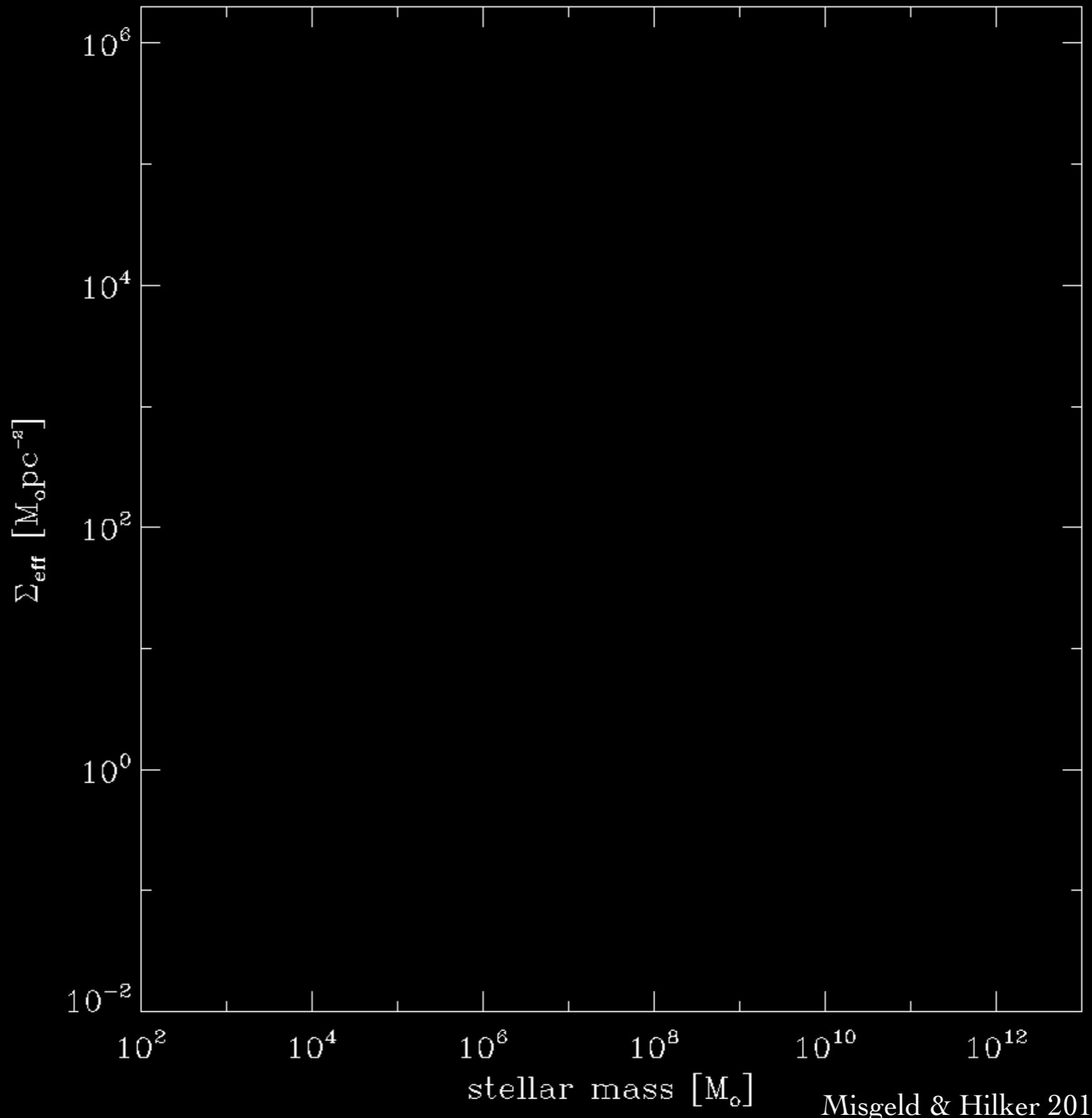


THE FUNDAMENTAL PLANE AND DYNAMICS OF YOUNG MASSIVE CLUSTERS

N A T E B A S T I A N
E X C E L L E N C E C L U S T E R , G A R C H I N G

OUTLINE

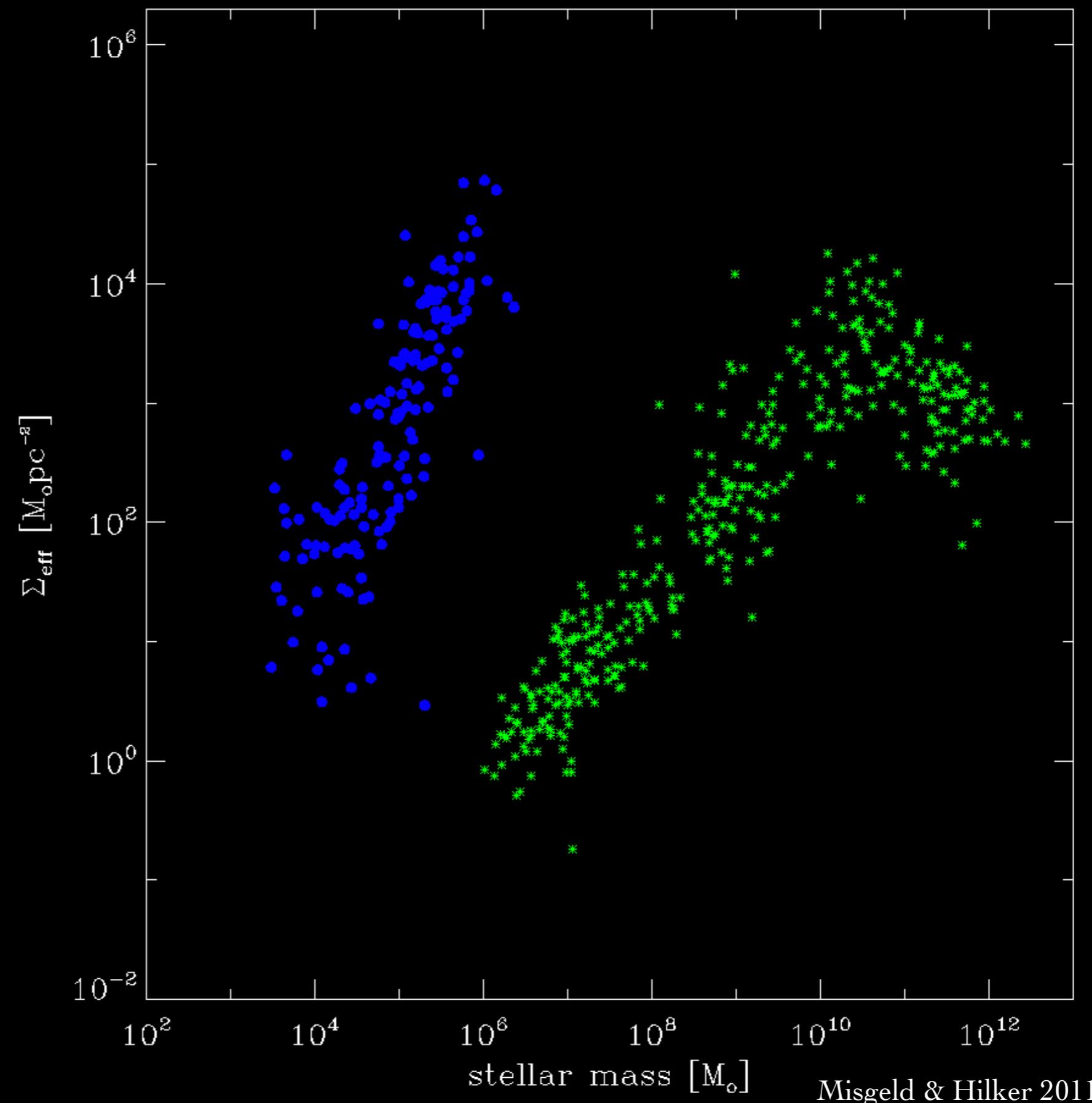
- ✿ The relation of young massive clusters (YMCs) to other hot dynamical systems - the fundamental plane
- ✿ Constraints on the stellar IMF within clusters
- ✿ Defining a cluster dynamically
- ✿ The evolution of massive clusters - cluster disruption



Misgeld & Hilker 2011

Galactic Globular
Clusters

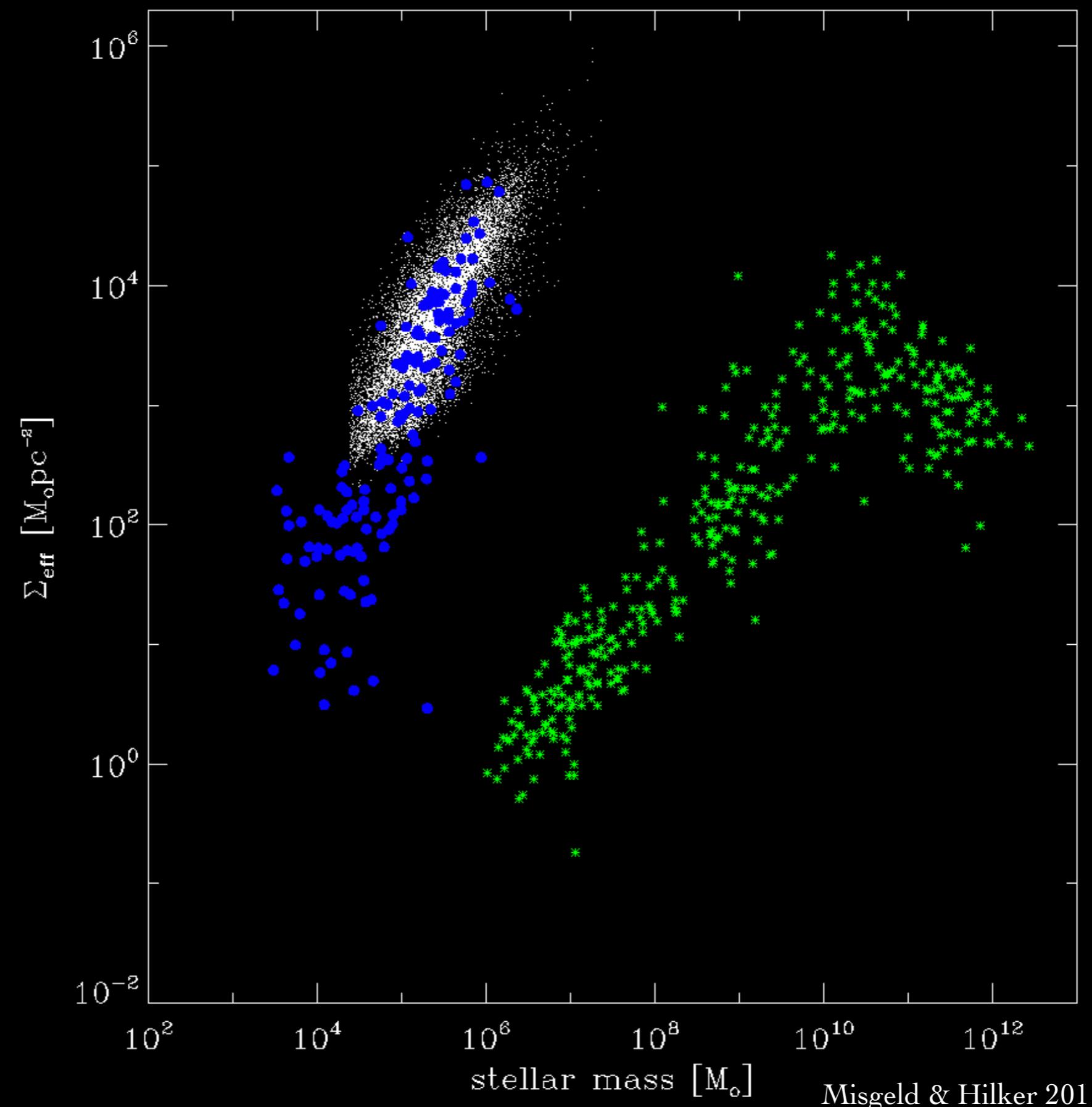
Dwarf and elliptical
galaxies



Galactic Globular
Clusters

Dwarf and elliptical
galaxies

Virgo globular
clusters

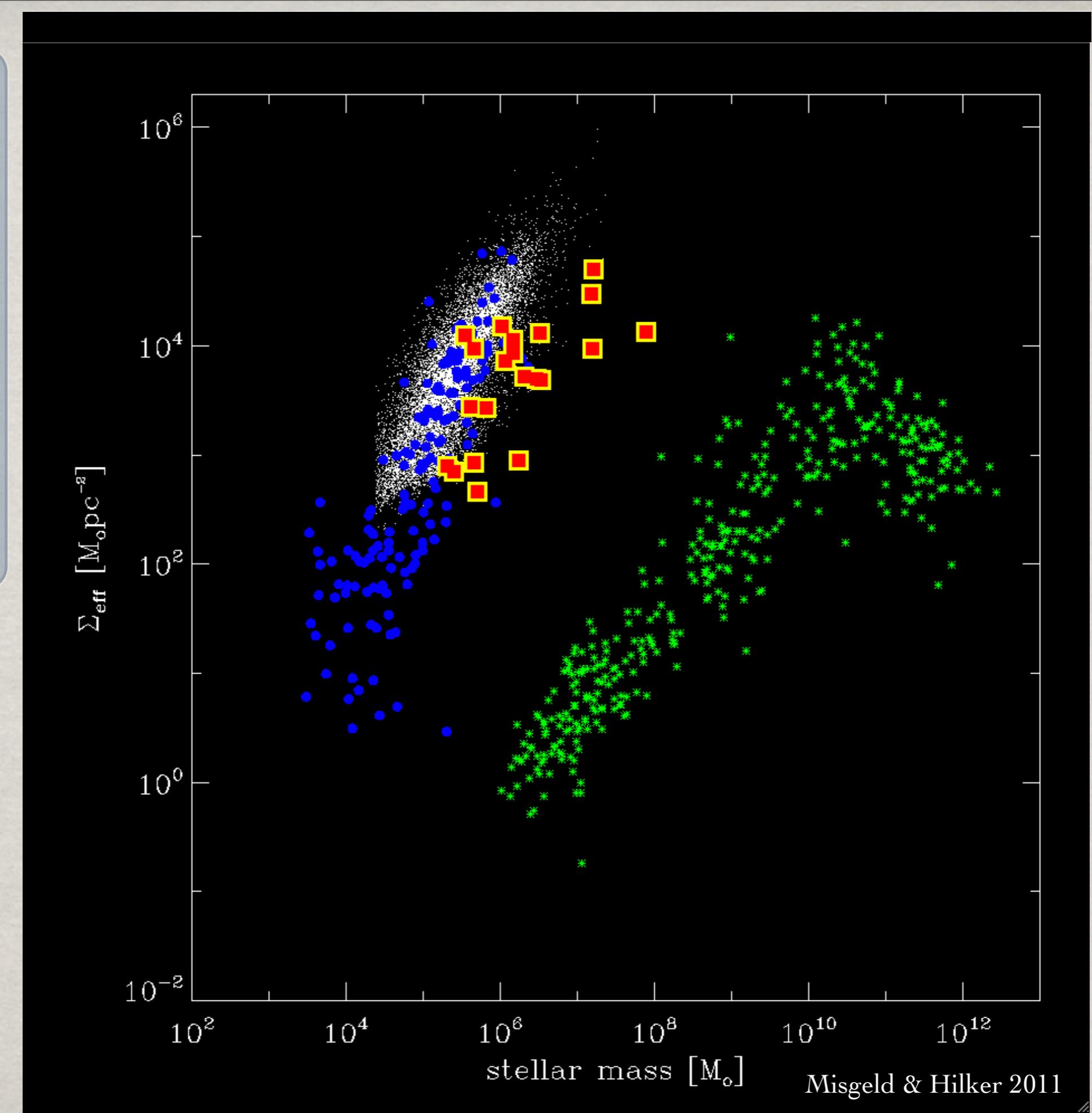


Galactic Globular
Clusters

Dwarf and elliptical
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Virgo globular
clusters

Young Massive
Clusters



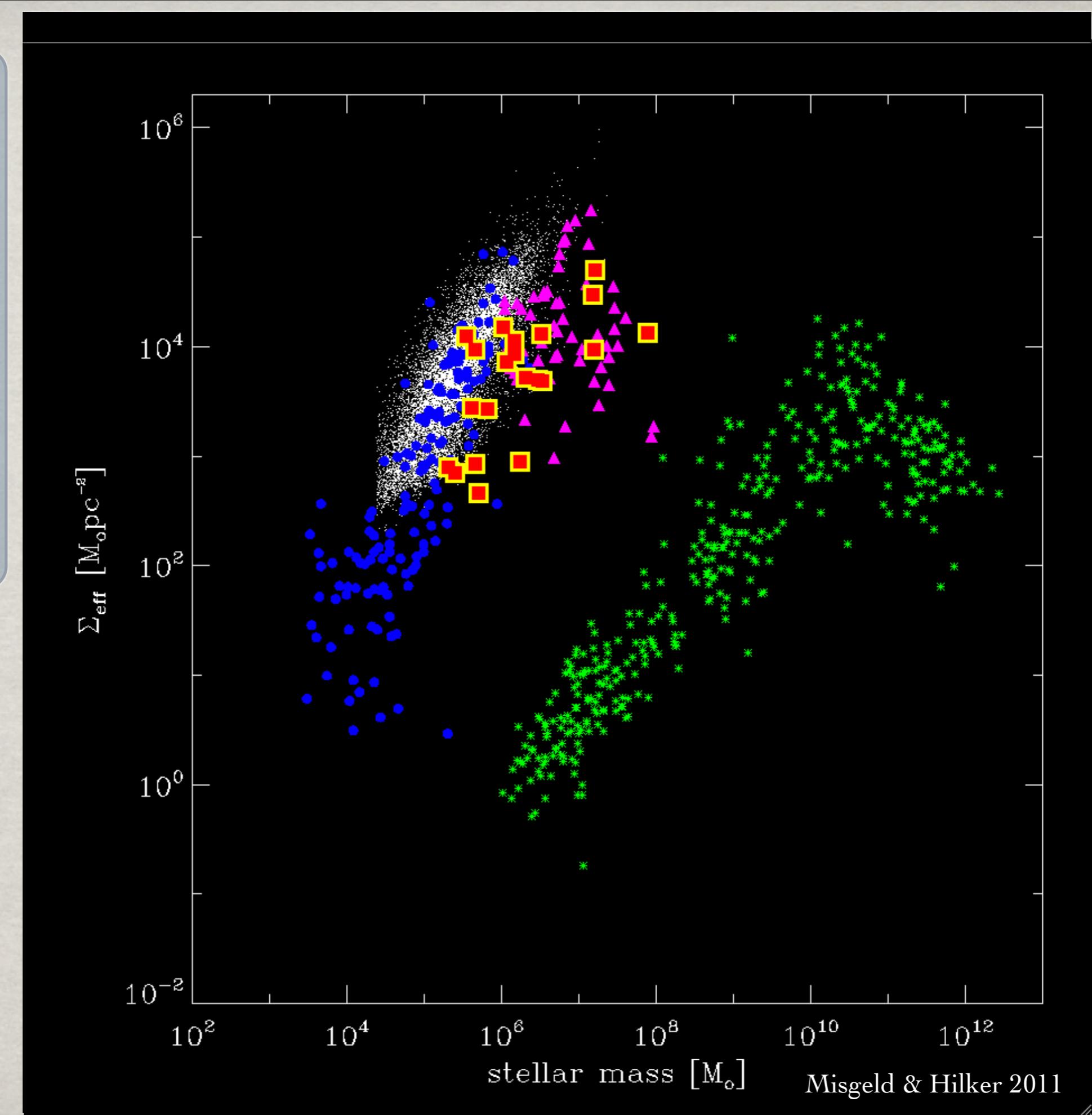
Galactic Globular
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Young Massive
Clusters

