Searching for Multiple Generations of Star Formation in Young Massive Clusters

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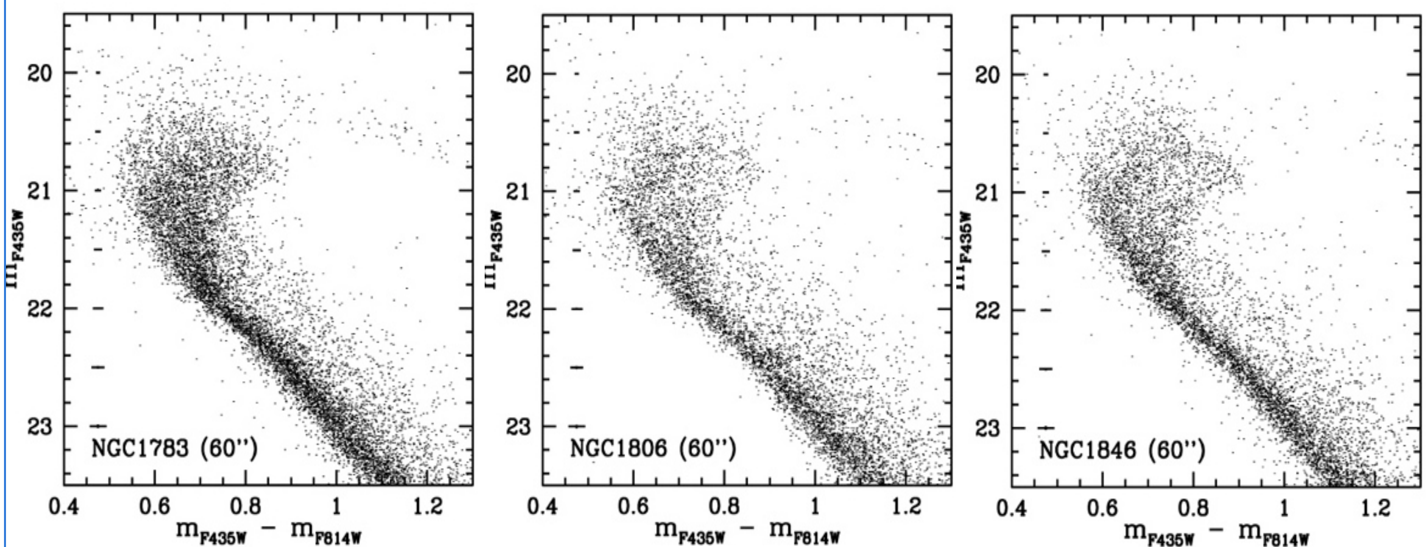
NGC 2100 Credit: ESO

Searching for Age Spreads

- Color-magnitude diagrams of intermediate age (1-2 Gyr) massive clusters in the LMC show extended or double main sequence turn-offs (MSTO)

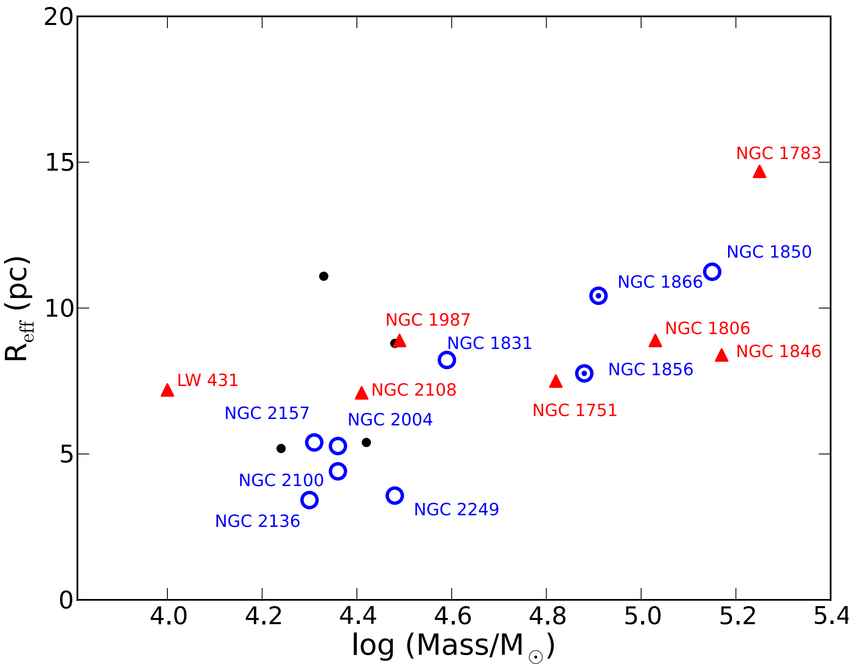


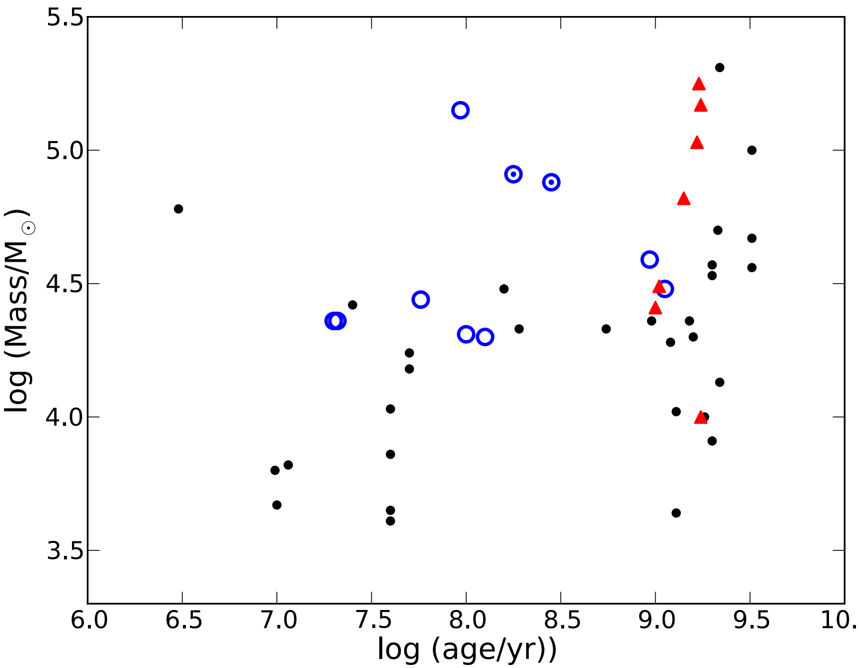
NGC 1783, NGC 1806 and NGC 1846 (Mackey et al. 2008)

