Studying the stellar populations in the fuzzy cores of young massive clusters

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Cardiff University
Young Massive clusters

Dense aggregate of newly formed stars with lots of difficulties!

- Immersed in gas/dust: High (inhomogeneous) extinction

Observations in longer wavelength

- Most of them are not close enough: their individual members probably are not resolved

High angular resolution observations

- Massive hot stars mask the faint low-mass stars.

High contrast imaging
Young Massive Clusters

DSS2 Blue

Stellar populations in the fuzzy cores of YMCs

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DSS2 Red
2MASS J,H,K

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Young Massive Clusters

2MASS J,H,K

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SFM

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Next step ...

1. Proper evolutionary/atmosphere model

2. Estimating stellar masses, ages

3. Investigate physics of the newly formed cluster:
   - MF, density profile, Virial status, mass-segregation
   - Feeding cluster-formation simulations, gravitational-dynamical evolution
   - Filling the gap between cluster formation and evolution
To compare simulations with observations we should use **synthetic observations**

With **MYSO** feel free to

**Make Your Synthetic Observations!**
Two similar clusters (age and stellar population) in different distances
NGC 3603

LMC

SMC

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NGC 3603

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MF example: NGC3603

$M_{\text{total}} \sim 10^4 M_\odot$

Age $\sim 1 - 2 \text{Myr}$

$D_{\text{is}} \sim 6 - 7 \text{Kpc}$

Constellation: Carina
### NGC 3603

<table>
<thead>
<tr>
<th>MF slope</th>
<th>condition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-0.73$</td>
<td>$(1 - 30) M_\odot$</td>
<td>[Eisenhauer et al.1998]</td>
</tr>
<tr>
<td>$-0.9$</td>
<td>$(2.5 - 100) M_\odot$</td>
<td>[Sung &amp; Bessell2004]</td>
</tr>
<tr>
<td>$-0.5 \pm 0.1$</td>
<td>$r &lt; 6''$</td>
<td>[Sung &amp; Bessell2004]</td>
</tr>
<tr>
<td>$-0.8 \pm 0.2$</td>
<td>$6'' - 12''$</td>
<td>[Sung &amp; Bessell2004]</td>
</tr>
<tr>
<td>$-1.2 \pm 0.2$</td>
<td>$r &gt; 12''$</td>
<td>[Sung &amp; Bessell2004]</td>
</tr>
<tr>
<td>$-0.91 \pm 0.15$</td>
<td>$(0.4 - 20) M_\odot$</td>
<td>[Stolte et al.2006]</td>
</tr>
<tr>
<td>$-0.31$</td>
<td>$0 - 5''$</td>
<td>[Harayama et al.2008]</td>
</tr>
<tr>
<td>$-0.55$</td>
<td>$5'' - 10''$</td>
<td>[Harayama et al.2008]</td>
</tr>
<tr>
<td>$-0.72$</td>
<td>$10'' - 13''$</td>
<td>[Harayama et al.2008]</td>
</tr>
<tr>
<td>$-0.75$</td>
<td>$13'' - 30''$</td>
<td>[Harayama et al.2008]</td>
</tr>
<tr>
<td>$-0.26$</td>
<td>$0 - 5''$</td>
<td>[Pang et al.2013]</td>
</tr>
<tr>
<td>$-0.55$</td>
<td>$5'' - 10''$</td>
<td>[Pang et al.2013]</td>
</tr>
<tr>
<td>$-0.76$</td>
<td>$10'' - 15''$</td>
<td>[Pang et al.2013]</td>
</tr>
</tbody>
</table>

Different MF slopes

Different observations
WFPC2
Filters: V,R,I
50mas/pix

ACS/HRC
Filters: Ux,U,B,V,R,I
25mas/pix
WFPC2 shows the decreasing trend in MF slope... signature of mass-segregation BUT this is not the case for HRC data
High angular and contrast images from VLT/SPHERE
No signature of mass segregation in the core of NGC 3603:
1) The MF slope in its very core is not flatter than the next radial bin
2) Both slopes are similar to the MF values found in previous works for the outer regions

Stellar populations in the fuzzy cores of YMCs

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30 Doradus Nebula and Star Cluster

*Hubble Space Telescope* - WFC3

**Visible WFC3/UVIS**

**Infrared WFC3/IR**

- **Dis ~ 50Kpc**
- **Constellation: 30Doradus**
- **$M_{\text{total}} \sim 10^5 M_\odot$**
- **Age ~ 2 – 3Myr**

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Mass function slopes for R 136 from previous analyses.

