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THE LAMBDA ORIONIS STAR FORMING REGION: THE SPITZER PERSPECTIVE

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RESUMEN

La Cabeza de Orión es una región de formación estelar compleja que incluye un cúmulo abierto joven (Collinder 69, ∼5 Myr), dos nubes oscuras (Barnard 30 y Barnard 35, más jóvenes) y otras regiones más jóvenes (LDN1588 y LDN1603). Hemos observado con Spitzer un grado cuadrado de cada una de estas regiones para estudiar la población estelar y subestelar. Estas observaciones han sido complementadas con observaciones en el óptico e infrarrojo cercano así como con espectroscopía. Hemos estudiado la población relativa de objetos Clase I y Clase II poniendo especial interés en las diferencias en el entorno local y de la evolución.

ABSTRACT

The Head of Orion is a complex star forming region which includes a young open cluster (Collinder 69, about 5 Myr), two dark clouds (Barnard 30 and Barnard 35, with younger populations) and other younger areas (LDN1588 and LDN1603). We have observed one square degree in each of these regions with Spitzer in order to study the stellar and substellar population. These data have been complemented with optical and near infrared photometry and spectroscopy. We have studied the Class I and II relative population and tried to understand it in the context of the differences in the local environment and the evolution.

Key Words: **H II REGIONS — ISM: JETS AND OUTFLOWS — STARS: MASS LOSS — STARS: PRE-MAIN SEQUENCE**

1. INTRODUCTION

The Lambda Orionis Star Forming Region (LOSFR), the Head of Orion, represents a unique laboratory to study young stars and their environment. The central cluster in the association –Collinder 69– includes at least one O star, the eponymous λ Ori, with spectral type O8III. However, a number of lines of evidence suggests that one –now extinct– of the Coll 69 stars has already passed through its post-main sequence evolution and become a supernova, hence indicating that it was more massive than λ Ori. A census of the stars in Coll 69 indicates that the cluster is now strongly unbound; Dolan & Mathieu (2001) argue this is due to rapid removal of molecular gas from the region that occurred about 1 Myr ago when the supernova exploded. Dolan & Mathieu (DM) interpreted the color-magnitude diagram of Coll 69 as indicating a significant age spread with a maximum age of order 6 Myr; an alternative interpretation is that the cluster has negligible age spread (with age ∼6 Myr) and a significant number of binary stars. While DM identified a large population of low mass stars in Coll 69, only four of 72 for which they obtained spectra are classical T Tauri stars (based on their Hα emission equivalent widths). Much younger stars, including classical T Tauri stars, are present elsewhere in the Lambda Ori SFR, which DM attribute to star-formation triggered by the supernova remnant shock wave impacting pre-existing molecular cores in the region (the B30 and B35 dark clouds, in particular).

We are conducting a comprehensive study of these regions, including mid IR data –from Spitzer, X ray –from XMM, and optical and near-IR photometry and spectroscopy. Here, we present a comparative study of the Spitzer survey, giving some emphasis on the Barnard 35 and LDN 1603 dark clouds.

2. ANALYSIS AND DISCUSSION

We have surveyed several areas with Spitzer covering about one sq. deg in Collinder 69, Barnard 30 –including a region in between these two SFRs, Barnard 35, LDN1588 and LDN1603. The observations were reduced in a standard way. Details can be found in Barrado y Navascués et al. (2006) and Morales-Calderón et al. (2007). Figure 1 displays data taken with IRAS as contours. The C69 cluster is located at the center of a bubble of about 10 degrees in diameter. The dark clouds are either at the edges or, in the case ofBarnard 35, mid-way. Young stars, identified by Dolan & Mathieu (1999), appear

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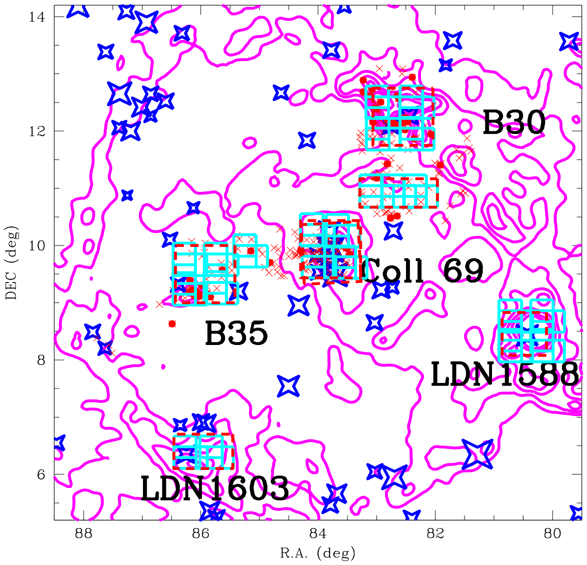

