Study of Stellar Clusters Containing Massive Stars

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Stellar Systems Group

The World of Clusters

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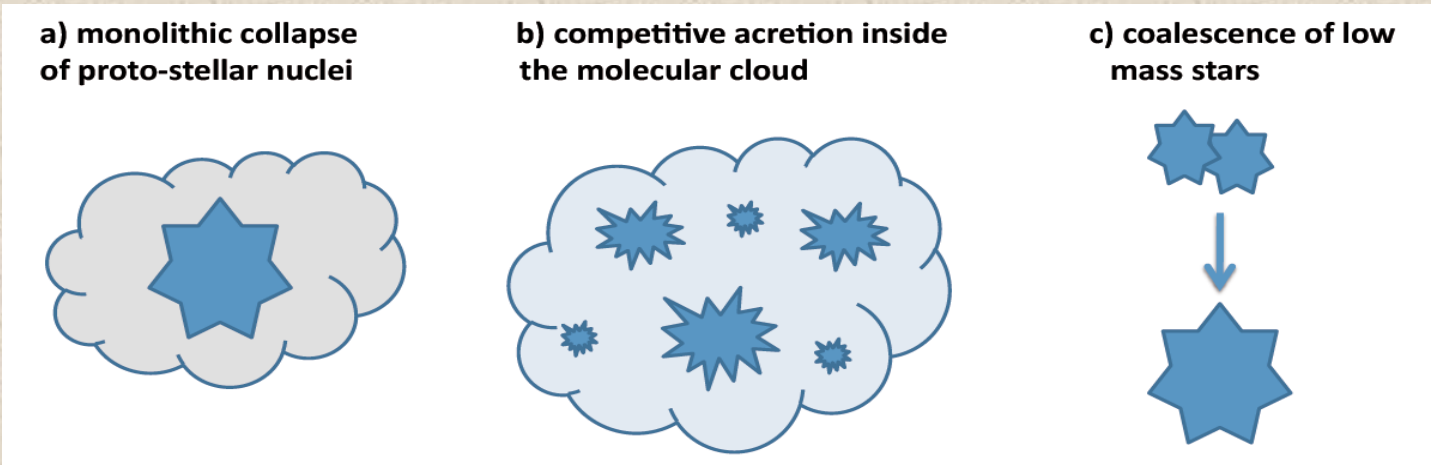
The talk

- 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



Project Objectives

- Massive stars properties ➔ GOSSS (Sota et al. 2011, ApJS, 193, 24)

  http://ssg.iaa.es/en/content/galactic-o-star-catalog

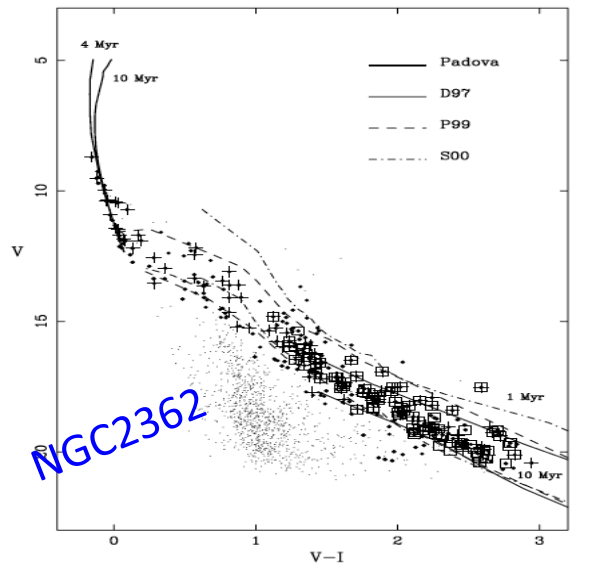
- Young open clusters showing wide mass range are excellent labs for studying the formation of stellar cluster

