THE ASTROPHYSICAL JOURNAL, 630:L153–L156, 2005 September 10

DETECTION OF A YOUNG STELLAR POPULATION IN THE BACKGROUND OF OPEN CLUSTERS IN THE THIRD GALACTIC QUADRANT

GIOVANNI CARRARO[1,2]
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile; gcarraro@das.uchile.cl
RUBEN A. VÁZQUEZ
Facultad de Ciencias Astronómicas y Geofísicas de la Universidad Nacional de La Plata, IALP-CONICET, Paseo del Bosque s/n 1900, La Plata, Argentina; rvazquez@fcaglp.fcaglp.unlp.edu.ar
ANDRÉ MOITINHO
CAAUL, Observatório Astronómico de Lisboa, Tapada da Ajuda, 1349-018 Lisbon, Portugal; andre@oal.ul.pt
AND
GUSTAVO BAUME
Facultad de Ciencias Astronómicas y Geofísicas de la Universidad Nacional de La Plata, IALP-CONICET, Paseo del Bosque s/n 1900, La Plata, Argentina; gbaume@fcaglp.fcaglp.unlp.edu.ar
Received 2005 June 5; accepted 2005 August 2; published 2005 August 18

ABSTRACT

We report the detection of a young stellar population (≤100 Myr) in the background of nine young open clusters belonging to a homogenous sample of 30 star clusters in the third Galactic quadrant (at $217° \leq l \leq 260°$). Deep and accurate *UBVRI* photometry allows us to measure model-independent age and distance for the clusters and the background population with high confidence. This population is exactly the same population (the blue plume) recently detected in three intermediate-age open clusters and suggested to be a ≤1–2 Gyr old population belonging to the Canis Major (CMa) overdensity (Bellazzini et al.; Martínez-Delgado et al.). However, we find that the young population in those three clusters and in six clusters of our sample follows the pattern of the Norma-Cygnus spiral arm as defined by CO clouds remarkably well, while in the other three program clusters it lies in the Perseus arm. We finally provide one example (out of 21) of a cluster that does not show any background population, demonstrating that this population is not ubiquitous toward CMa.

Subject headings: Galaxy: structure — Hertzsprung-Russell diagram — open clusters and associations: general — stars: general

1. INTRODUCTION

The detection of the Canis Major (CMa) overdensity by Martin et al. (2004) produced a renaissance of interest in the third Galactic quadrant ($180° \leq l \leq 270°$) of the Milky Way. The lively debate in the last year (Momany et al. 2004; Bellazzini et al. 2004) on this overdensity clearly demands a better picture of the Galaxy structure in this region.

For the last several years our group has been conducting a systematic homogeneous and accurate *UBVRI* photometric survey of Galactic open clusters in this part of the Galaxy (see Moitinho 2001; Giorgi et al. 2005; Carraro et al. 2005b and references therein) with the aim of understanding the detailed structure of the spiral arm pattern in this quadrant. Young open clusters are recognized as ideal spiral arm tracers (Becker & Fenkart 1970; Feinstein 1994). Their young ages mean that they are near the spiral arm in which they formed, and we can obtain precise determinations of their reddening and distance, especially when deep *U*-band photometry (which is very effective in pinning down stars with spectral type earlier than A0) is available. Surprisingly, the shape and extent of the Perseus and Norma-Cygnus arms in the third quadrant are far from being clear and settled. Russeil (2003) using star-forming complexes finds that both the Perseus and Norma-Cygnus arms are not visible at all in the third quadrant, confirming previous results by May et al. (1997), who mapped the region with CO clouds and at that time showed a lack of any grand design spiral features in this Galaxy location. Nevertheless, they could confirm previous suggestions about the shape and location of the Galactic warp and show how bridges of material are present in a few anticenter directions. To date, no published study has probed the spiral structure of the third Galactic quadrant using young star clusters. Modern surveys are therefore vital to better trace the spiral pattern in this interesting but largely overlooked region of the Galaxy.

