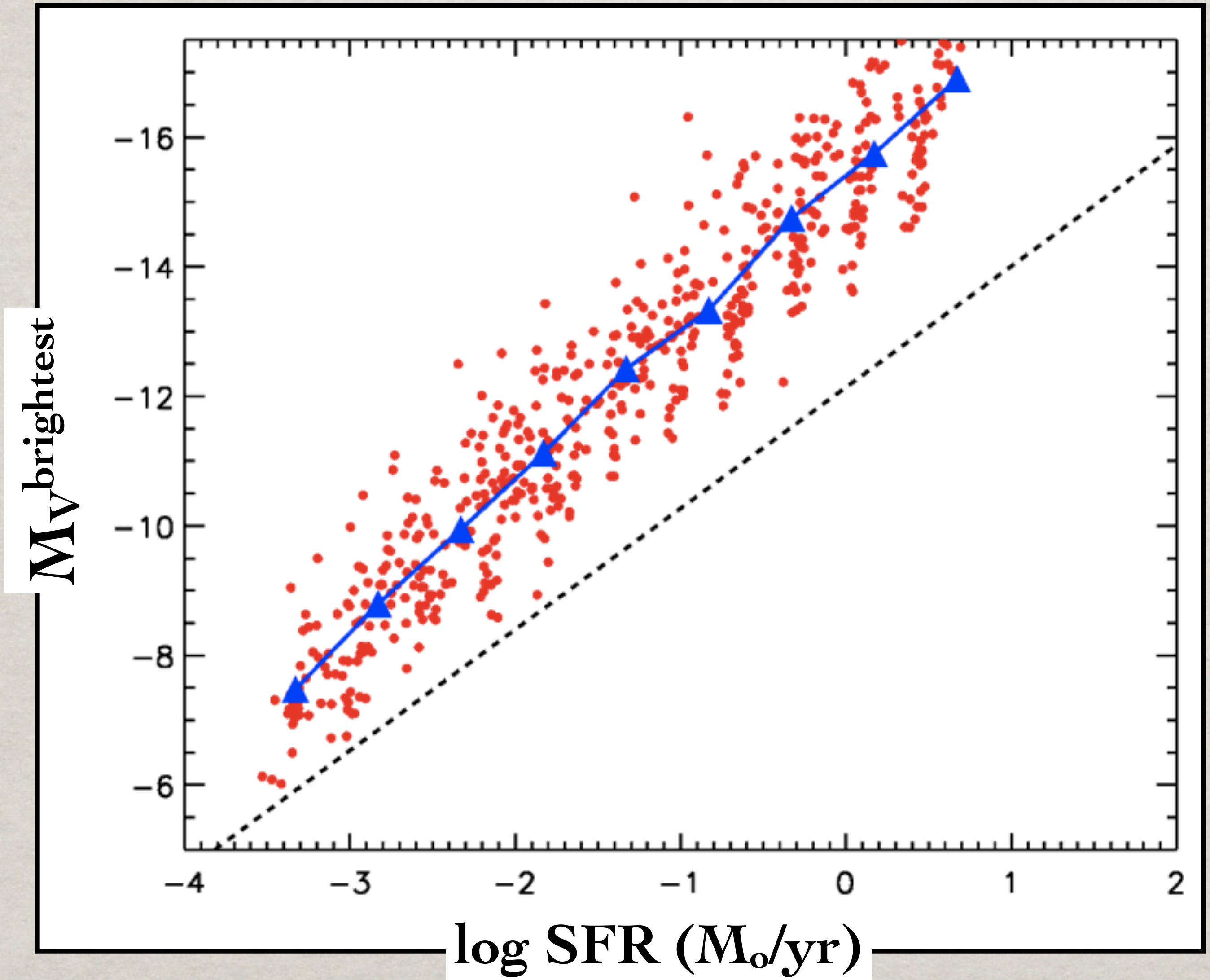
Brightest cluster is (normally) a good tracer of the *current* SFR



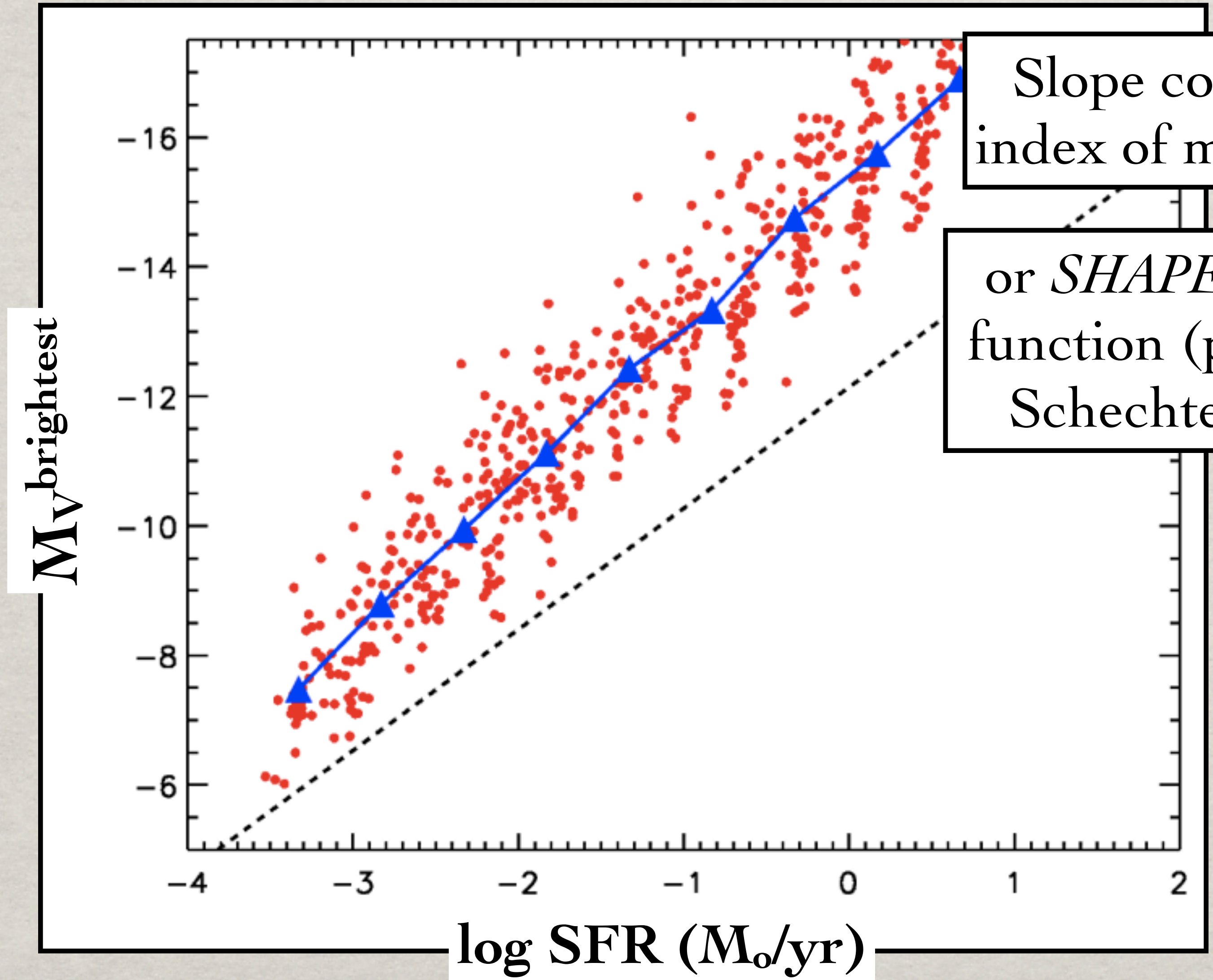
Cluster Populations

- Now build hundreds of cluster populations (stochastically)
- Vary average CFR
- Vary mass function
- Compare to observations (SFR vs. $M_V^{brightest}$)

Cluster Populations



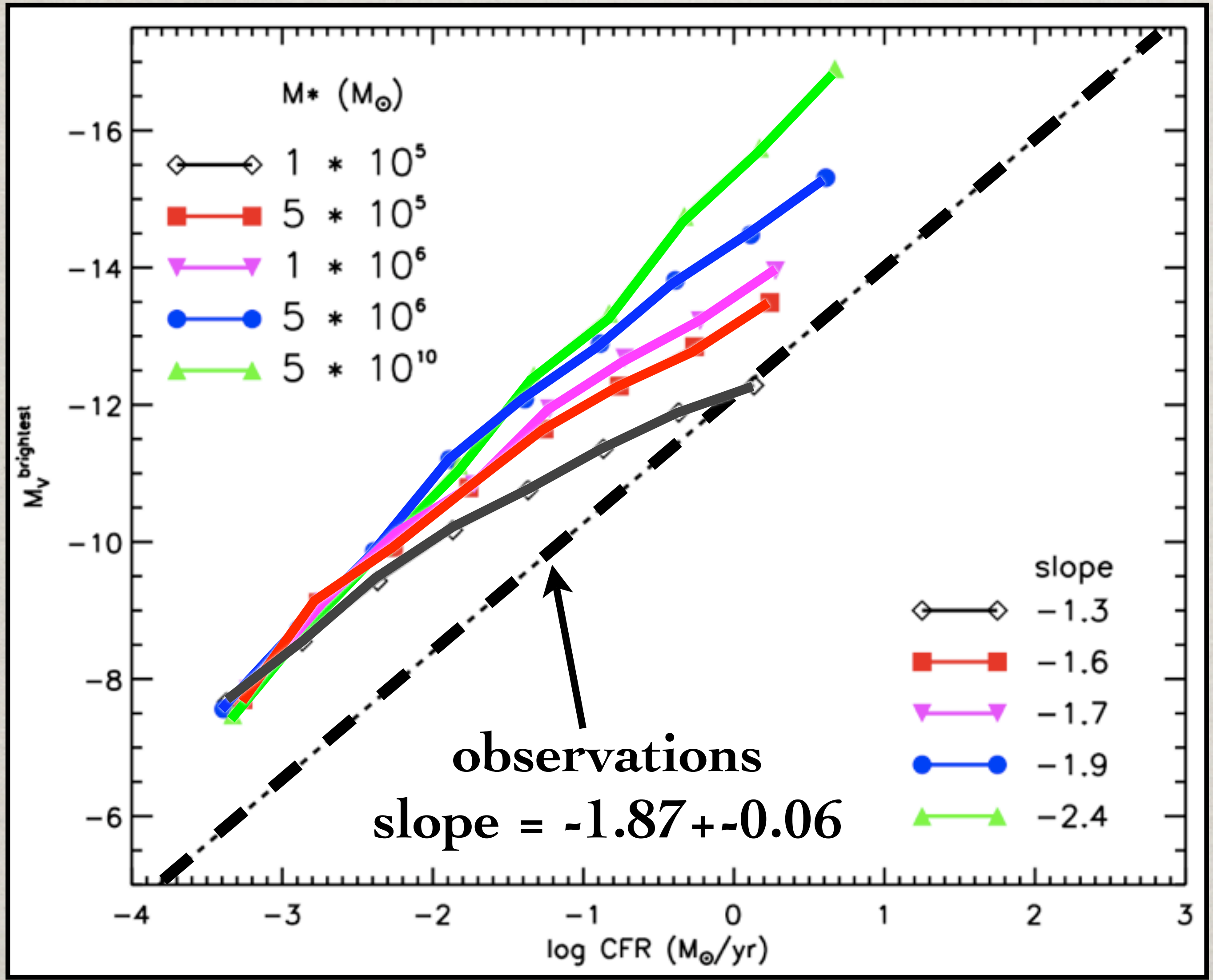
Cluster Populations



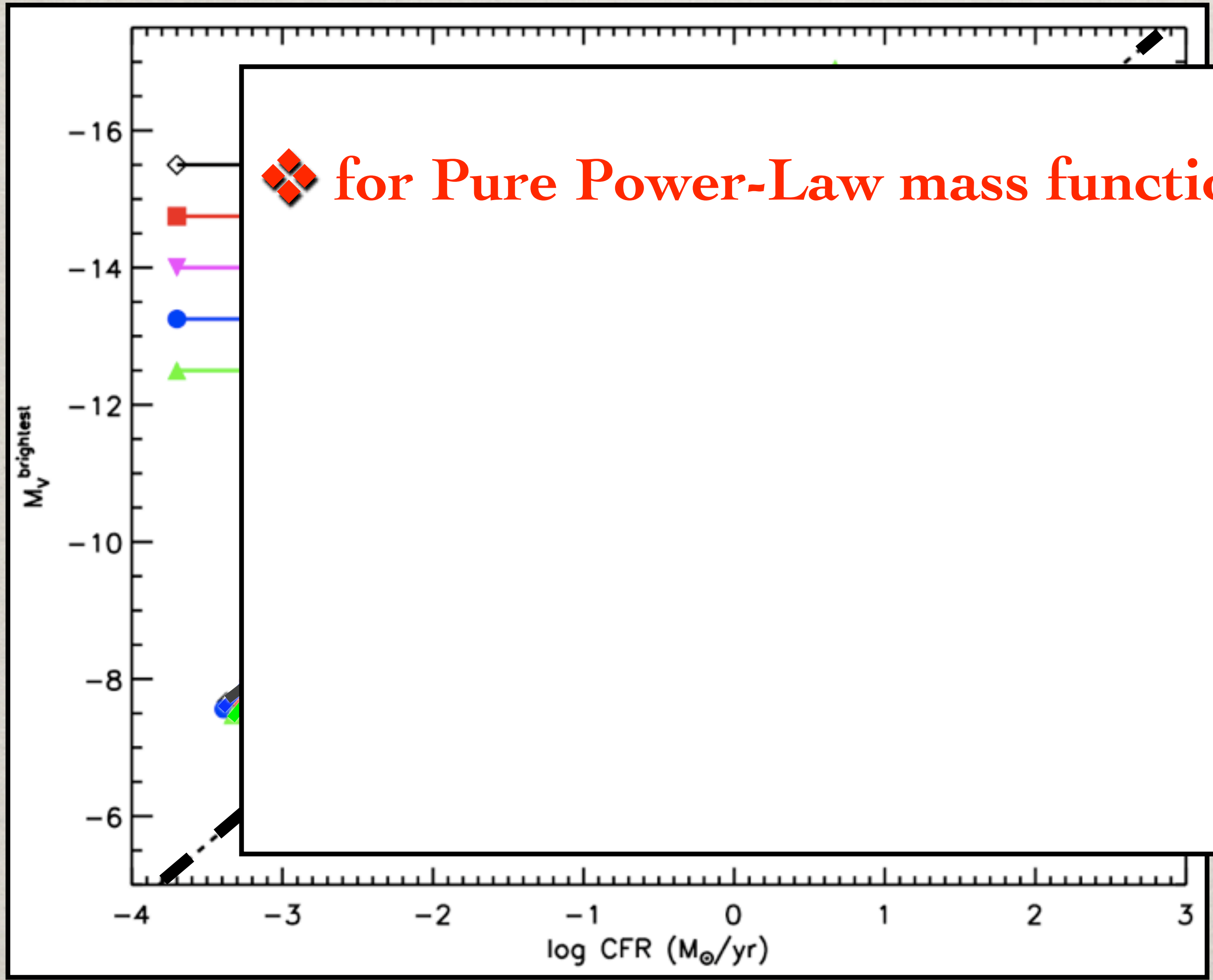
Slope controlled by index of mass function

or *SHAPE* of the mass function (power-law or Schechter function)