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

Methodology

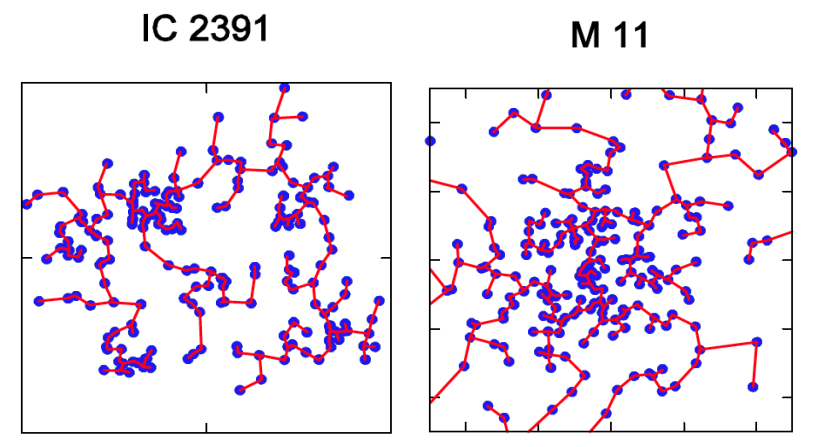
- Determination of the Spectral Energy Distribution (SED) of star, from multiband *UBVRIHα* + *JHKs* photometric survey:
  - Stellar population Post MS + MS + PMS + field
  - Obtaining the physical parameters
  - Infrared excess for the study of circumstellar disks and extinction law

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



Methodology

- Determination of the Spectral Energy Distribution (SED) of star, from multiband *UBVRIHα* + *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

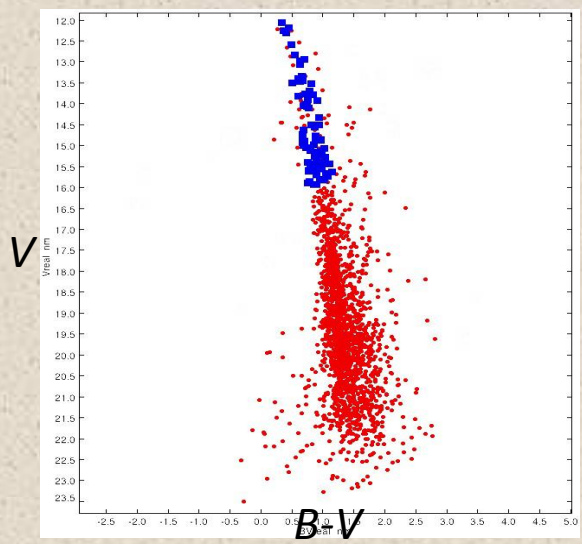
The photometric membership method

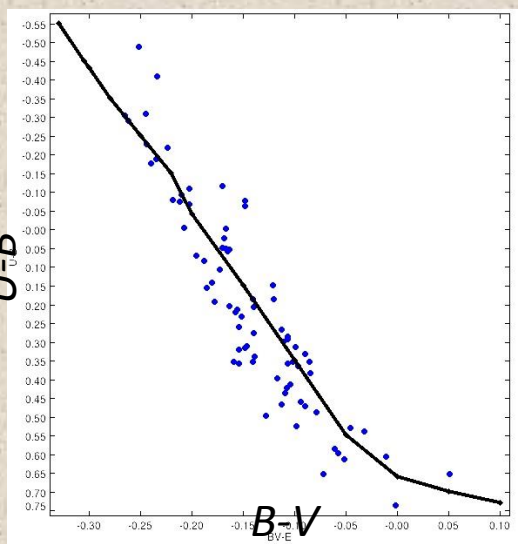
Delgado et al. 2007, A&A, 467, 1397; Delgado et al. 2011, A&A, 531, 141

- 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 ➔ average values of E(B-V) and DM (distance)