- If these features are related to an age spread of 200-500 Myr, young clusters (<1 Gyr) with similar properties should have age spreads of the same order, as well
- We searched for age spreads in a sample of eight young (< 1.1 Gyr) massive (> $10^4 M_\odot$) LMC clusters
- The data set consists of archival HST WFPC2 data from Brocato et al. 2001, Fischer et al. 1998 and the Hubble Legacy Archive

Our Cluster Sample

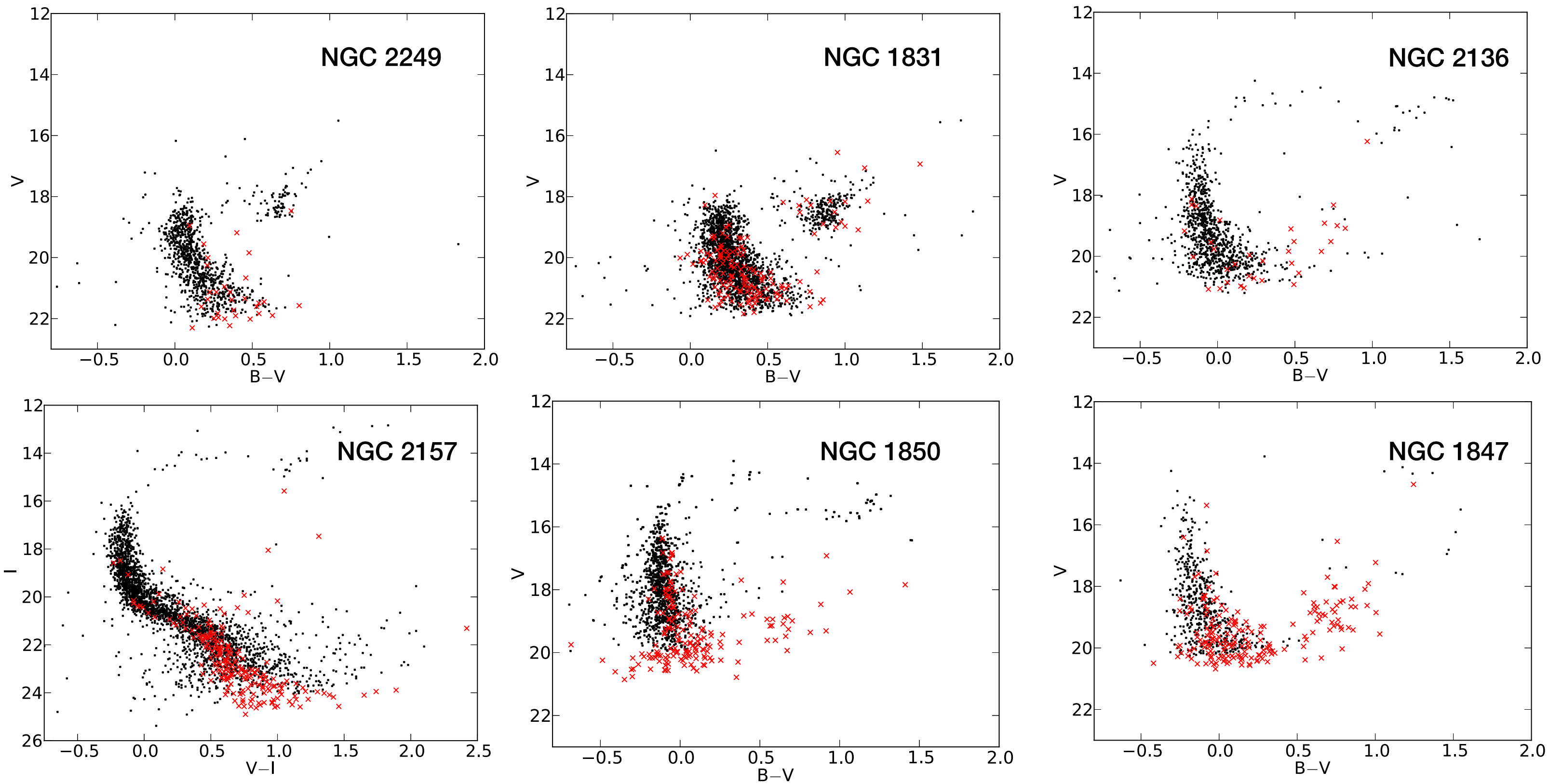
- The selected clusters cover the age range from 20 Myr to ≈ 1 Gyr
- They follow the same mass-effective radius relation as the intermediate age clusters that show an extended MSTO





- Blue circles: Clusters analyzed in this study
- Blue dots surrounded by circles: Clusters already analyzed by Bastian & Silva-Villa 2013
- Red triangles: Intermediate age (1-2 Gyr) clusters that show extended or double MS turn-offs (Goudfrooij 2009,11a)
- Black dots: Other LMC clusters