UCDs/DGTOs



Galactic Globular
Clusters

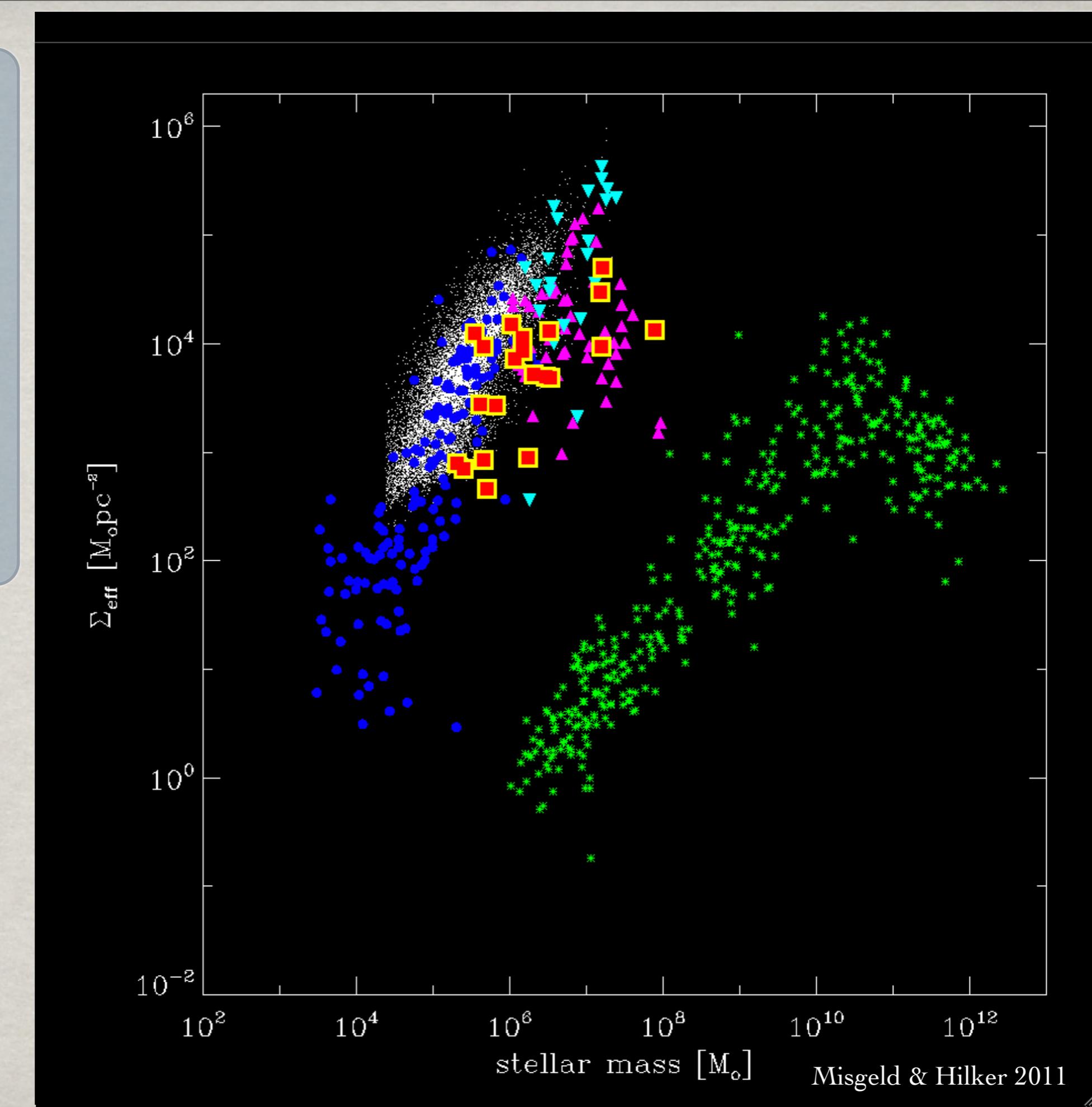
Dwarf and elliptical
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Virgo globular
clusters

Young Massive
Clusters

UCDs/DGTOs

Nuclear Clusters



Galactic Globular
Clusters

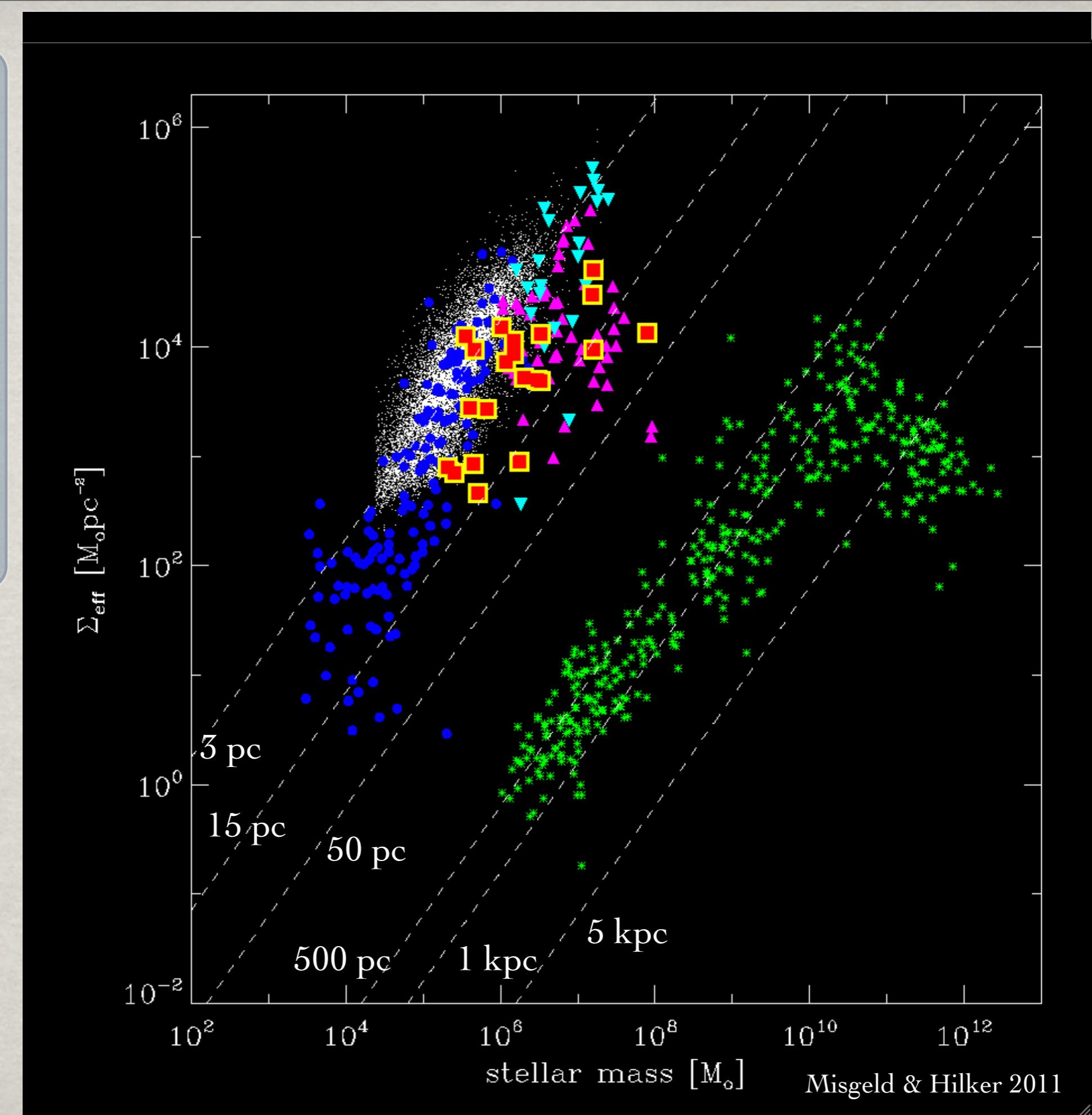
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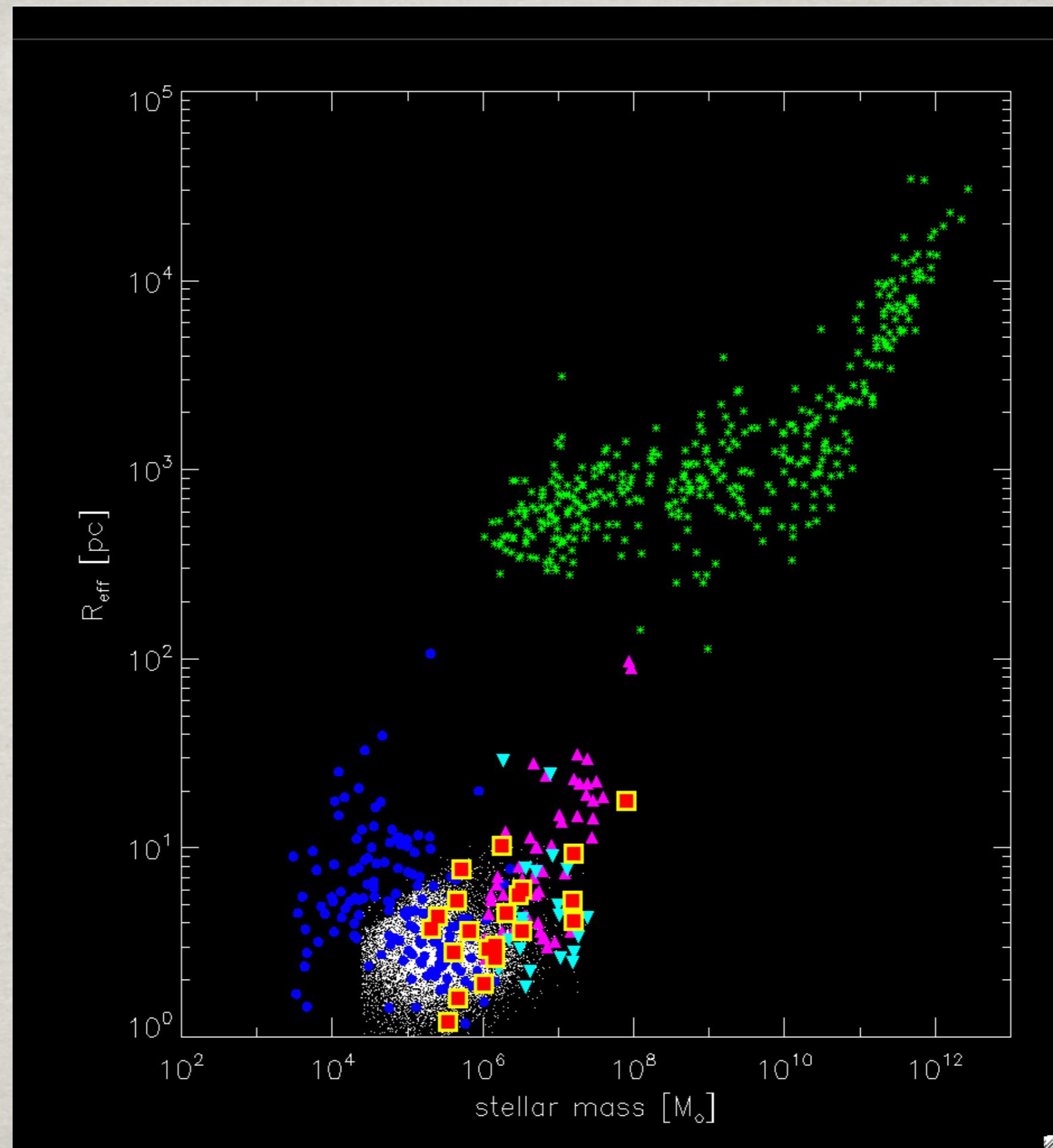
Hasegan et al. 2005

Kissler-Patig et al. 2006

Dabringhausen et al. 2008

Gieles et al. 2010

Misgeld & Hilker 2011



Galactic Globular Clusters

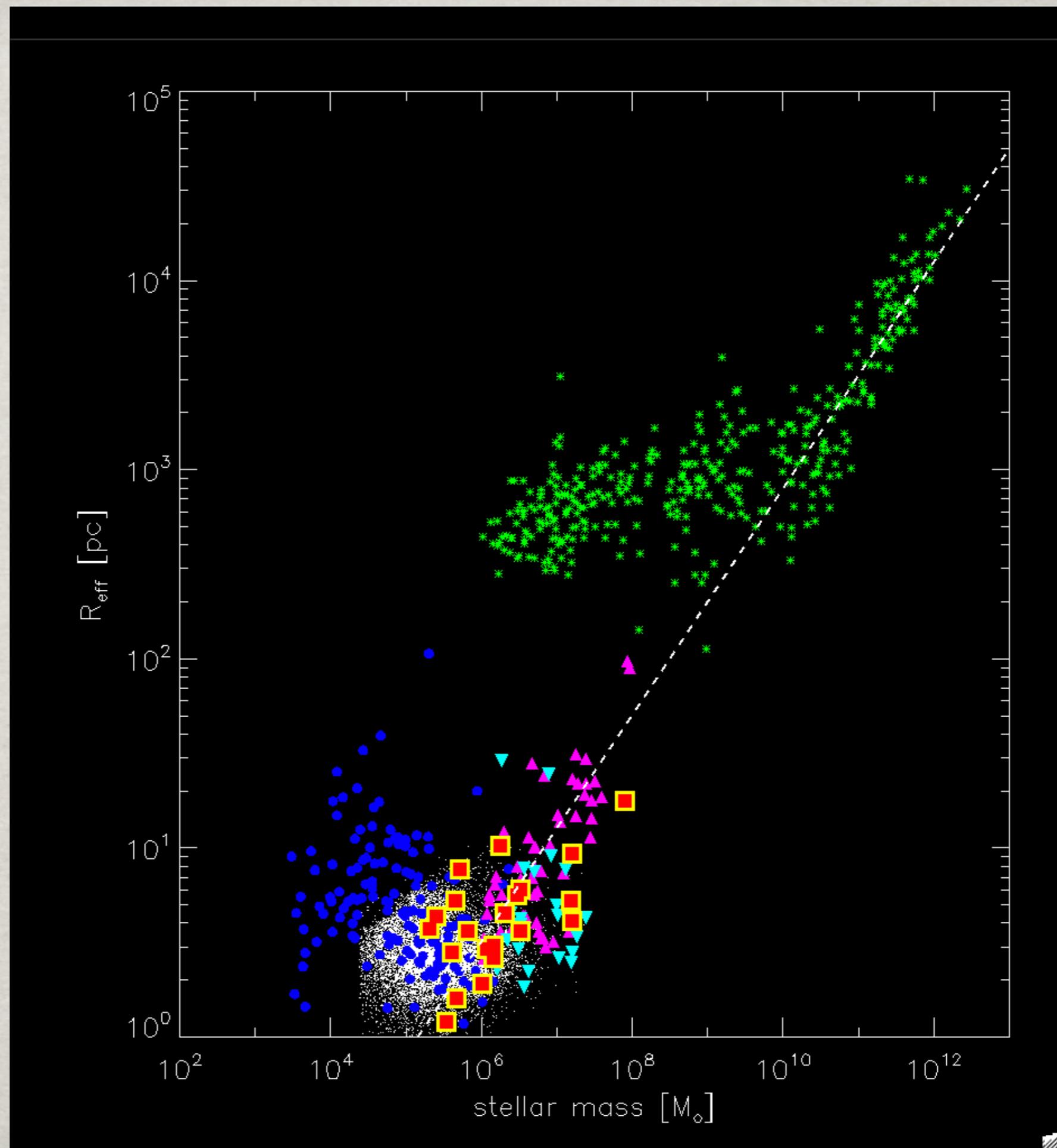
Dwarf and elliptical galaxies

Virgo globular clusters

Young Massive Clusters

UCDs/DGTOs

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- Kissler-Patig et al. 2006
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Galactic Globular
Clusters