     b) PostMS members ➔ estimation of cluster age





The photometric membership method

Delgado et al. 2007, A&A, 467, 1397; Delgado et al. 2011, A&A, 531, 141

- 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

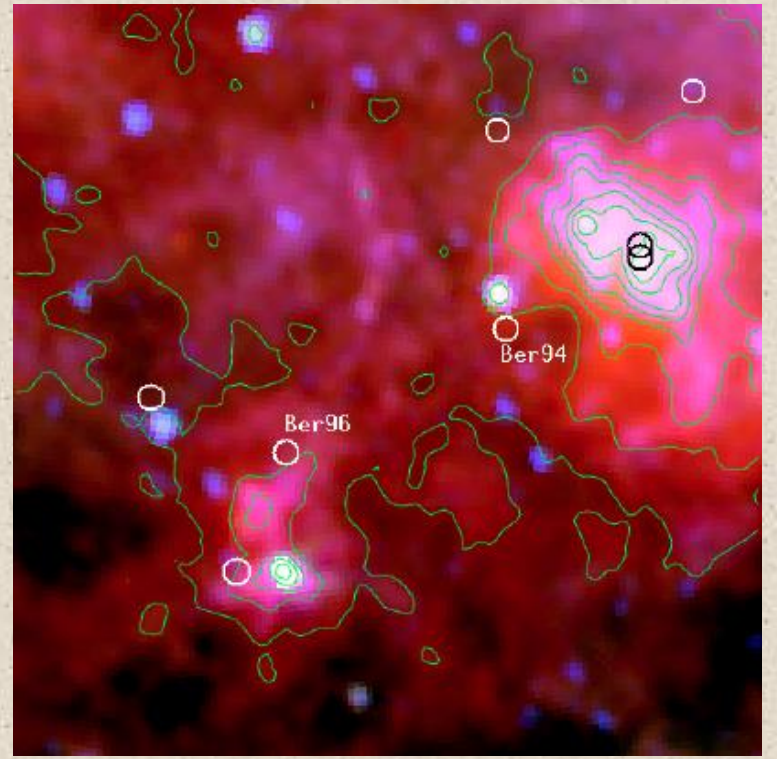
- Current database containing 11 southern clusters is available online at ***http://ssg.iaa.es/en/content/photometric-catalog-11-young-open-clusters-southern-hemisphere***

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
  - Sh2-285 = Dolidze 25 (Delgado et al. 2010, A&A, 509, 104)
  - Berkeley 94 and Berkeley 96 (Delgado et al. 2013, MNRAS, 435, 429)

Berkeley 94 and Berkeley 96

- Located at Perseus Arm
- ALFOSC ; optical study (*UBVRIHα)* ; FoV 6.5 x 6.5 arcmin^2 ; *V*=22
- NOTCAM ; near infrared study (*JHKs)* ; FoV 4 x 4 arcmin^2 ; *J*=19.5
- Membership analysis
- Spatial Distribution
- Mass distribution
- Mass segregation

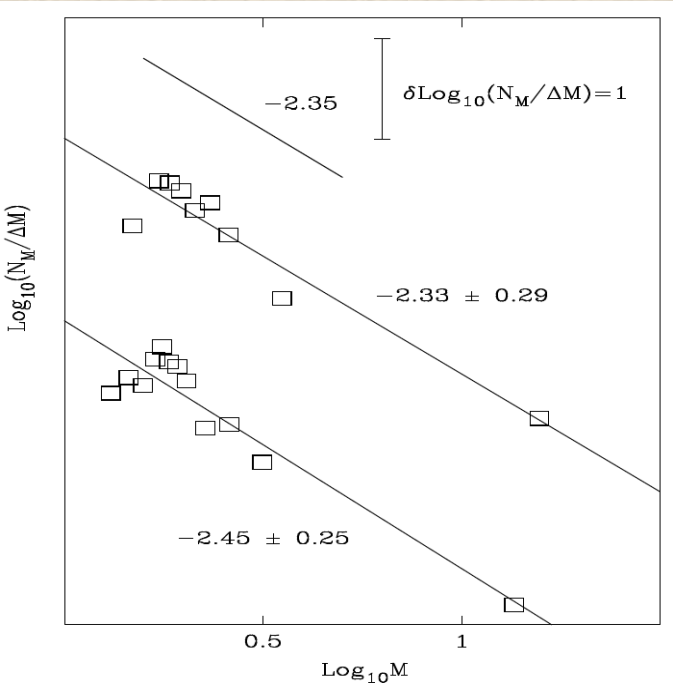


CLUSTER(name)	RA (hms)	DEC (dms)
Berkeley 94	22:22:42	+55:51:00
Berkeley 96	22:29:24	+55:24:00