In this Letter we report on a serendipitous result—namely, the detection of a young stellar population behind a few young open clusters—that we obtained during the analysis of our large data set of open clusters.

2. OBSERVATIONAL MATERIAL

The CCD *UBVRI* photometry we use here comes primarily from the third Galactic quadrant survey ($217° \leq l \leq 260°$, $-5° \leq b \leq +5°$) described in full detail by Moitinho (2001). Thirty open clusters were observed with the Cerro Tololo Inter-American Observatory (CTIO) 0.9 m telescope in two runs in 1994 and 1998. The data are homogeneous, with color errors of 0.1 mag in all combinations to a typical limiting magnitude of $V = 21$. The analysis presented in Moitinho (2001) shows that the CTIO photometry is accurate and consistent with other previously published works. For this reason we consider here the nine open clusters NGC 2302, NGC 2383, NGC 2384, NGC 2367, NGC 2362, NGC 2439, NGC 2533, NGC 2432, and Ruprecht 55 (see Table 1). Eight of these clusters belong to the CTIO survey, while NGC 2362 was observed with the Danish 1.5 m telescope at La Silla in 2001. In all cases the field of view

[1] Astronomy Department, Yale University, P.O. Box 208101, New Haven, CT 06520-8101.

[2] ANDES fellow, on leave from Dipartimento di Astronomia, Università di Padova, Vicolo Osservatorio 2, I-35122, Padua, Italy.

TABLE 1
BASIC PROPERTIES OF THE CLUSTERS AND THE BACKGROUND POPULATION

Name (1)	l (deg) (2)	b (deg) (3)	$E(B-V)_{\rm FIRB}$ (mag) (4)	$E(B-V)$ (mag) (5)	$d_\odot$ (kpc) (6)	Age (Myr) (7)	$E(B-V)_{\rm BP}$ (mag) (8)	$d_{\odot,\rm BP}$ (kpc) (9)	Age$_{\rm BP}$ (Myr) (10)
NGC 2302	219.28	−03.10	0.84	0.23	1.5	12	0.70 ± 0.05	7.5 ± 0.5	≤100
NGC 2383	235.27	−02.43	0.73	0.30	3.4	120	0.56 ± 0.05	8.8 ± 0.5	≤100
NGC 2384	235.39	−02.42	0.72	0.29	2.9	12	0.56 ± 0.05	8.8 ± 0.5	≤100
NGC 2367	235.64	−03.85	1.07	0.05	1.4	5	0.62 ± 0.05	8.5 ± 0.5	≤100
NGC 2362	238.18	−05.55	0.53	0.13	1.4	5	0.40 ± 0.15	10.8 ± 1.2	≤100
NGC 2439	246.41	−04.43	0.58	0.37	1.3	10	0.47 ± 0.10	10.9 ± 1.1	≤100
NGC 2533	247.80	+01.29	0.67	0.14	1.7	700	0.48 ± 0.05	6.5 ± 0.3	≤100
NGC 2432	235.48	+01.78	0.76	0.23	1.9	500	0.48 ± 0.10	6.0 ± 0.5	≤100
Ruprecht 55	250.68	+00.76	0.80	0.45	4.6	10	0.50 ± 0.05	7.0 ± 0.5	≤100
NGC 2477	253.56	−05.84	0.65	0.24	1.3	600	0.56 ± 0.10	11.7 ± 1.0	≤100
Berkeley 33	225.40	−03.12	0.80	0.47	4.0	800	0.61 ± 0.10	7.7 ± 0.5	≤100
Tombaugh 1	232.33	−06.31	0.54	0.40	3.0	1000	0.52 ± 0.10	7.7 ± 0.5	≤100

is 13′ × 13′, except for NGC 2362, which was surveyed with a mosaic of five 12′.9 × 13′.3 fields covering 540 arcmin^2. None of the clusters have been investigated in much detail before except for NGC 2362, studied by Moitinho et al. (2001). They found that this cluster is nearby (1.5 kpc), very young (5 million years), and exhibits a prominent pre–main-sequence (MS) population.