Cluster Populations Continued

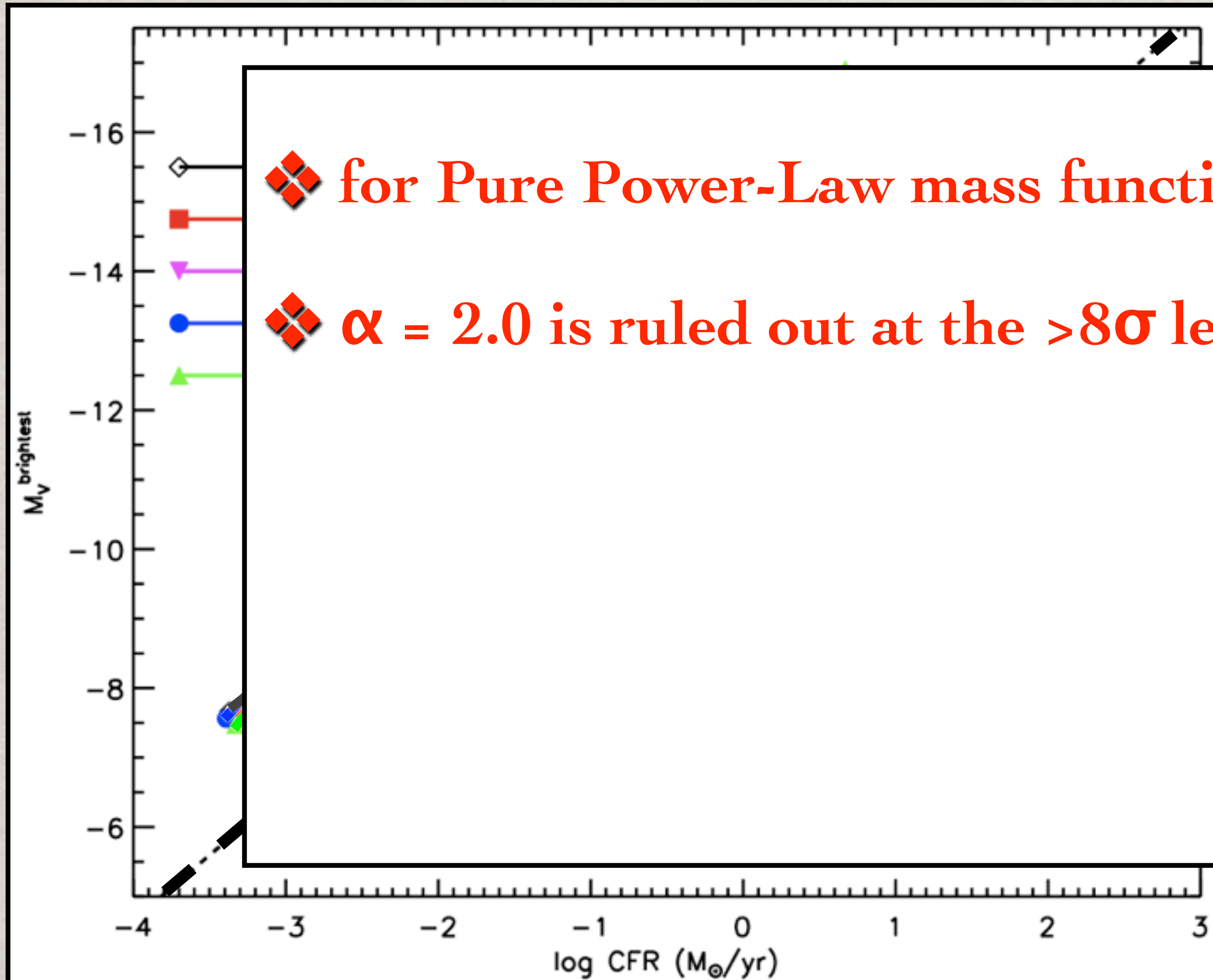


Cluster Populations Continued



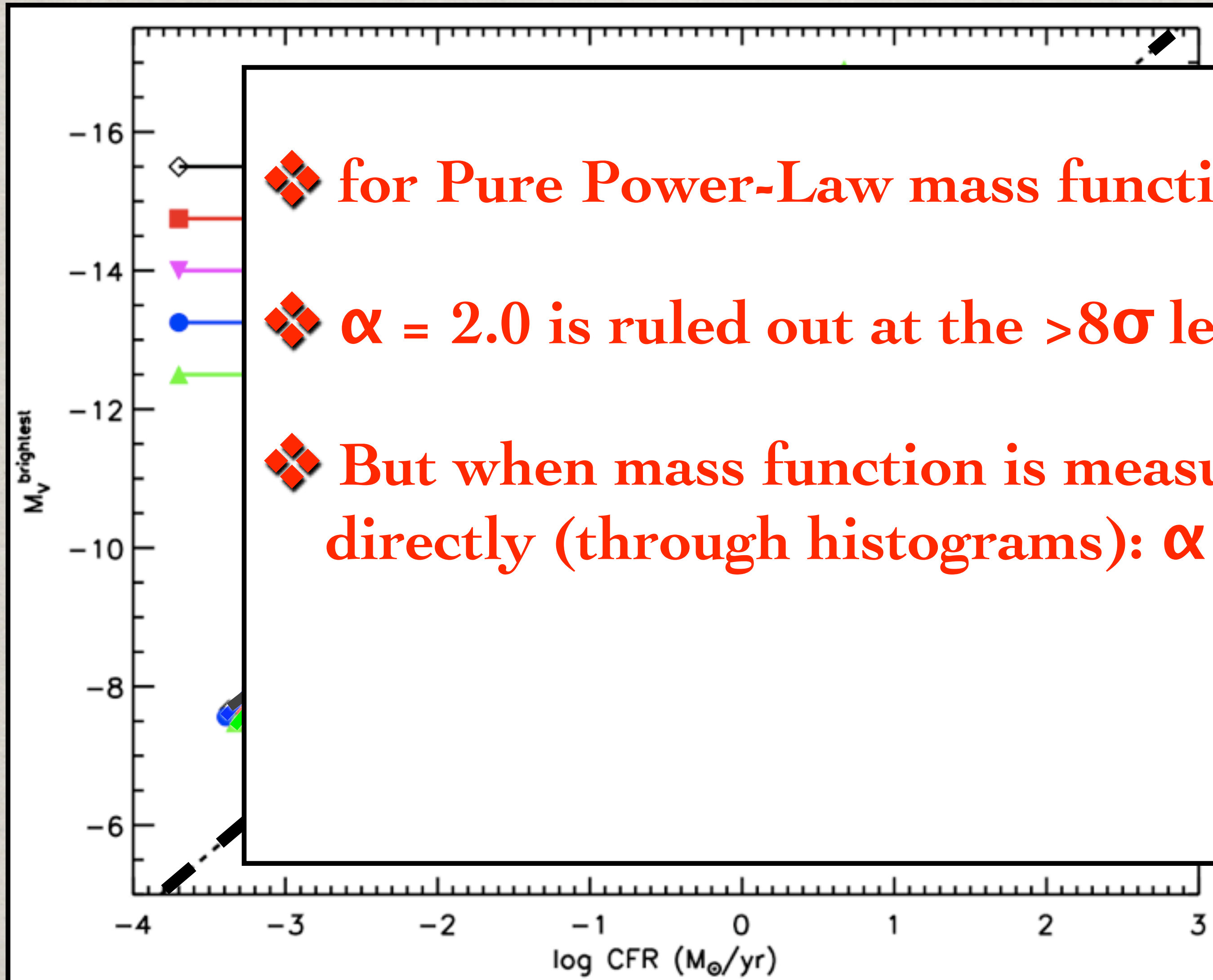
- for Pure Power-Law mass function: α = 2.3

Cluster Populations Continued



- for Pure Power-Law mass function: $\alpha = 2.3$
- $\alpha = 2.0$ is ruled out at the $>8\sigma$ level

Cluster Populations Continued



- for Pure Power-Law mass function: $\alpha = 2.3$
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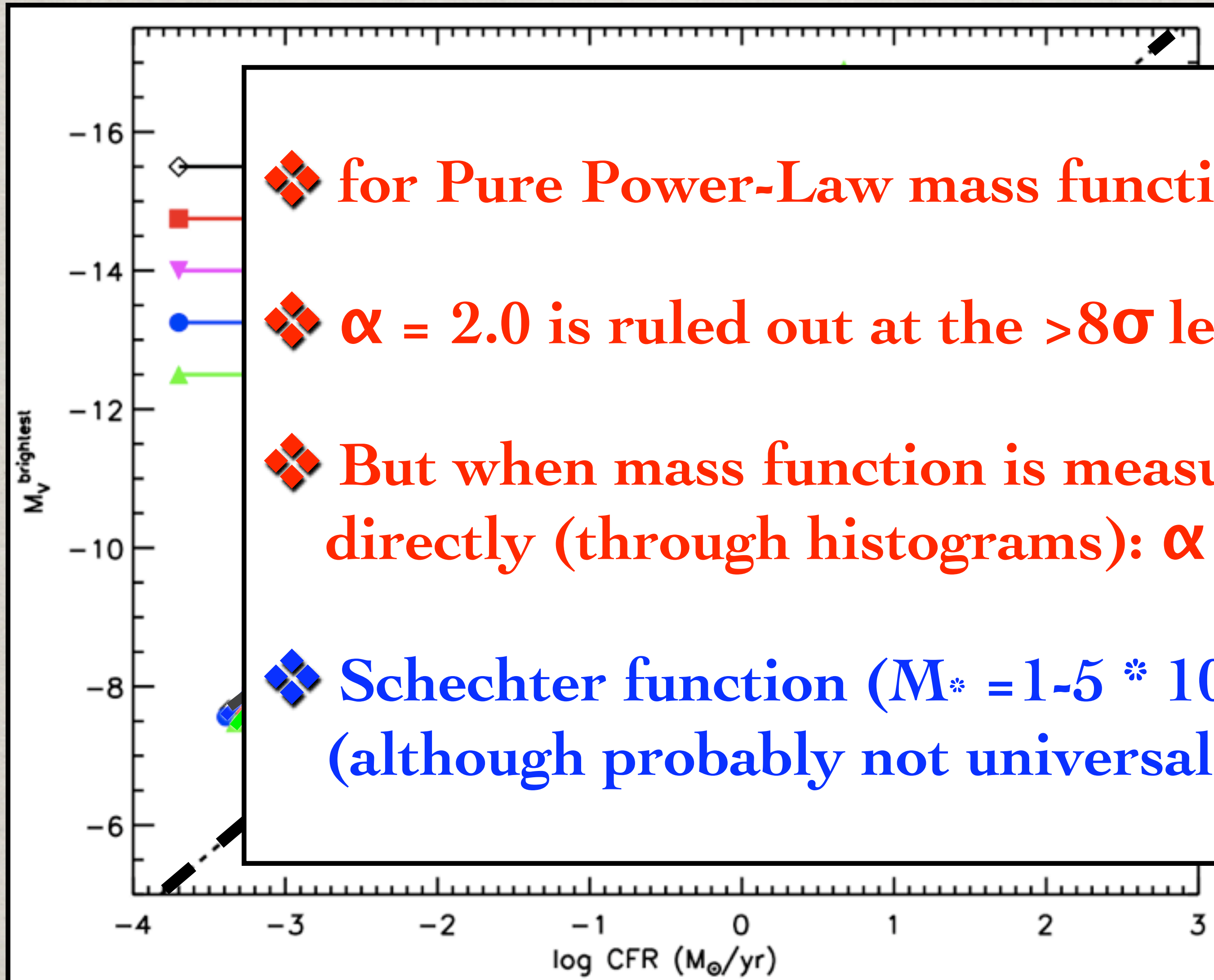
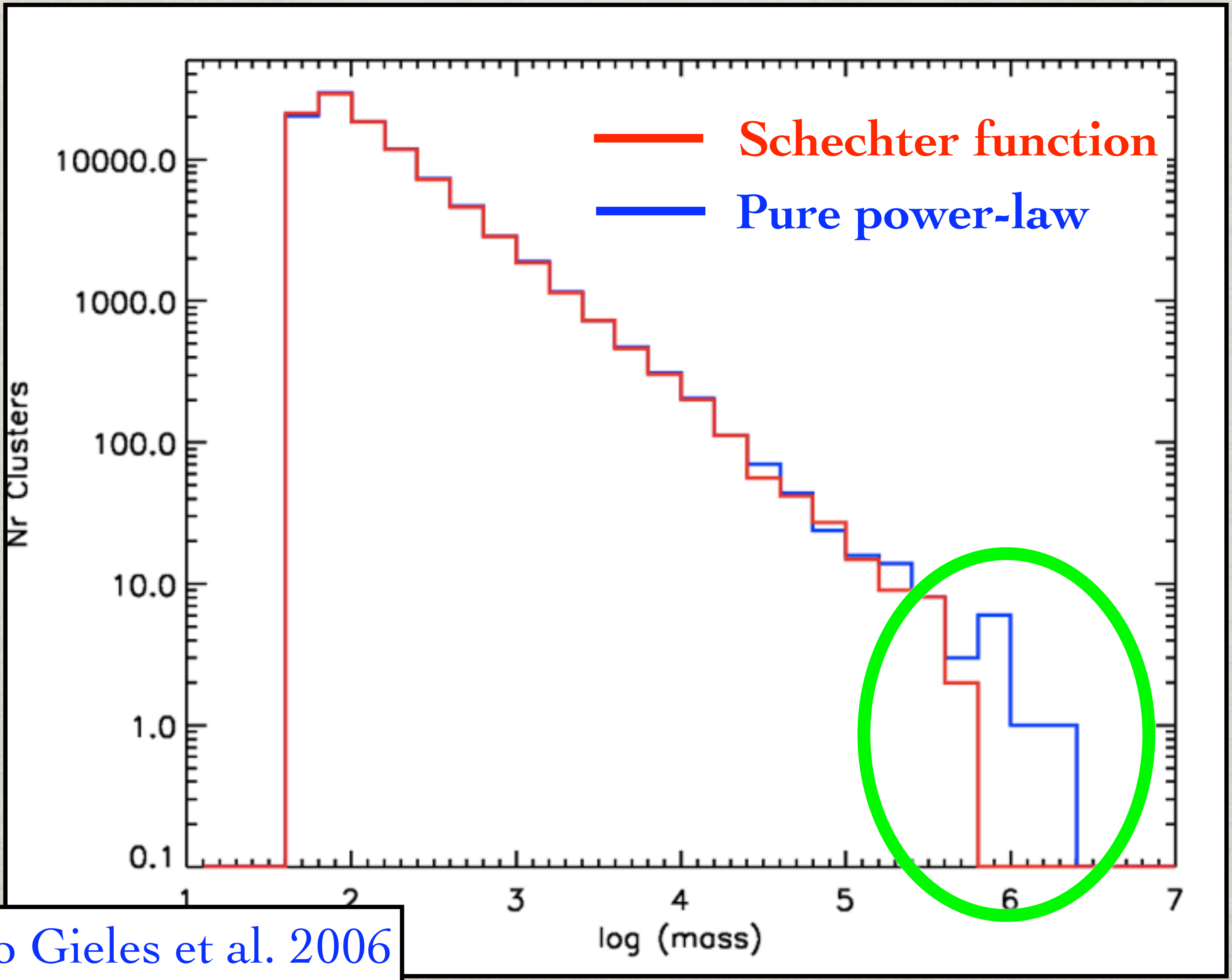
- But when mass function is measured directly (through histograms): $\alpha = 2.0$?!?!

Cluster Populations Continued



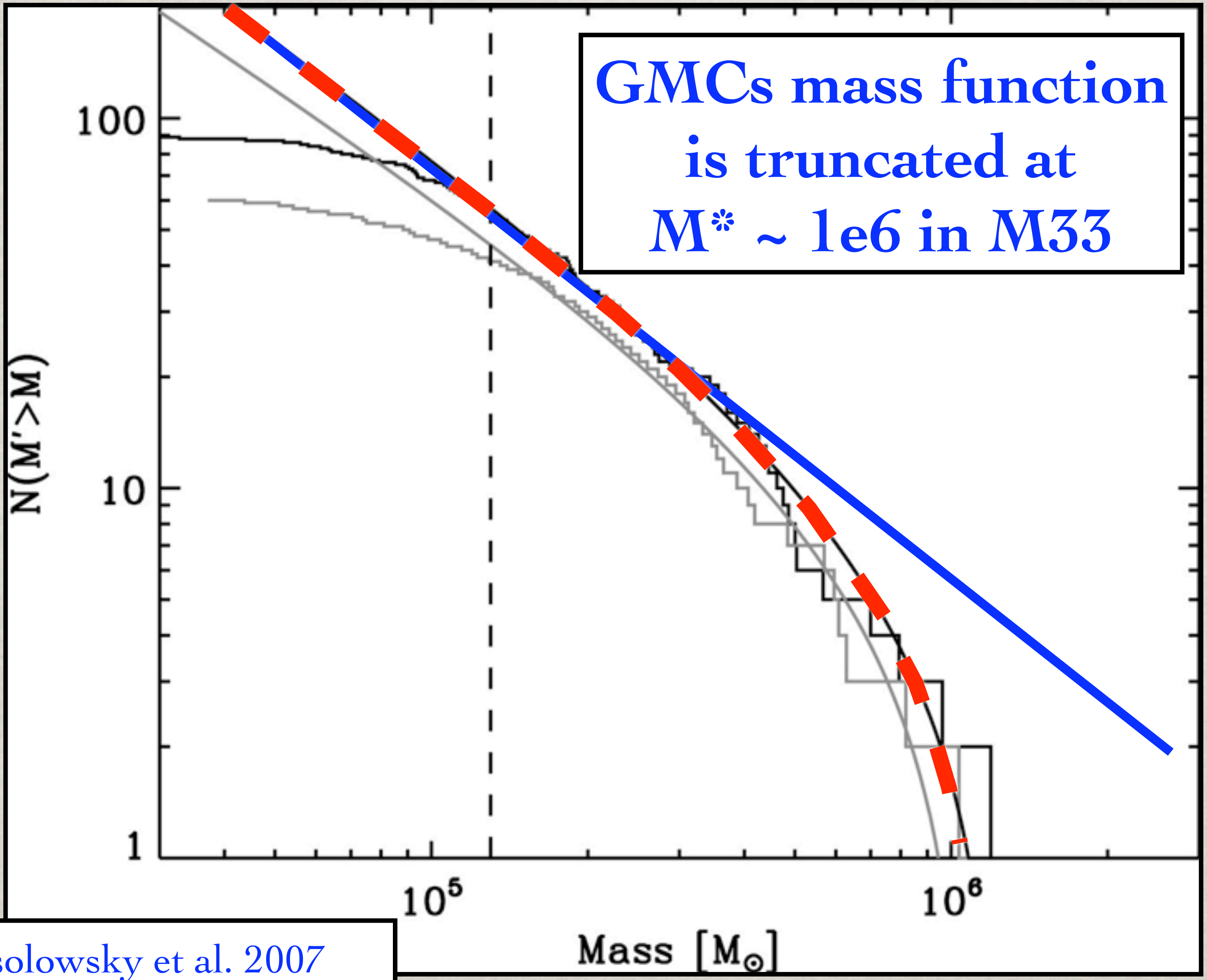
- for Pure Power-Law mass function: $\alpha = 2.3$
- $\alpha = 2.0$ is ruled out at the $>8\sigma$ level
- But when mass function is measured directly (through histograms): $\alpha = 2.0$?!?!
- Schechter function ($M_* = 1\text{-}5 * 10^6$) fits well (although probably not universal value)