Dwarf and elliptical
galaxies

Virgo globular
clusters

Young Massive
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UCDs/DGTOs

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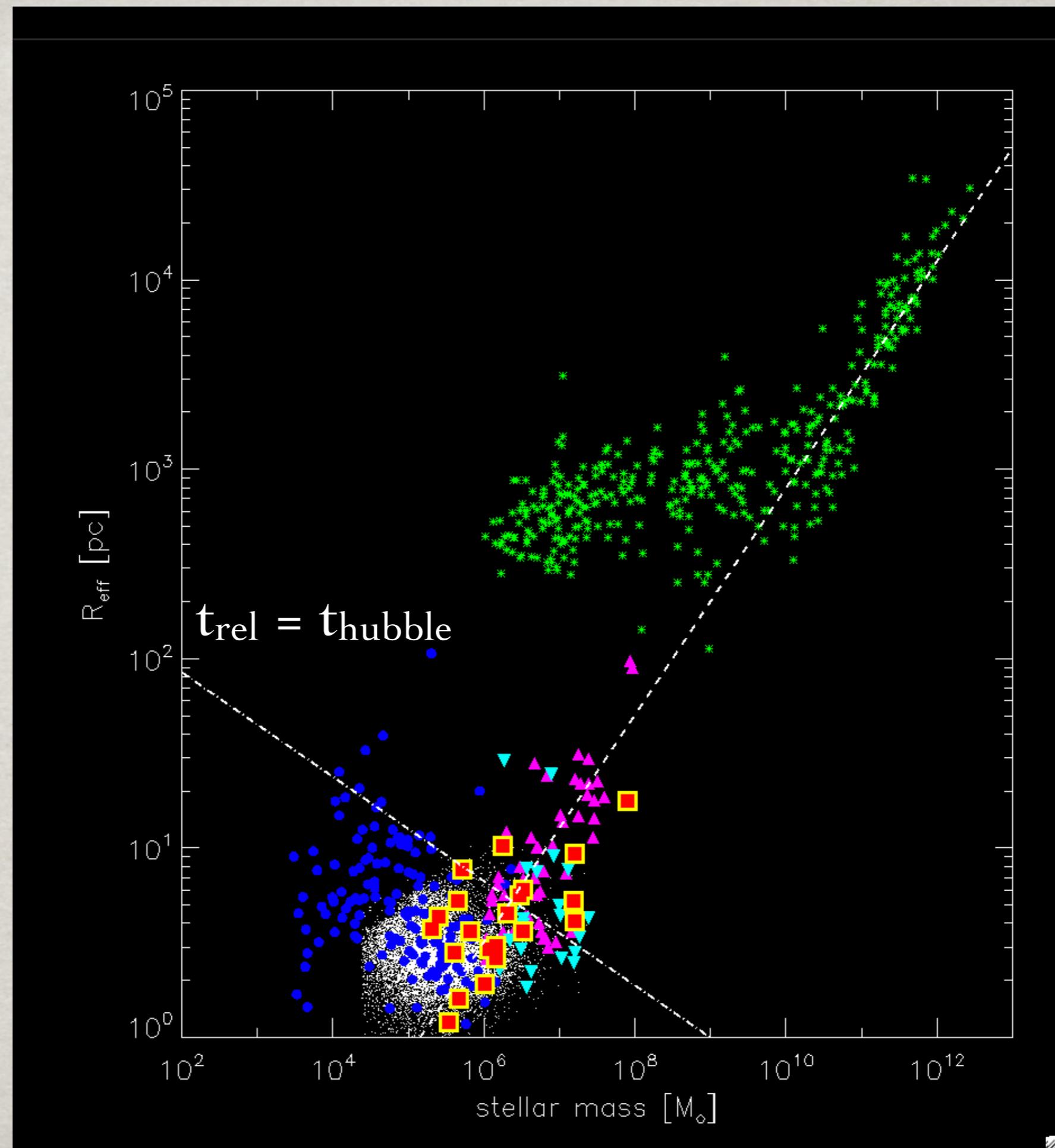
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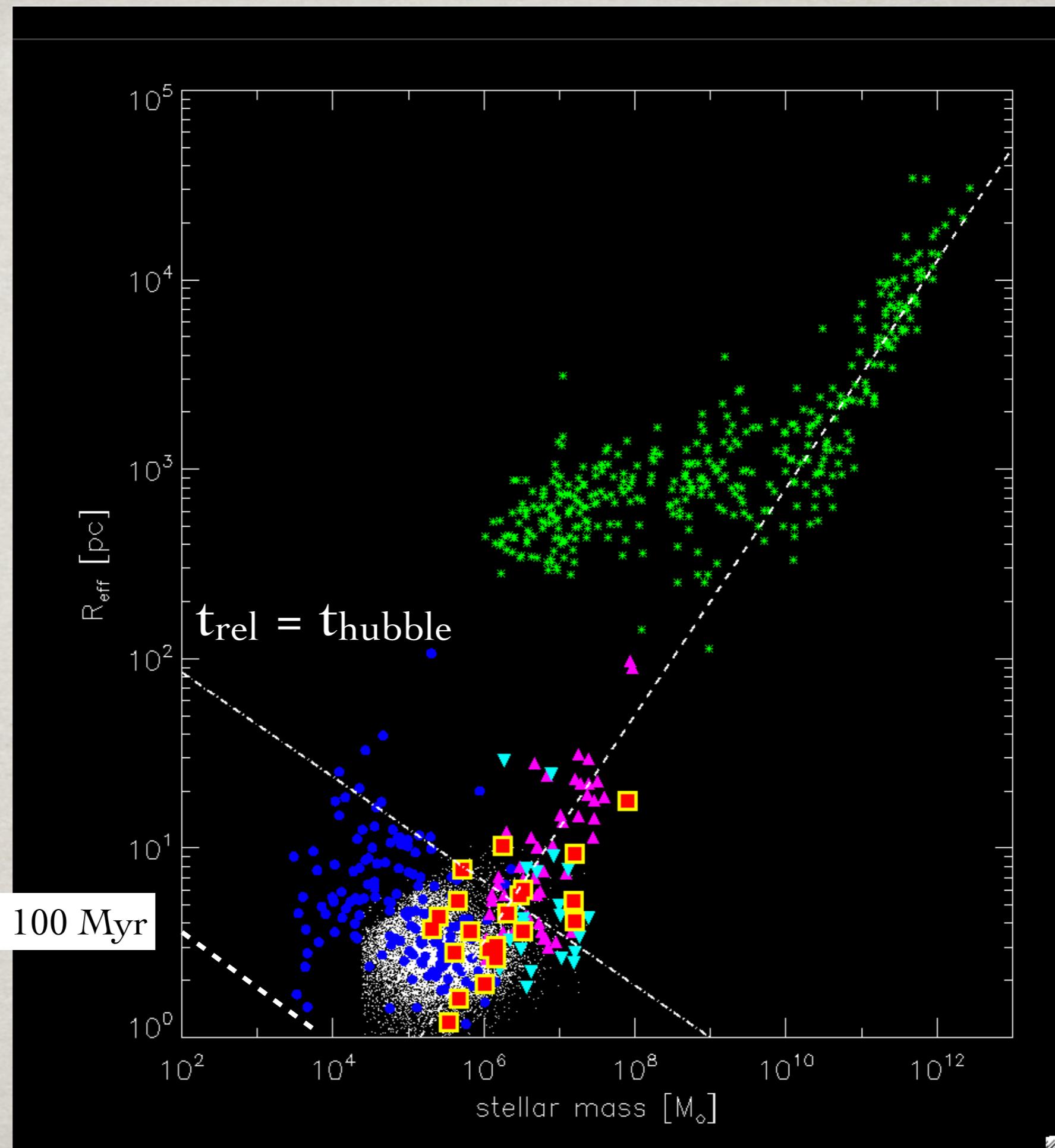
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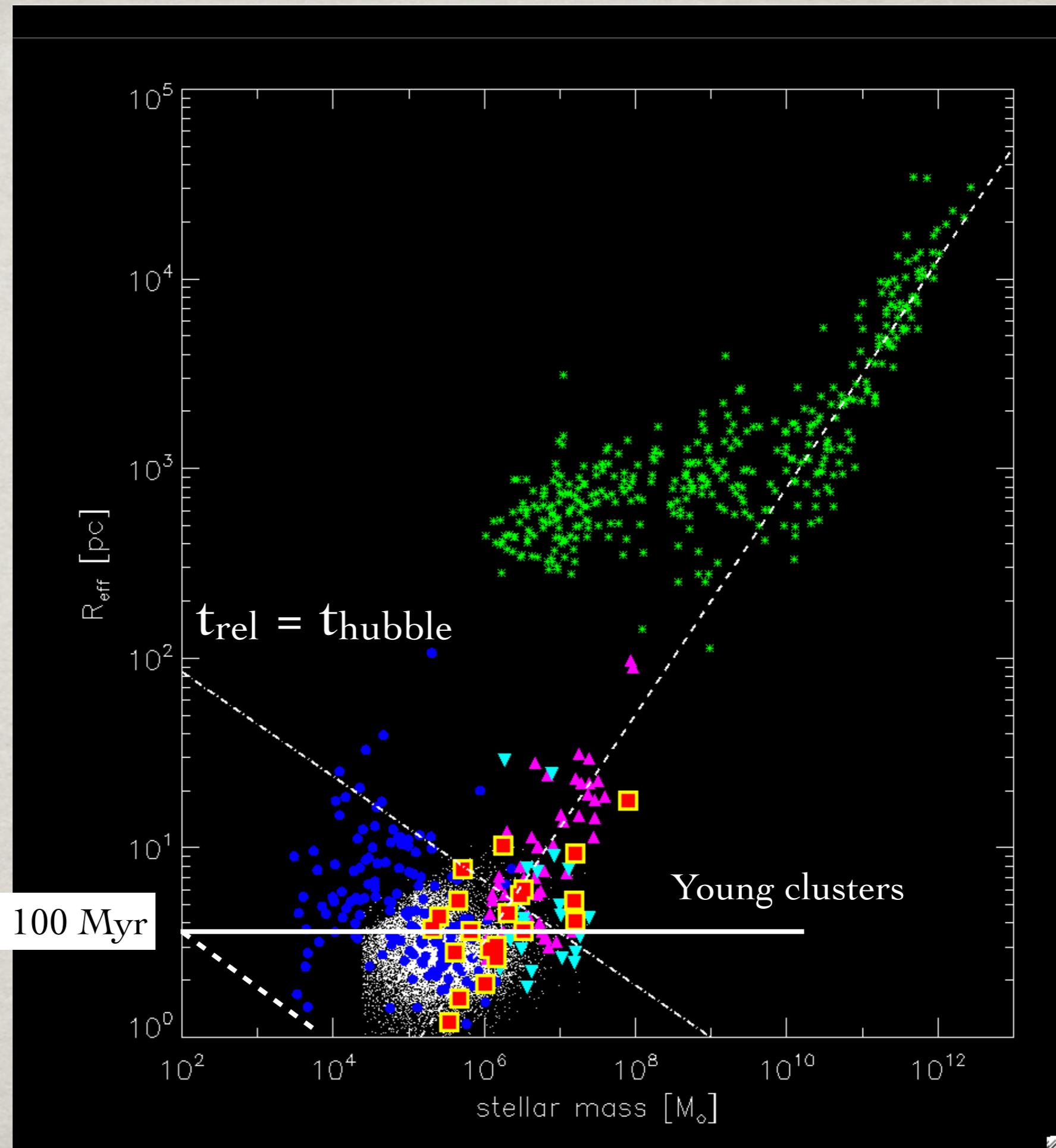
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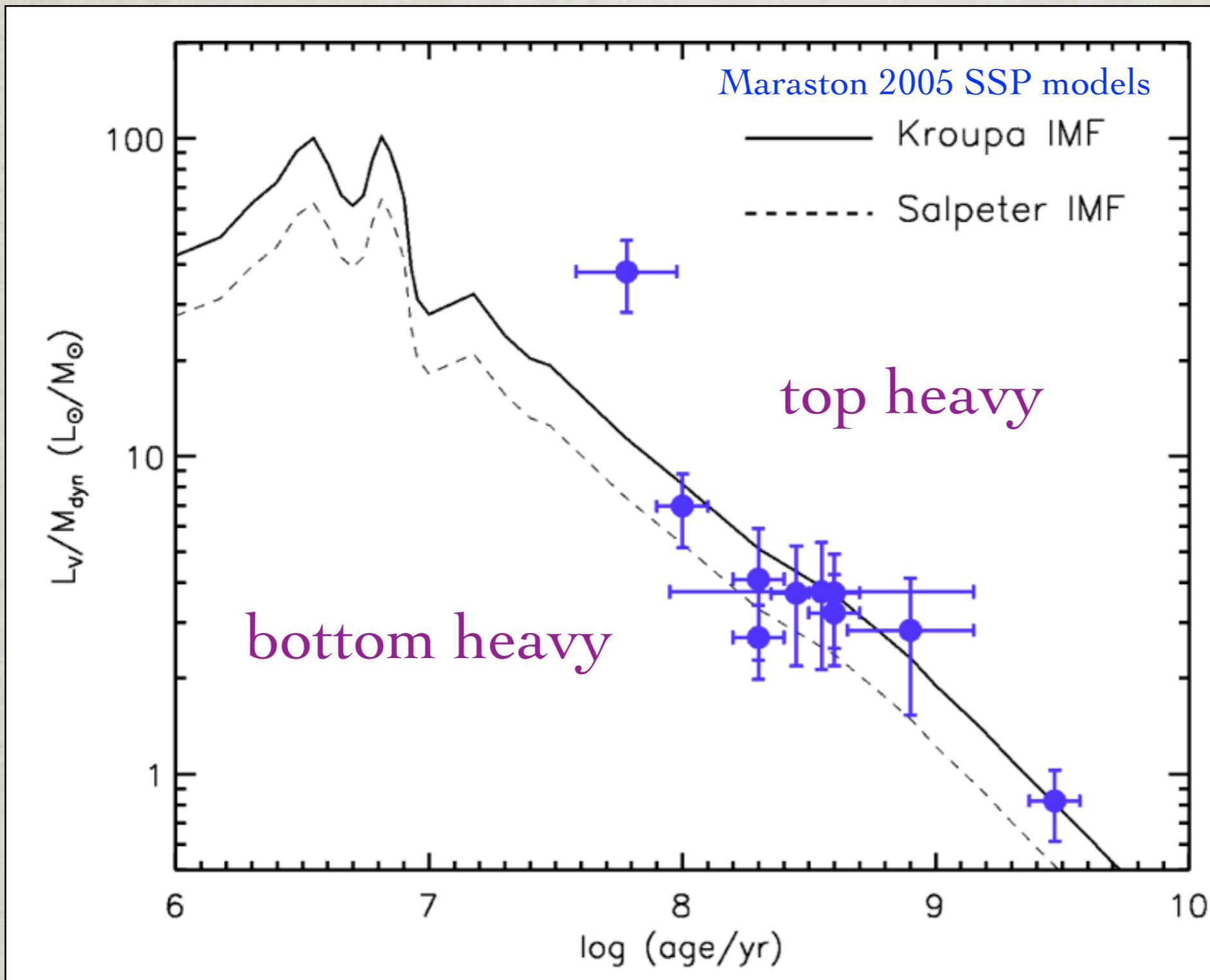
Gieles et al. 2010

Misgeld & Hilker 2011



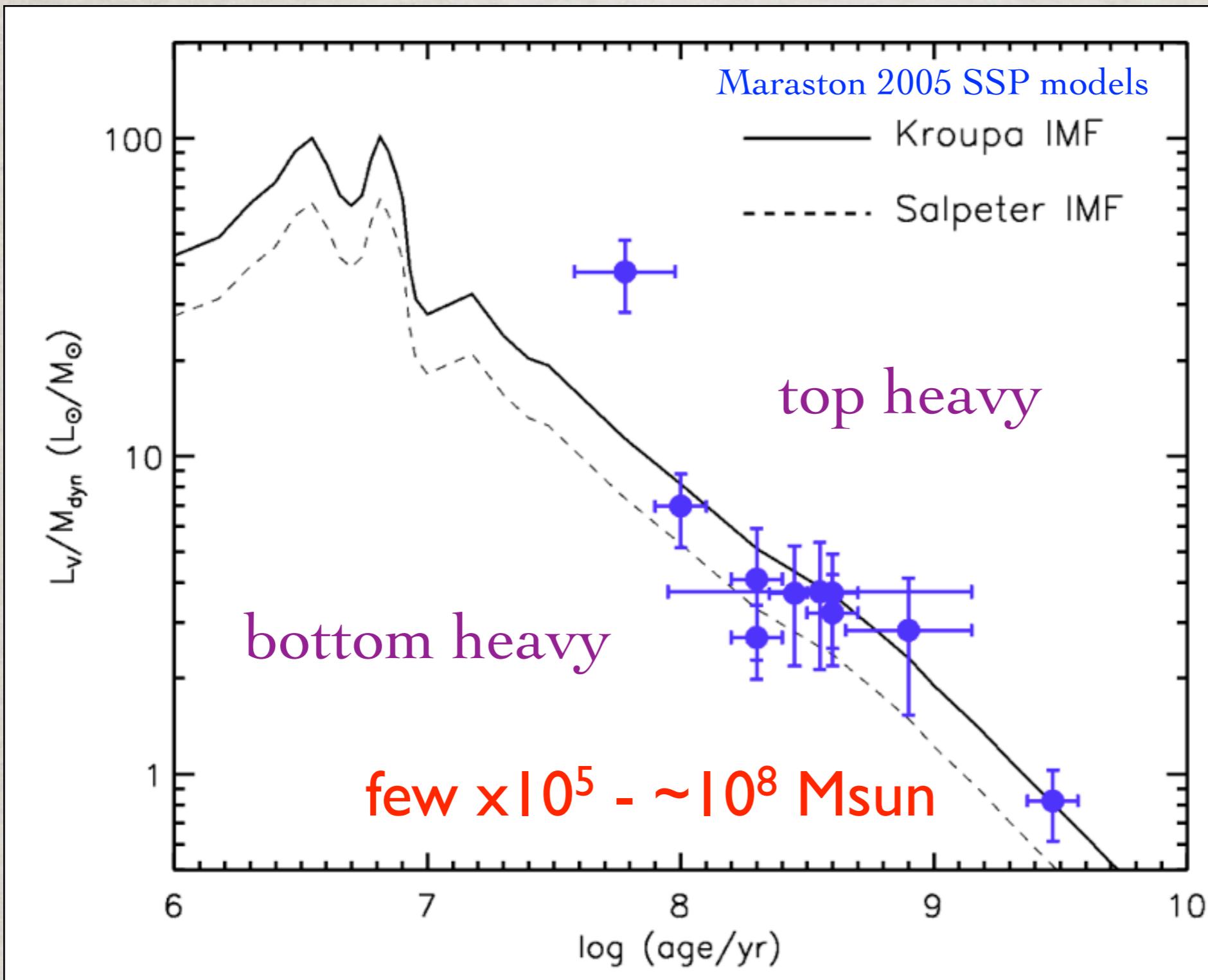
Young massive clusters (>20 Myr)

Bastian, Covey & Meyer ARAA 2010



Young massive clusters (>20 Myr)

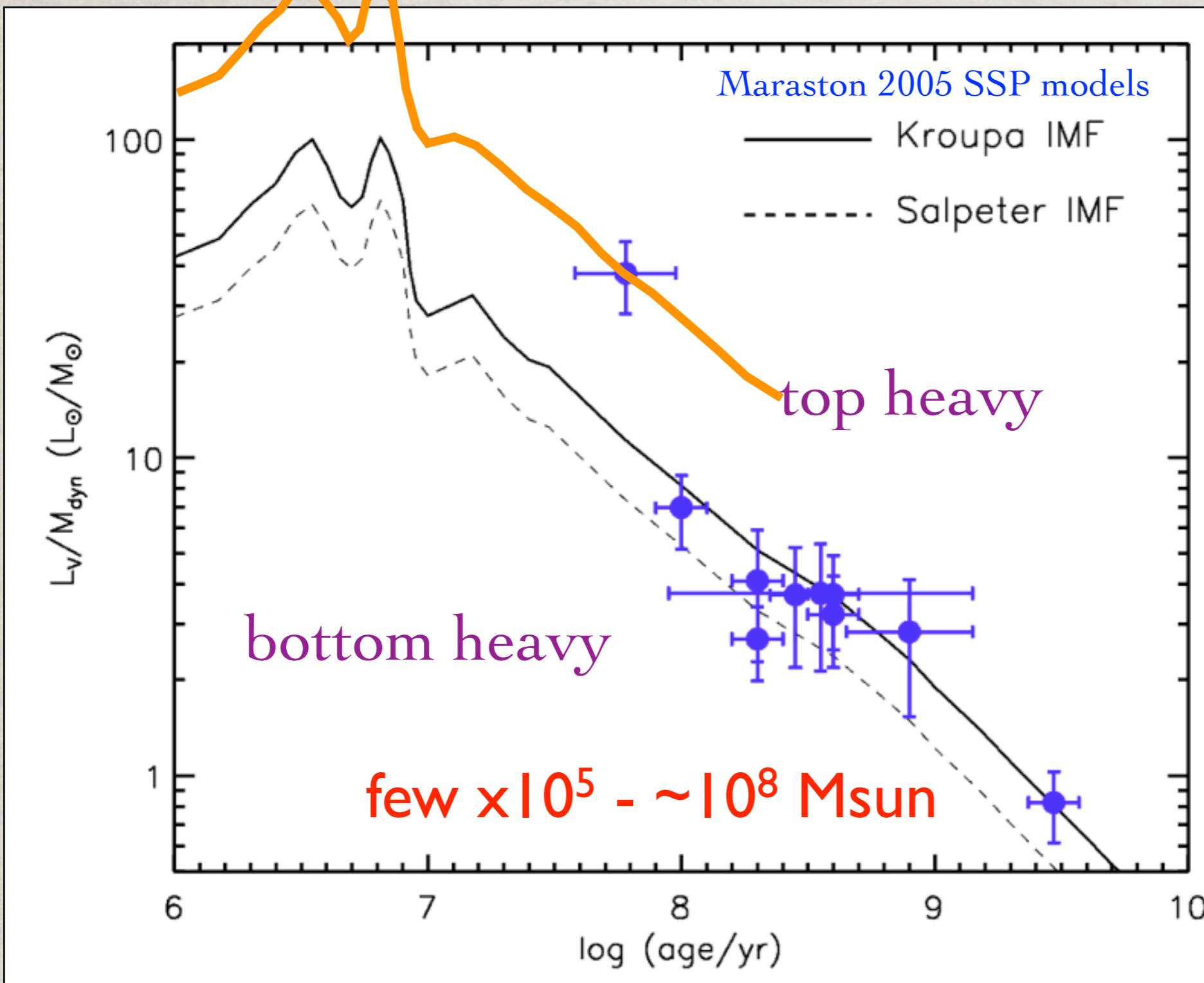
Bastian, Covey & Meyer ARAA 2010



Young massive clusters (>20 Myr)

> 3 Msun

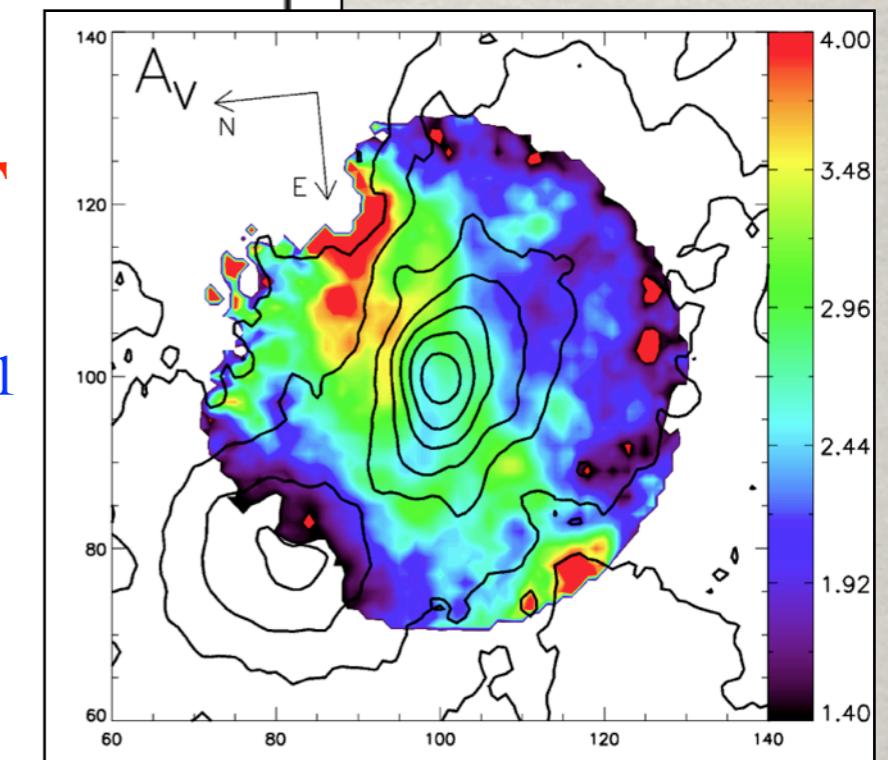
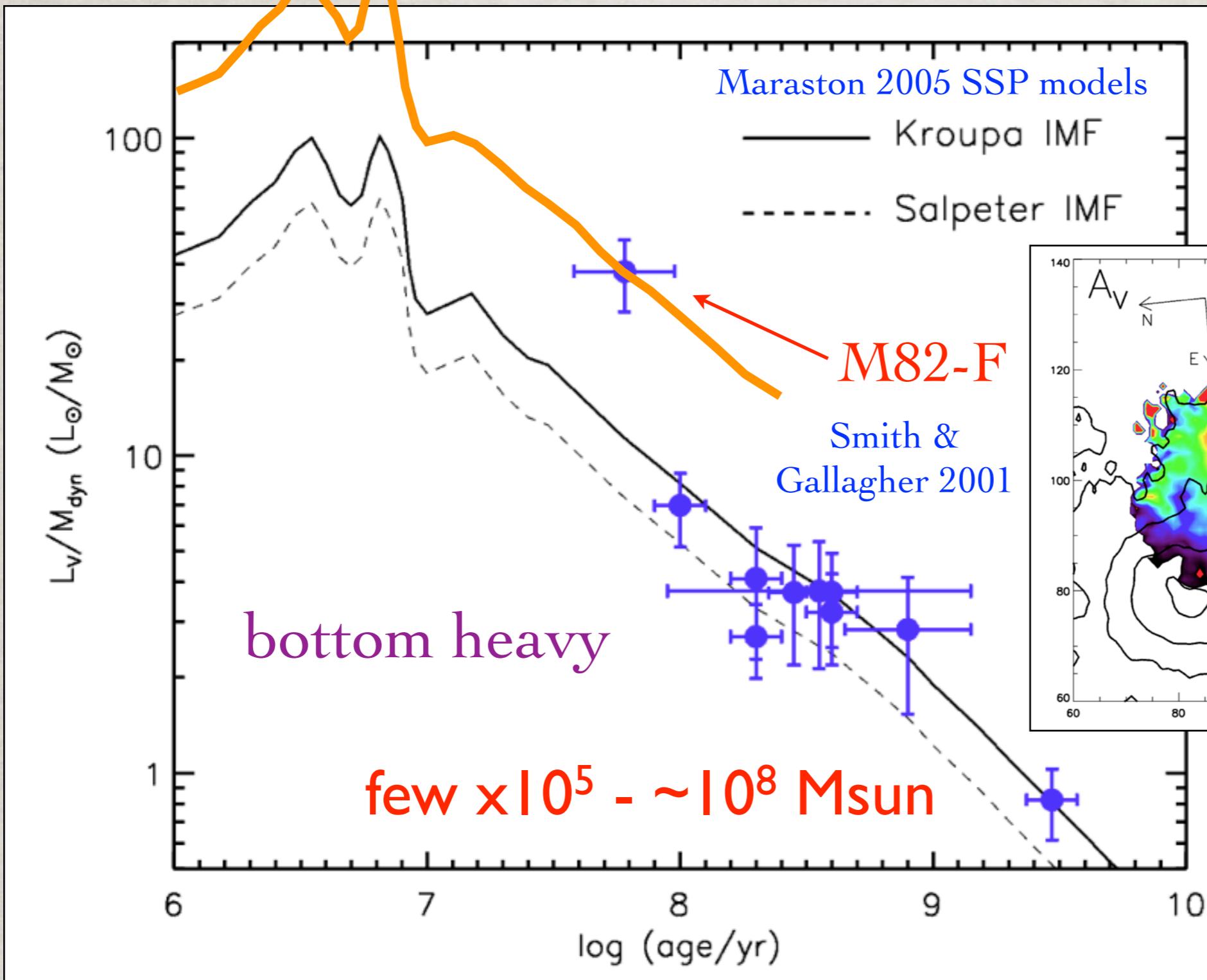
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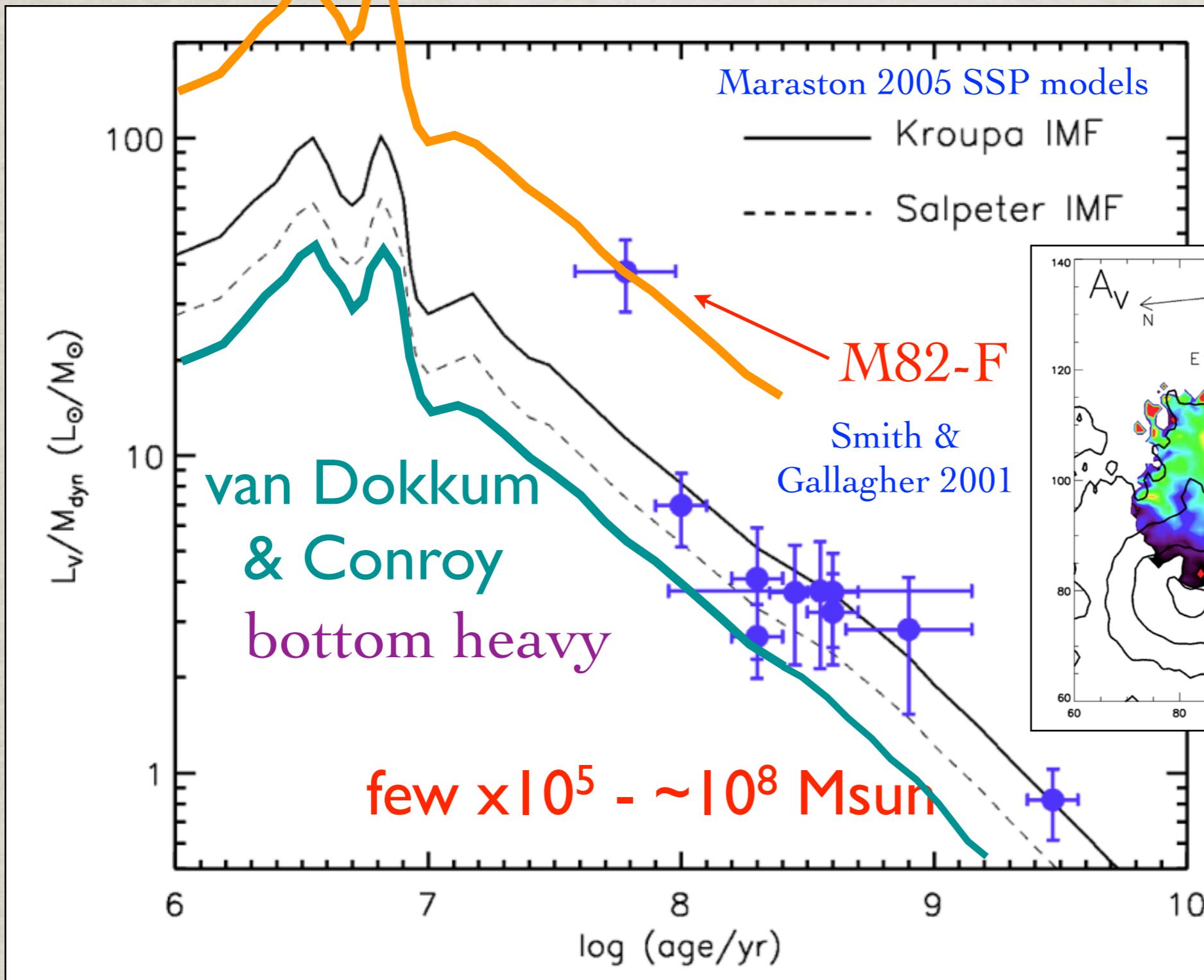