Delgado et al. 2013, MNRAS, 435, 429

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

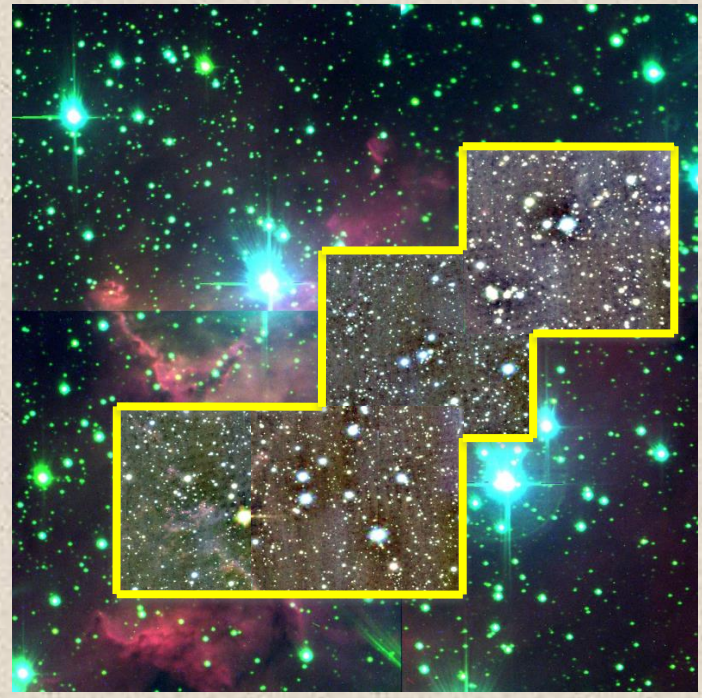


CLUSTER	Log Age	E(B-V)	d	Mem
Berkeley 94	7.5	0.62	3.9	227
Berkeley 96	7.0	0.58	4.3	295

Observations current state

NAME OBJECT	RA (hms)	DEC (dms)	OPTICAL	NIR	LOG AGE (yr)	DISTANCE (kpc)	E(B-V)
IC 1805	02:32:47	+61:29:29	yes	yes	6.2	2.4	0.8
IC 1848	02:49:20	+60:34:30	yes	-	6.8	2.0	0.6
Alicante 1	03:59:10	+57:14:00	yes	yes	6.5	4.0	0.6
NGC 1502	04:07:50	+62:19:51	-	-	7.0	0.8	0.7
SH2-211	04:36:57	+50:52:36	yes	-	-	5.1	-
NGC 1893	05:22:42	+33:25:00	yes	yes	6.6	3.3	0.6
NGC 1931	05:31:27	+34:14:54	yes	-	7.0	3.1	0.7
NGC 2244	06:31:54	+04:56:00	yes	-	6.9	1.4	0.4
NGC 6823	19:43:09	+23:18:00	yes	yes	6.8	1.9	0.8
Collinder 419	20:17:48	+40:41:30	yes	yes	6.8	0.7	0.3
Dolidze 8	20:24:21	+42:15:54	yes	yes	-	-	-
NGC7235	22:12:25	+57:16:10	-	-	7.1	2.8	0.8
Markarian 50	23:15:13	+60:26:20	-	-	7.1	2.1	0.[illegible]