3. PHOTOMETRIC DIAGRAMS

In Figure 1 we show the two-color diagrams (TCDs) and color-magnitude diagrams (CMDs) of four open clusters : NGC 2302, NGC 2362, NGC 2409, and NGC 2453. We use the first three as templates in this work. The data we show in the plots have been selected according to photometric errors, and in particular only the stars having $\sigma_{(U-B)}$, $\sigma_{(B-V)}$, and σ_V simultaneously ≤0.09 are shown. Although some data are available for these clusters, we note that this is the first time deep and accurate CCD multiband photometry has been obtained and analyzed. The full detailed analysis of these data will be presented in forthcoming papers.

Briefly, we follow the zero-age main-sequence (ZAMS) fitting method to derive reddenings, distances, and ages of stellar sequences in photometric diagrams. The TCDs allow us to infer the reddenings and the spectral types of early-type stars. The CMDs are then used to derive each cluster's distance modulus and absolute distance. Finally, the age is derived from the luminosity of the earliest spectral type star still on the MS. The fits were performed using the empirical solar-metallicity ZAMS

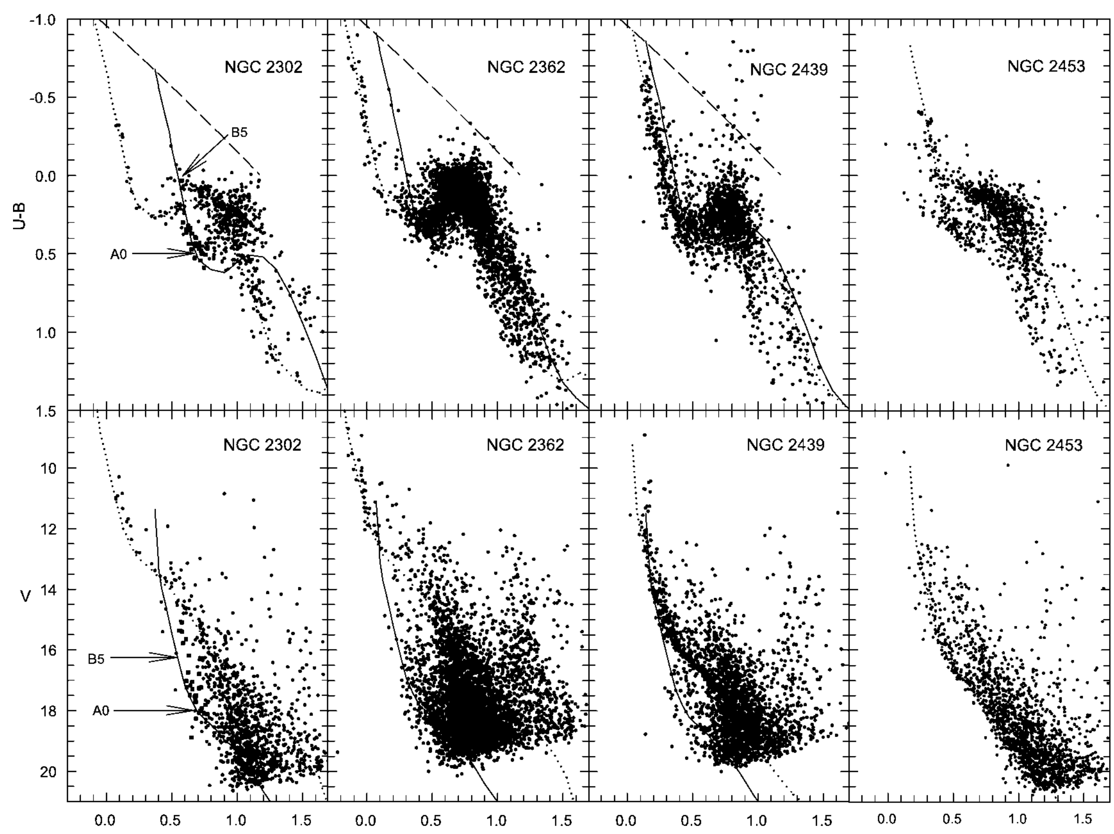

FIG. 1.—TCDs and CMDs for the three template clusters NGC 2302, NGC 2362, and NGC 2439, and for NGC 2453 All the solid and dotted lines represent Schmidt-Kaler empirical ZAMS. See text for further details. The dashed lines in the TCDs indicate the reddening path.