Bastian et al. 2007

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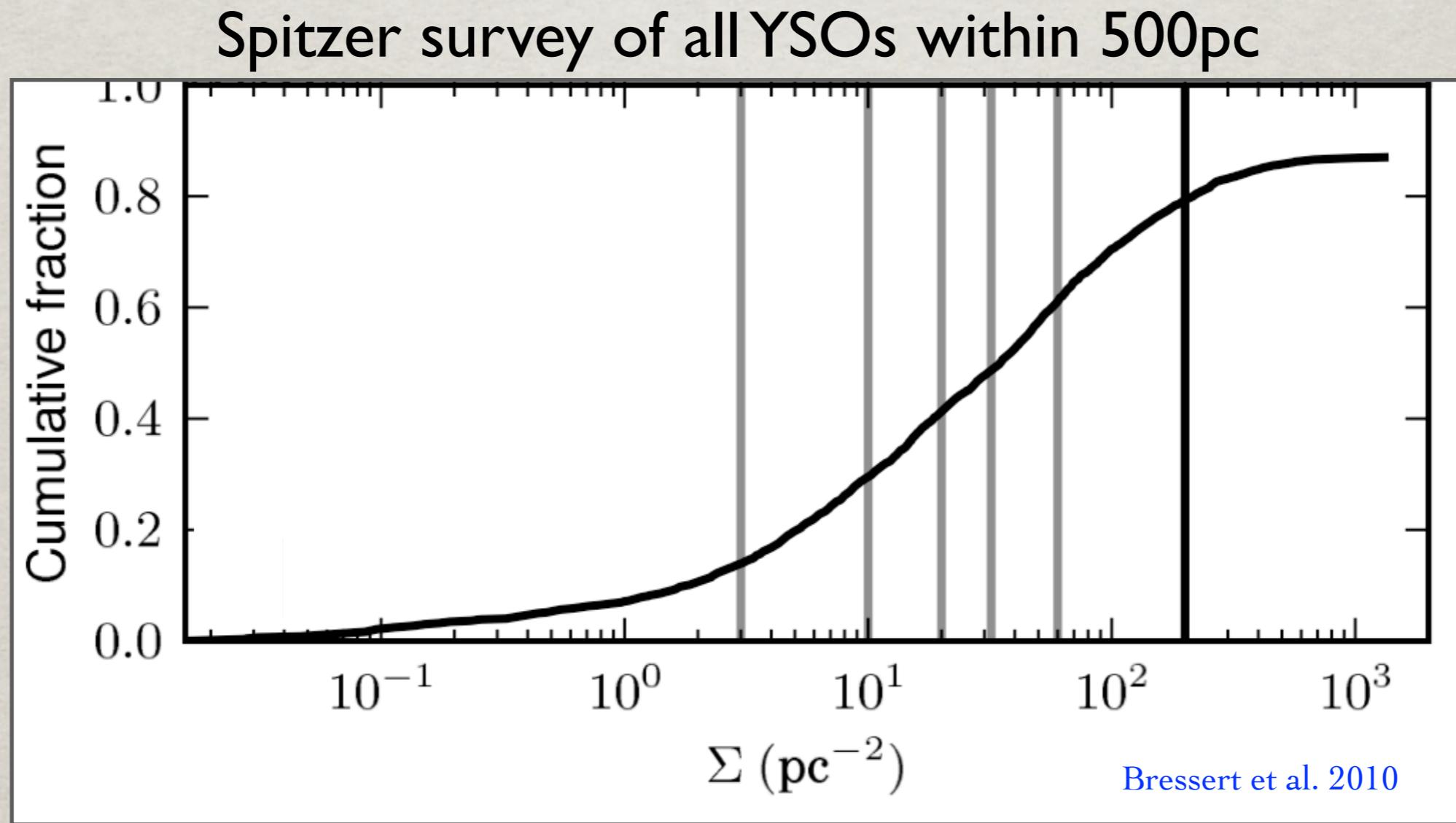
IMF in Young massive clusters

IMF in Young massive clusters

- ❖ IMF in these ‘extreme’ environments appears to be the same as seen locally
- ❖ (<1) $< \rho [\text{Msol pc}^{-3}] < (>10^5)$
- ❖ SFR surface densities $> 5 \times 10^4 \text{ Msol kpc}^{-2} \text{ yr}^{-1}$
- ❖ Orders of magnitude above even the most extreme galactic starbursts in the nearby or distant universe

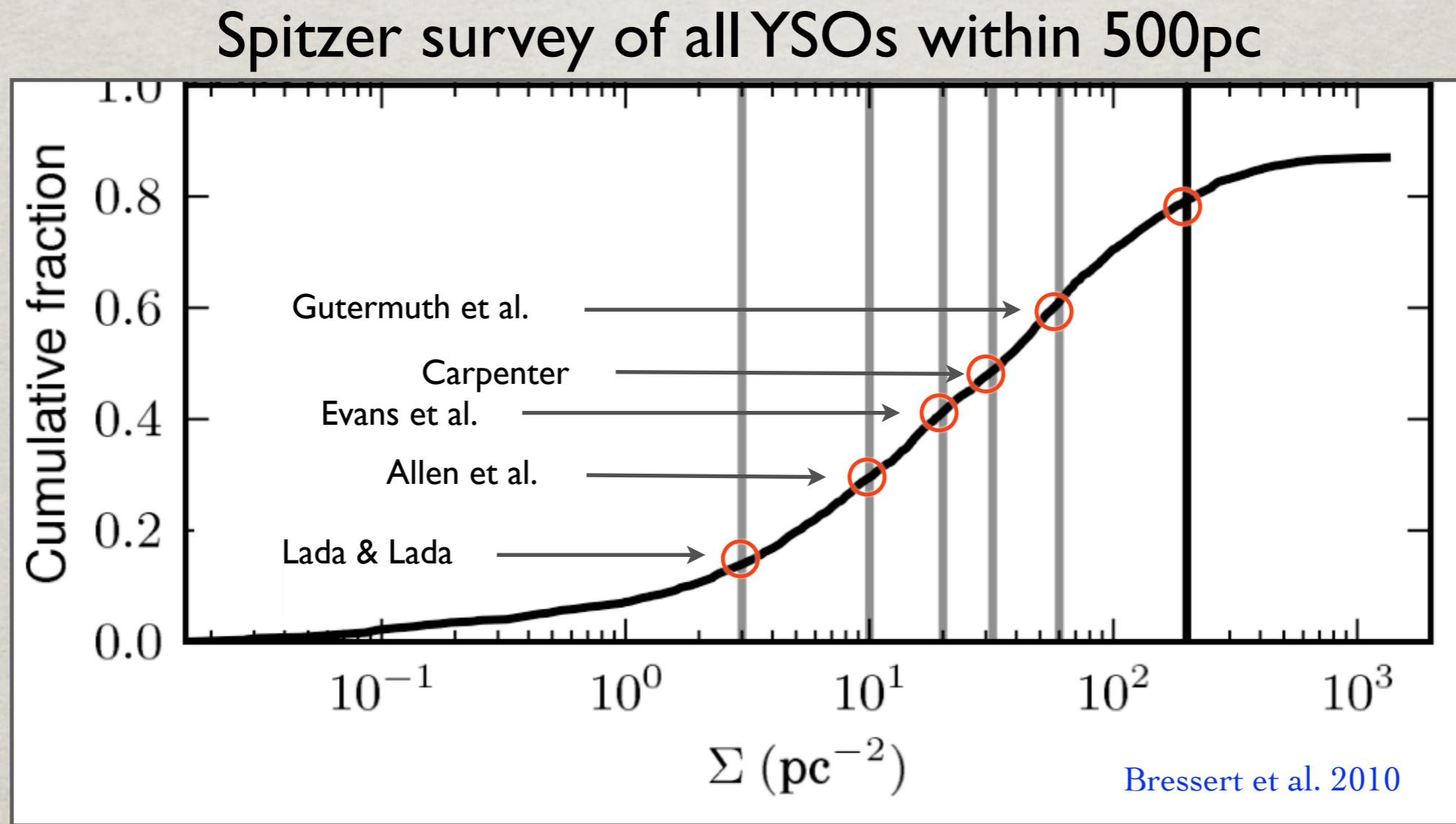
WHAT IS A ‘CLUSTER’?

- ✿ Bound group of stars - dynamically separated from their environment
- ✿ Star formation is hierarchical - no set scale at young ages



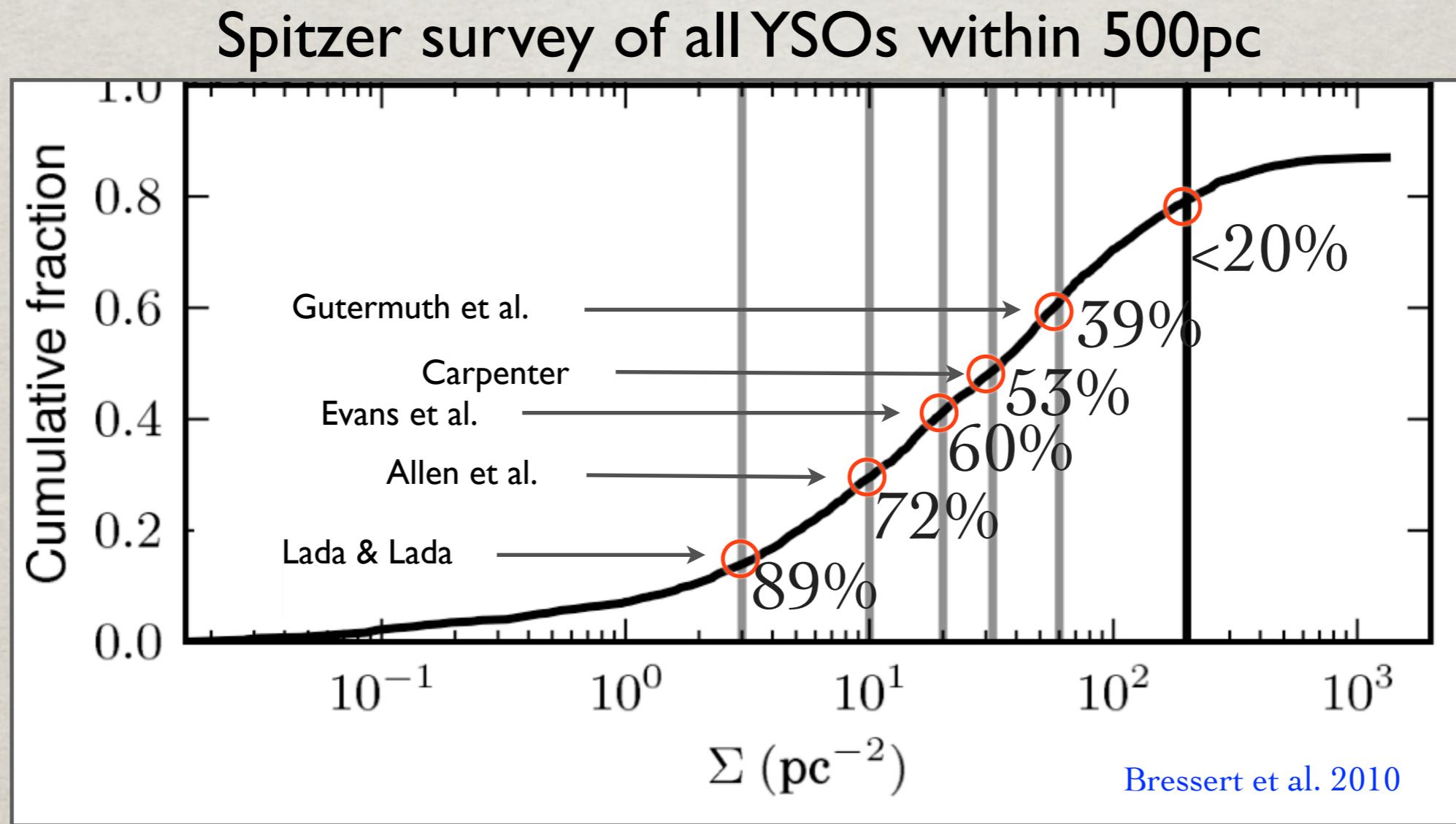
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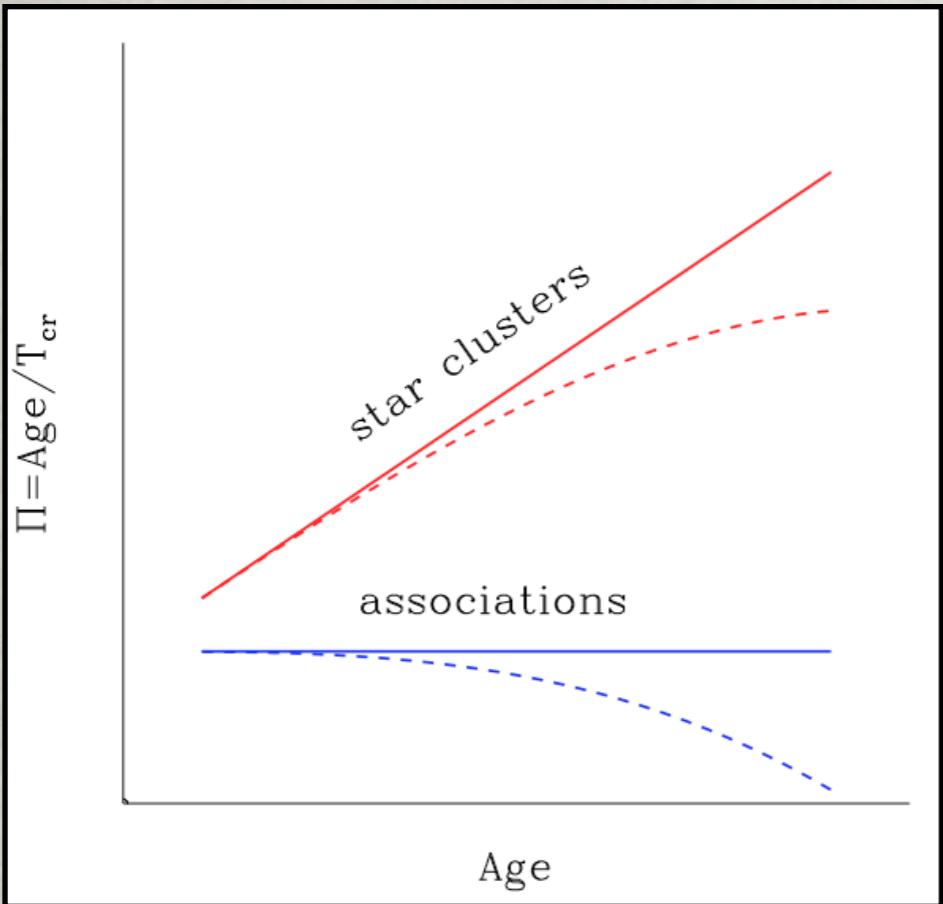
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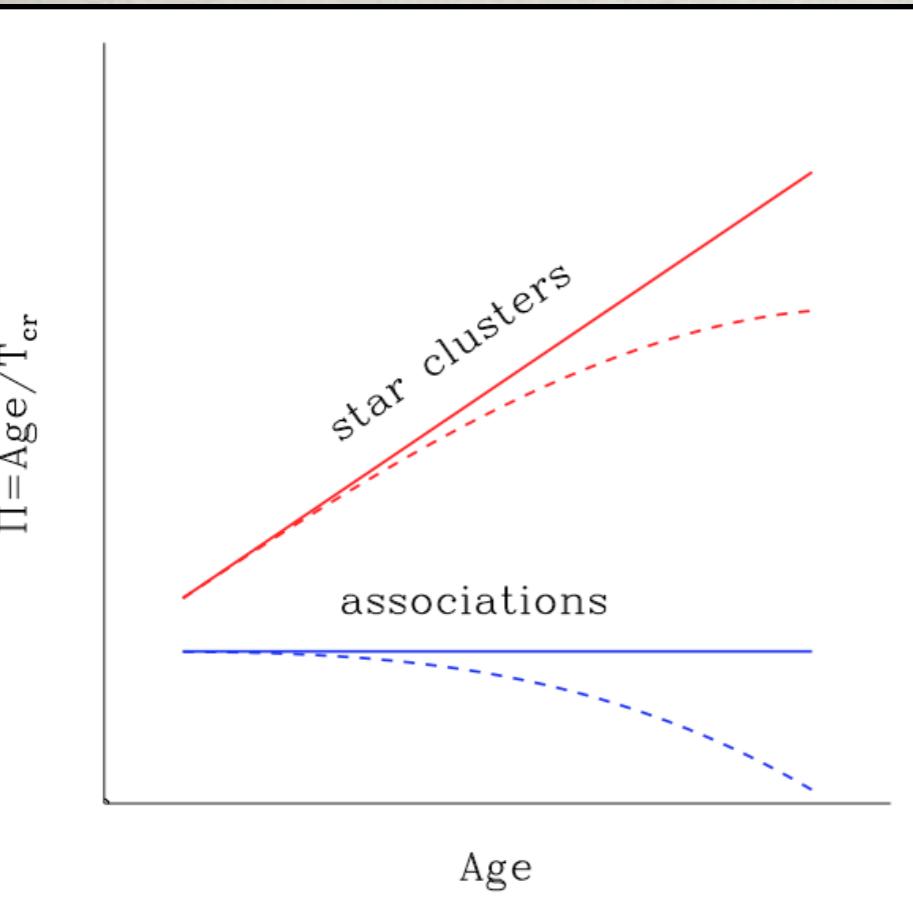