MASS FUNCTIONS



see also Gieles et al. 2006

MASS FUNCTIONS: GMCs IN M33



Rosolowsky et al. 2007

Other Evidence for Schechter Function

High mass end of the mass function of Globular Clusters in Virgo & Coma are best fit by a Schechter function with $M^* \sim$ few * 10^6 Msun

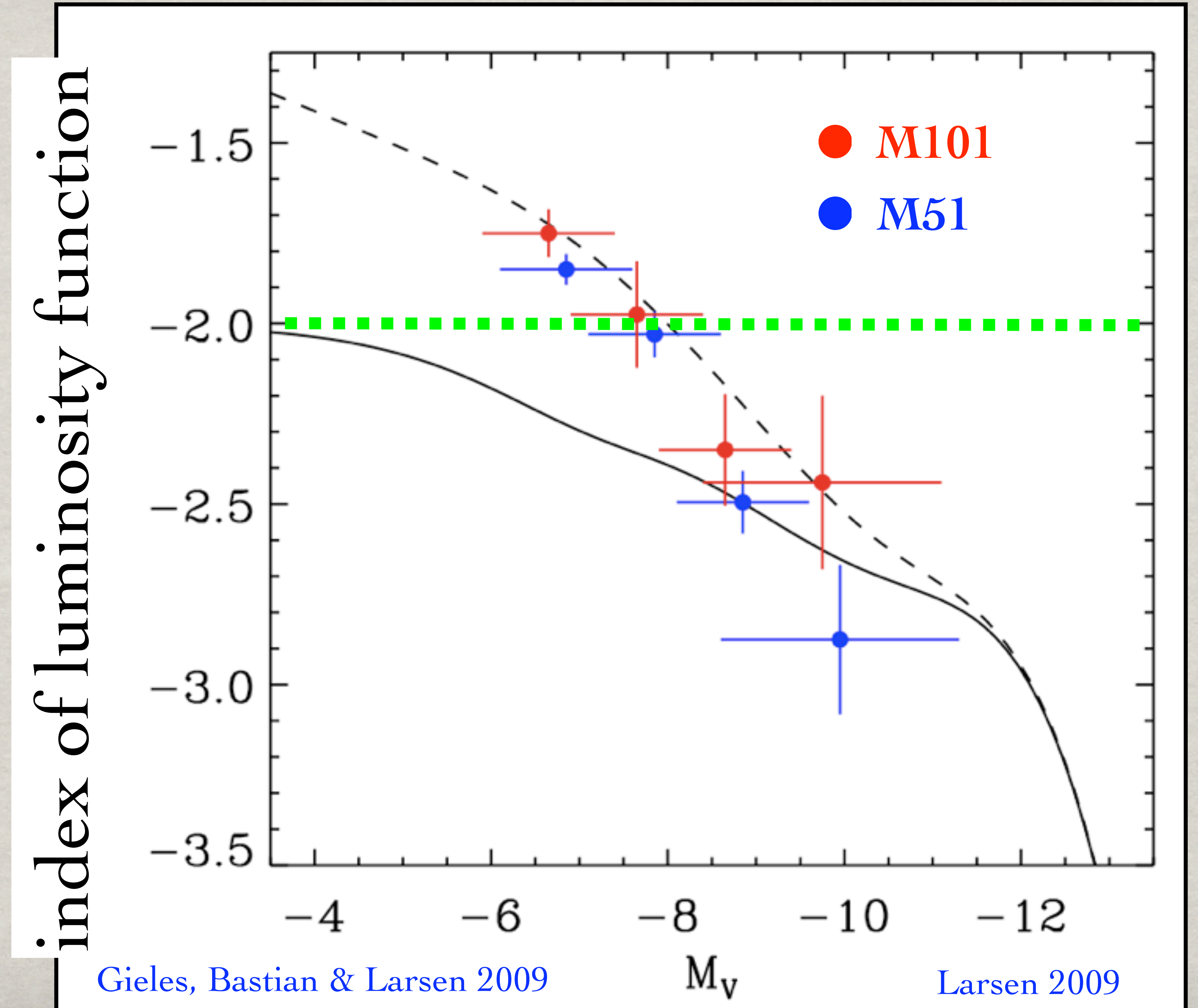
Jordan et al. 2007; Harris et al. 2008

Preferred in direct fit to mass function of clusters in spiral galaxies - also age distribution of brightest cluster

Larsen 2009

Can explain observed bend in luminosity function of young clusters

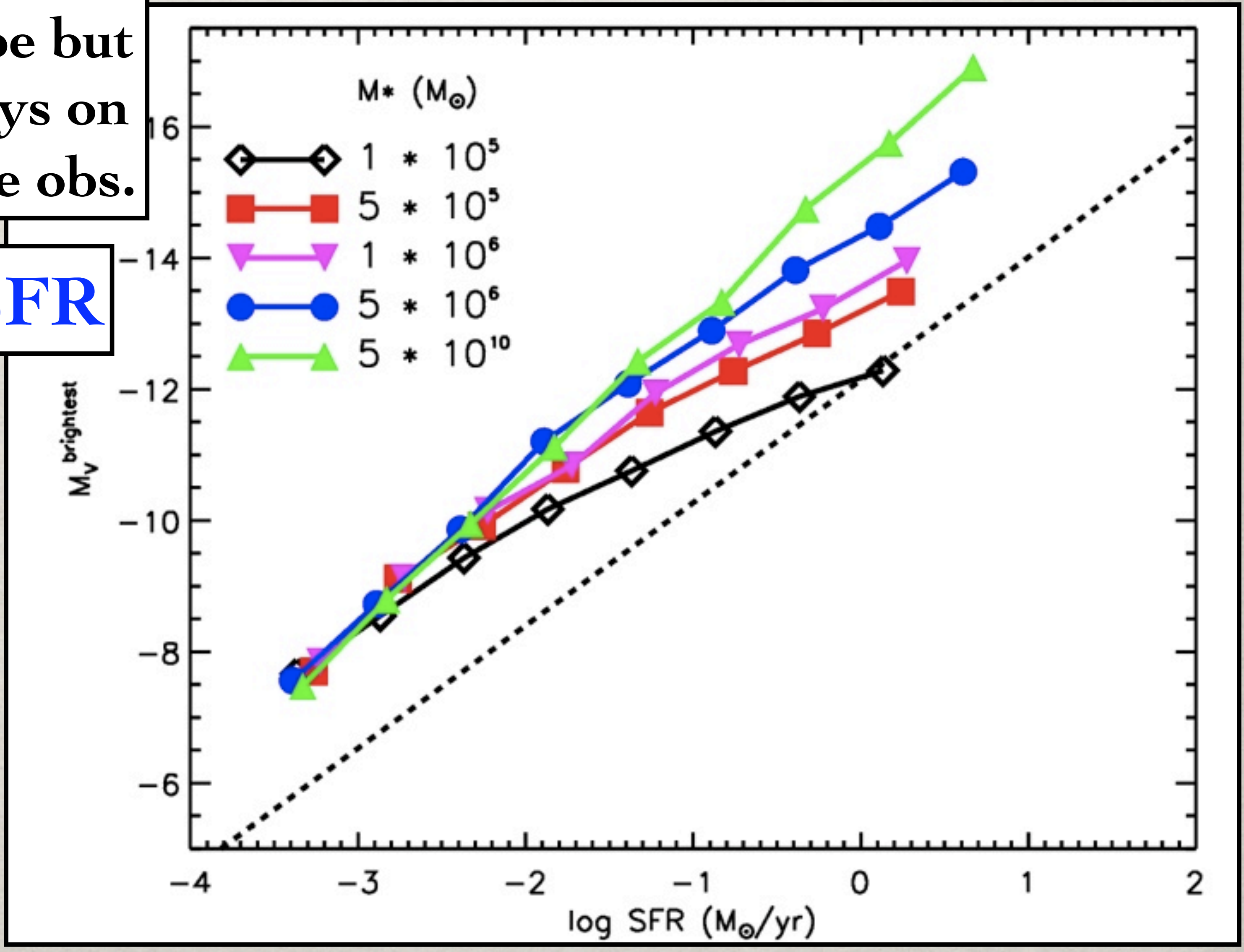
Gieles et al. 2006a,b


index of luminosity function
−1.5
−2.0
−2.5
−3.0
−3.5
−4
−6
−8
−10
−12
M_V
M101
M51
Gieles, Bastian & Larsen 2009
Larsen 2009

Star Formation Efficiencies

Correct shape but models always on the left of the obs.

CFR ≠ SFR



Star Formation Efficiencies

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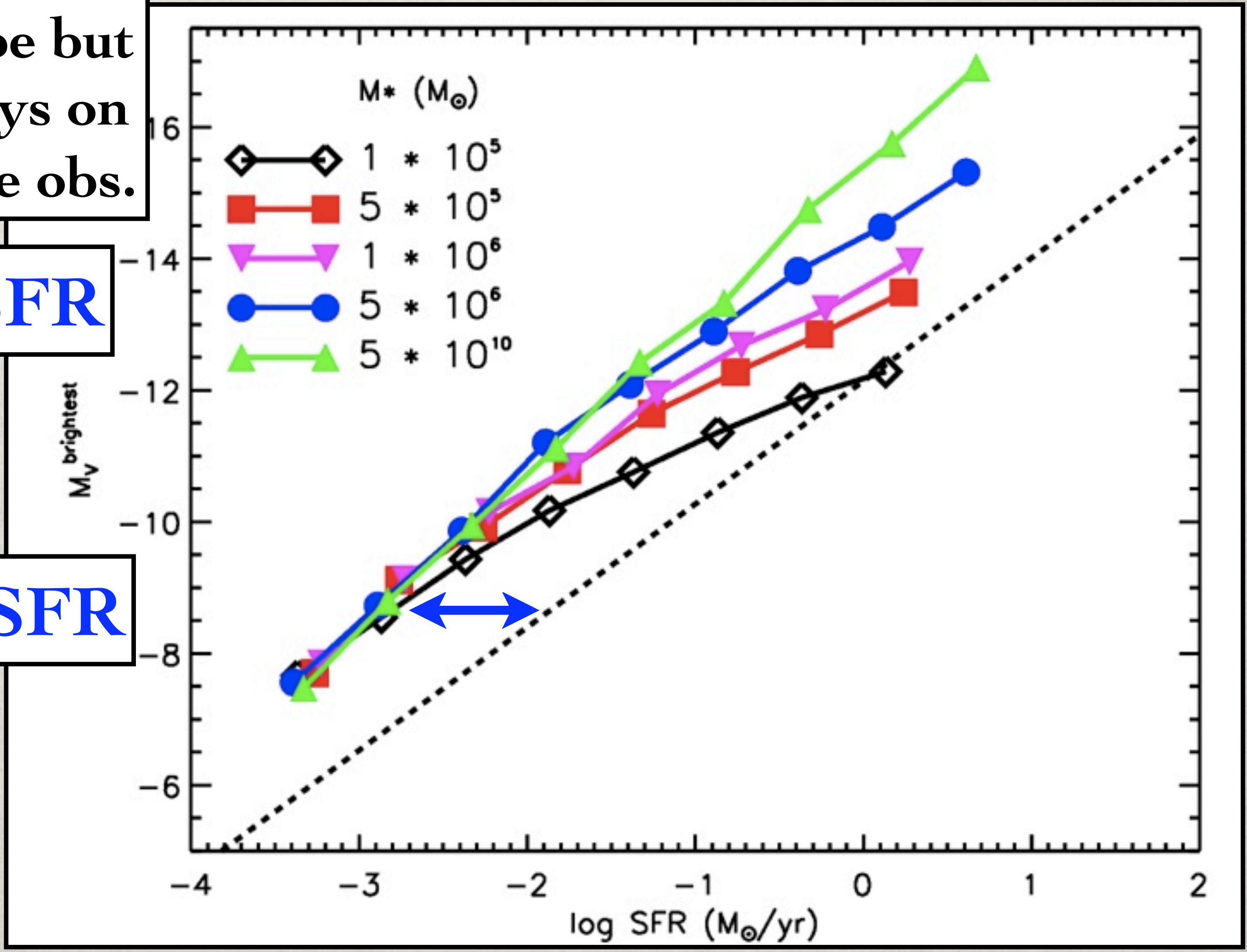
CFR ≠ SFR

Γ = CFR/SFR



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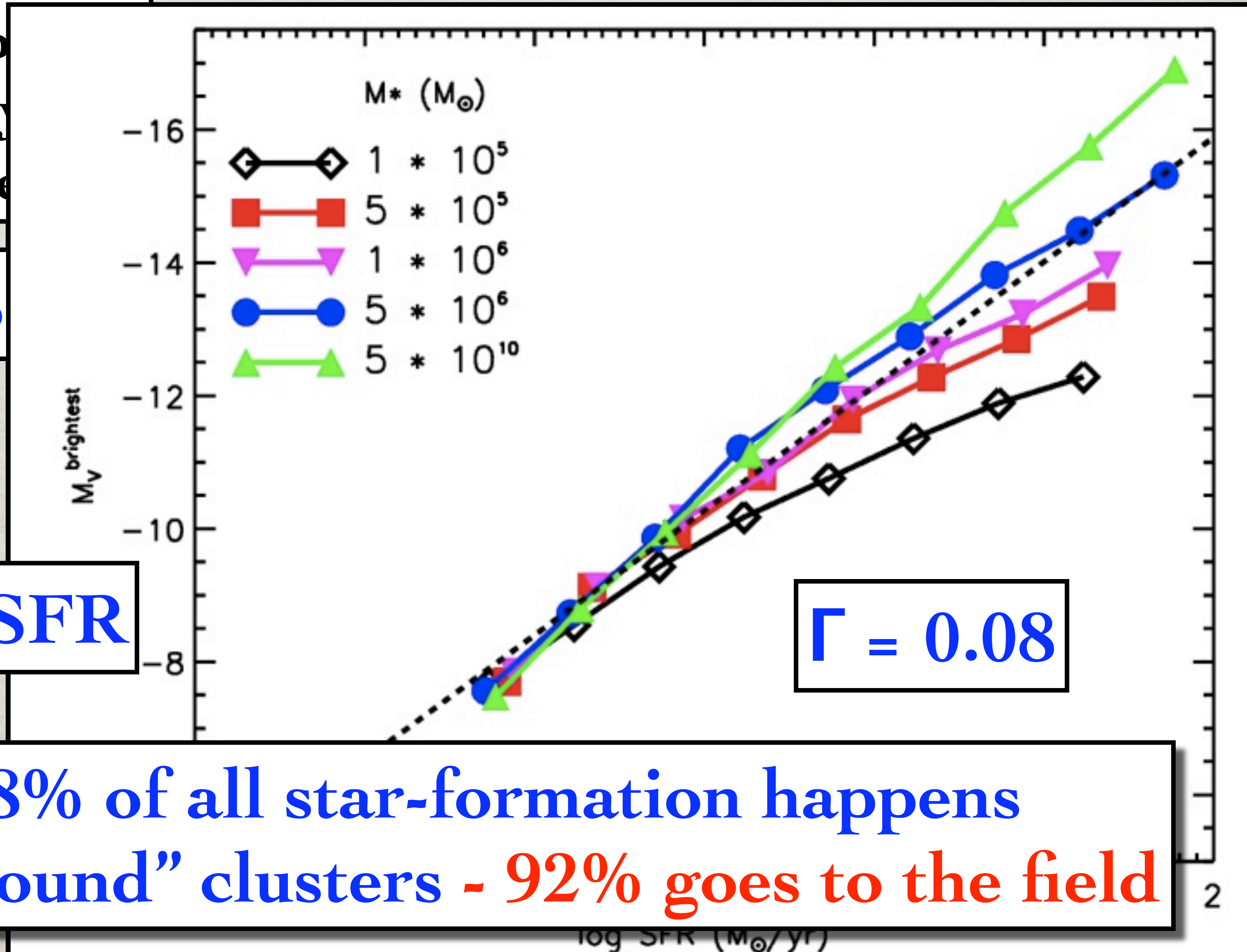