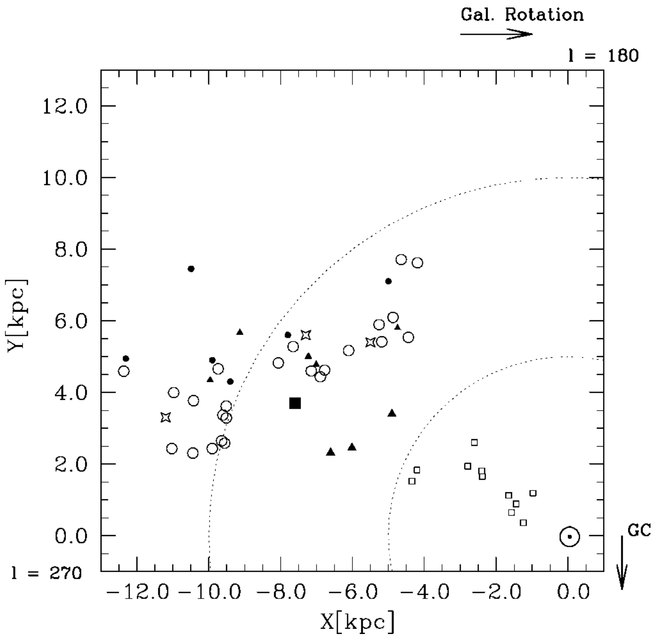

FIG. 2.—Sketch of the third Galactic quadrant. The *X-Y* plane. *Open squares*: Location of the open clusters discussed in the Letter. *Filled triangles*: Location of the BP population in all the program clusters. *Open circles*: Location of the CO clouds by May et al. (2005). *Open stars*: Location of the BP population in NGC 2477, Tombaugh 1, and Berkeley 33. *Large filled square*: Position of the CMa overdensity. *Filled circles*: Location of open and globular clusters suggested to be possibly associated with CMa. At (0, 0) the Sun position is indicated. The direction of the Galactic center and rotation are indicated with solid arrows, whereas we show with the dotted symbols two constant heliocentric distance (5 and 10 kpc) circles.

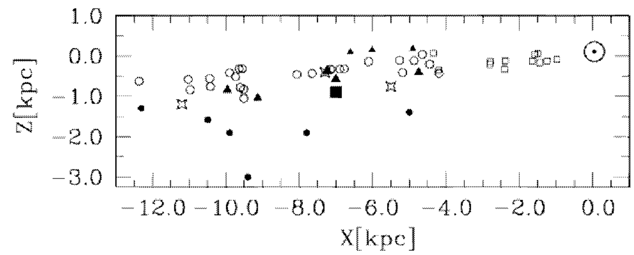

FIG. 3.—Sketch of the third Galactic quadrant. The *X-Z* plane. Symbols are as in Fig. 2. The Sun is located at $Z = +40$ pc.

from Schmidt-Kaler (1982). The empirical ZAMS does not suffer from the many uncertainties affecting theoretical isochrones, and possible uncertainties due to chemical abundance are negligible in early spectral type stars. The fits were done by eye, yielding estimates of reddenings, distances, and ages of their uncertainties. This is quite a solid method, traditionally used in studies of young star clusters. See for reference Moffat (1971), Vogt & Moffat (1972), Fitzgerald & Moffat (1980), or more recently Baume et al. (2004).