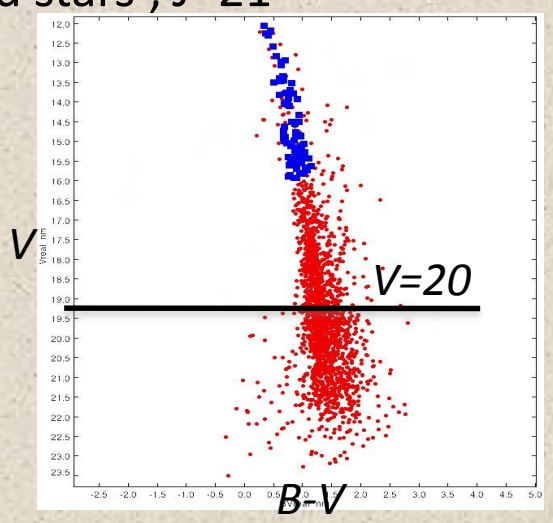
IC 1805

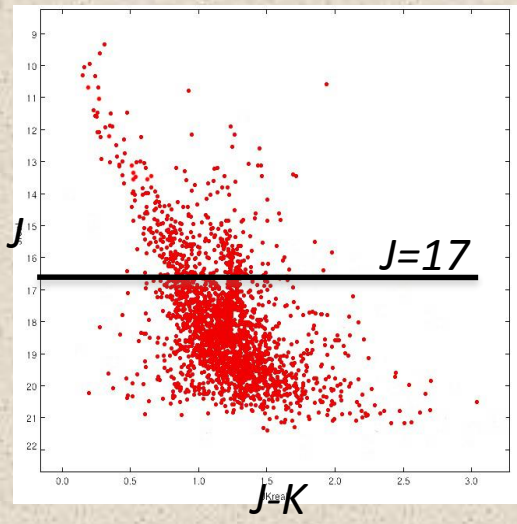


- Located at Perseus Arm
- Associated to emission nebula
- Optical study (*UBVRIHα)* with 4 pointings ; FoV 196 arcmin^2 ; 1978 observed stars ; *V*=22
- Near infrared study (*JHKs)* with 4 pointings ; FoV 55 arcmin^2 ; 2393 observed stars ; *J*=21
- Distance = 2.8 kpc (DM=12.25)

  E(B-V) = 0.84 mag

  Log Age (yr) = 6.5





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Thanks for your atention !!

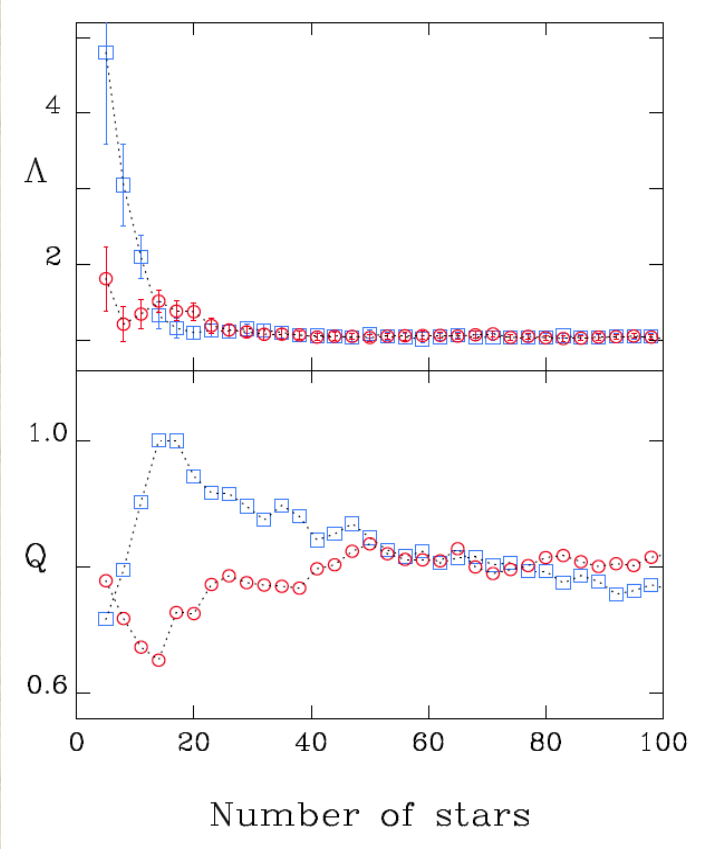
Berkeley 94 and Berkeley 96

- Λ 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 ➔ absence MSG

  Values > 1 ➔ presence mass concentration
- MSG in both clusters (more concentrated distribution for higher mass stars)
- Berkeley 94 (Q≈0.70, red circles)➔ high degree substructure