Γ = 0.08

8% of all star-formation happens in “bound” clusters - 92% goes to the field

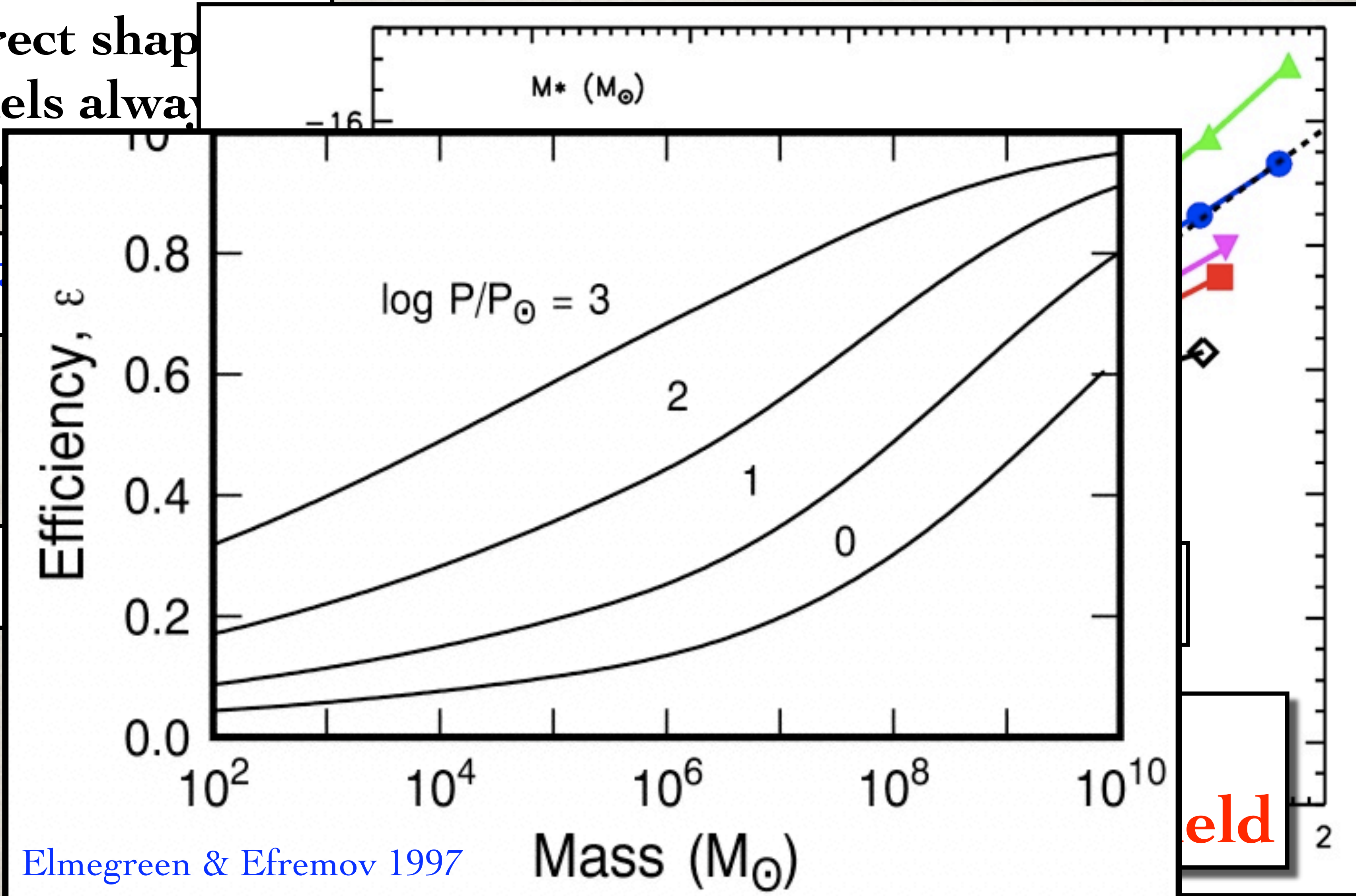
Star Formation Efficiencies

Correct shap
models alwa
the l

CR

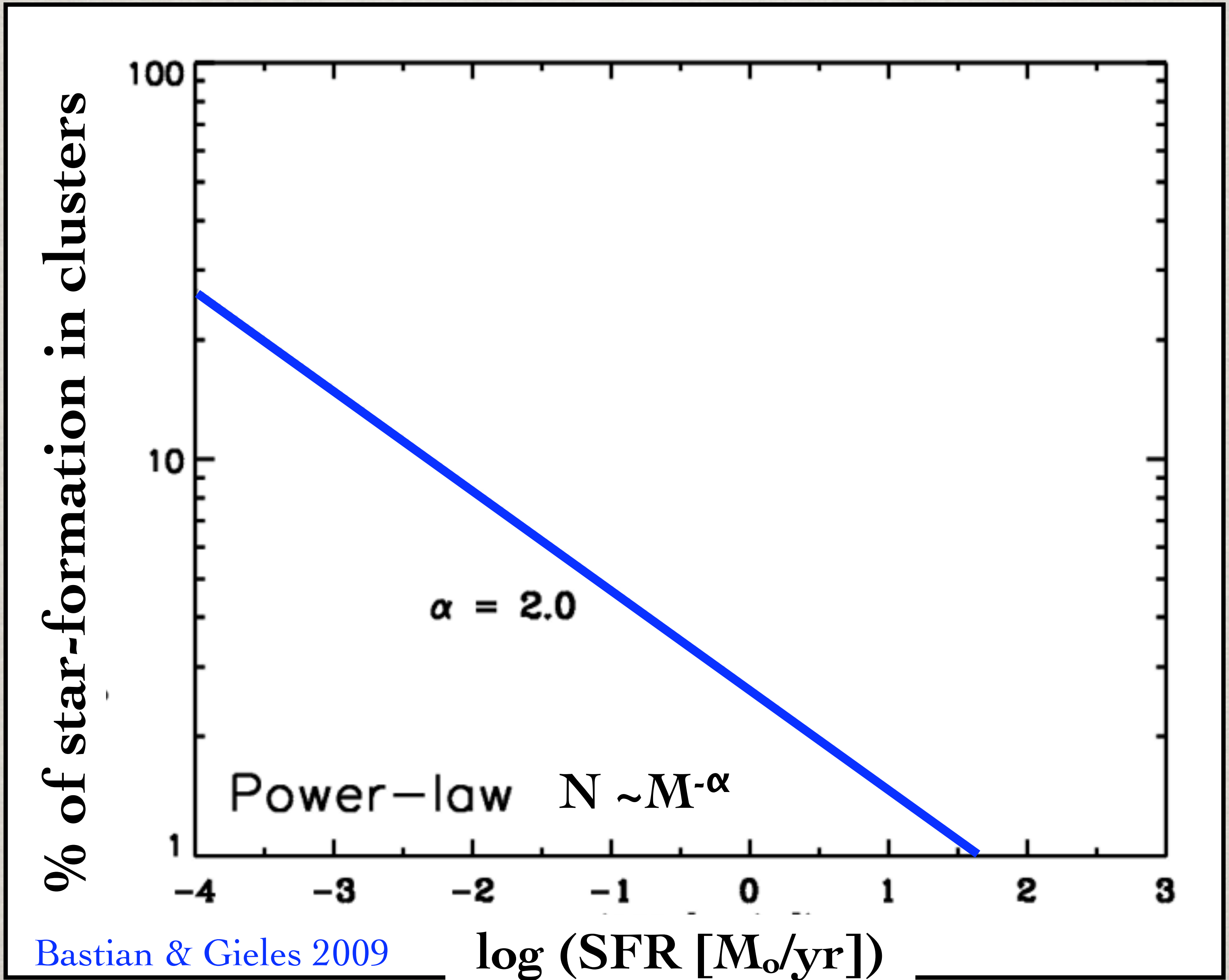
Γ =

eld



Elmegreen & Efremov 1997

Star-formation Efficiency



Bastian & Gieles 2009

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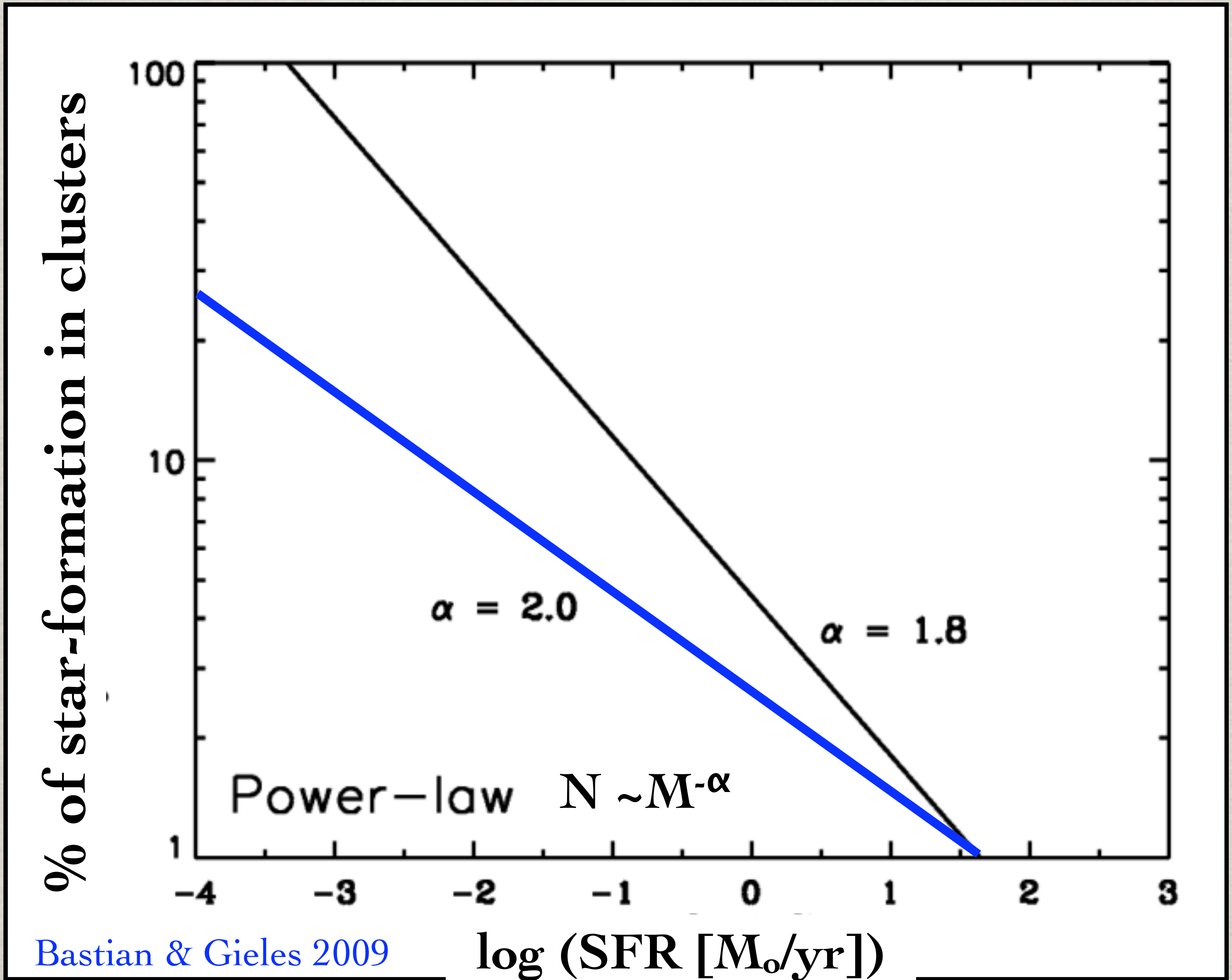

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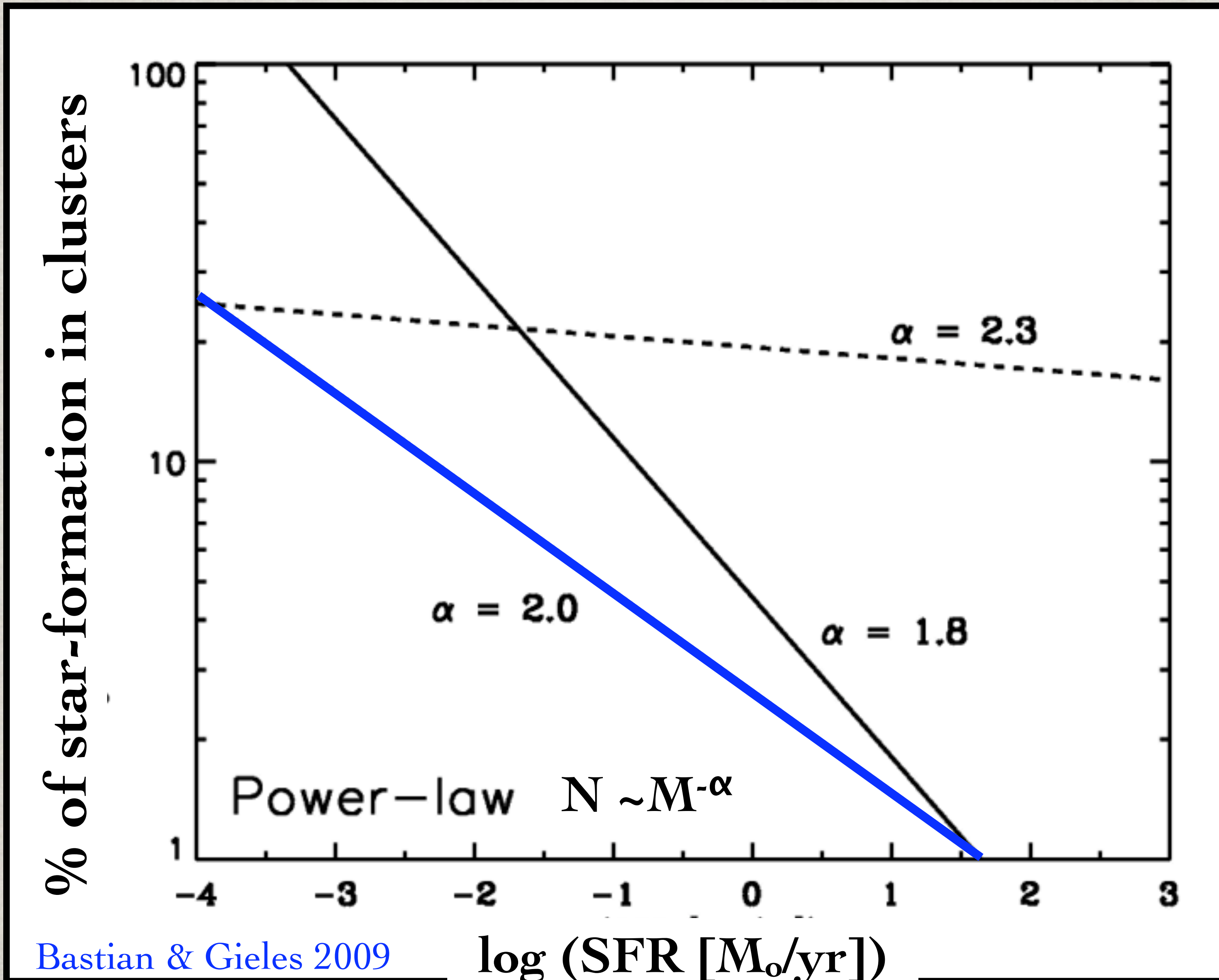
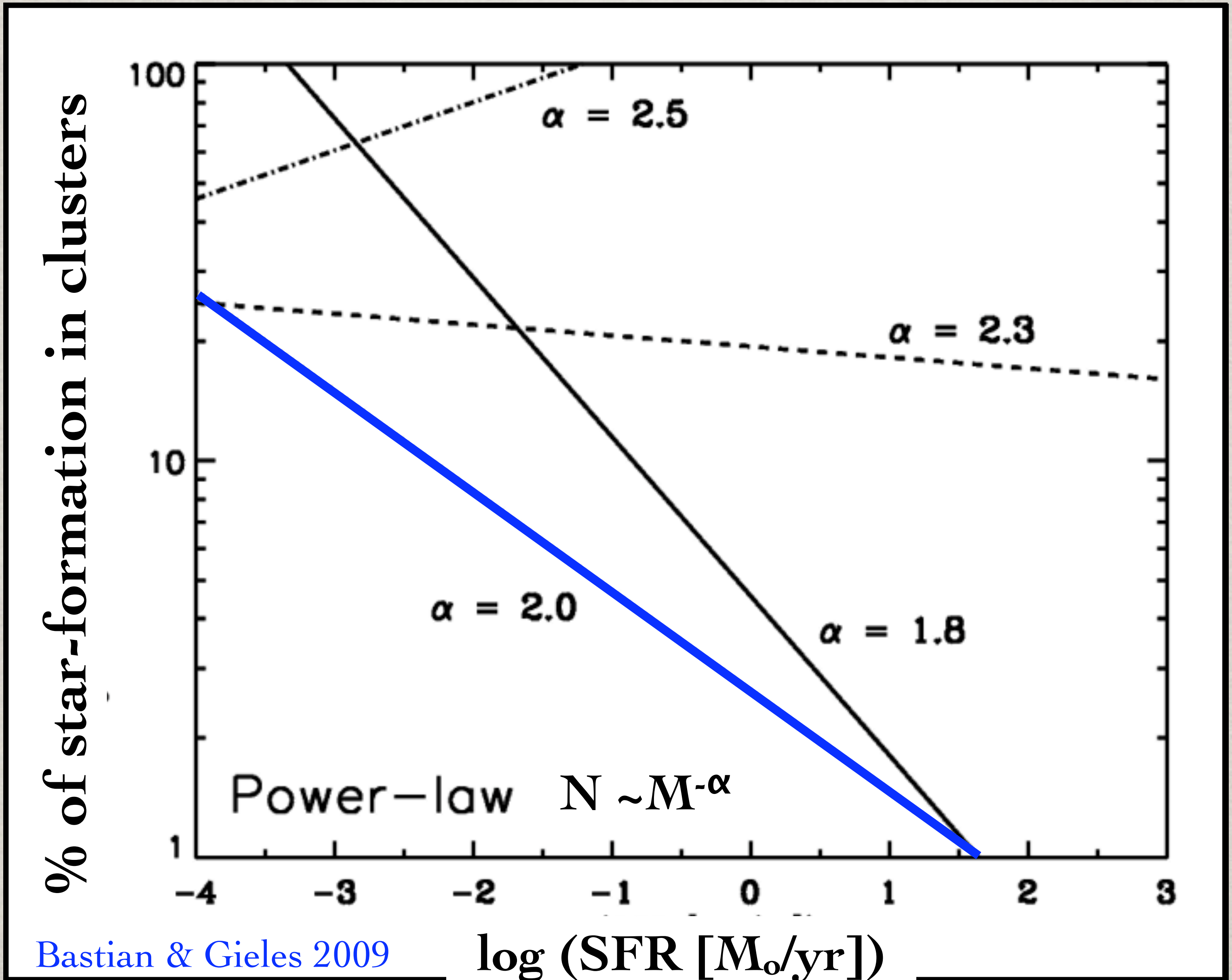