CMDs of the Clusters



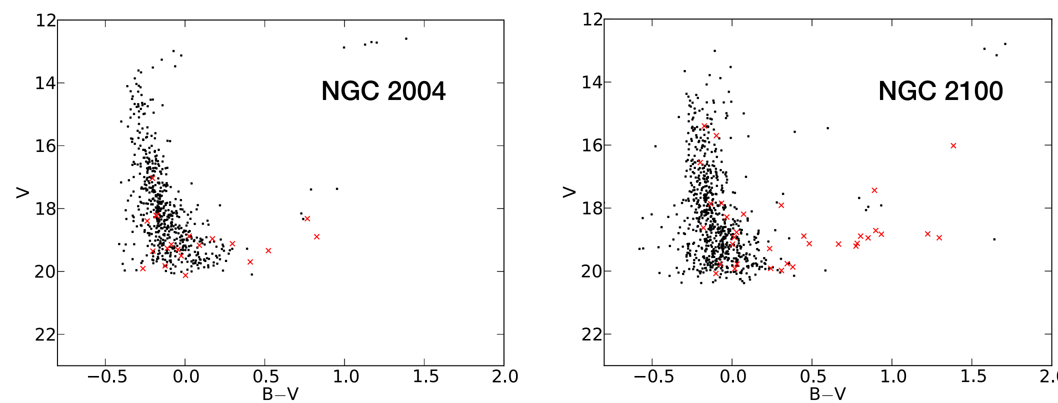
Black dots:

Stars that are used for further analysis

Red crosses:

Stars that are removed as field stars

Niederhofer et al. (submitted)



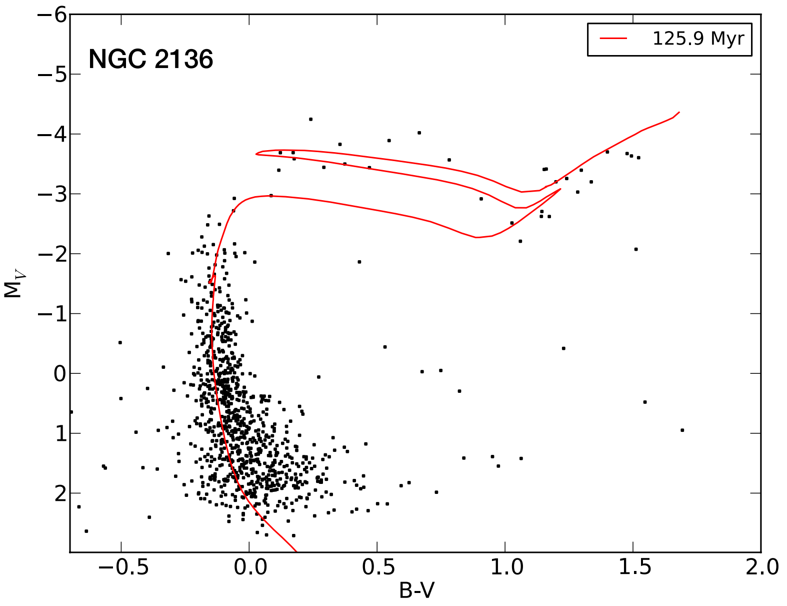
Study of the Clusters

Steps of the Analysis:

- Processed data: Field stars subtracted and extinction corrected
- Comparison of the clusters' CMDs with model Hess diagrams
- Fitting of the star formation history of the clusters

Used Tools and Parameters:

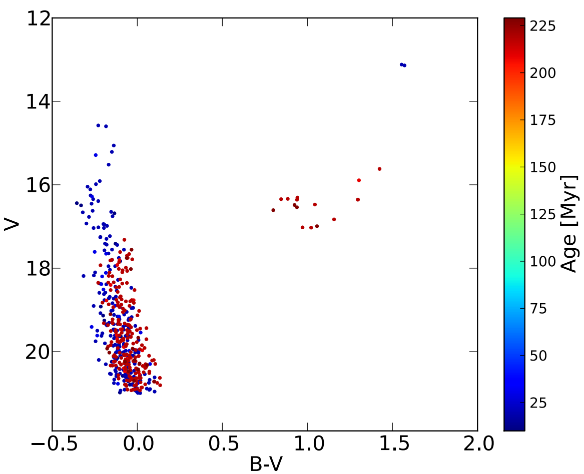
- *FITSFH* code (Silva-Villa & Larsen 2010, Larsen et al. 2011)
- Parsec 1.1 isochrones from the Padova set (Bressan et al. 2012) at the respective metallicities of the clusters
- Metallicities and DM from fitting theoretical isochrones to the CMDs of the clusters
- Salpeter 1955 initial mass function, above $1M_{\odot}$

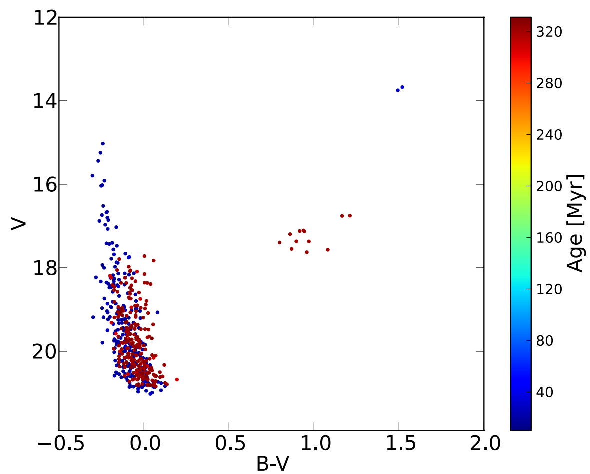


Expectations

This is what we would expect for a young cluster with the kinds of age spreads proposed for the intermediate age clusters