Gieles & Portegies Zwart 2011

$$\pi = \text{Age}/T_{\text{cross}}$$

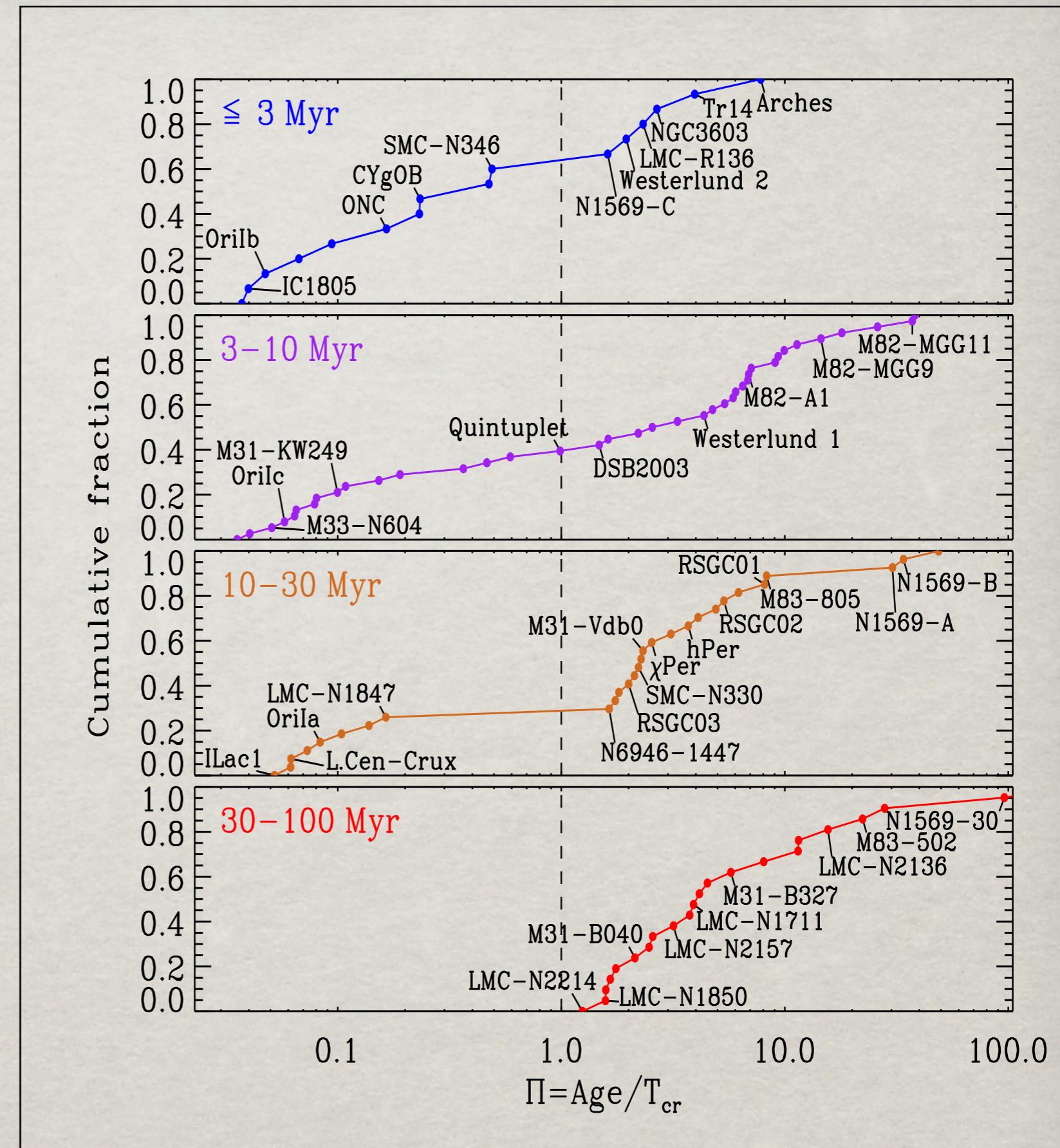
DYNAMICAL DEFINITION OF A YOUNG CLUSTER



Gieles & Portegies Zwart 2011

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DYNAMICAL DEFINITION OF A YOUNG CLUSTER