<table>
<thead>
<tr>
<th>MF slope</th>
<th>Condition</th>
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</tr>
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<tbody>
<tr>
<td>−0.90</td>
<td>(20–70) $M_\odot$ $r &lt; 3'' 3$</td>
<td>Malumuth &amp; Heap (1994)</td>
</tr>
<tr>
<td>−1.89</td>
<td>(20–70) $M_\odot$ $3'' 3 &lt; r &lt; 17'' 5$</td>
<td>Malumuth &amp; Heap (1994)</td>
</tr>
<tr>
<td>−1.0 ± 0.1</td>
<td>(2.8–15) $M_\odot$ $2'' 0 &lt; r &lt; 18'' 8$</td>
<td>Hunter et al. (1996)</td>
</tr>
<tr>
<td>(−1.3)–(−1.4)</td>
<td>(15–120) $M_\odot$</td>
<td>Massey &amp; Hunter (1998)</td>
</tr>
<tr>
<td>−1.59</td>
<td>$r &lt; 1'' 6$</td>
<td>Brandl et al. (1996)</td>
</tr>
<tr>
<td>−1.33</td>
<td>$1'' 6 &lt; r &lt; 3'' 2$</td>
<td>Brandl et al. (1996)</td>
</tr>
<tr>
<td>−1.63</td>
<td>$3'' 2 &lt; r$</td>
<td>Brandl et al. (1996)</td>
</tr>
<tr>
<td>−1.17 ± 0.05</td>
<td>$4'' 6 &lt; r &lt; 19'' 2$</td>
<td>Selman et al. (1999)</td>
</tr>
<tr>
<td>−1.37 ± 0.08</td>
<td>$15'' &lt; r &lt; 75''$</td>
<td>Selman et al. (1999)</td>
</tr>
<tr>
<td>−1.28 ± 0.05</td>
<td>(2–6.5) $M_\odot$ $4'' \lesssim r \lesssim 20''$</td>
<td>Sirianni et al. (2000)</td>
</tr>
<tr>
<td>−1.2 ± 0.2</td>
<td>(1.1–20) $M_\odot$ $20'' &lt; r &lt; 28''$</td>
<td>Andersen et al. (2009)</td>
</tr>
</tbody>
</table>
MF example: R136

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MF example: R136

WFPC2/F555W

VLT/SPHERE/Ks

WFPC2/F555W
MF at 0.6, 1 and 1.5 Myr; \( N_{\text{total}} = 818 \)

0.6 Myr = -0.88 +/- 0.12
1.0 Myr = -0.90 +/- 0.13
1.5 Myr = -0.98 +/- 0.18

MF is sensitive to the observations and models

How can we simulate observations?
Make Your Synthetic Observations

Inputs:

Stars information (from N-body): 3D position and Velocity, Mass, age, metallicity
Cloud information (from SPH): 3D position, particle's mass, smoothing lengths

Observational Filter (from the list)
Imaging angular resolution AND Spectroscopic resolution

Distance of the centre of mass
FoV

R_v for extinction
Adaptive optics: seeing and SR

OB-treatment: TLUSTY model atmosphere
Velocity dispersion
Euler angles for line-of-sight
Signal/Noise ratio for the faintest star

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*_cube_spectra.fits*: 3D cube, X-Y is the position of stellar sources, z is flux in different wavelengths

**Gaia-G filter**

R=700
* _cube_spectra.fits_: 3D cube, X-Y is the position of stellar sources, z is flux in different wavelengths

Gaia-G filter
R=700
* _cube_spectra.fits_ : 3D cube, X-Y is the position of stellar sources, z is flux in different wavelengths

Gaia-G filter

R=700

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$M_{\text{tot}} = 10^5 \, M_\odot$, BF=0%, $R_h=0.8$ pc, Age=2 Myr

WFPC2/F555W

IRDIS/K
SR: 0.7
$M_{\text{tot}}=10^5 M_\odot$, $BF=0\%$, $R_h=0.8$ pc, $Age=2$ Myr

Real: $\Gamma = -1.30 \pm 0.01$

IRDIS/K: $\Gamma = -1.24 \pm 0.14$

WFPC2/F555W: $\Gamma = -0.78 \pm 0.04$

MF slope: $-1.3$

$K \sim -1.24$

$V \sim -0.78$
Synthetic Observations with MYSO

IRDIS/Ks: SR 0.7  
SR 0.8  
SR 0.9  
HST/WFC3/F555W

Non-segregated

Segregated

1'
Synthetic Observations with MYSO

**MF slope**

**K** ~ -1.38

**V** ~ -0.93

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Minimum Spanning Tree

\[ \Lambda_{\text{MSR}} = \frac{\langle I_{\text{norm}} \rangle}{l_{\text{massive}}} \pm \frac{\sigma_{\text{norm}}}{l_{\text{massive}}} \]

\[ \Lambda_{\text{MSR}} = 1.0: \text{No-segregation} \]

\[ \Lambda_{\text{MSR}} > 1.0: \text{Segregated} \]

[Yu et al. 2017]

[Allison et al. 2009]
MST method for mass-segregation

FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”

FoV: 16”x16”
HST/WFPC2/F555W

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MST method for mass-segregation

FoV: 16”x16”
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SR=0.75
Seeing=0.8”

$M_{\text{tot}} = 10^4 M_\odot$, BF=50%, $R_{\text{h}}=0.5 \text{pc}$, $D=1.6$

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Summary and conclusion

• MF is sensitive to the resolution of the observational instrument

• Observers need to compare the data with different resolution

• We always need higher angular resolution data with better contrast

• Synthetic observations are needed to compare simulations with Observations

• MST method can detect mass-segregation in the simulated data
Thanks for your attention!

Děkujeme za pozornost!