Fig. 1. The LOri Star Forming Region. We indicate the location of our optical and Spitzer surveys.

as crosses (Weak TTauri stars) or solid circles (Classical TTauri stars), following the low resolution spectroscopic criterion, based on Hα emission, by Barrado y Navascués & Martín (2003). Our surveys are identified as rectangles. The population of B stars, as listed in SIMBAD database, are included as four-pointed stars.

Based on Spitzer/IRAC data, Allen et al. (2004) and Hartmann et al. (2005), among others, have shown that data from this observatory constitute a formidable tool to reveal the young population, especially Class I and Class II. They have defined a rectangular area in the IRAC color-color diagram ([3.6]-[4.5] vs. [5.8]-[8.0]) where Class II (Classical TTauri stars) sit. Class I objects present much redder colors both in the [5.8]-[8.0] and the [3.6]-[4.5] color indices. The largest number of objects are located around indices close to zero and they would be Class III, diskless member of the field population.

Figure 2 displays IRAC Color-Color Diagrams for Barnard 35 and LDN1603. In the case of these two dark clouds, three facts are evident: (i) both have a young population of stars, (ii) the raw numbers are much different, and (iii) the fraction of Class I to Class II seems to be very different. Dolan & Mathieu (1999) identified young stars, with strong to moderate Hα emission. For the first time, we are able to show that the dark cloud LDN1603, in principle younger than Barnard 35, has also undegone an episode of star formation, induced either by the supernova postulated by those authors, or by the

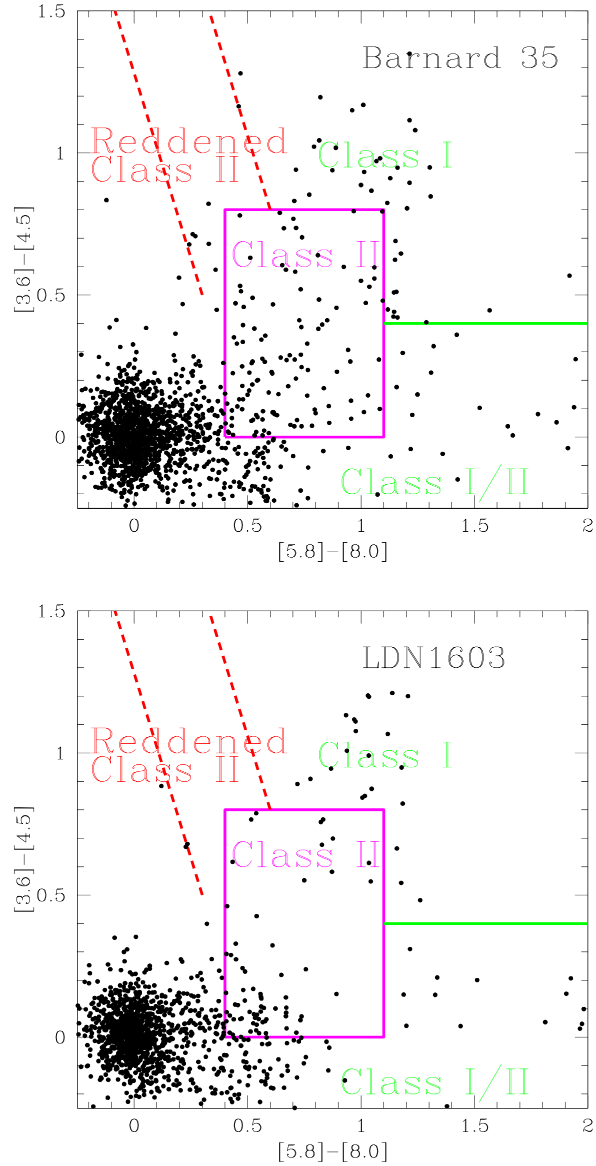

Fig. 2. Spitzer/IRAC color-color diagrams of the dark clouds Barnard 35 and LDN1603.