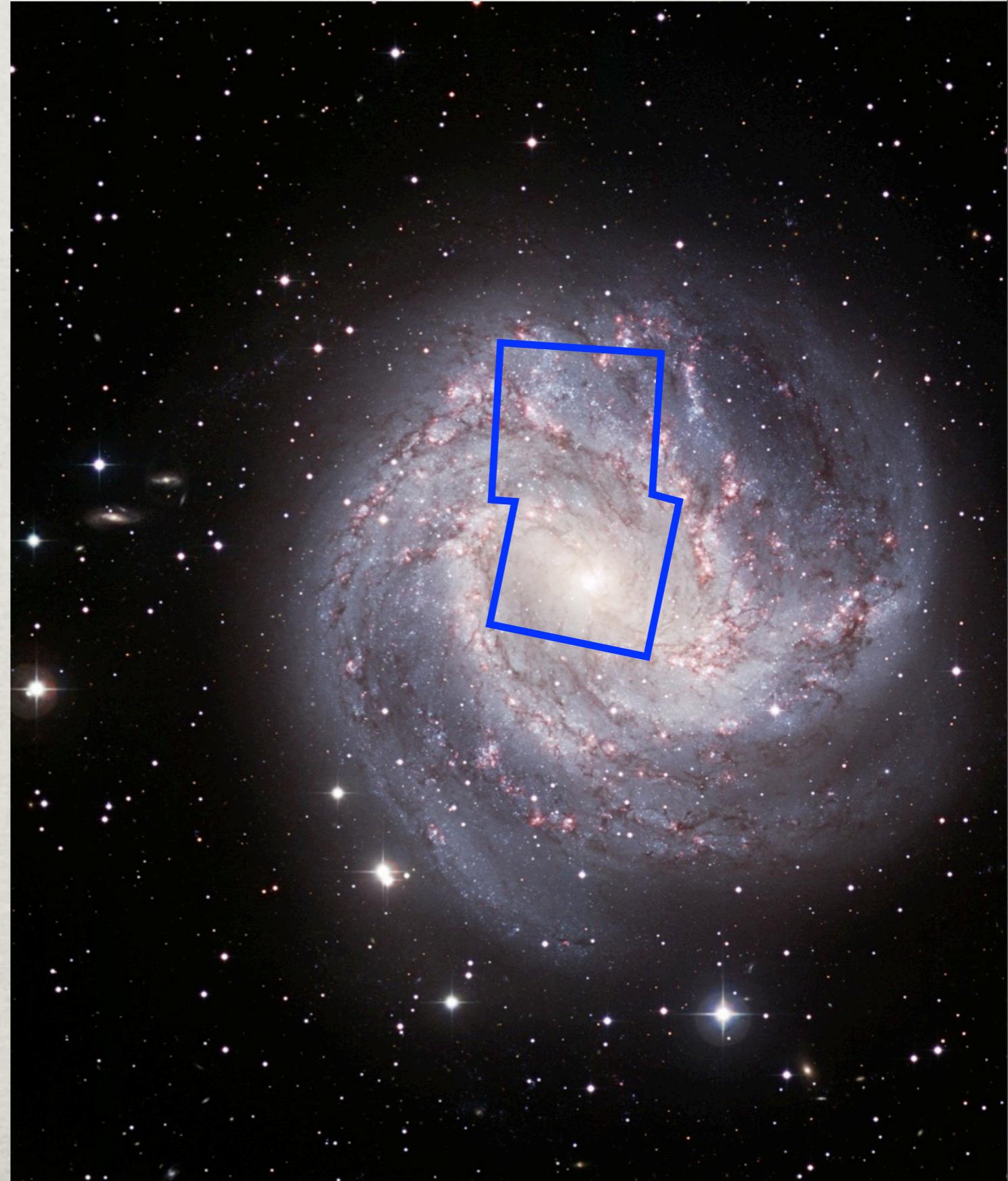


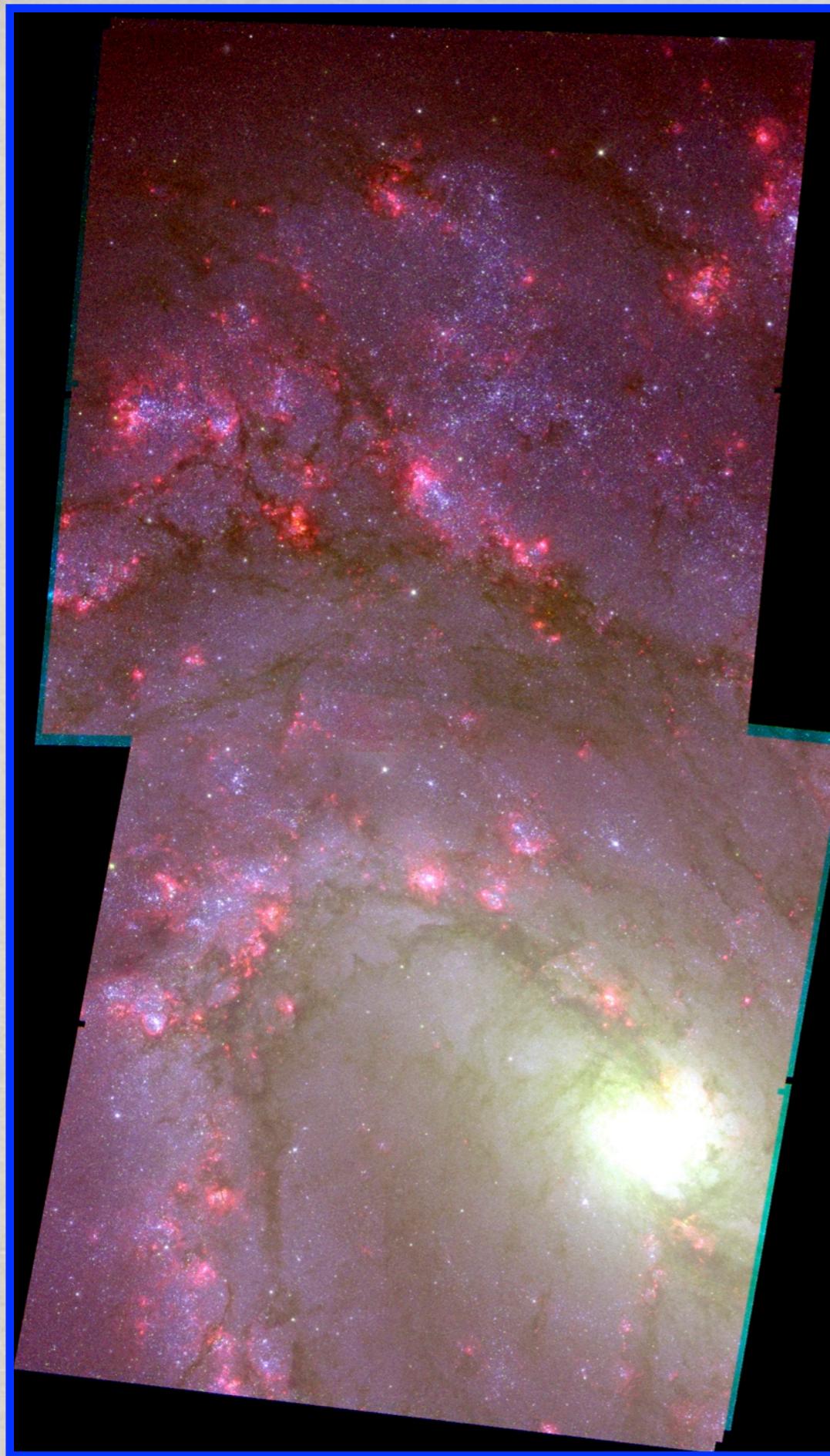
Portegies Zwart, McMillan & Gieles 2010

APPLIED TO EXTRAGALACTIC SURVEYS - M83

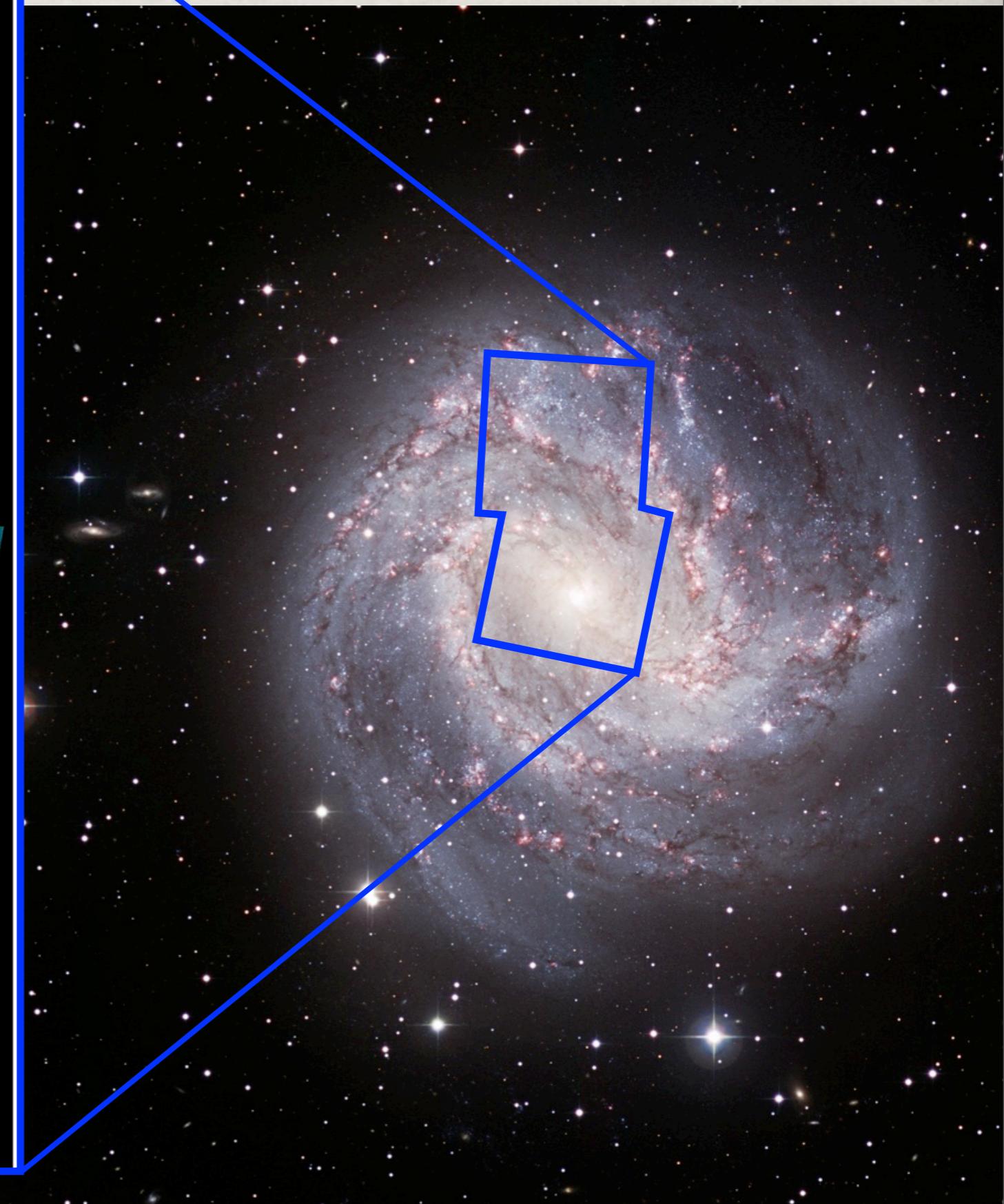


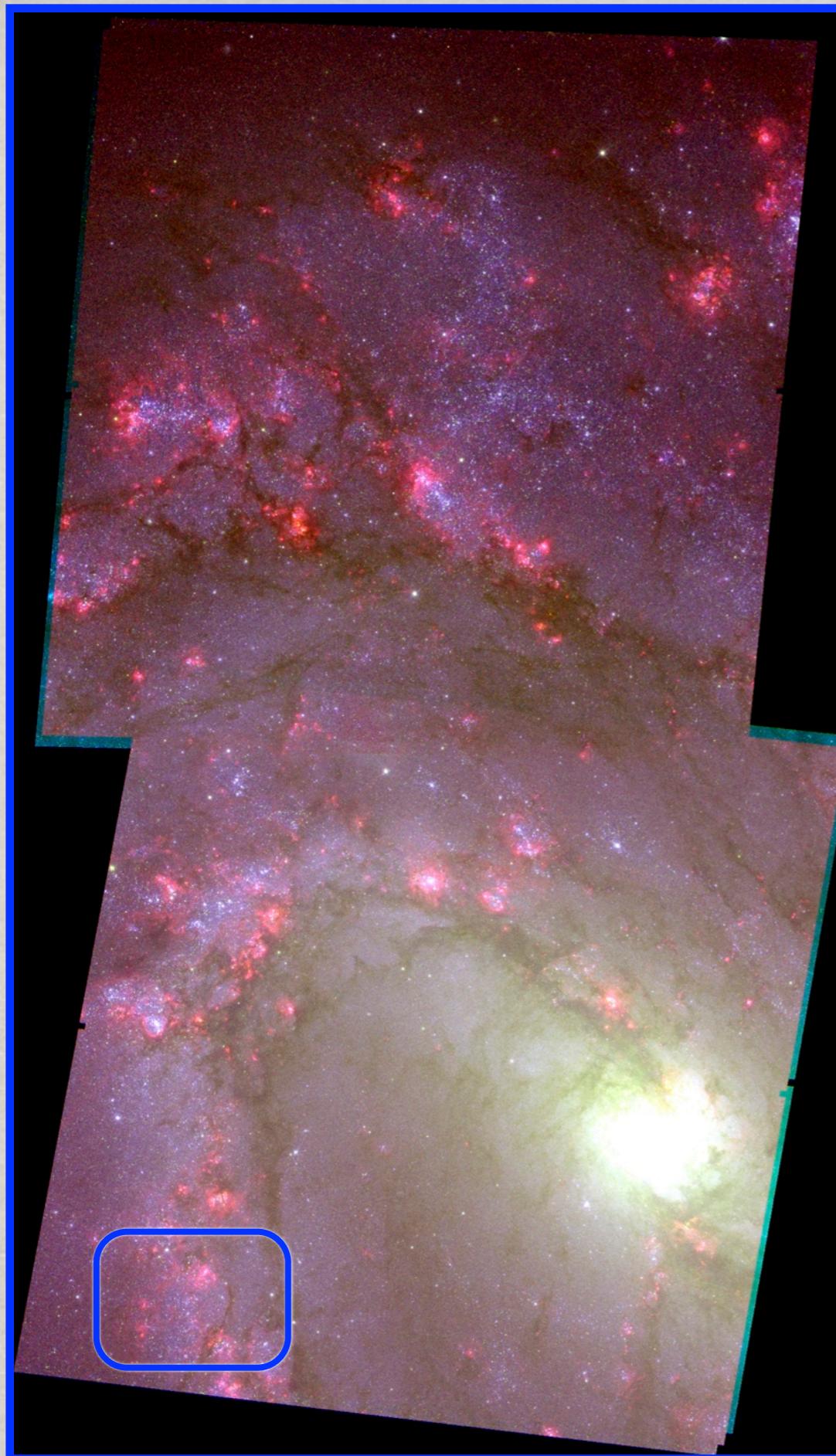
APPLIED TO EXTRAGALACTIC SURVEYS - M83



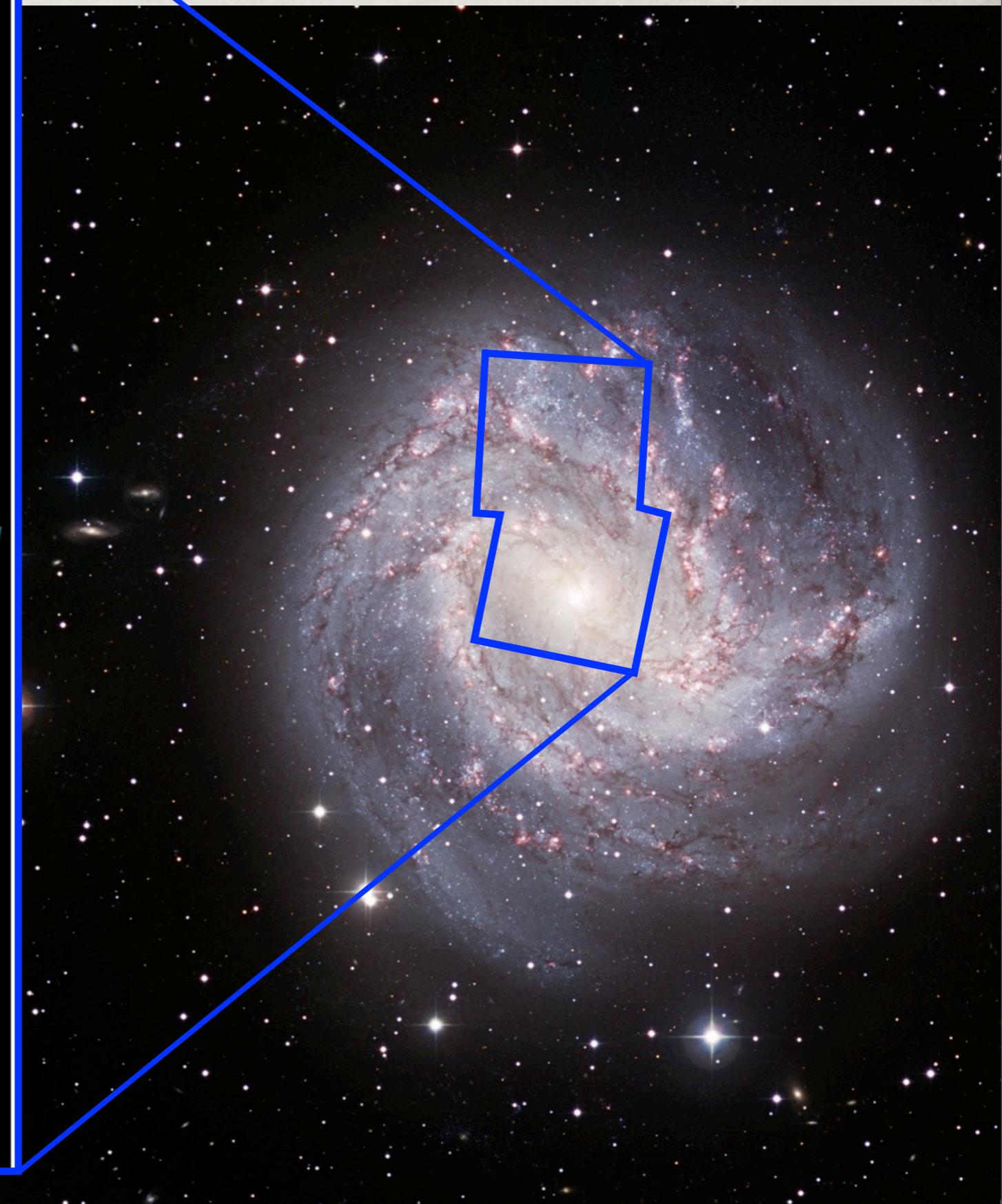


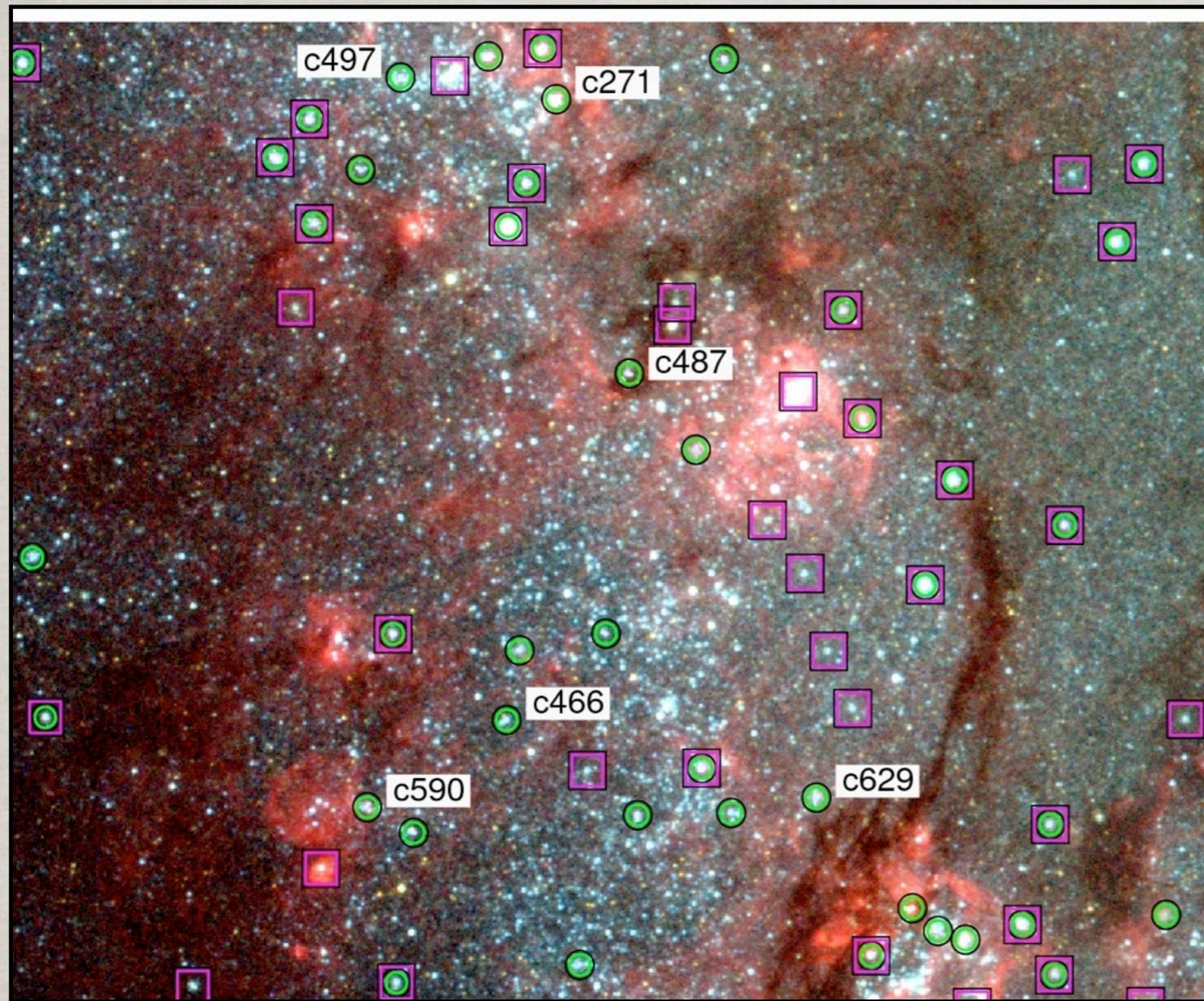
HALACTIC SURVEYS - M83



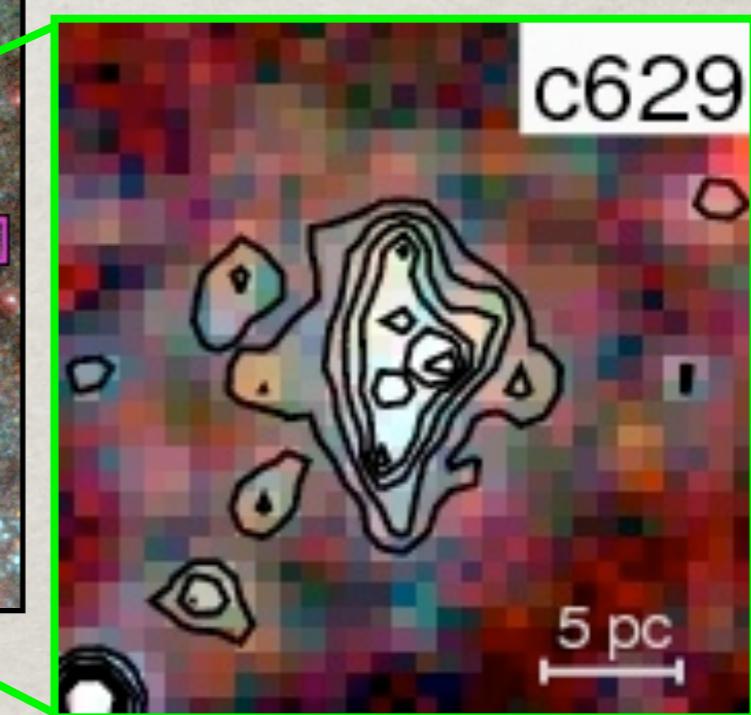
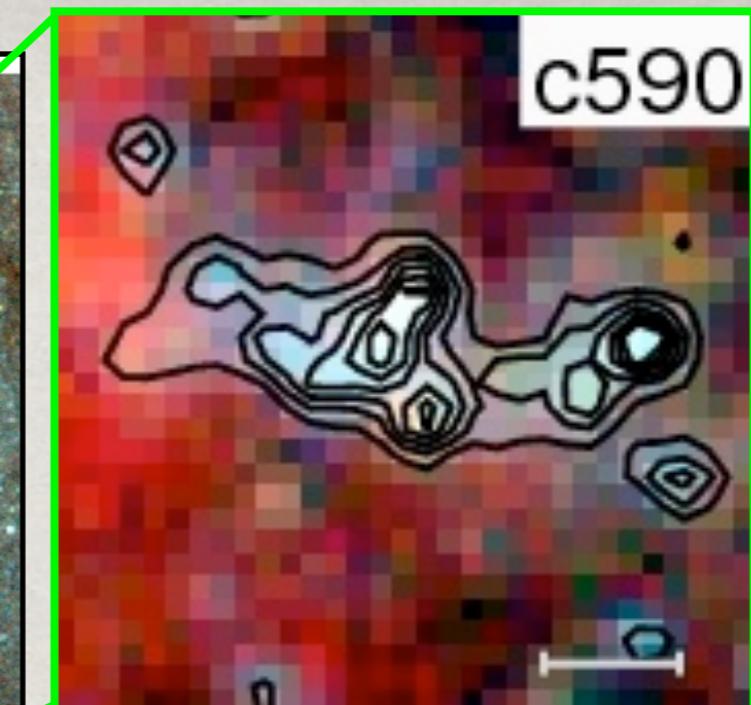
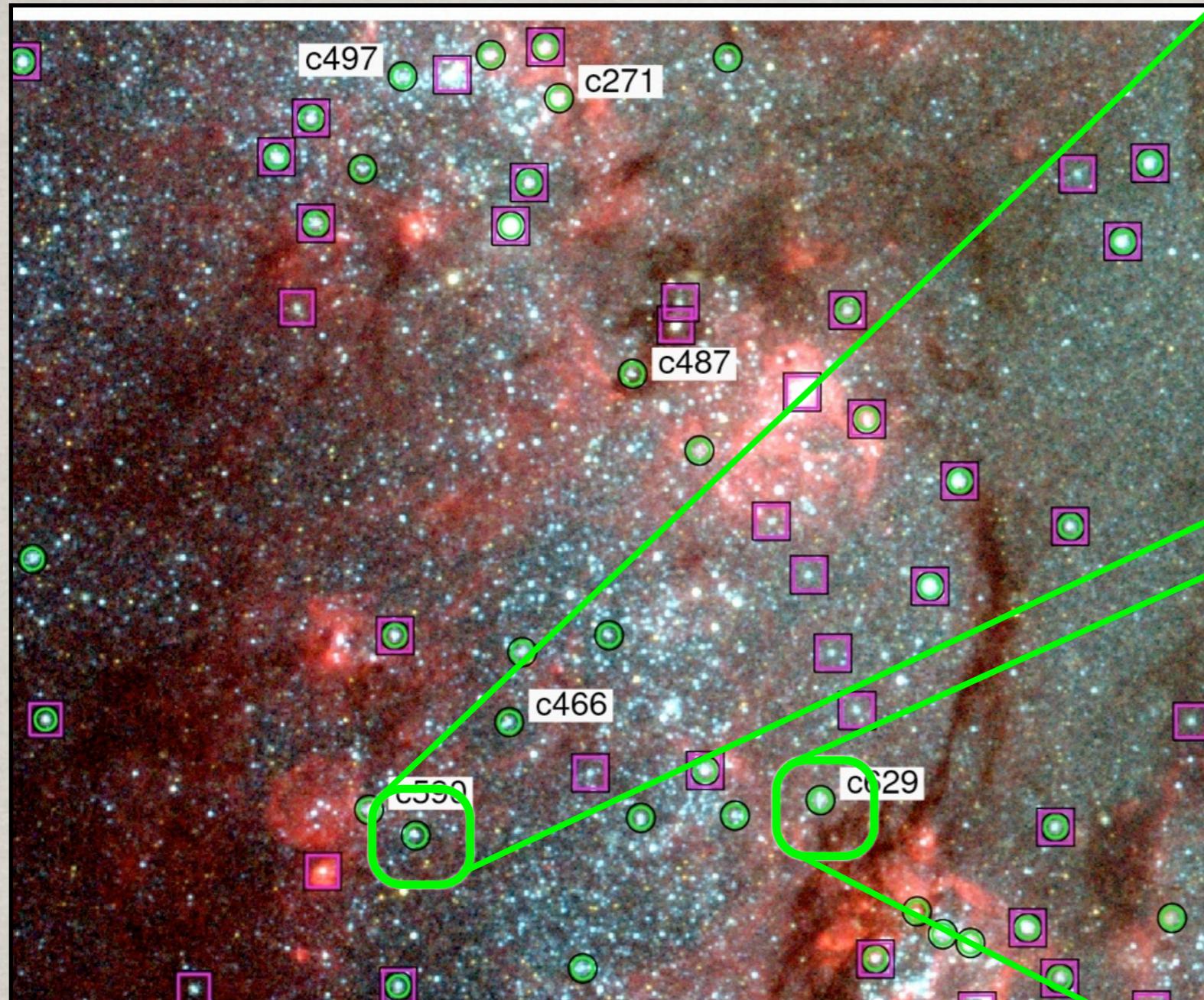


HALACTIC SURVEYS - M83

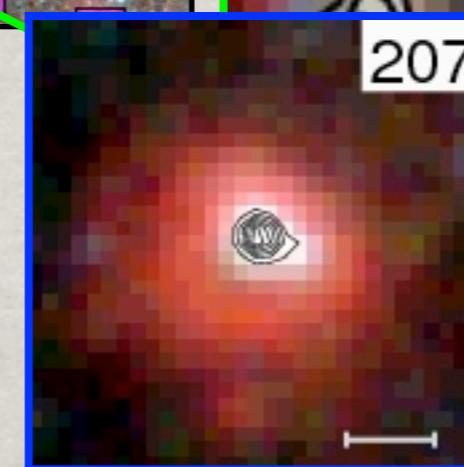
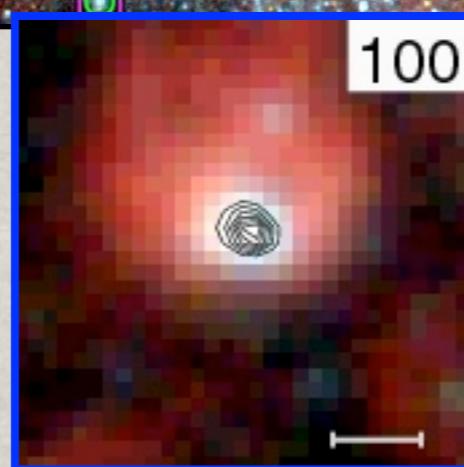
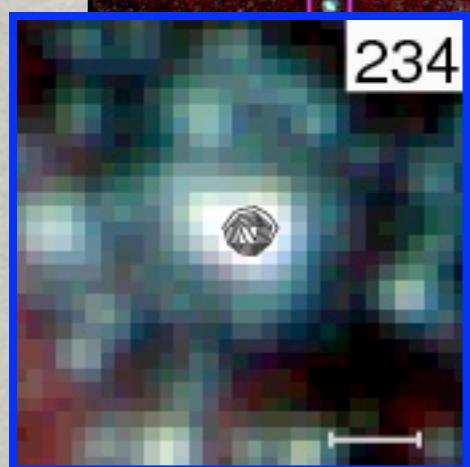
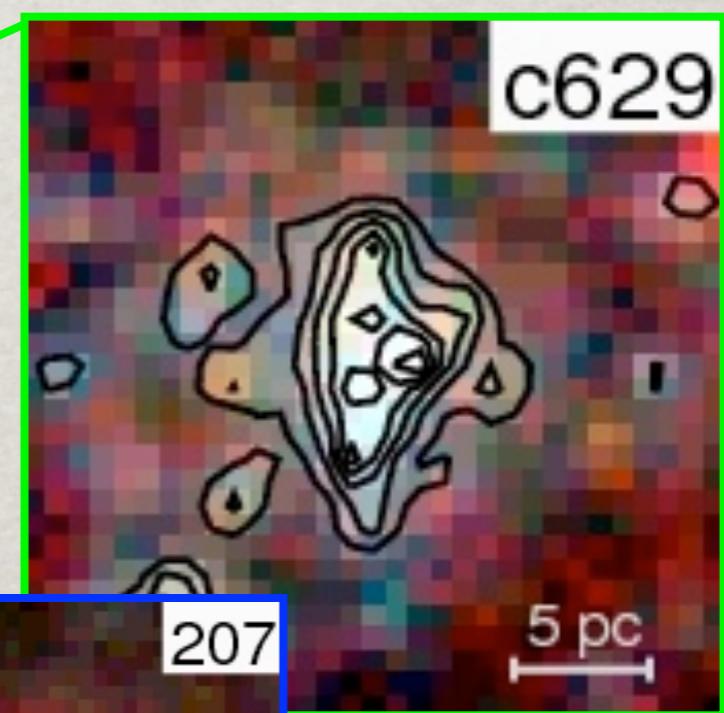
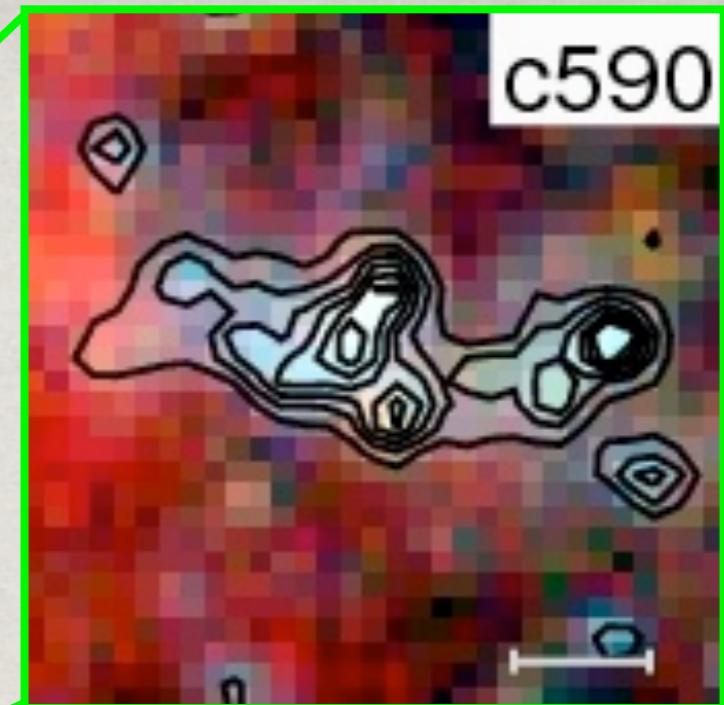
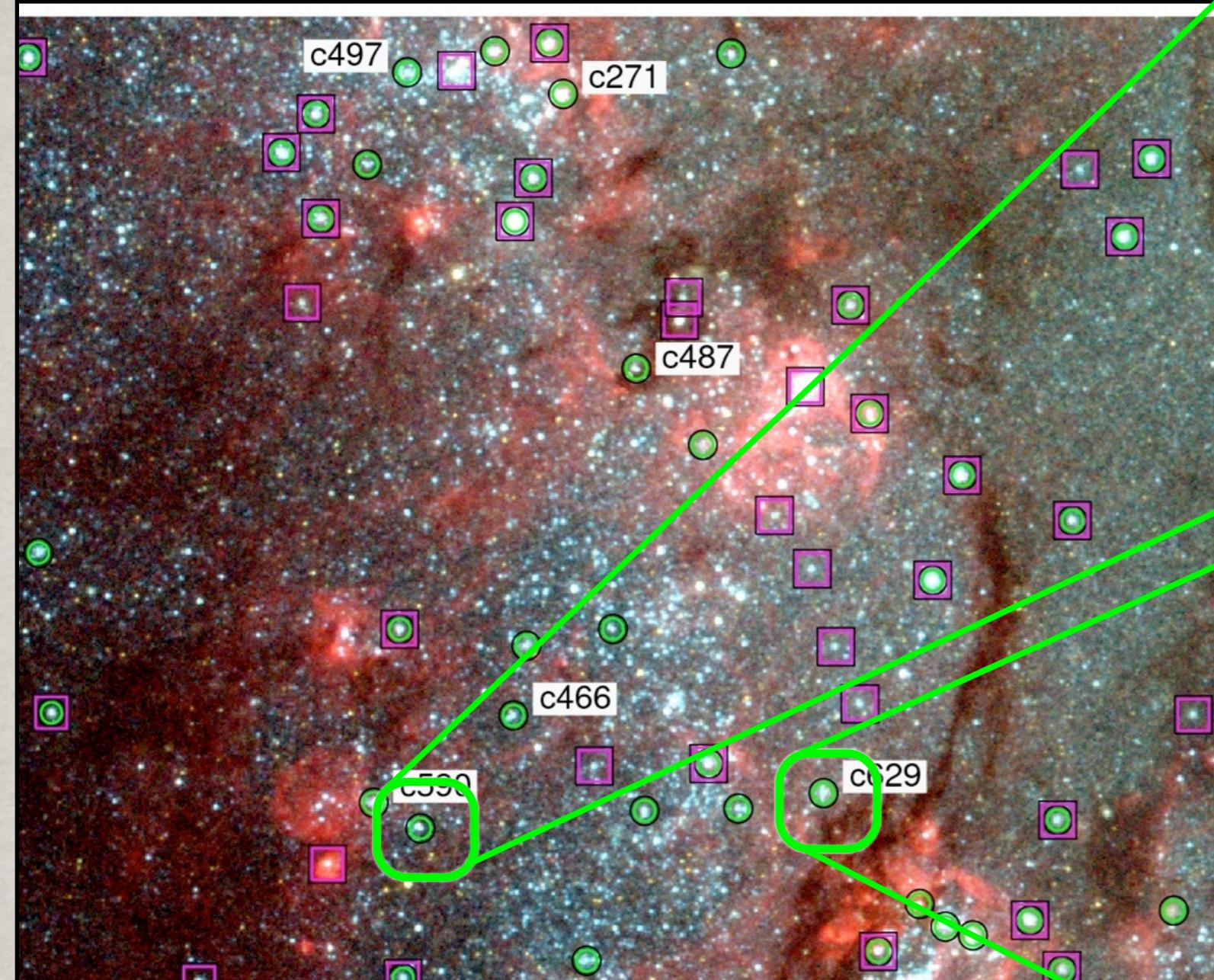