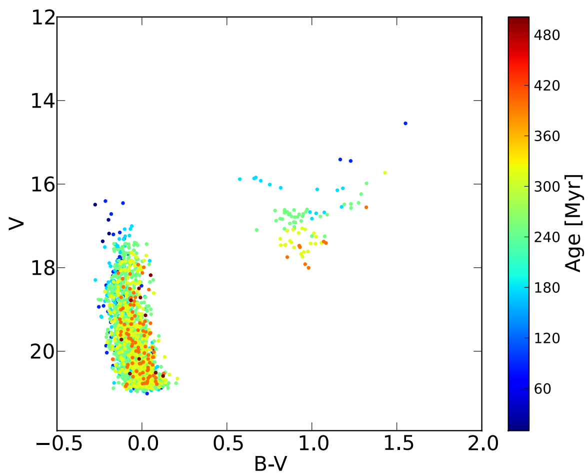
Bimodal age spread with peaks at 20 and 220 Myr



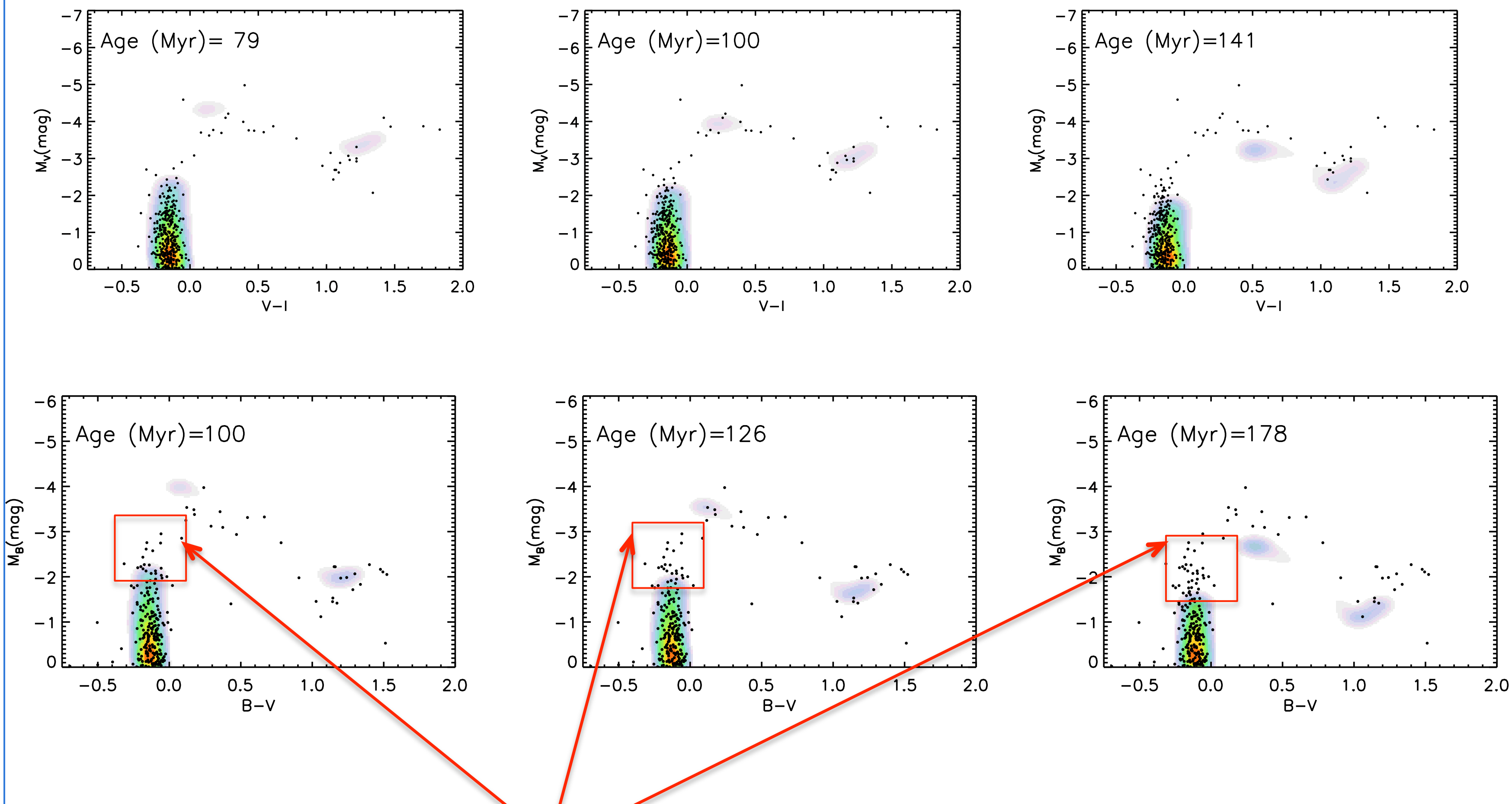


Bimodal age spread with peaks at 20 and 320 Myr

Gaussian like SFH with a peak at 250 Myr that lasted 500 Myr

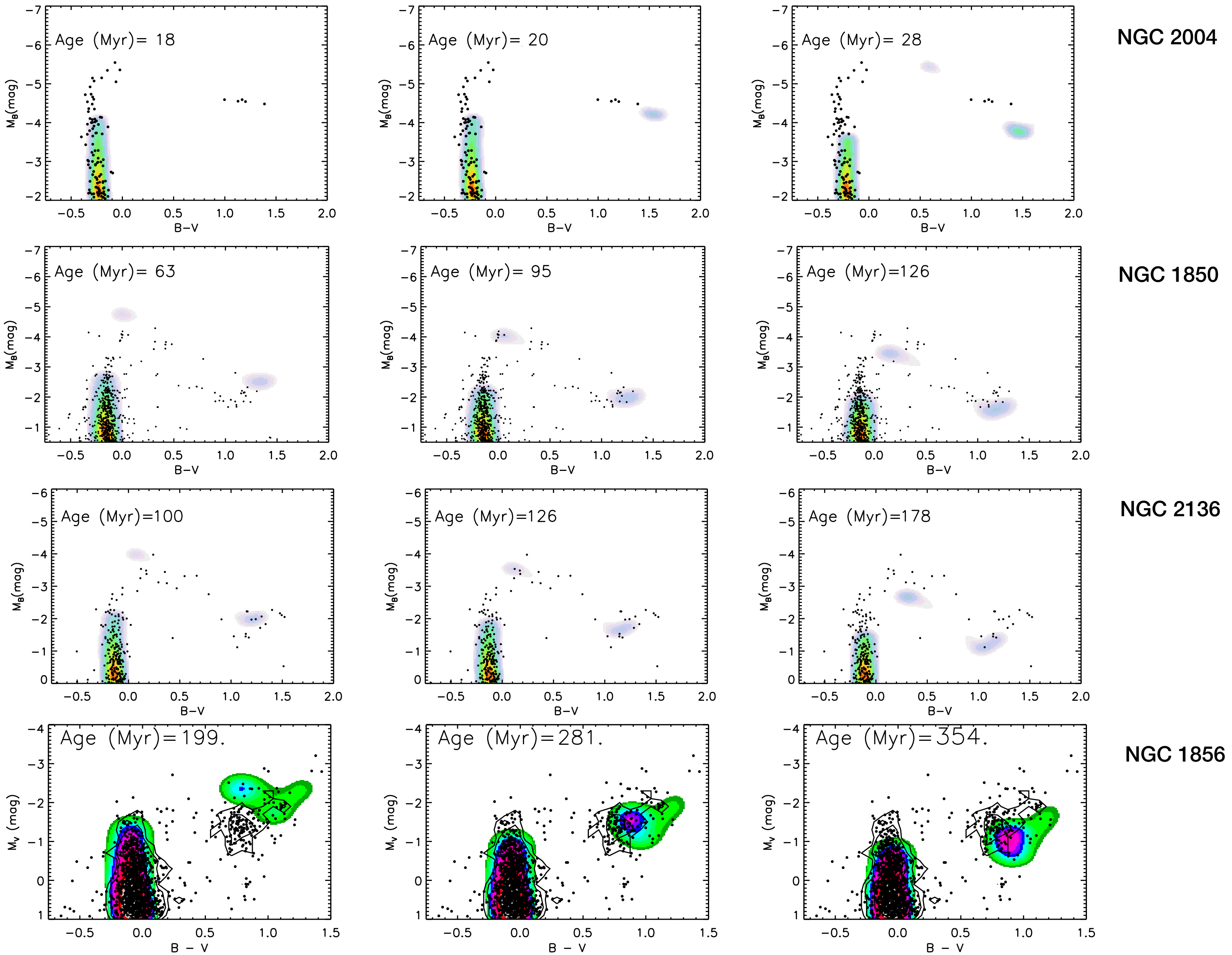


Hess Diagram of NGC 2157