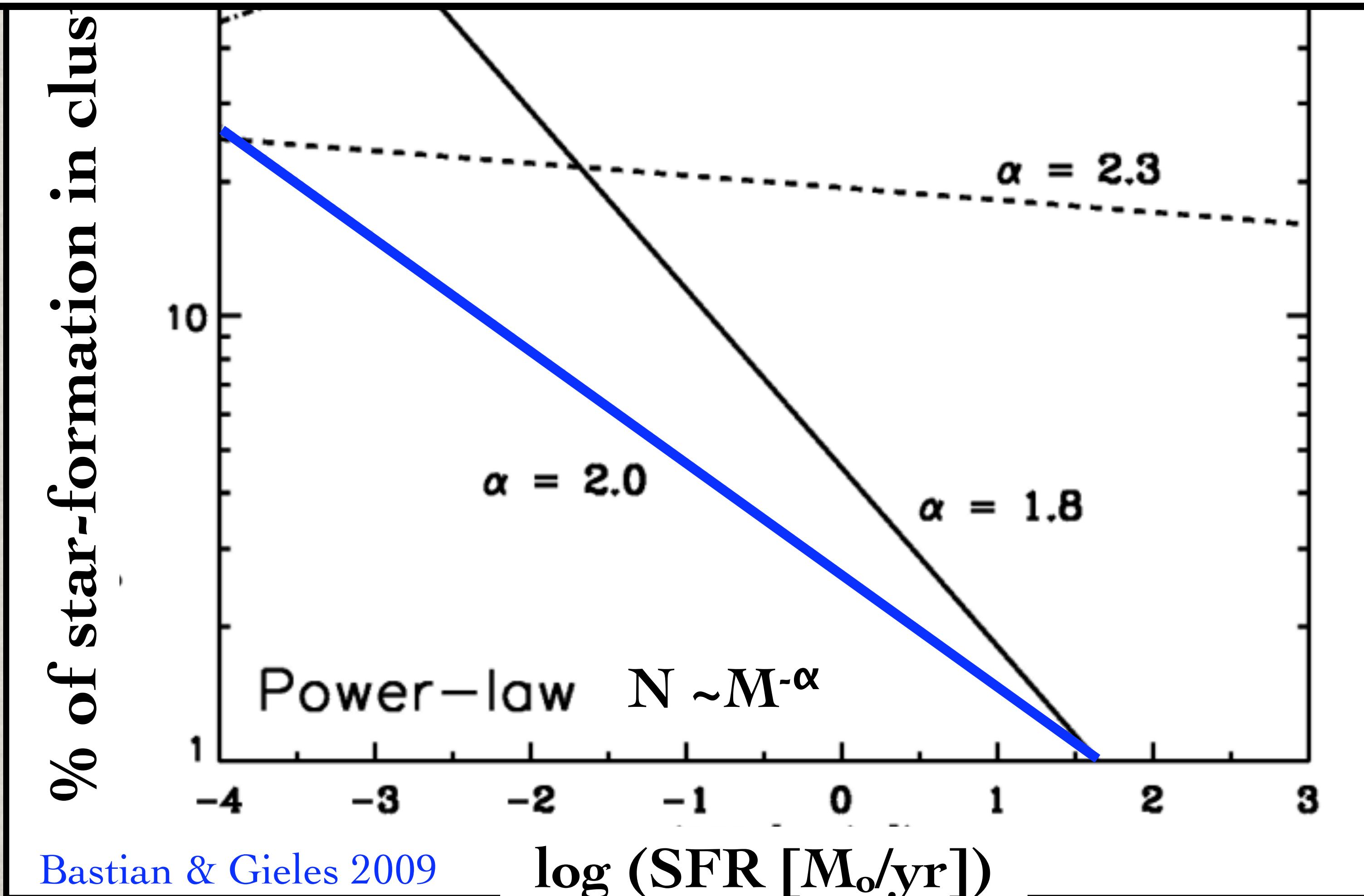
Bastian & Gieles 2009

Star-formation Efficiency



Star-formation Efficiency

if α=2.0: starbursts have *lower* cluster-formation efficiencies than dwarf or spiral galaxies!



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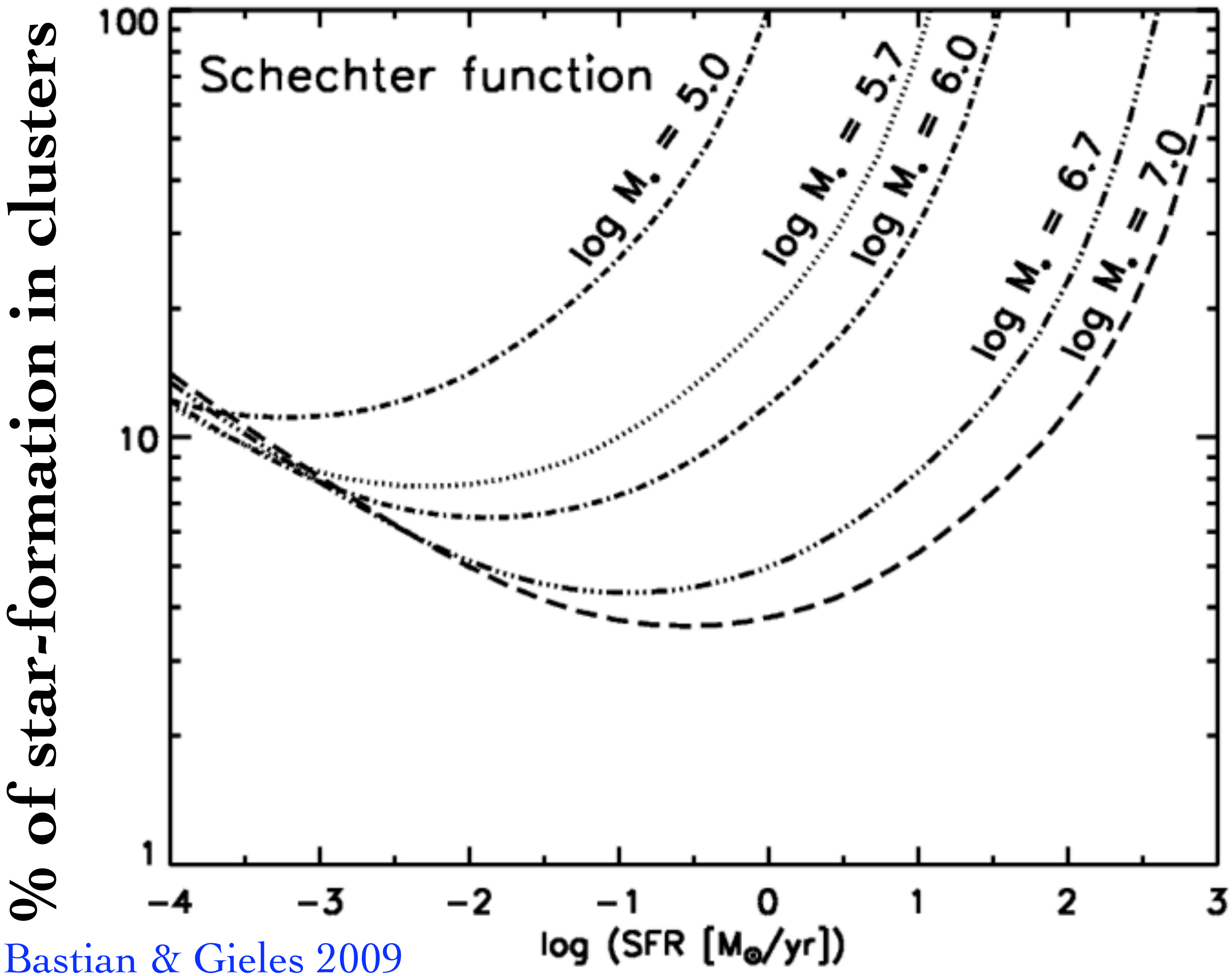

Bastian & Gieles 2009

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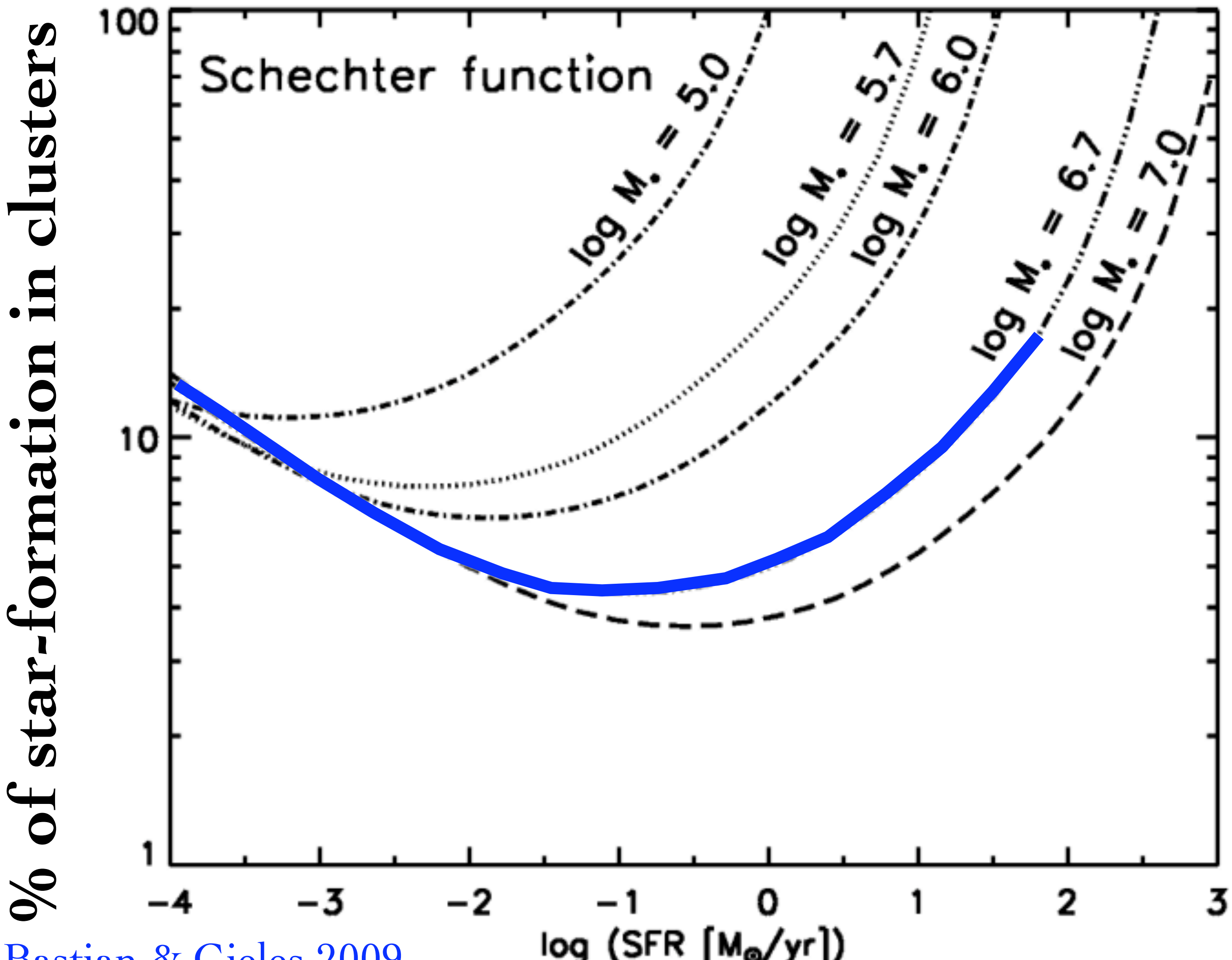

Bastian & Gieles 2009

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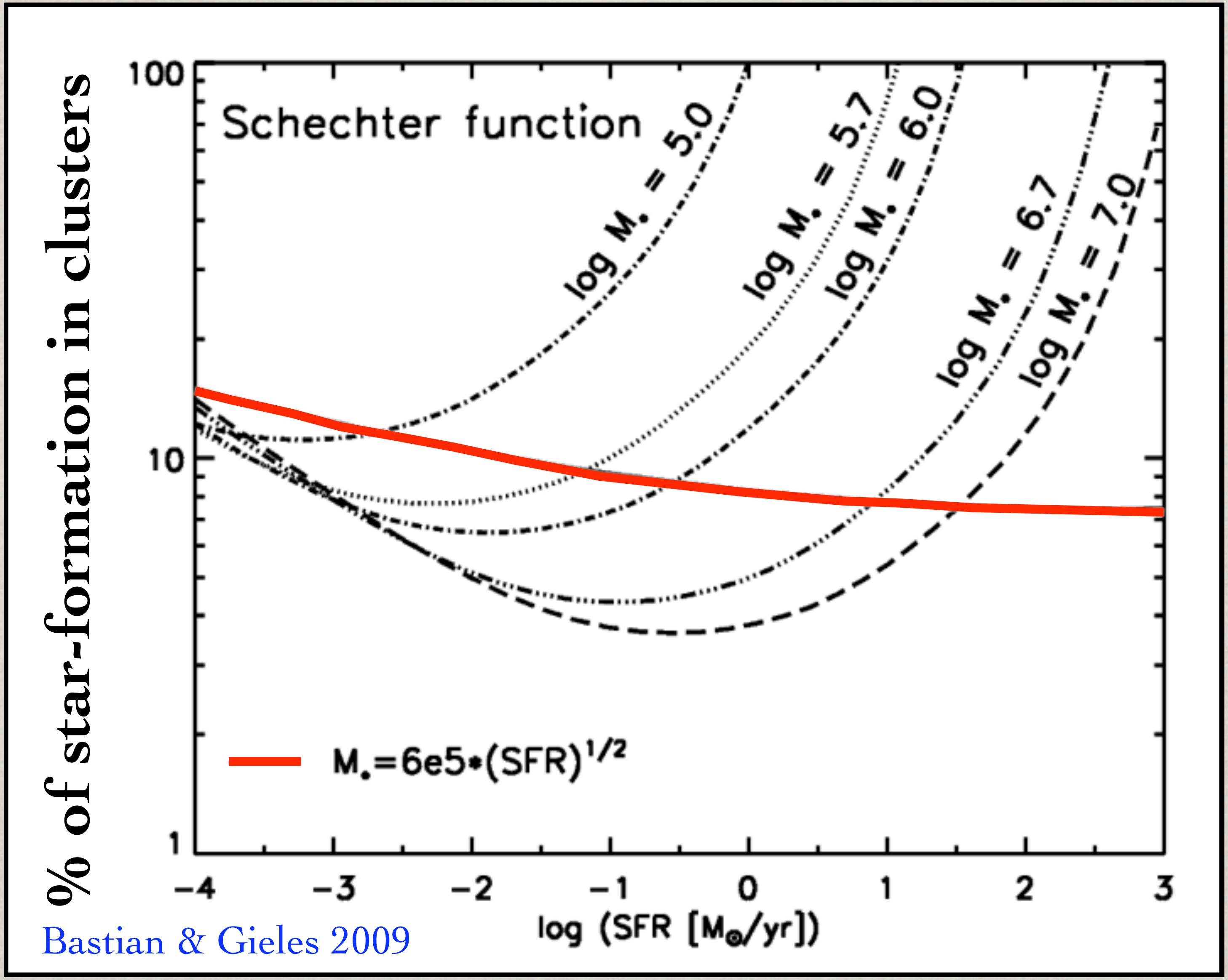

Bastian & Gieles 2009

Star-formation Efficiency Cont...

8 +- 3% of all star-formation occurs in clusters which will survive long enough to become optically selected

- Lada & Lada (2003): 4-7% for the solar neighborhood
- Lamers & Gieles (2007): 5-11% for solar neighborhood
- Gieles & Bastian (2008): 2-4% for the SMC
- Scheepmaker et al. (2009): 5-20% for star forming regions in M51
- Larsen (2008): 4-12% for the Antennae merging galaxies

Star-formation Efficiency Cont...