Associations



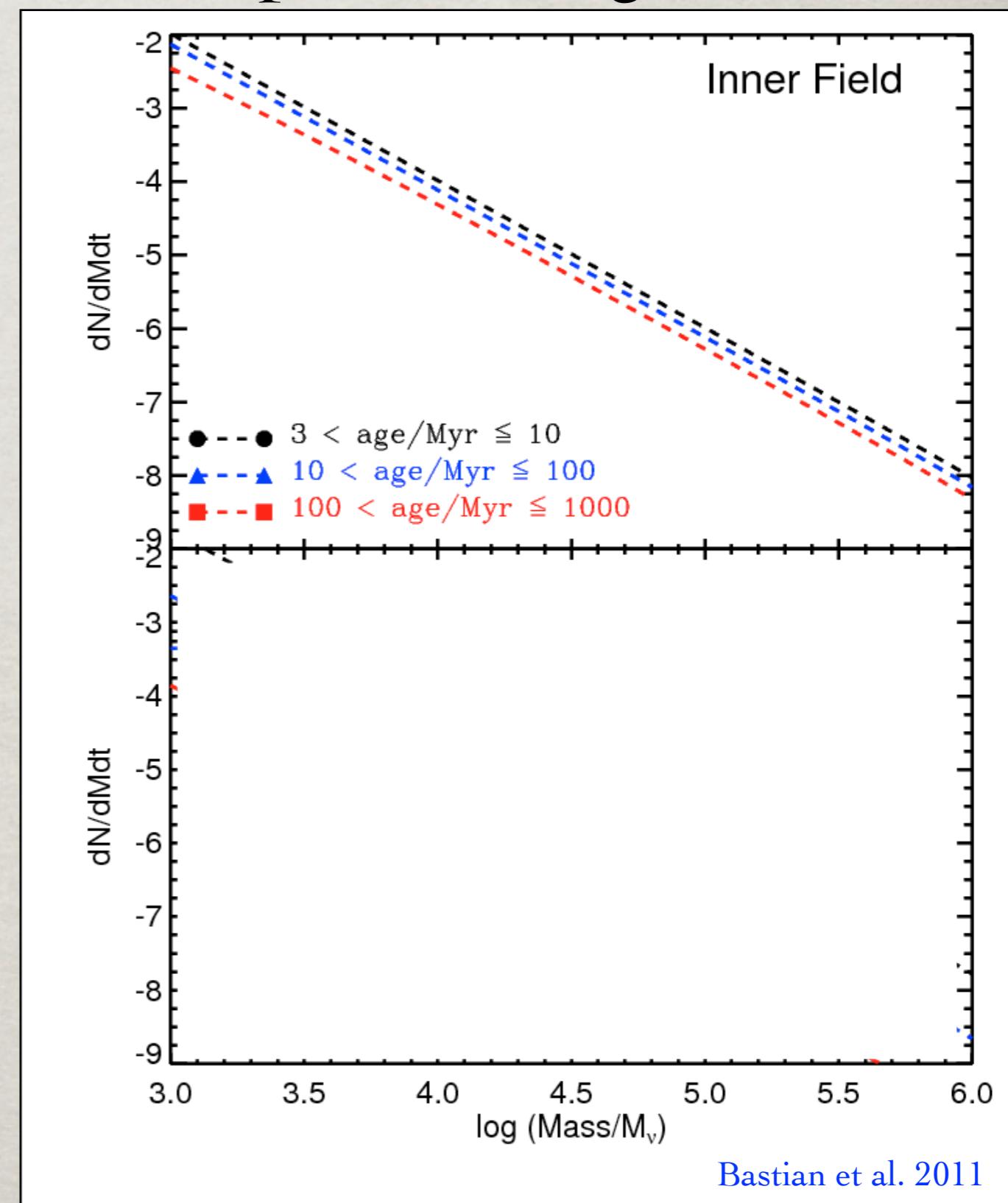
Associations



Clusters

CLUSTER DESTRUCTION

Mass function of clusters - split into 3 age bins

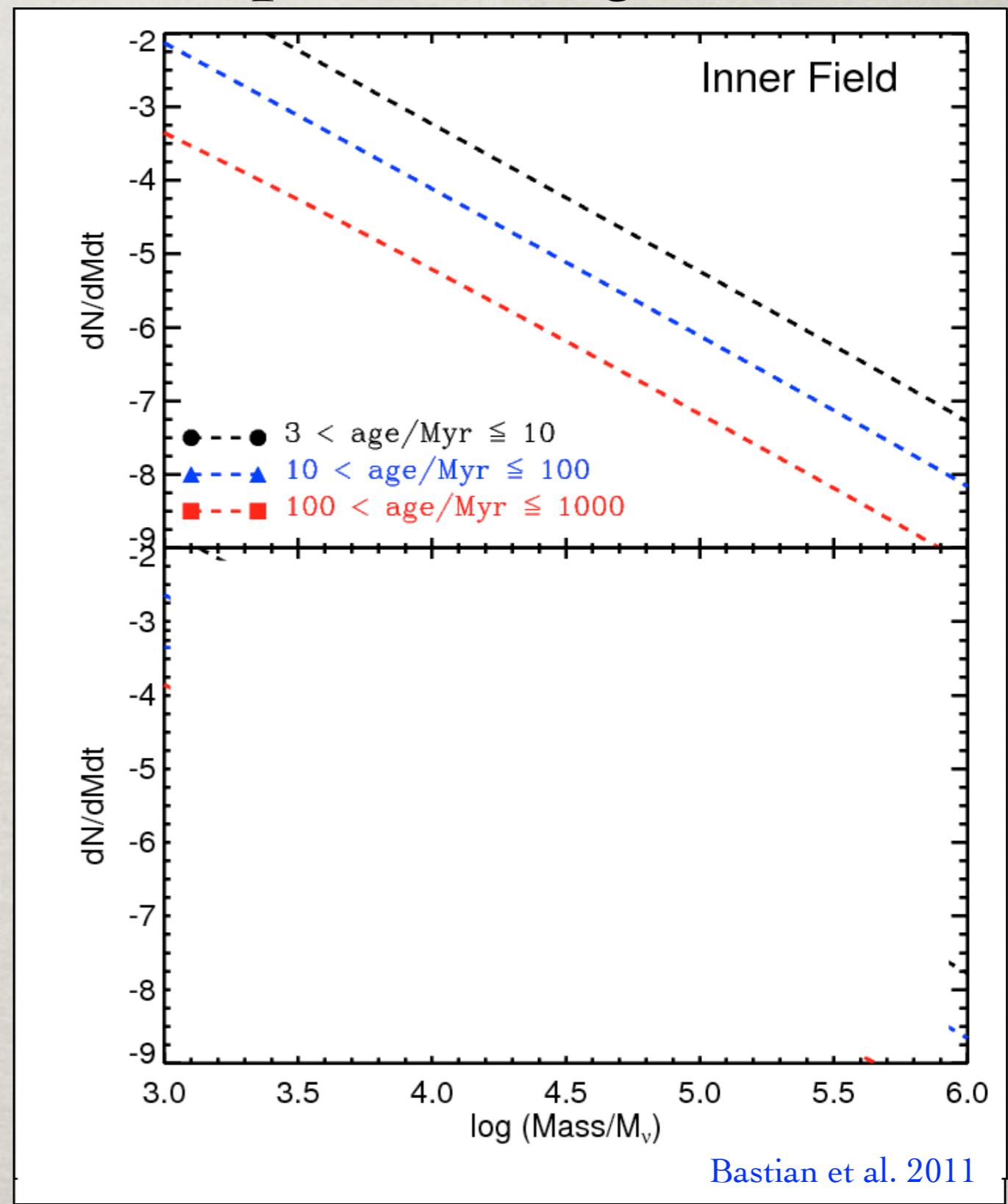


CLUSTER DESTRUCTION

‘Universal’ age and
mass distributions

Fall et al. 2005, 2009
Whitmore et al. 2007
Chandar et al. 2010

Mass function of clusters -
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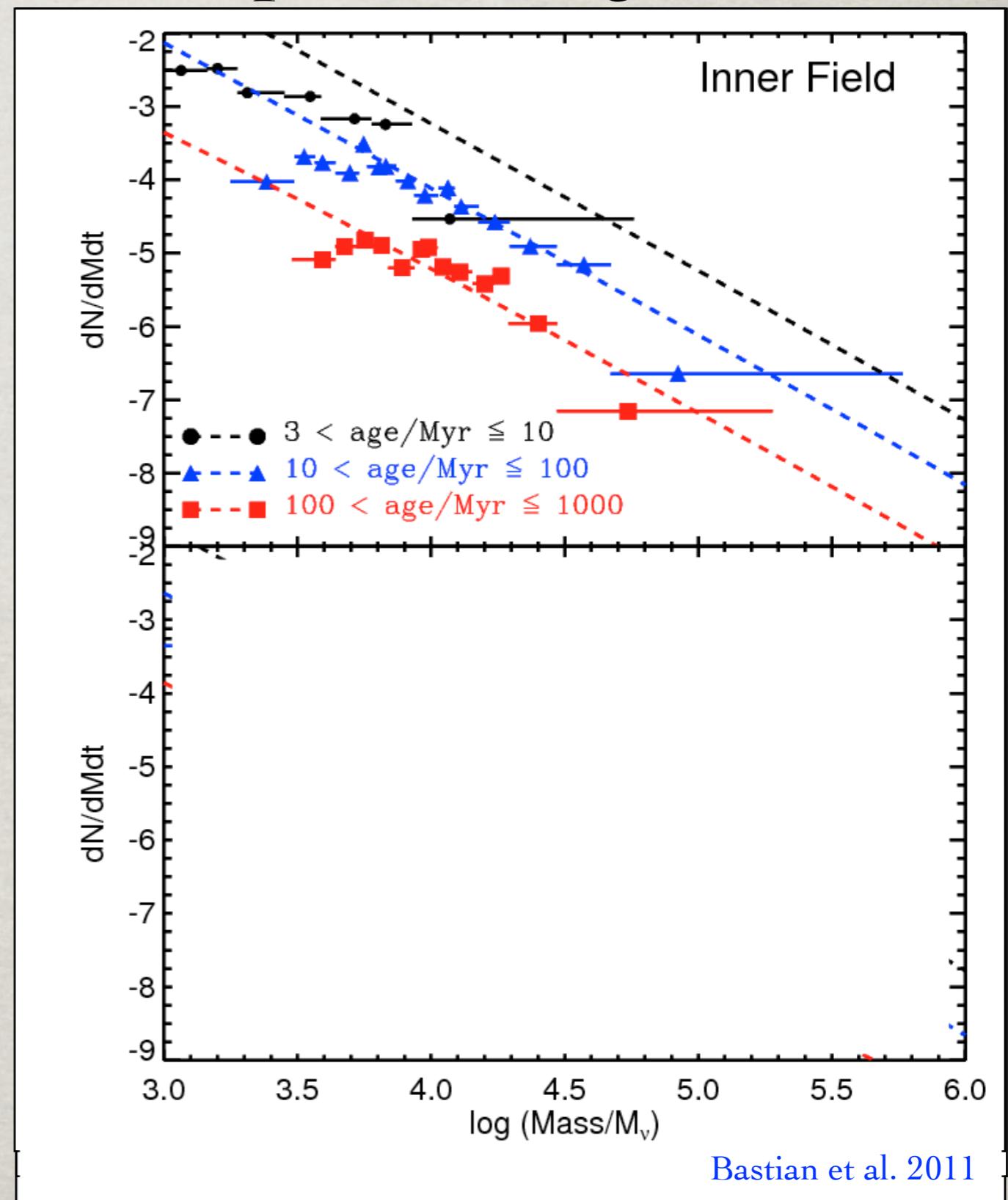


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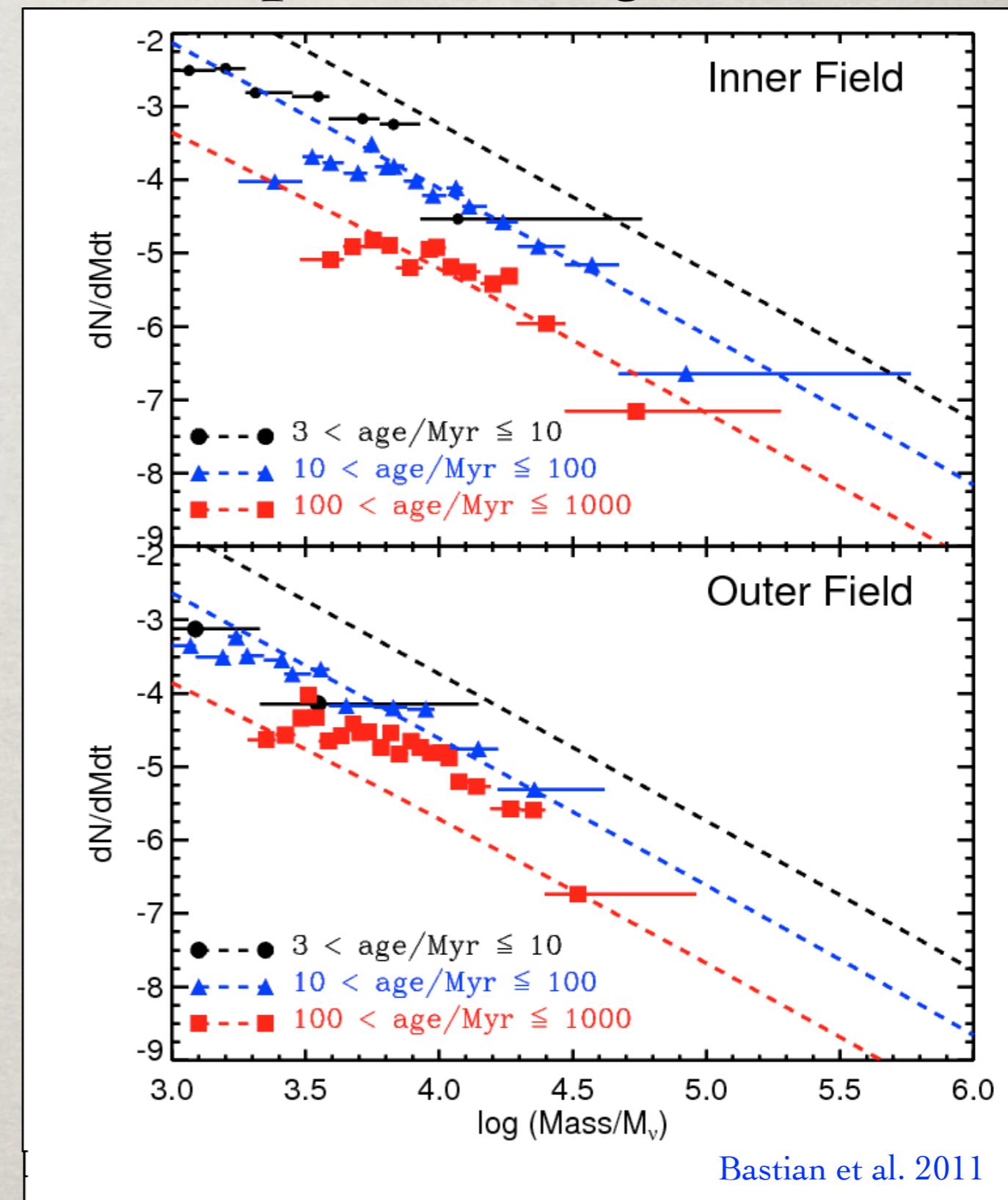
Bastian et al. 2011

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'Universal' age and mass distributions

Fall et al. 2005, 2009
Whitmore et al. 2007
Chandar et al. 2010

Mass function of clusters - split into 3 age bins



CLUSTER DESTRUCTION

- Clear evidence that disruption is dependent on *environment*

- Consistent with:

- Analytic/numerical predictions

Spitzer 1956, Hénon 1961;
Baumgardt & Makino 2003

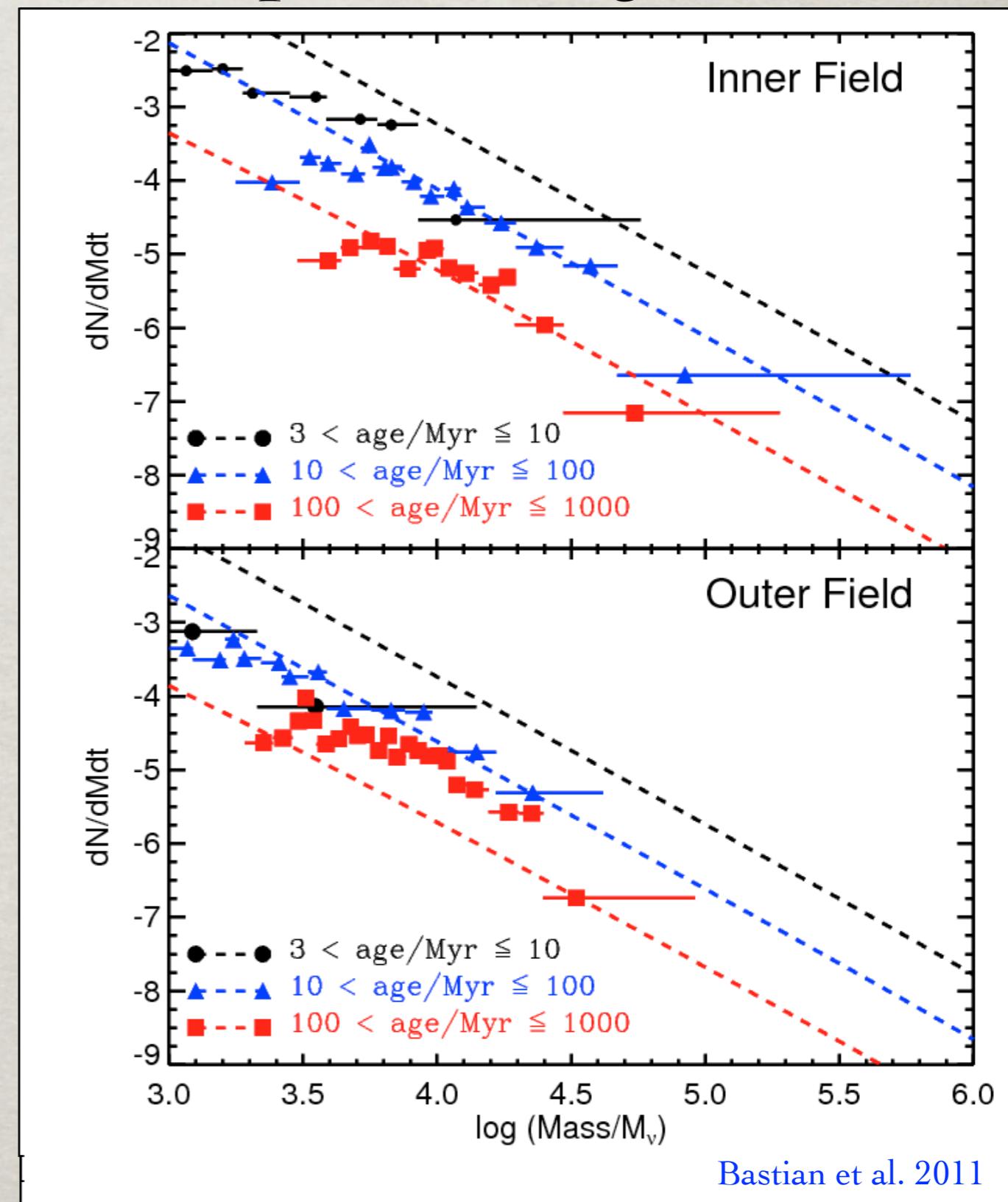
- Lamers empirical disruption law

Boutloukos & Lamers 2003;
Lamers et al. 2003

- “Cruel Cradle” disruption

Elmegreen & Hunter 2010
Kruijssen et al. 2011

Mass function of clusters - split into 3 age bins

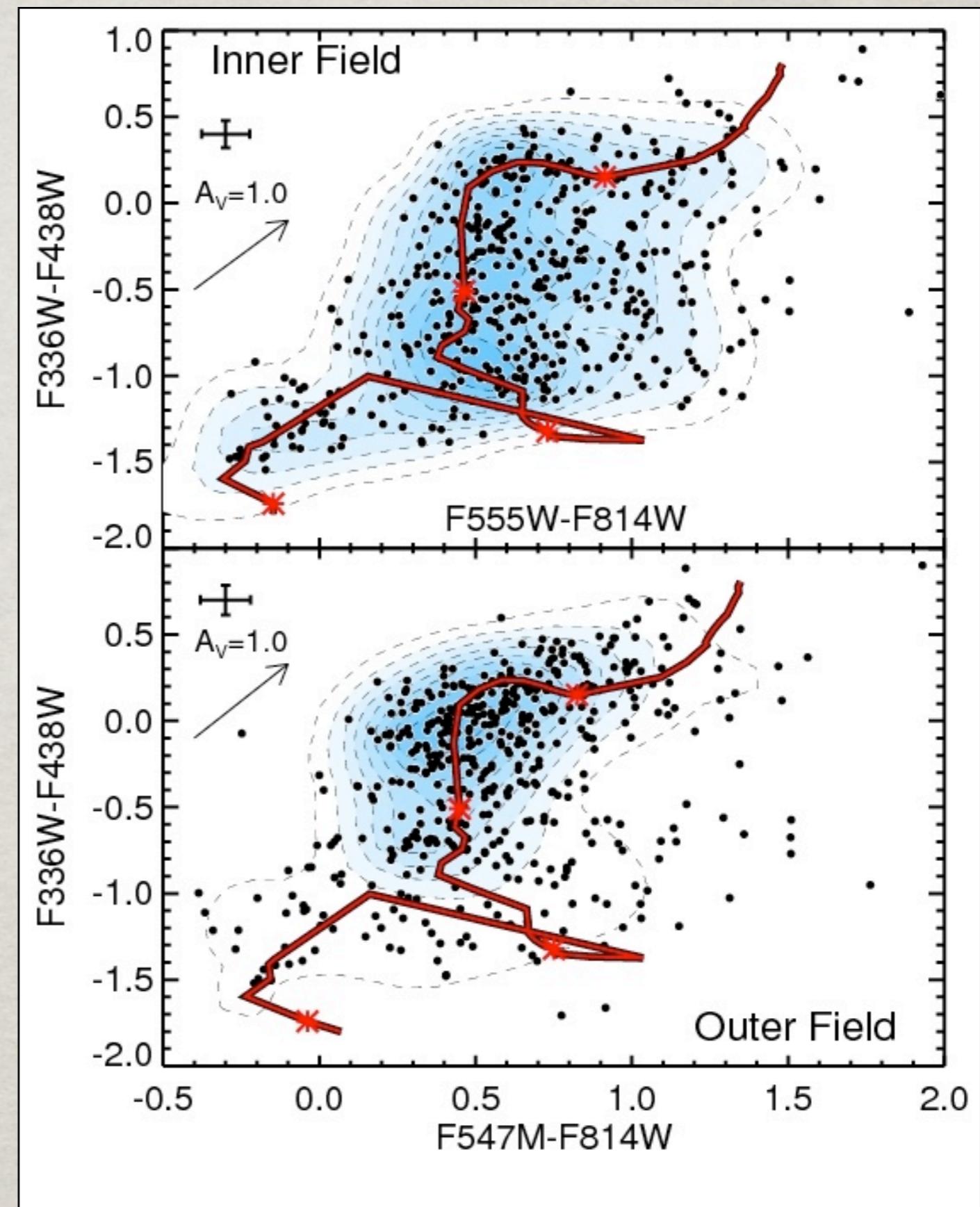


SUMMARY

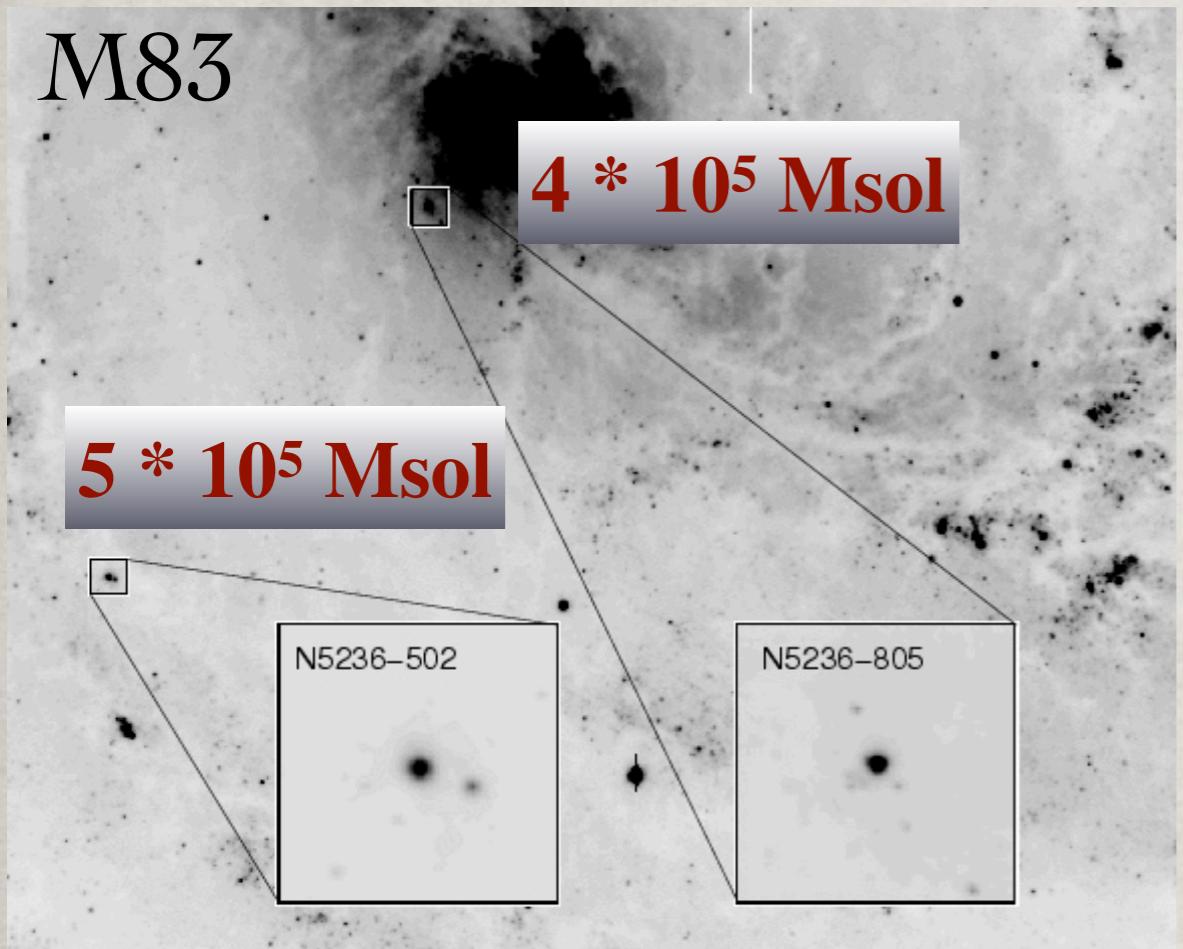
- ✿ YMCs follow the basic scaling relations as globulars - although they are a bit less concentrated
- ✿ They fall in the same parameter space as UCDs/DGTOs - massive objects obey the same mass-radius relation as elliptical galaxies - perhaps a remnant of their formation and evolution
- ✿ The IMF within YMCs is consistent with that seen locally - no gross variation with environment
- ✿ *Not all stars form in clusters* - star-forming regions are messy, hard to define ‘clusters’
- ✿ Cluster disruption in M83 is clearly environmentally dependent

COLOUR DISTRIBUTIONS OF M83 CLUSTERS

Bastian et al. 2011

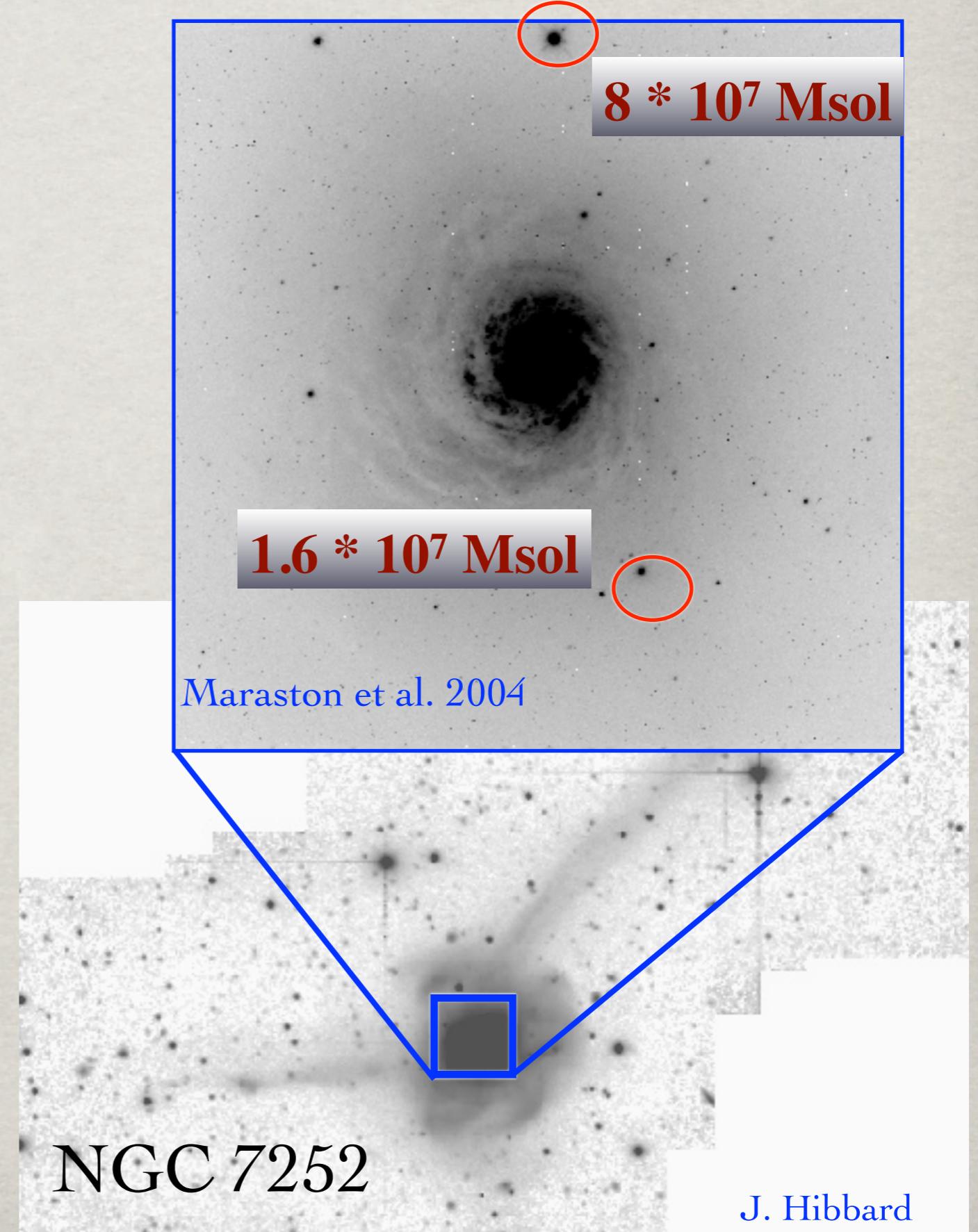
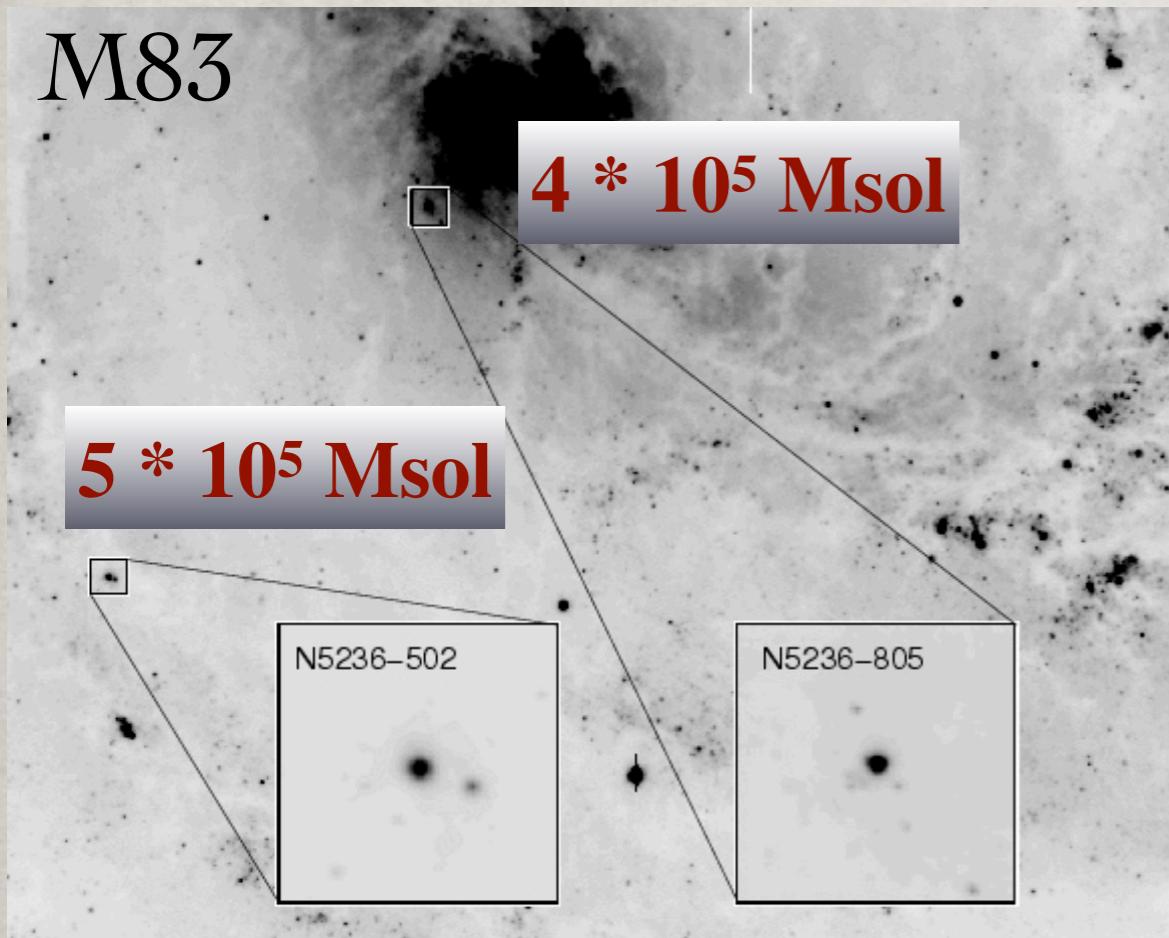


Young massive clusters

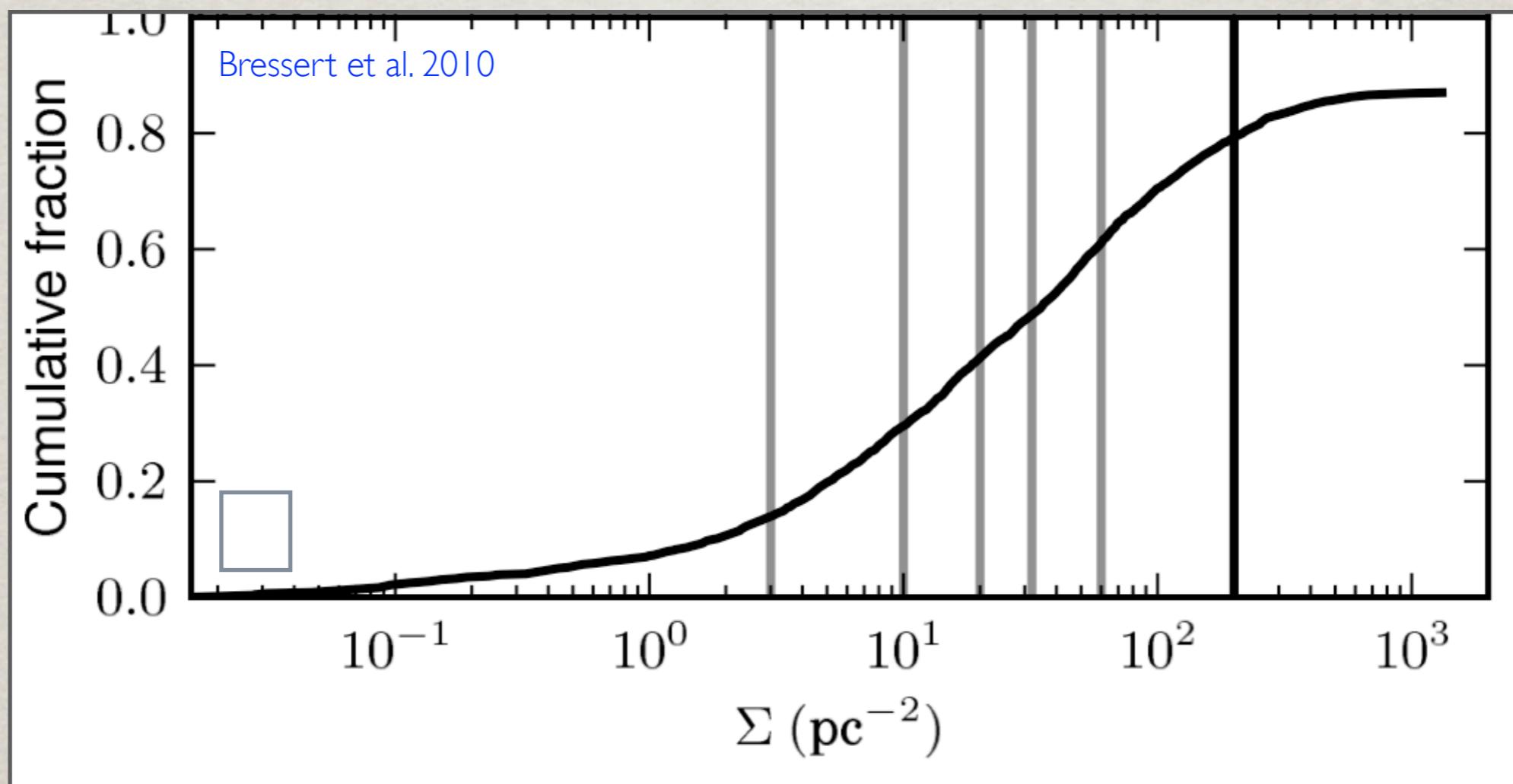


Larsen & Ritchler 2004

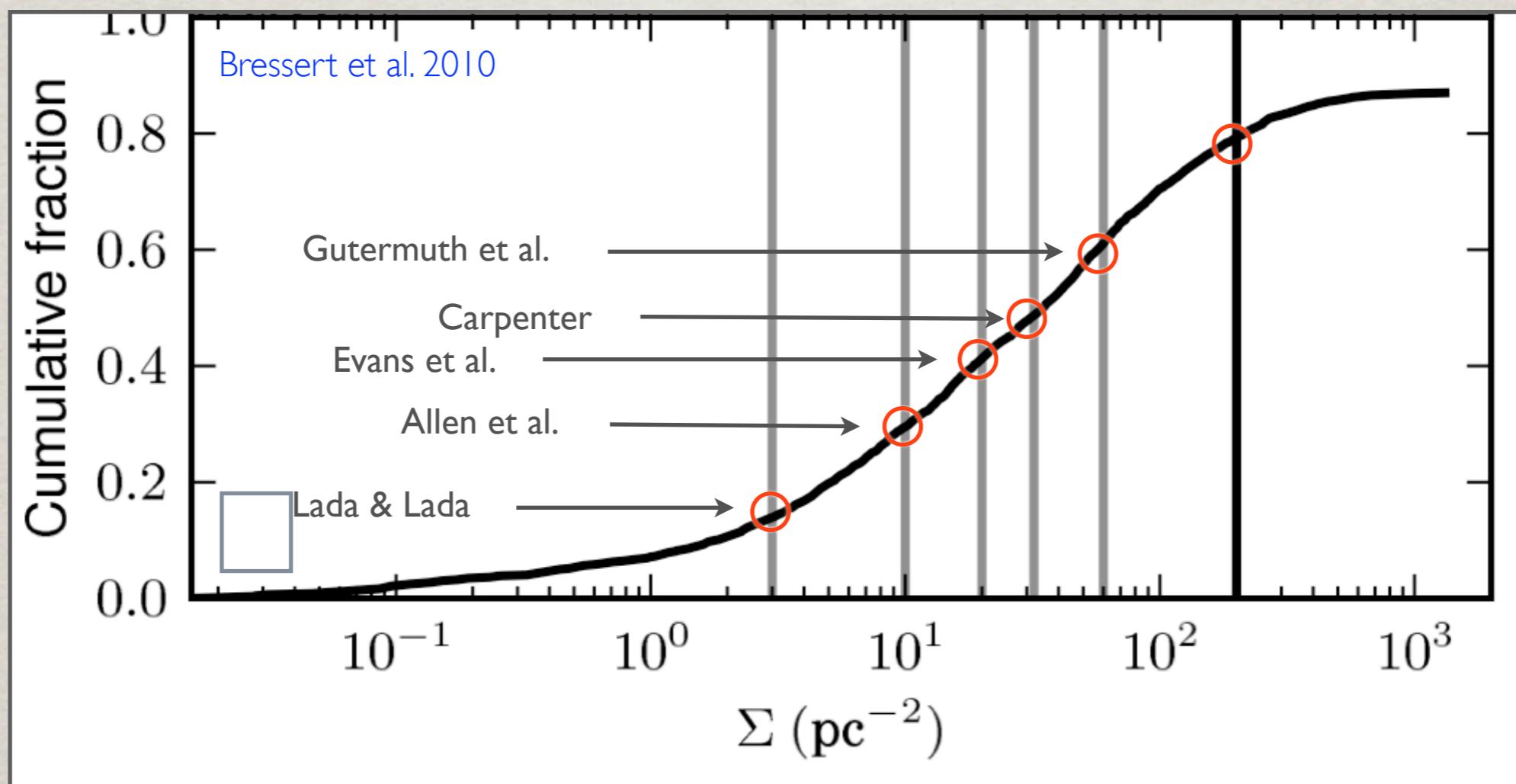
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FRACTION OF STARS FORMING IN ‘CLUSTERS’



FRACTION OF STARS FORMING IN 'CLUSTERS'



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