  Berkeley 96 (Q≈0.96, blue squares) ➔ radial

  structure



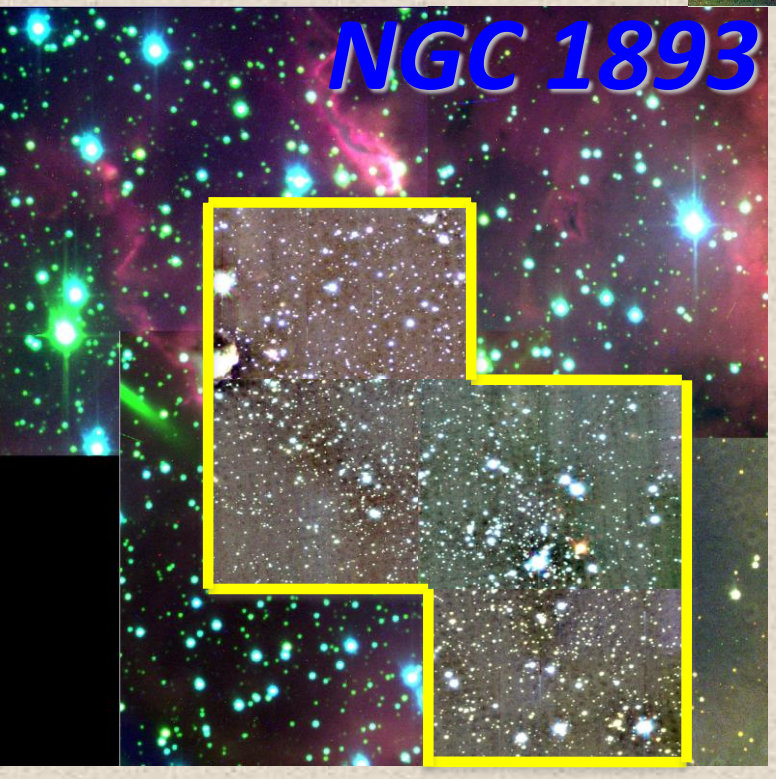
Collinder 228 & NGC 3293

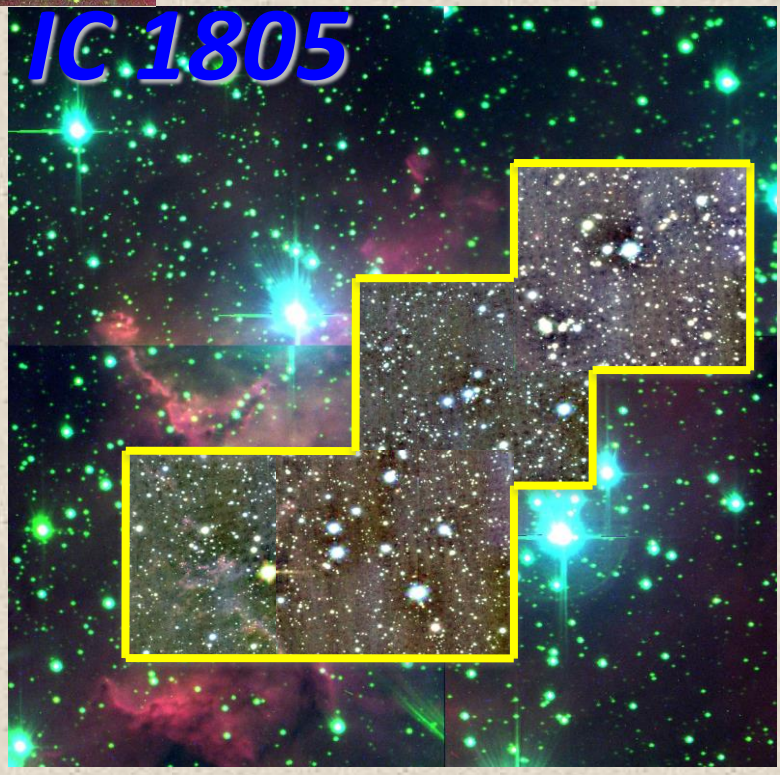
Delgado et al. 2007, A&A, 467, 1397; Delgado et al. 2011, A&A, 531, 141

CLUSTER(name)	RA (hms)	DEC (dms)	Members	E(B-V)	DM	Log Age	MF
Collinder 228	10:43:01	-60:00:45	321/2724	0.32	12.0	6.7	-1.93
NGC 3293	10:35:49	-58:13:28	319/1337	0.29	12.0	6.8	-0.64

- 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


ALICANTE 1


NGC 1893


IC 1805