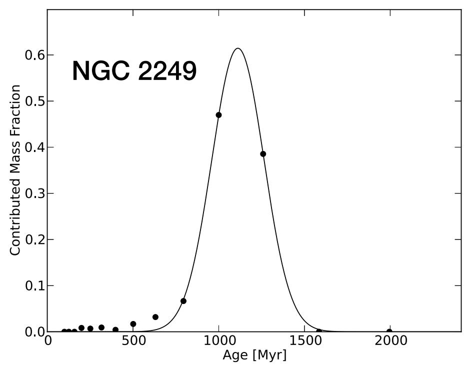


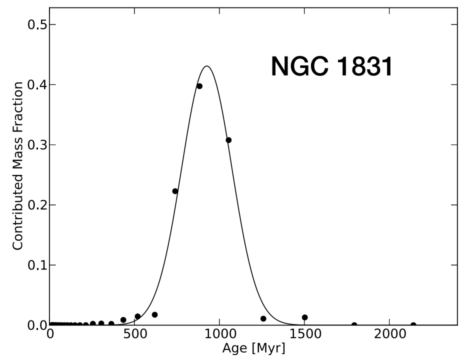
Stars in the 'Blue Hertzsprung Gap' where models predict no stars
Also seen in other clusters (e.g. Larsen et al. 2011)
Could be crowded stars, fast rotating stars, interactive binaries or blue stragglers