A careful inspection of all the photometric diagrams reveals common signatures, in particular, the presence of three distinct populations:

1. The cluster population is revealed by the upper bluer MSs. These MSs are fitted in each case with the Schmidt-Kaler (1982) ZAMS properly shifted following a normal reddening law, which we know to hold in this direction of the Galaxy (Moitinho 2001). These fits are indicated in all diagrams as dotted lines.
2. A fainter and more reddened young population is indicated by filled squares in the NGC 2302 diagrams. We are going to refer to this population as the blue plume (BP). The ZAMS fits to the BP are indicated in all the diagrams with solid lines.
3. The Galactic disk field population is present.

The ZAMS fit allows us to obtain the basic parameters for the clusters and the BPs. The results are summarized in Table 1, which lists for all the clusters their Galactic coordinates, reddening estimates (col. [4]) for the whole line of sight from the far-infrared background (FIRB) maps of Schlegel et al. (1998), and their reddenings, distances, and ages derived from our fitting method (cols. [5], [6], and [7]).

The BP is visible in all the photometric diagrams of all the clusters we mentioned in § 2. In particular, in the TCDs of Figure 1 (*upper panels*) the BP is prominent in the case of NGC 2302 and a bit less detached from the cluster stars in NGC 2362 and NGC 2439. However, all the corresponding CMDs (Fig. 1, *lower panels*) show its presence beyond any doubt. For comparison, we also show in Figure 1 the TCD and CMD of the cluster NGC 2453 (*right panel*), where the BP is completely absent. It is remarkable that NGC 2453 ($l = 243\overset{\circ}{.}53$, $b = -0\overset{\circ}{.}93$) does not show this feature. The fit to the BPs (*solid lines*) provides us with the parameters for this population in different galactic directions (see cols. [8], [9], and [10] in Table 1). In particular, we note that the inferred heliocentric distances are always greater than 6 kpc, indicating that this population is placed in the outskirts of the Galaxy. On the other hand, the spectral types of the BP stars (in all the diagrams) go from B3–B5 to late A and F, suggesting that this population is actually young (ages less than 100 Myr).

4. DISCUSSION AND CONCLUSIONS

In Figures 2 and 3 we plot the location of the studied clusters (the three templates plus other six clusters; see Table 1) with open squares and their BPs with solid triangles in the *X-Y* and *X-Z* planes. We adopt filled circles to place six more clusters that are believed to be associated with CMa or that lie in the same region. They are one globular and two old open clusters (NGC 2298, Tombaugh 2, and AM-2) taken from Frinchaboy et al. (2004) and three other old open clusters (Berkeley 25, 73, and 75) taken from Carraro et al. (2005b).

To facilitate the interpretation we also include the distribution of CO clouds from the recent study by May et al. (2005) depicted as open circles. In this study, the authors provide the result of a new large survey of CO clouds in the third Galactic quadrant with high-quality data taken at the Nanten telescope (Chile), showing that they trace very well the expected position of the Norma-Cygnus spiral arm. Many of these clouds harbor *IRAS* sources (Bronfman et al. 2005), suggesting that star formation is still ongoing at their location. It therefore seems that the existence of the Norma-Cygnus arm (often referred to as the outer arm) in the third Galactic quadrant, previously not very clear, is a reality. Moreover, the spiral arm extension is mostly detected low in the Galactic plane at $+0.5 \leq b \leq -6.50$ (May et al. 1997, 2005), this being a clear effect of the Galactic warp.

The BP population of six of the nine clusters closely follows the distance, longitude, and latitude of the outer spiral arm in both projections. The three clusters that deviate are NGC 2432, NGC 2533, and Ruprecht 55, which lie above the Galactic plane (see Fig. 3); they are closer to the Sun and follow the expected extension of the Perseus arm in the third Galactic quadrant (Russeil 2003; May et al. 1997, 2005).

It is remarkable that the BP is seen with the same age and shape in all the cluster fields irrespective of their position. It seems clear that the BP is a possible spiral arm indicator.