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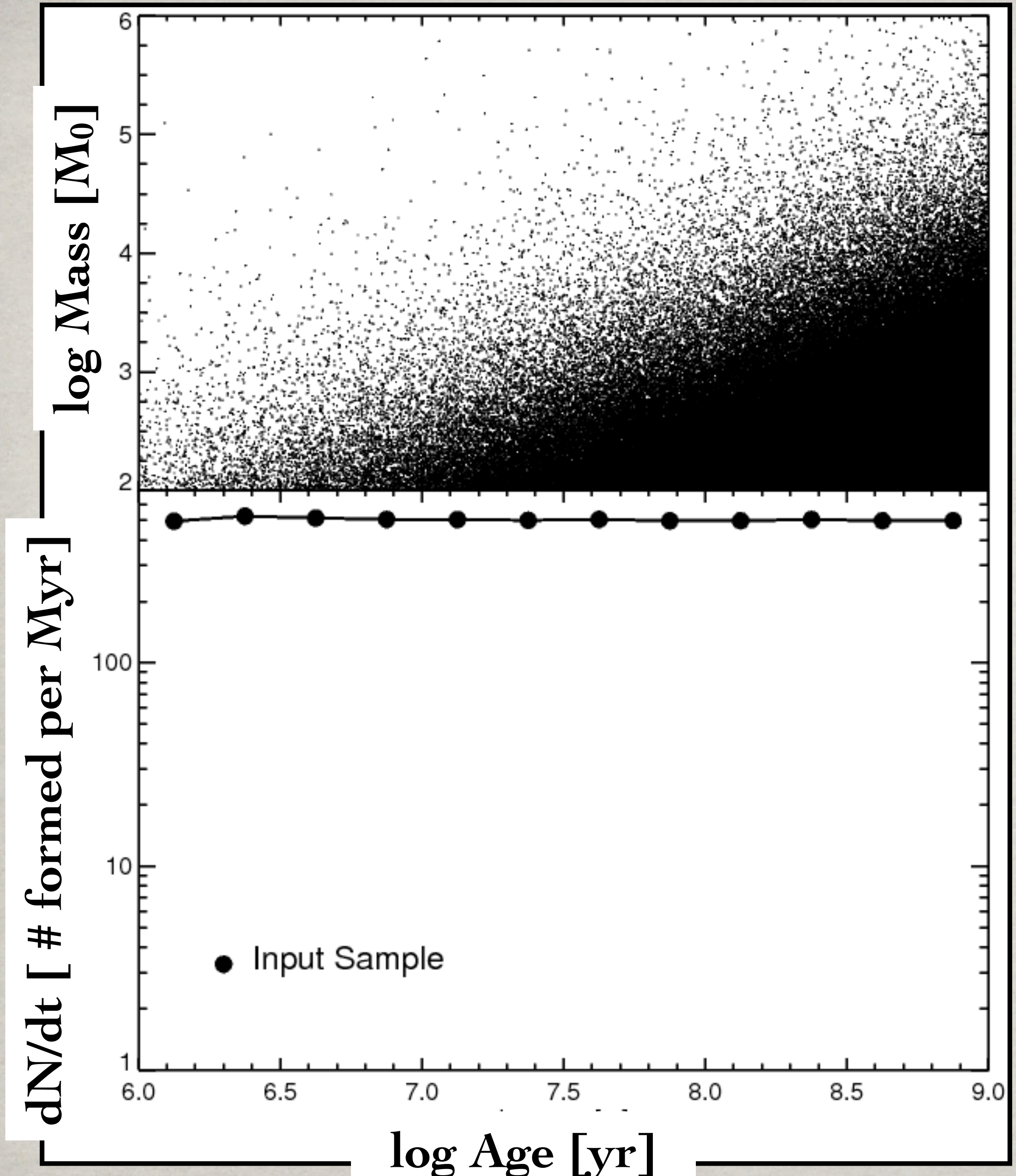
constant fraction: cluster formation accurately reflects star formation

Constraining Cluster Disruption

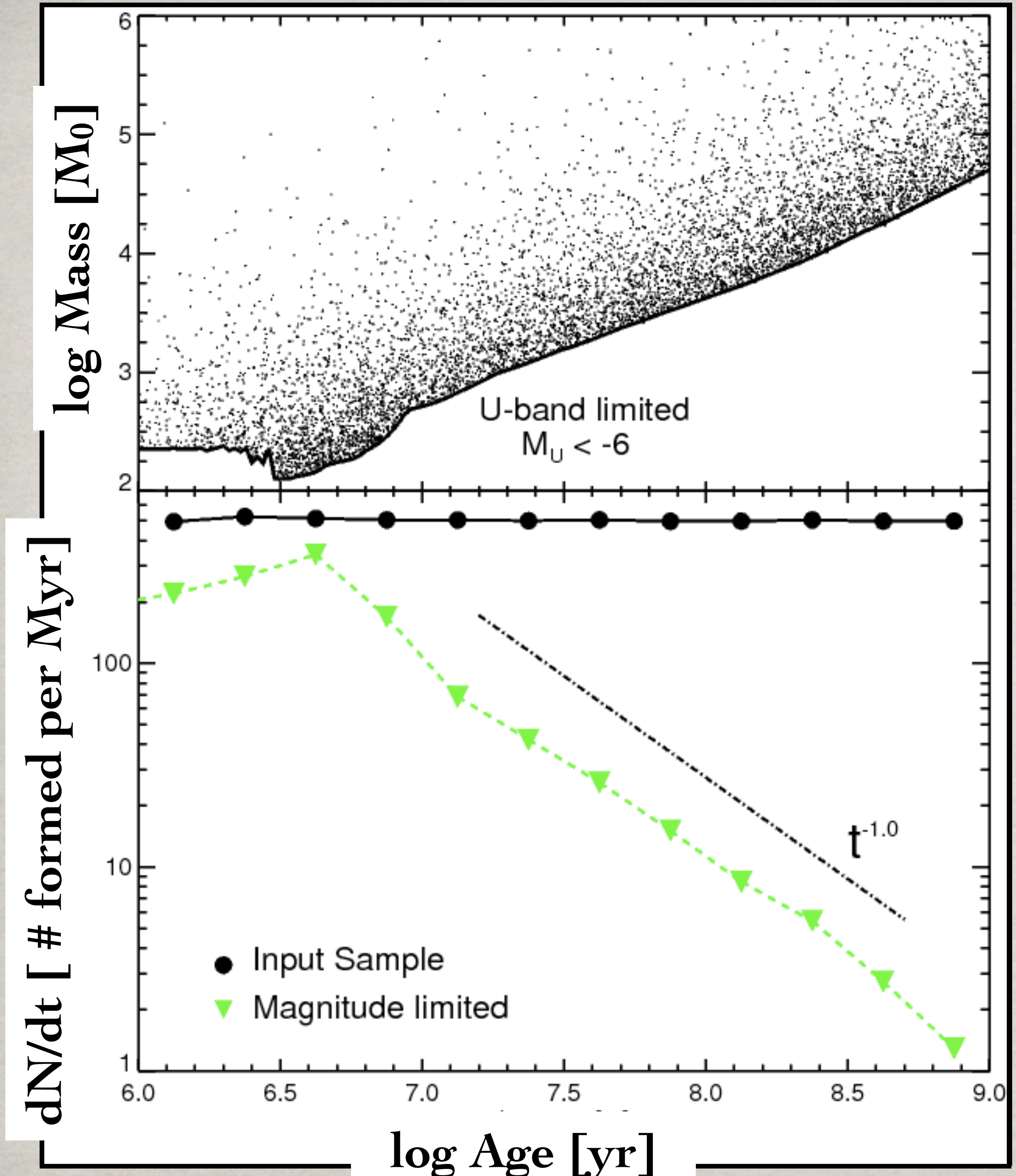
- see my poster....
- Theoretically well understood, mass and tidal field dependence.
- Important in order to use clusters to trace SFH of galaxies
- Observational selection effects can influence results

1) *M*ass dependent disruption (e.g. Lamers et al. 2005)

2) *M*ass independent disruption (MID: Fall et al. 2005)