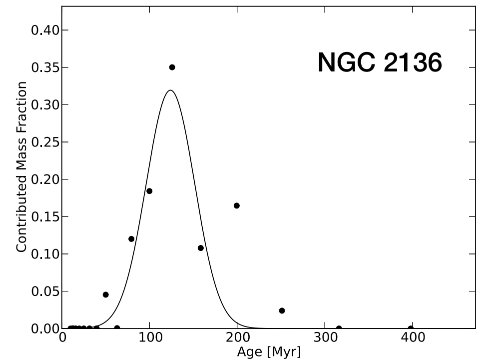
Hess Diagrams

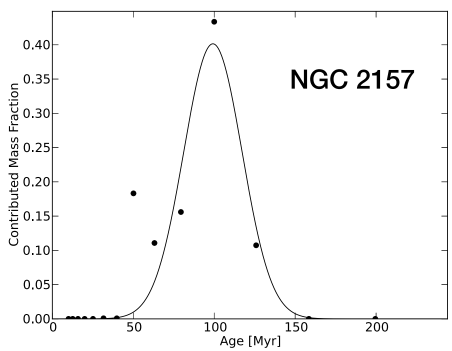


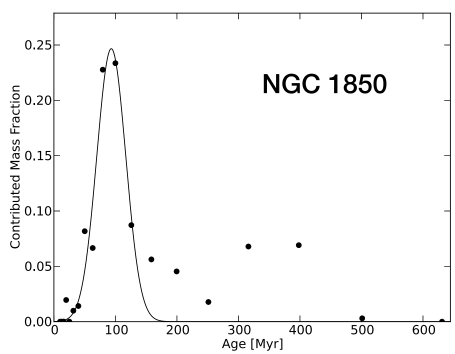
Results

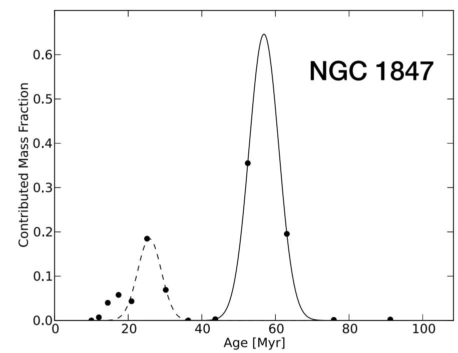




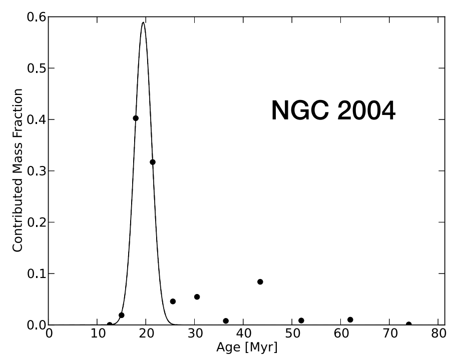


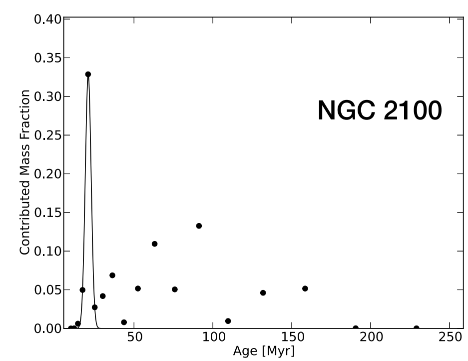






Black dots:
Fitting results at individual ages
Solid line:
Best Gaussian fit to the points





Niederhofer et al. (submitted)

Results

Cluster	Fitted SFH
NGC 1831	926 ± 148 Myr
NGC 1847	56.9 ± 4.0 Myr
NGC 1850	93.3 ± 23.6 Myr
NGC 2004	19.5 ± 8.0 Myr
NGC 2100	21.0 ± 1.9 Myr
NGC 2136	124.0 ± 27.7 Myr
NGC 2157	99.2 ± 18.1 Myr
NGC 2249	1110 ± 152 Myr
NGC 1856	281 ± 33.6 Myr
NGC 1866	177 ± 18.4 Myr

- Fitted age spread increases with increasing cluster age
- All age spreads listed here are upper limits
- Clusters are consistent with a SSP within the errors
- Results are in conflict with proposed age spreads in intermediate age clusters
- Either intermediate age clusters do not have age spreads
- Or YMC and intermediate age clusters are different in nature

Results

Revised age for NGC 1850

Cluster	Fitted SFH
NGC 1831	926 ± 148 Myr
NGC 1847	56.9 ± 4.0 Myr
NGC 1850	93.3 ± 23.6 Myr
NGC 2004	19.5 ± 8.0 Myr
NGC 2100	21.0 ± 1.9 Myr
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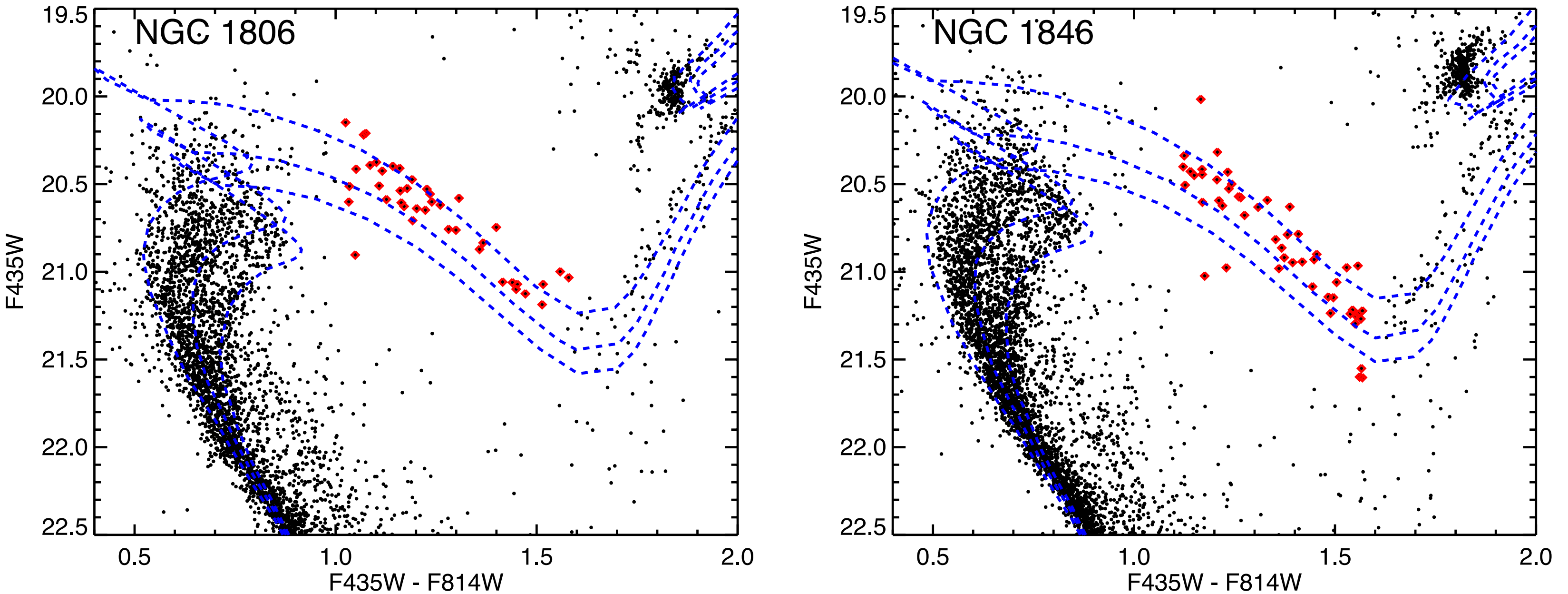
NGC 1866	177 ± 18.4 Myr