Very interestingly, the BP we find also appears in the field of NGC 2477 (Momany et al. 2001), Tombaugh 1 (Carraro & Patat 1995), and Berkeley 33 (Carraro et al. 2005a), three negative-latitude open clusters (see Table 1), and it is currently suggested to be an intermediate-age ($\leq$1–2 Gyr) population associated with the CMa overdensity, or the last burst of star formation experienced by *this galaxy*. We estimated the age and distance of the BP in these three clusters (see Table 1) and plot its position in Figures 2 and 3 with stars. The BP population in all these three clusters was found to be young and to lie in the outer arm.

Our findings support the idea that the BP in the CMa (plotted with a large filled square) direction is a young population mostly associated with the Norma-Cygnus arm, since it is much younger than previously suggested, more distant, and situated in an area encompassing a significant sector (more than 40° in longitude) of the third quadrant, where the arm is expected to lie.

Along this vein, an interesting consideration comes from the inspection of the CMD of NGC 2168 ($l = 186.59$, $b = +2.19$) by Kalirai et al. (2003, Fig. 1). This cluster shows the BP and the same MS as in NGC 2477, the F-XMM field shown in Bellazzini et al. (2004), and the Martinéz-Delgado et al. (2005) deep CMD. Now the CMa stream at the position of NGC 2168 is far more distant and at a different latitude. We fitted an empirical ZAMS to the publicly available data and find that the BP in NGC 2168, with a distance of 6.4 ± 0.5 kpc, belongs to the Norma-Cygnus arm.

We also show (Fig. 1) that NGC 2453 does not show the BP. In fact, most of the clusters in our sample from this region of the Galaxy do not show the BP. This is remarkable and means that the BP is not ubiquitous toward CMa area, as we would expect for a young population associated to a galaxy, but it closely follows the structure of the Perseus and Norma-Cygnus spiral arms in the third Galactic quadrant.

In conclusion, our data support the idea that, whatever the nature of CMa, the BP population is more consistent with a young population in the Perseus and Norma-Cygnus spiral arms.

As a final note, we surely agree that a significant stellar concentration is visible in the CMD of NGC 2362 (see Fig. 1) at $V \approx 19$, remarkably similar to that seen in NGC 2477, in the F-*XMM* field by Bellazzini et al. (2004) and in the deep CMD by Martinéz-Delgado et al. (2005). This population lies between the cluster and its BP, thus in the interarm zone, since it is the same population ascribed to CMa, which lies at 8.5 kpc from the Sun. By looking carefully at NGC 2362 CMD, we can see four populations:

1. NGC 2362 at $-0.2 \leq (B-V) \leq 0.6$;
2. the blue plume at $0.2 \leq (B-V) \leq 0.6$;
3. the Milky Way unevolved disk population at $0.4 \leq (B-V) \leq 1.1$;
4. the disk giants at $1.1 \leq (B-V) \leq 1.6$.

Now the extension of the CMa overdensity is estimated to be around 40° ($220° \leq l \leq 260°$) and to have a line-of-sight depth of about 1 kpc (Martínez-Delgado et al. 2005), which is more or less the interarm separation between Perseus and Norma-Cygnus at these longitudes (Russeil 2003).

Intermediate-age and old stars are expected to populate the interarm region both in our Galaxy and in external ones; bridges of matter connecting spiral arms are not rare. The Local arm containing the Sun is a nice example. May et al. (1997) actually show at $l \approx 240°$ a clear bridge of material extending for more than 6 kpc, exactly toward the CMa overdensity direction.

We acknowledge very interesting discussions with Jorge May and Leonardo Bronfman at Universidad de Chile, and we thank them very much for providing us with the results of their work before publication. The work of G. C. is supported by Fundación Andes. A. M. acknowledges support from FCT (Portugal) through grant SFRH/BPD/19105/2004. This work has been also developed in the framework of the Programa Científico-Tecnológico Argentino-Italiano SECYT-MAE Código: IT/PA03-UIII/077 período 2004–2005. This study made use of the Simbad and WEBDA databases.

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