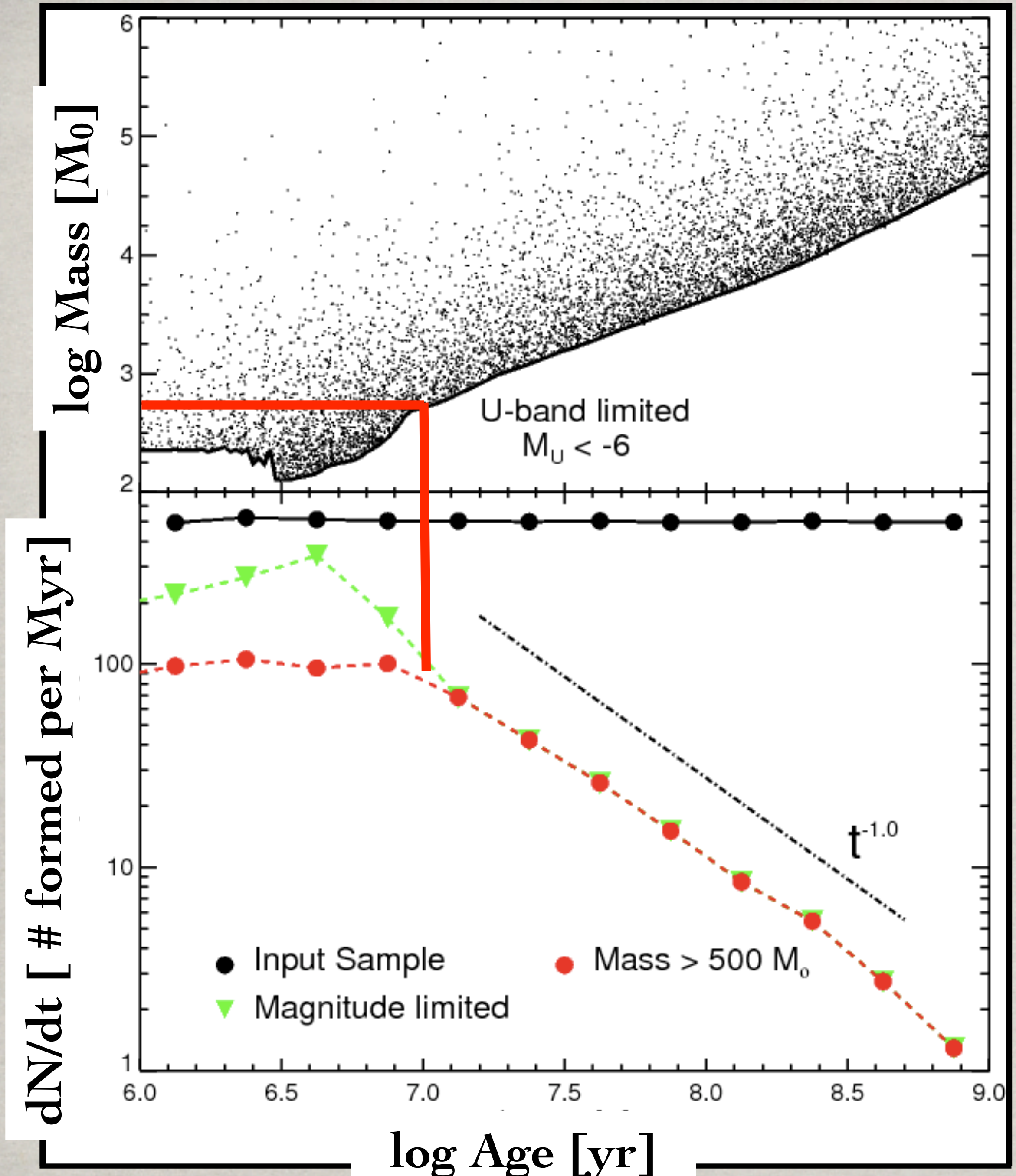


input constant SFR



input constant SFR

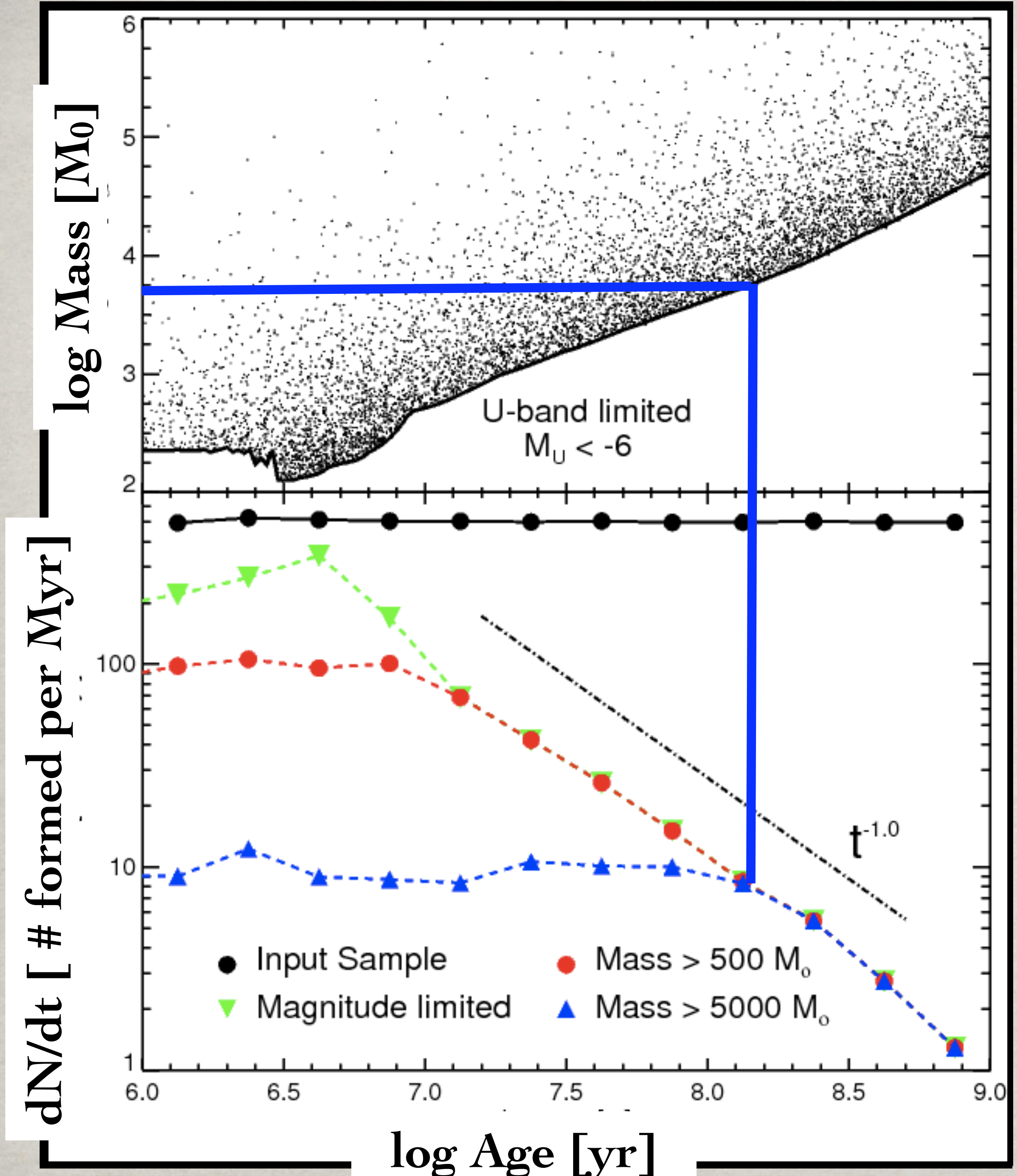
apply 'observational' detection limits



input constant SFR

apply 'observational' detection limits

apply mass cut



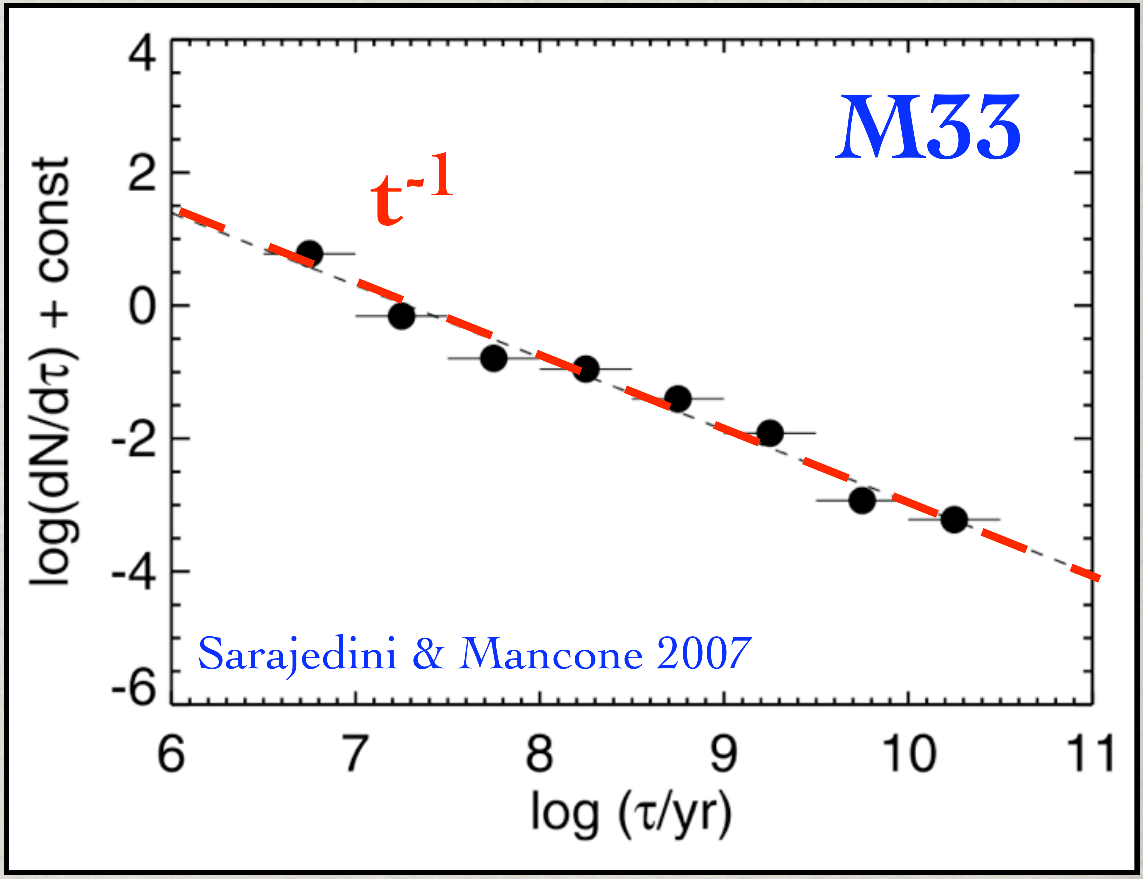
input constant SFR

apply 'observational' detection limits

apply mass cut

apply higher mass cut

Observed Cluster Populations



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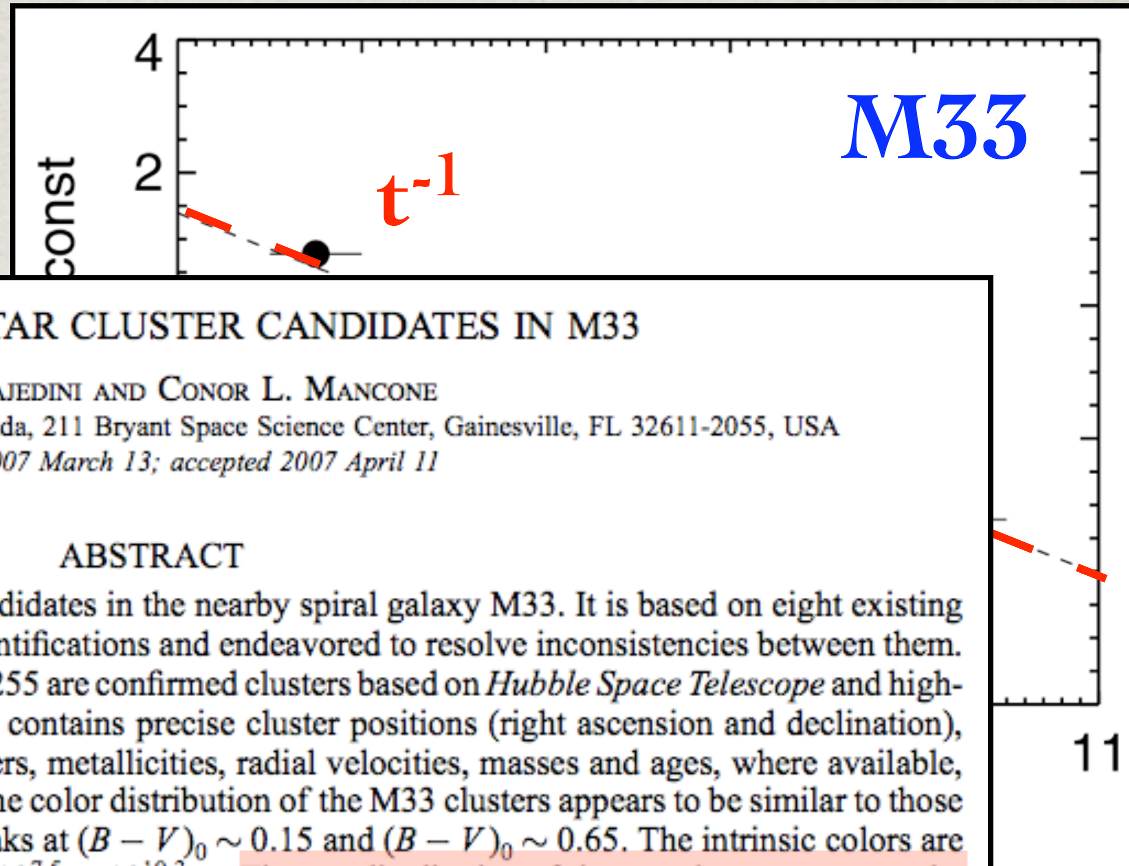


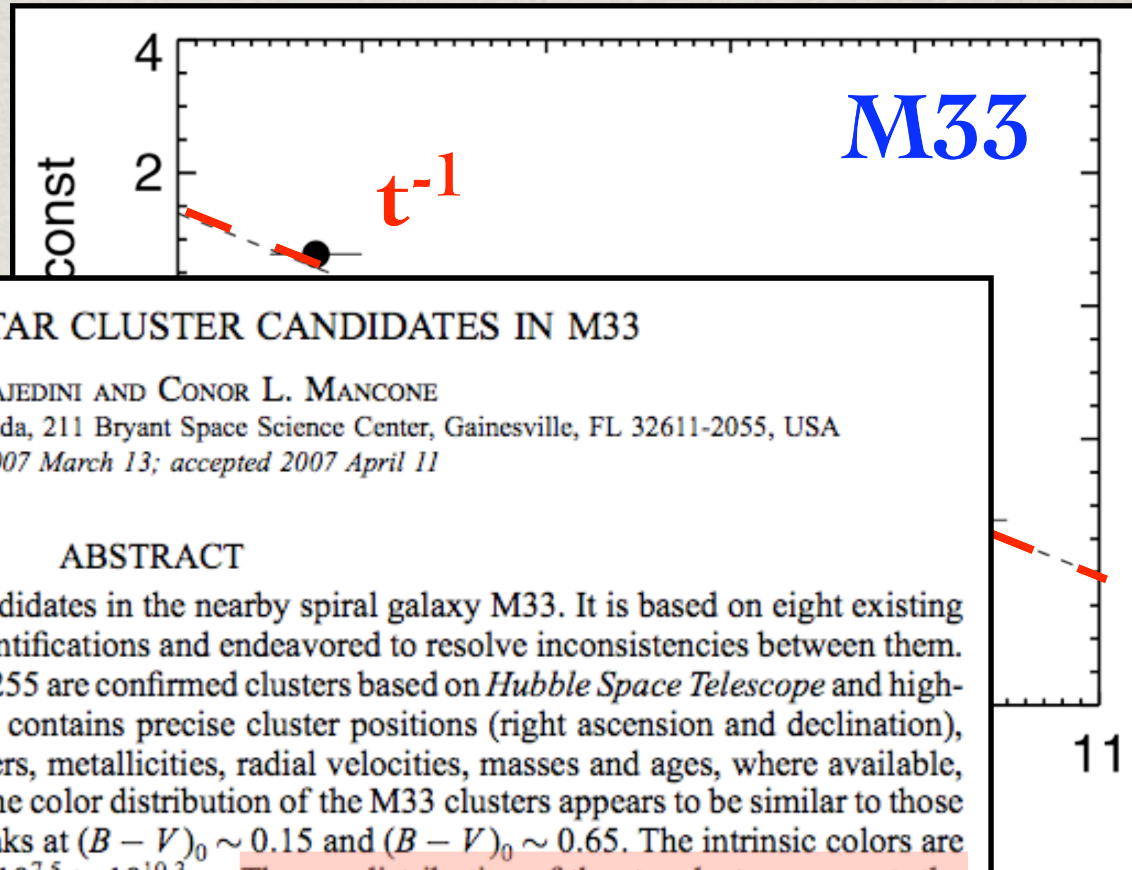
A CATALOG OF STAR CLUSTER CANDIDATES IN M33

Ata Sarajedini and Conor L. Mancone
Department of Astronomy, University of Florida, 211 Bryant Space Science Center, Gainesville, FL 32611-2055, USA
Received 2007 March 13; accepted 2007 April 11

ABSTRACT

We present a new catalog of star cluster candidates in the nearby spiral galaxy M33. It is based on eight existing catalogs wherein we have cross-referenced identifications and endeavored to resolve inconsistencies between them. Our catalog contains 451 candidates, of which 255 are confirmed clusters based on *Hubble Space Telescope* and high-resolution ground-based imaging. The catalog contains precise cluster positions (right ascension and declination), magnitudes and colors in the $UBVRIJHK_S$ filters, metallicities, radial velocities, masses and ages, where available, and galactocentric distances for each cluster. The color distribution of the M33 clusters appears to be similar to those in the Large Magellanic Cloud, with major peaks at $(B-V)_0 \sim 0.15$ and $(B-V)_0 \sim 0.65$. The intrinsic colors are correlated with cluster ages, which range from $10^{7.5}$ to $10^{10.3}$ yr. The age distribution of the star clusters supports the notion of rapid cluster disruption with a slope of $\alpha = -1.09 \pm 0.07$ in the $dN_{\rm clus}/d\tau \propto \tau^{\alpha}$ relation. In addition, comparison to theoretical single stellar population models suggests the presence of an age-metallicity relation among these clusters, with younger clusters being more metal-rich. Analysis of the radial distribution of the clusters yields some evidence that younger clusters (age $\lesssim$1 Gyr) may be more concentrated toward the center of M33 than older ones. A similar comparison with the radial profile of the M33 field stars shows the clusters to be more centrally concentrated at the greater than 99.9% confidence level. Possible reasons for this are presented and discussed; however, the overwhelming conclusion seems to be that a more complete and thorough cluster search is needed, covering at least 4 deg^2 centered on M33.

Observed Cluster Populations



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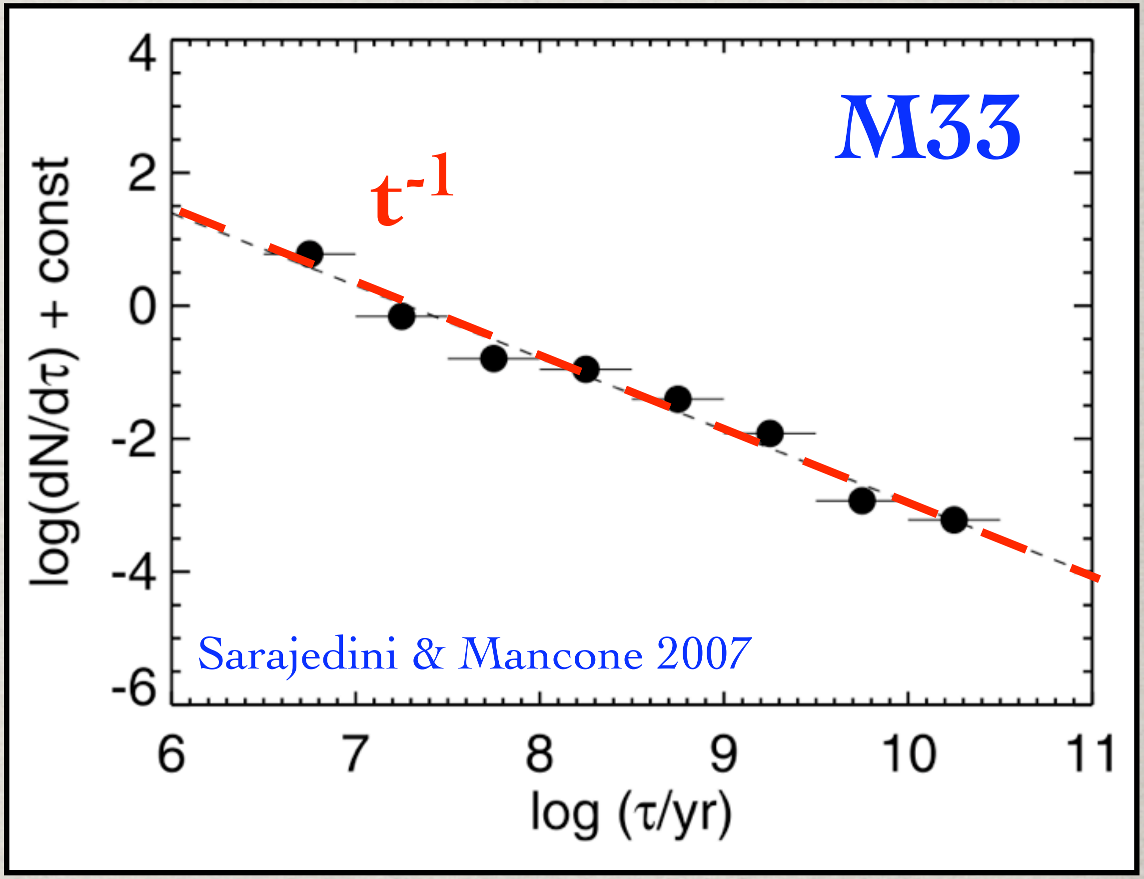
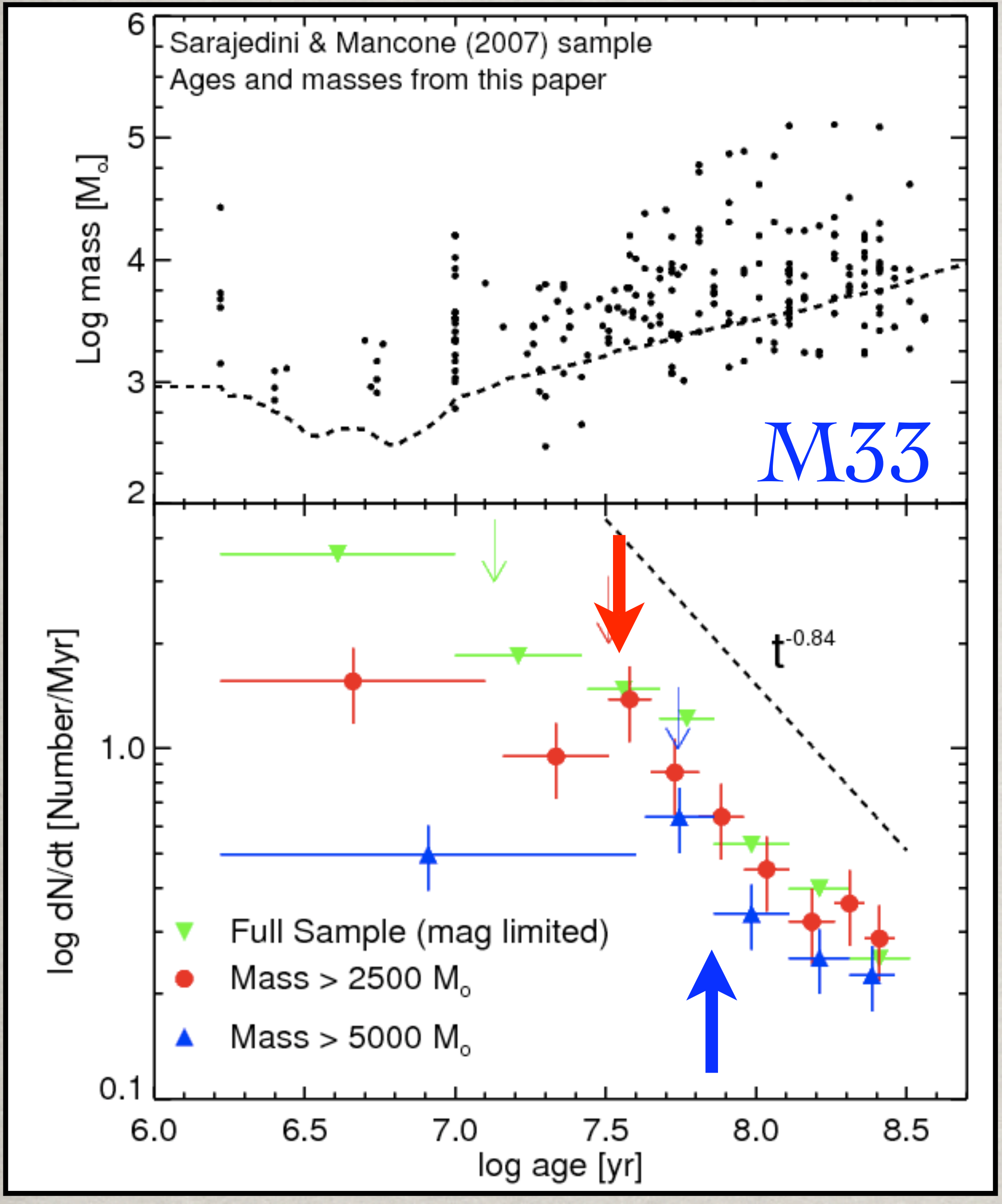
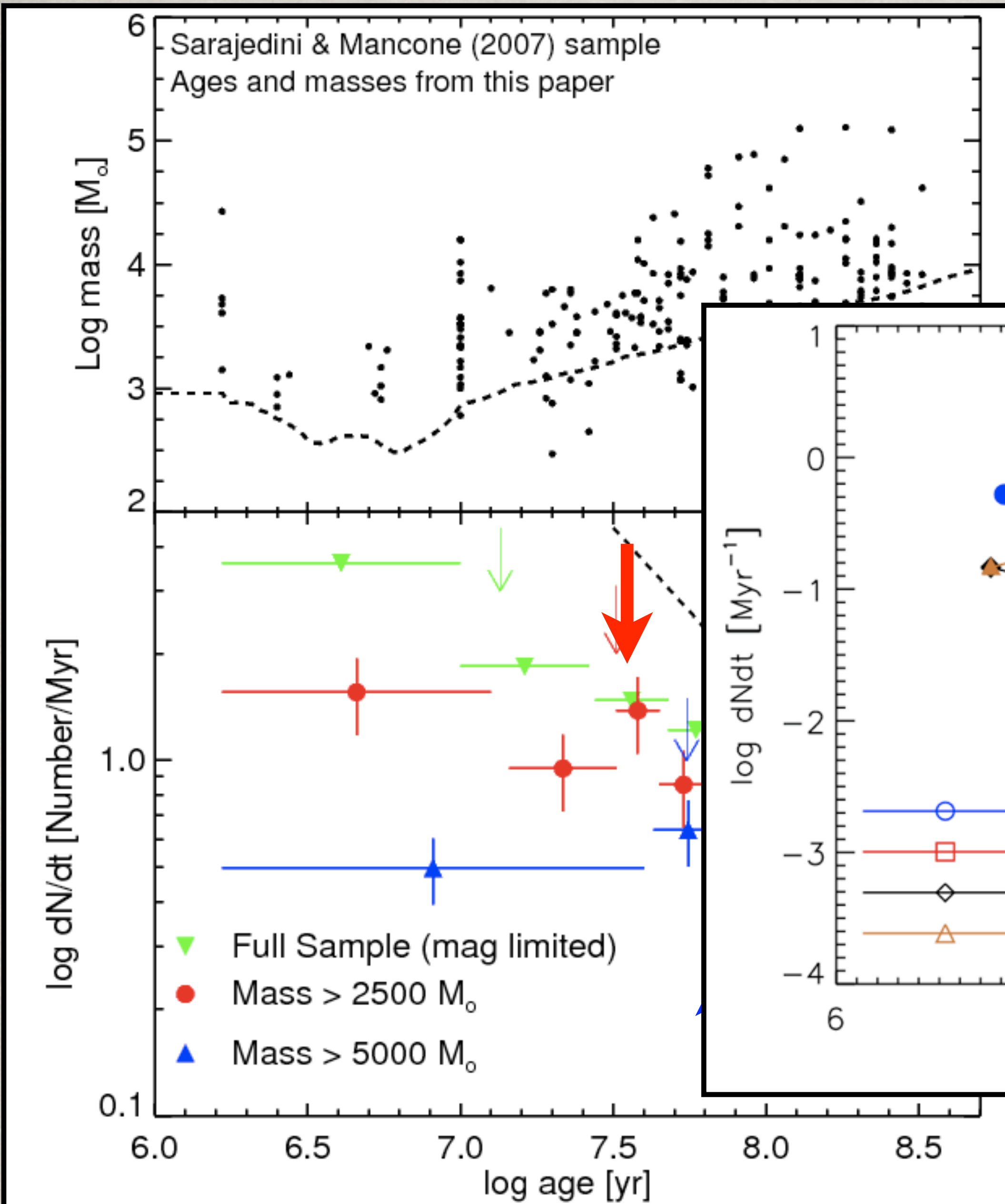
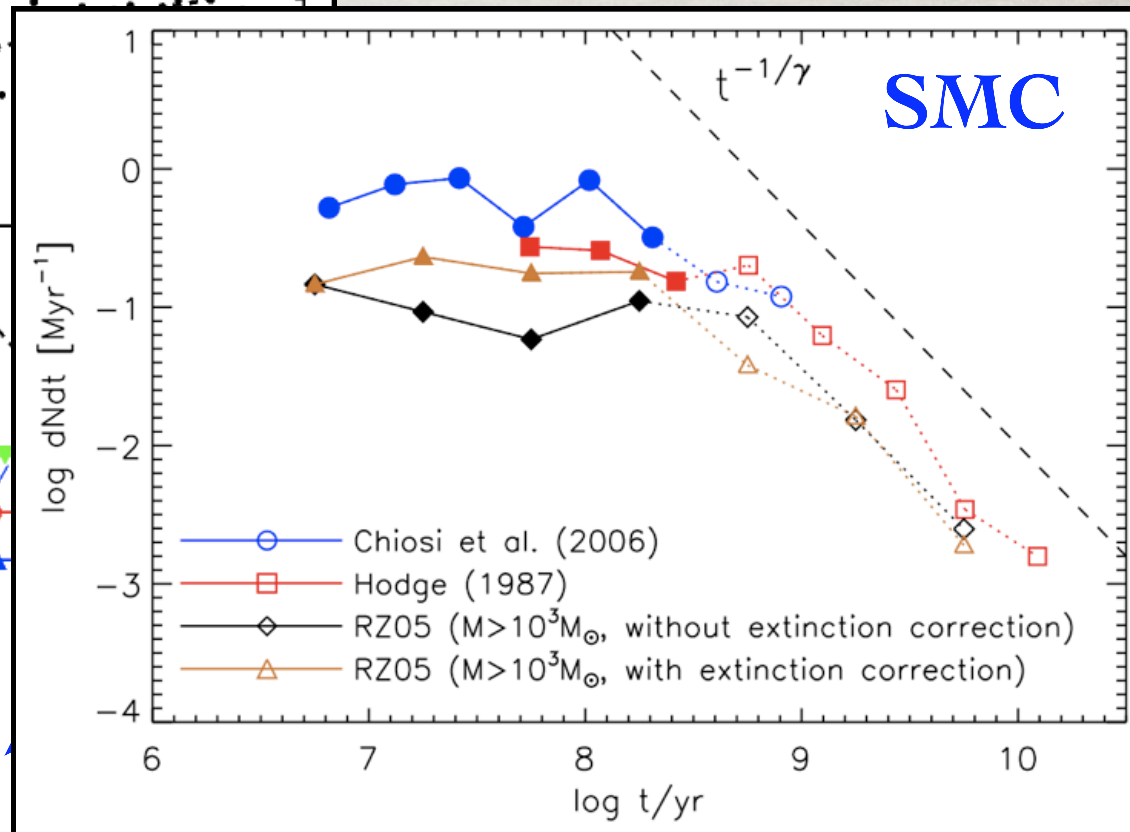