Consistent with previous study by Fischer et al. 1993
Significantly higher than the commonly used value of about 30 Myr (e.g. Elson 1991, McLaughlin & van der Marel 2005, Baumgardt et al. 2013)

Results in a mass of $1.4 \times 10^5\ M_\odot$
and an escape velocity of 12.3 km/s

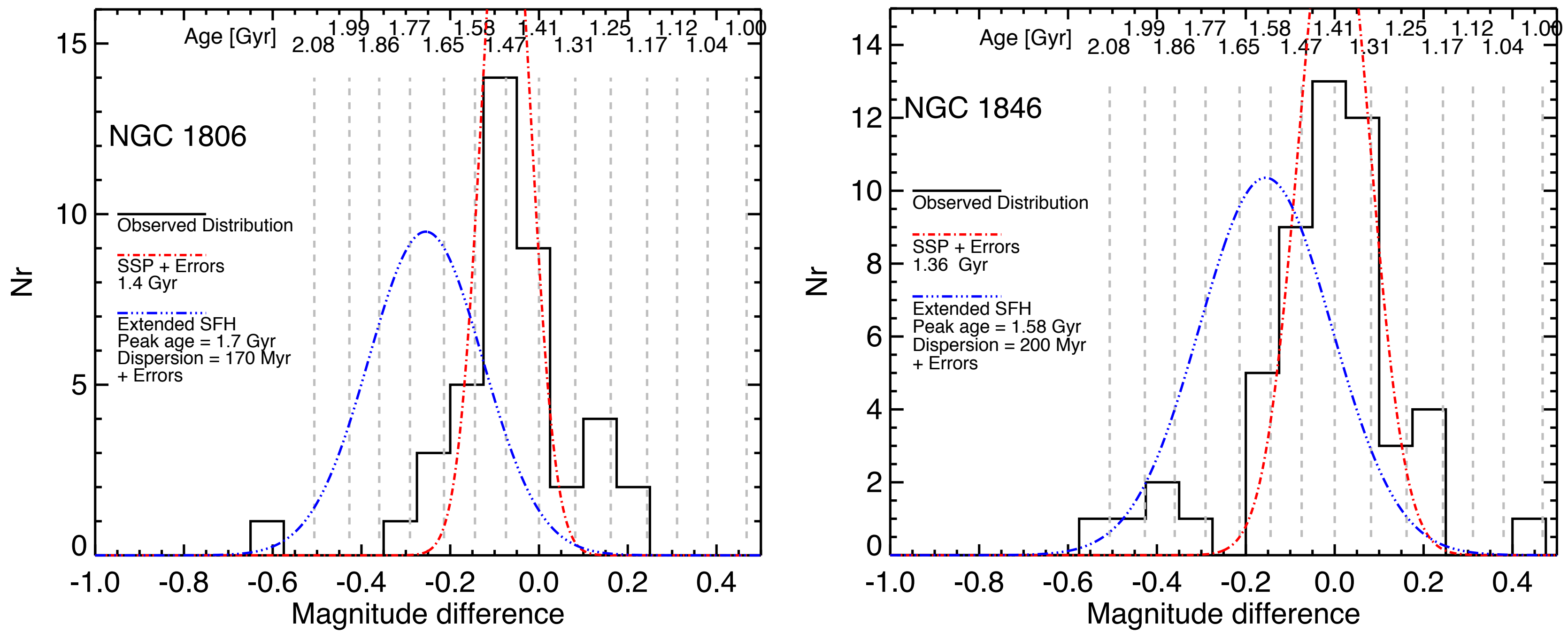
A Closer Look at Intermediate Age Clusters



Bastian & Niederhofer (submitted)

Width of the sub-giant branches does not seem to cover the range in ages that would be expected from the extended MSTO feature