strong wind of the λ Orionis triple system (note that the spectral type of the most massive component is O8 III). Regarding the second and third issues, the members in each association and the Class I to Class II ratio, the differences in the Color-Color Diagram are striking. The population of LDN1603 seem to be quite poor in relative numbers and, on top of that, there is a large number of Class I objects. Our optical photometry (presented in a forthcoming paper) cannot be of any help, since the very large extinction –as an IRAS map easily shows, precludes the use of optical data for cluster membership confirma-

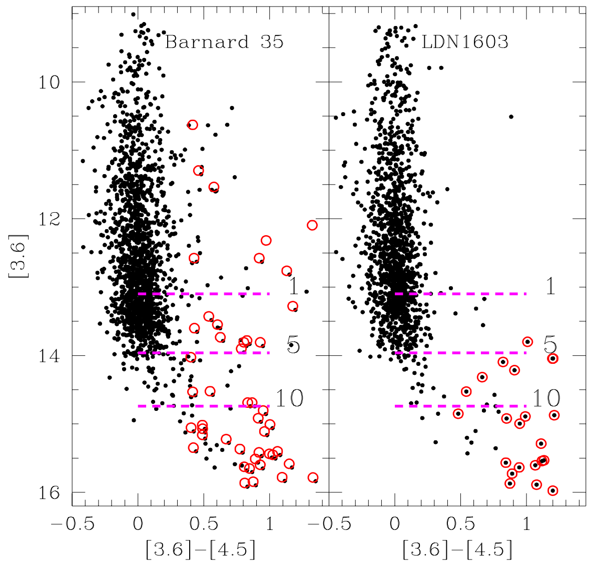

Fig. 3. Spitzer/IRAC color-magnitude diagram of the dark clouds B35 and LDN1603. Circles correspond to Class I and II sources, as defined by a IRAC CCD.

tion. Since extinction at X ray wavelengths is basically the same as in the case of near- to mid-IR, our XMM survey can help to remove spurious members. Unfortunately, although the program has been accepted, the data have not been taken at the present time.

We have also collected a number of low resolution optical spectra, but only in the central associations (C69 and B35) and in any case, we would need IR spectroscopy to pierce the other dark clouds due to their very high intra-association extintion.

In order to understand the evolutionary status of the population revealed by Spitzer, we have displayed our data in a Color-Magnitude Diagram (see Figure 3). Those objects identified as Class I or Class II are plotted as open circles in the diagrams. As indicated in Figure 2, most of the stars in the figure are probably foreground or background stars (with IRAC colors close to zero), though some of the stars with neutral color could be WTT members We have also marked, for the LOSFR distance, the location of the substellar borderline for ages of 1, 5 and 10 Myr (horizontal, dashed segments) based on NextGen isochrones (from 1 to 10 Myr) as well as 5 Myr –DUSTY and COND– isochrones by the Lyon group (Baraffe et al. 2003 and references therein).

One important fact is, again, the paucity of LDN1603 members, specially for intermediate mass stars. The figures indicate that both SFRs contain a large number of brown dwarfs candidates. Again, we will need spectroscopy to weed out spurious members and to study the properties (spectral type, accretion, etc) of bone-fide members, but even admitting a high level of contamination, we can say that we have reached the substellar domain in both associations (as well as the others). An important point, especially in the case of LDN1603, is that some of the substellar objects have been classified as Class I objects based on the Spitzer/IRAC CCD (Figure 2). Since the LDN 1603 members are probably the youngest objects in the lambda ori association, and their accretion rate should therefore be comparatively large, a key question is the amount of mass they can accrete during these first million years. Can they start as "proto-brown dwarfs" – in the sense that the central object within the envelope has a mass smaller than 0.07 $M_\odot$– and end as very low mass stars when they remove the envelop/disk, 10 Myr later? Note that Natta et al. (2004) and Muzerolle et al. (2005) have measured accretion rates of 10^{-9} $M_\odot$ in Classical TTauri substellar analogs, and this rate should be much larger in Class I BD.

3. CONCLUSION

With *Spitzer*/IRAC images at 3.6, 4.5, 5.8, and 8.0 μm of several regions within the Lambda Orionis SFR we have identified sources with mid-infrared colors indicative of disk-bearing objects. Through this work, we have made a comparative study between two of these regions, B35 and LDN1603. There is a large population of young objects in both associations and the Class I ratio is high, especially in LDN1603. Lacking spectroscopic information on the membership but, even if the pollution rate is very large, this work shows that we have reached the substellar domain. If one of these detections is indeed a Class I BD it would provide direct support for in situ formation of BDs.

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