Konstantopoulos, Bastian, Gieles 2009

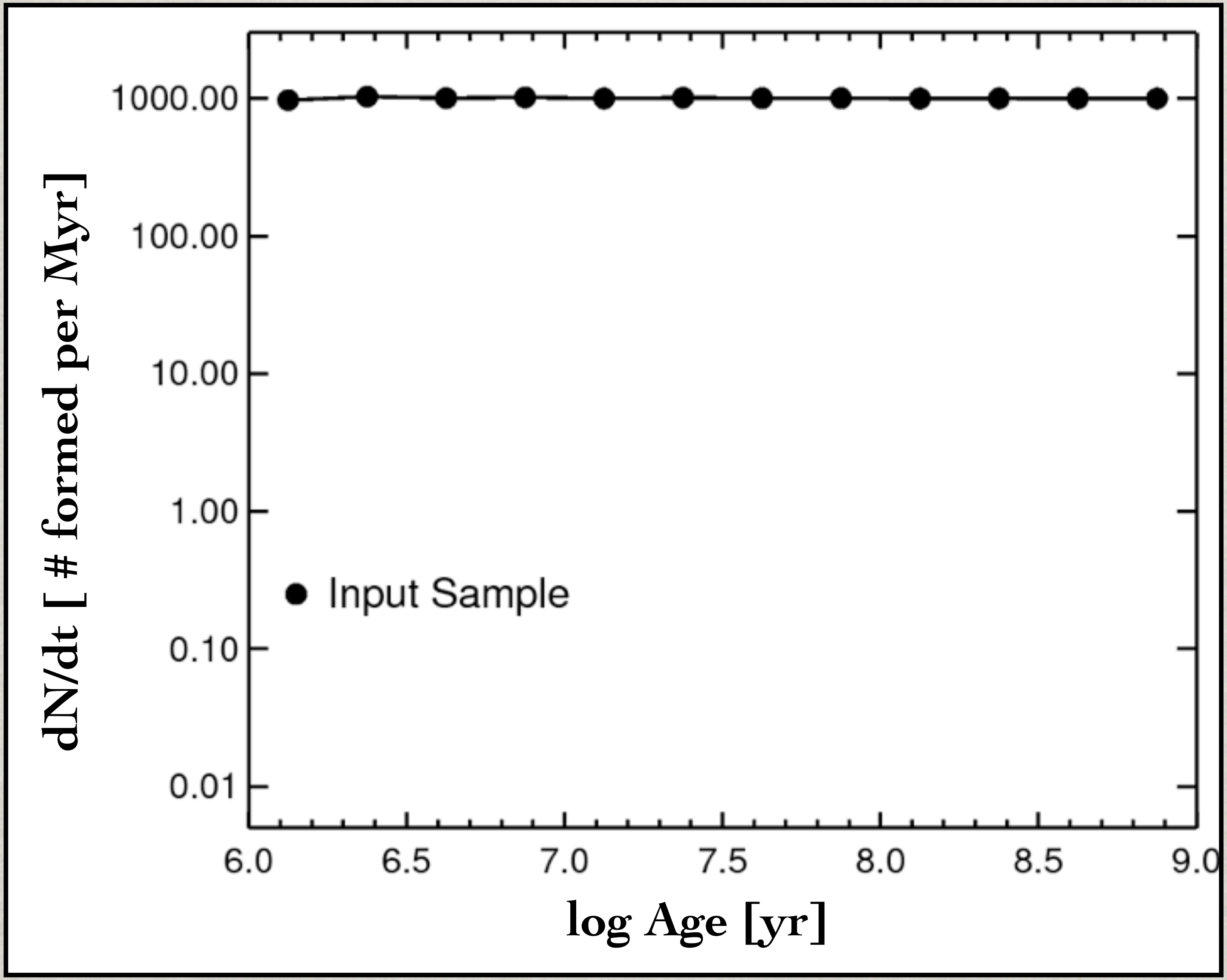


Konstantopoulos, Bastian, Gieles 2009

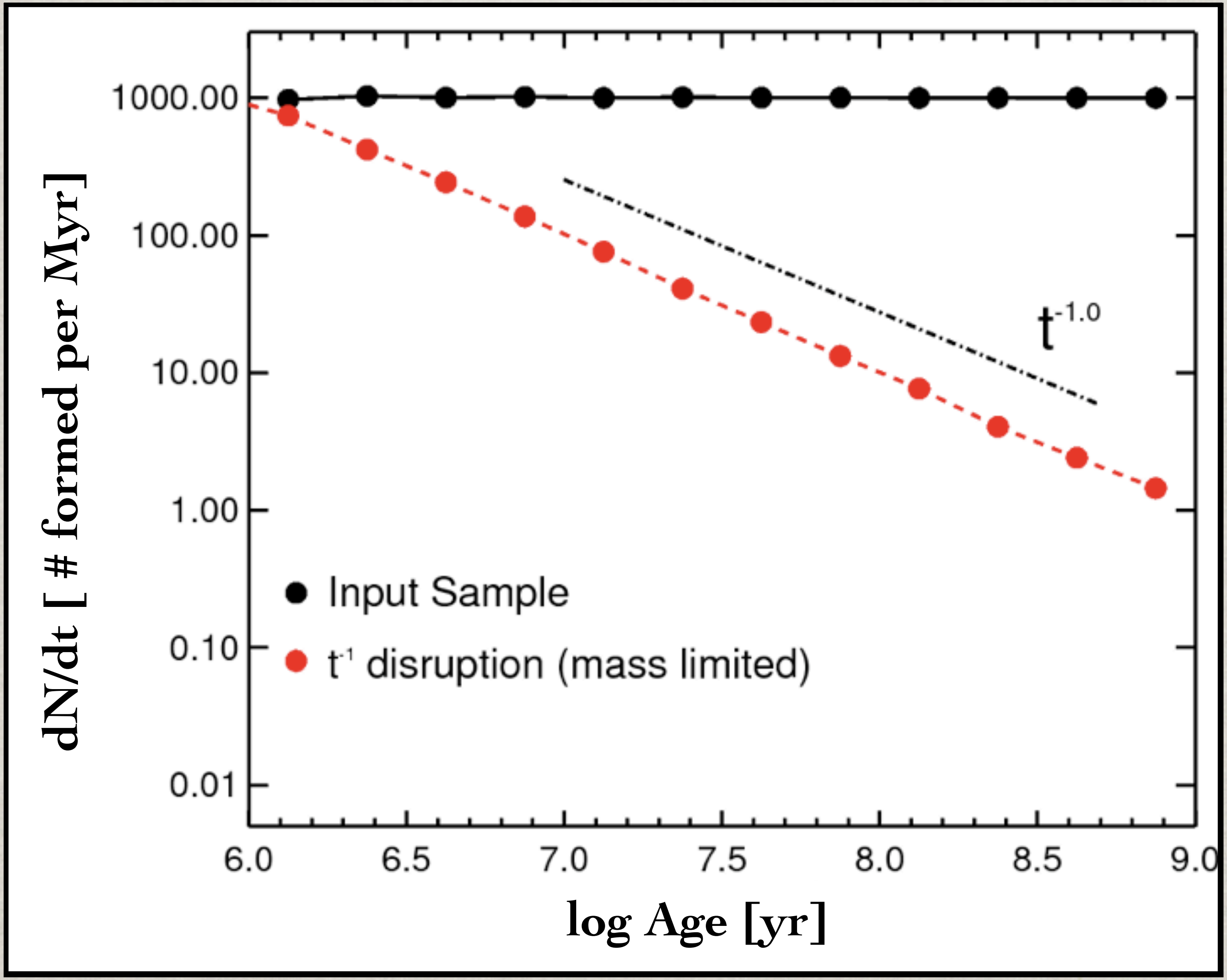


Gieles 2007

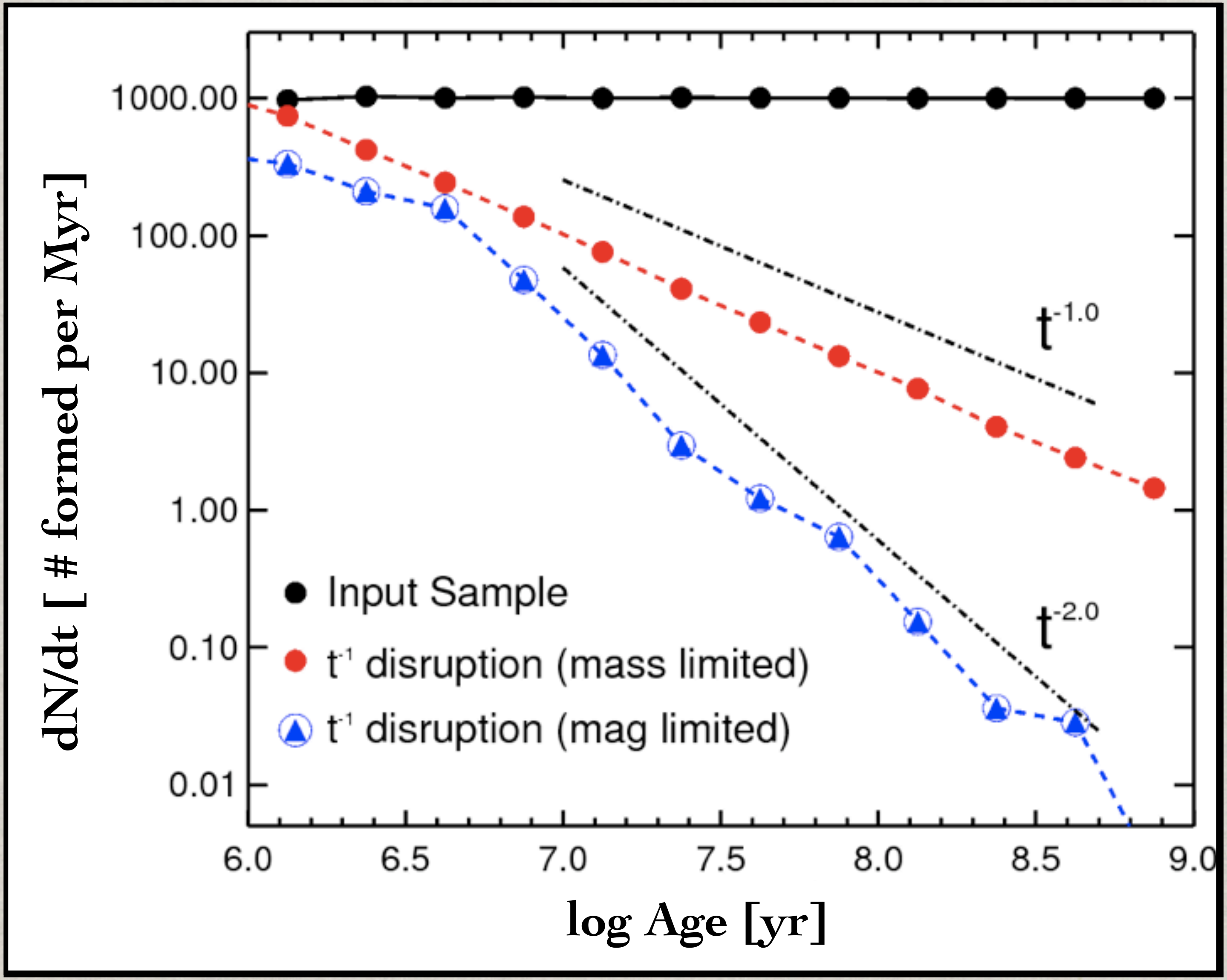
Age Distributions: T^{-1} disruption law



Age Distributions: t^{-1} disruption law



Age Distributions: t^{-1} disruption law



Conclusions

- The mass function of clusters is best described by a Schechter function (not a pure power-law)
- 8+-3% of all star-formation happens in "bound clusters"
  → cluster formation traces star formation
- Star/cluster formation is independent of environment and metallicity ([Fe/H] > -1.6)
- One mode of star/cluster formation over 6 orders of magnitude in the SFR
- incompleteness gives t^{-1} age distribution. need to check mass and luminosity limited sample for consistency