The Sub-Giant Branch Morphology



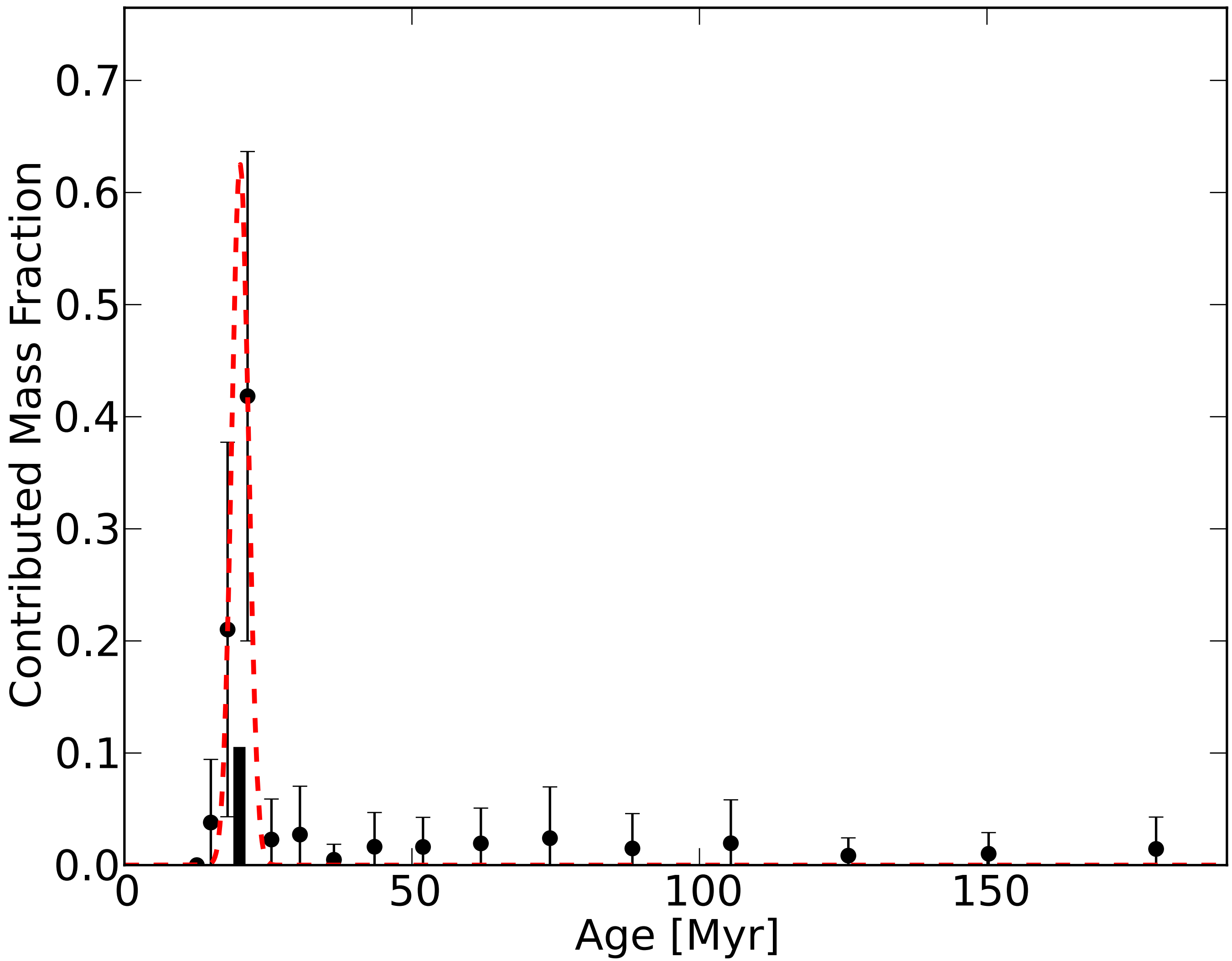
Bastian & Niederhofer (submitted)

Comparison of the sub-giant branch morphologies with single stellar population models (red) and extended star formation history (SFH) models (blue)

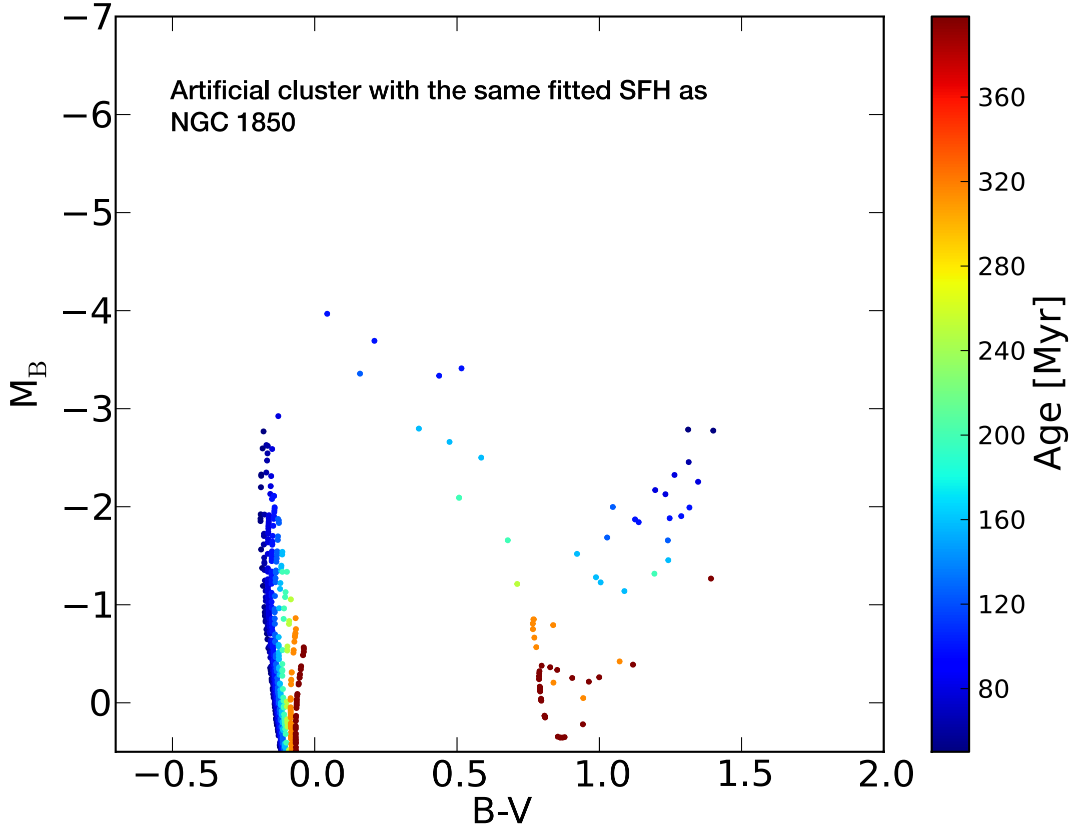
Morphologies in conflict with extended SFH model

(see also Li et al. (2014, Nature), for NGC 1651)

Simulations



Supplementary Material



Supplementary Material