Study of Stellar Clusters Containing Massive Stars

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The World of Clusters
Padova, 23-26 September 2013
The talk

- Project objectives
- The photometric membership method
- The survey
- Two specific examples
Project Objectives

- Better understanding of the formation of stellar clusters and massive stars
- Try to discriminate between the different scenarios proposed for the formation of massive stars
- The success of different scenarios will depend on their location in the galaxy and on the environment where they are born
- The whole stellar population will be strongly influenced by the dominant mechanism in the formation of its highest mass stars

- a) monolithic collapse of proto-stellar nuclei
- b) competitive accretion inside the molecular cloud
- c) coalescence of low mass stars
Project Objectives

❖ Massive stars properties ➔ GOSSS (Sota et al. 2011, ApJS, 193, 24)
   [http://ssg.iaa.es/en/content/galactic-o-star-catalog](http://ssg.iaa.es/en/content/galactic-o-star-catalog)

❖ Young open clusters showing wide mass range are excellent labs for studying the formation of stellar cluster

❖ Clusters selection:
  ▪ in two environments: isolated clusters and inside large star formation region
  ▪ Distributed in different parts of the galactic disk
Methodology

- Determination of the Spectral Energy Distribution (SED) of star, from multiband $UBVRIH\alpha + JHKs$ photometric survey:
  - Stellar population Post MS + MS + PMS + field
  - Obtaining the physical parameters
  - Infrared excess for the study of circumstellar disks and extinction law

Delgado et al. 2007, A&A, 467, 1397
Methodology

- Determination of the Spectral Energy Distribution (SED) of star, from multiband $UBVRI\text{Ha} + JHKs$ photometric survey:
  - Stellar population Post MS + MS + PMS + field
  - Obtaining the physical parameters
  - Infrared excess for the study of circumstellar disks and extinction law
  - Determine the MF of the cluster
  - Study the spatial distribution (Q parameter)
  - Presence or not of mass segregation

Sánchez & Alfaro 2010, LNEA, 4, 1

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The photometric membership method


- The method has the following stages:
  1. Comparing the ZAMS with the upper part of the CMDs, PostMS and MS members are assigned
    a) MS members \( \rightarrow \) average values of \( E(B-V) \) and DM (distance)
    b) PostMS members \( \rightarrow \) estimation of cluster age
The photometric membership method


- The method has the following stages:

  1. Comparing the ZAMS with the upper part of the CMDs, PostMS and MS members are assigned

  2. To determine membership to PMS candidates we use 4 PMS isochrones models (D’Antona & Mazzitelli (1997), Palla & Stahler (1999), Siess et al. (2000) and Yi et al. (2001))

  3. For each isochrone and for each candidate, we calculate the distance between them. The candidate is assigned as member when:

     a) one or more of these calculated distances is in agreement with the average distance estimated in at least 3 CMDs

     b) with photometric errors in V and in all color indices < 0.05 mag

We have mass and age for the cluster members
The survey

- All clusters in the survey were selected according to the following criteria:
  - Age < 30 Myr
  - Reddening E(B-V) < 1.0 mag
  - Particular attention to poorly observed clusters
  - Two environments: isolated and inside large star formation region

- Telescopes:
  - OPTICAL: Cerro Tololo (1m, ANDICAM), OSN (1.5m, CCD) & INT (2.5m, WFC) & NOT (2.5m, ALFOSC)
  - NIR: NOT (2.5m, NOTCam) & CAHA (3.5m, OMEGA2000)

- Current database mainly southern clusters (11). Extension to northern with 16 additional clusters (3 pub. + rest under study)
The survey

- Current database containing 11 southern clusters is available online at [http://ssg.iaa.es/en/content/photometric-catalog-11-young-open-clusters-southern-hemisphere](http://ssg.iaa.es/en/content/photometric-catalog-11-young-open-clusters-southern-hemisphere)

  NGC 2362, NGC 2367, NGC 3293, Collinder 228, Hogg 10, Hogg 11, Trumpler 18, NGC 3590, NGC 4103, NGC 4463, NGC 5506

- In a short time we will update with 3 published northern clusters
Berkeley 94 and Berkeley 96

- Located at Perseus Arm
- ALFOSC; optical study (UBVRIHa); FoV 6.5 x 6.5 arcmin²; V=22
- NOTCAM; near infrared study (JHKs); FoV 4 x 4 arcmin²; J=19.5
- Membership analysis
- Spatial Distribution
- Mass distribution
- Mass segregation


<table>
<thead>
<tr>
<th>CLUSTER (name)</th>
<th>RA (hms)</th>
<th>DEC (dms)</th>
</tr>
</thead>
<tbody>
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<td>Berkeley 96</td>
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<td>+55:24:00</td>
</tr>
</tbody>
</table>

The World of Clusters. Padova, 23-26 September 2013
Berkeley 94 and Berkeley 96

- First deep photometric study (5907 stars)
- NIR-excess sources in (H-Ks)
- Slope of mass distribution in agreement with Salpeter MF slope
- Different spatial distribution
- Mass segregation in both clusters

Comparing with theoretical models (Parker & Meyer 2012), we can suggest different initial conditions and formation processes.

<table>
<thead>
<tr>
<th>CLUSTER</th>
<th>Log Age</th>
<th>E(B-V)</th>
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<th>Mem</th>
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### Observations current state

<table>
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<tr>
<th>NAME OBJECT</th>
<th>RA (hms)</th>
<th>DEC (dms)</th>
<th>OPTICAL</th>
<th>NIR</th>
<th>LOG AGE (yr)</th>
<th>DISTANCE (kpc)</th>
<th>E(B-V)</th>
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</tbody>
</table>
IC 1805

- Located at Perseus Arm
- Associated to emission nebula
- Optical study \((UBVRIHa)\) with 4 pointings; FoV 196 arcmin\(^2\); 1978 observed stars; \(V=22\)
- Near infrared study \((JHKs)\) with 4 pointings; FoV 55 arcmin\(^2\); 2393 observed stars; \(J=21\)
- Distance = 2.8 kpc (DM=12.25) 
  \(E(B-V) = 0.84\ \text{mag}\)
  \(\log\ \text{Age (yr)} = 6.5\)
Study of Stellar Clusters Containing Massive Stars

Thanks for your attention!!
Berkeley 94 and Berkeley 96

- $\Lambda$ parameter (Allison et al 2009) allow to quantify the degree of mass segregation (MSG) and to examine how MSG change for different masses ranges
- Values close 1 $\Rightarrow$ absence MSG
- Values > 1 $\Rightarrow$ presence mass concentration
- MSG in both clusters (more concentrated distribution for higher mass stars)
- Berkeley 94 ($Q \approx 0.70$, red circles) $\Rightarrow$ high degree substructure
- Berkeley 96 ($Q \approx 0.96$, blue squares) $\Rightarrow$ radial structure
### Collinder 228 & NGC 3293


<table>
<thead>
<tr>
<th>CLUSTER(name)</th>
<th>RA (hms)</th>
<th>DEC (dms)</th>
<th>Members</th>
<th>E(B-V)</th>
<th>DM</th>
<th>Log Age</th>
<th>MF</th>
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<td>-60:00:45</td>
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</table>

- Filters $UBVRI$, $V=19$
- $\delta \log N_M / \delta \log M = -1.35$
- The fletter slope are reflected of low ratio between number of PMS members and the total member number
- NGC 3293 contains a large number of massive stars