RevMexAA (Serie de Conferencias), **24**, 66–69 (2005)

A NEAR-INFRARED AND MILLIMETER STUDY OF THE ROSETTE MOLECULAR CLOUD. AN EMIR TEASER

C. G. Román-Zúñiga,[1] E. A. Lada,[1] and J. P. Williams[2]

RESUMEN

Presentamos un resumen de nuestras investigaciones sobre las propiedades de cúmulos embebidos en la Nube Molecular de la Roseta (RMC). Nuestros datos fueron obtenidos con FLAMINGOS – un instrumento del infrarrojo cercano con características similares a las de EMIR – en las instalaciones de 2.1 m del KPNO. Estos datos se complementaron con mapas de emisión molecular de altas densidades críticas obtenidos en la antena de 30 m del IRAM; esto nos permite investigar la interacción de los cúmulos de la Roseta con sus ambientes locales previamente a haber emergido de la nube. En este reporte comentamos sobre cómo mejorar este tipo de estudios mediante el empleo de EMIR en las instalaciones del GTC.

ABSTRACT

We present a brief summary of our investigations on the properties of embedded clusters in the Rosette Molecular Cloud (RMC). Our data was obtained with FLAMINGOS -a near-infrared instrument of similar characteristics to those of EMIR- at the KPNO 2.1m facilities. These data were complemented with high critical density molecular emission maps obtained at the IRAM 30m antenna, and allow us to investigate the interaction of the Rosette clusters with their local environments previous to their emergence from the cloud. Along this report we comment on how studies like this one could be greatly improved with the use of EMIR at the GTC facilities.

Key Words: **ISM: MOLECULAR CLOUDS — STARS: PRE-MAIN SEQUENCE**

1. INTRODUCTION

Star formation in our galaxy is an ongoing process, in which a large fraction of the young population is born in clusters embedded in giant molecular clouds (GMC). Understanding how stellar clusters evolve into members of the field population in the disk of our galaxy requires studying in detail the relationship between stars and their local environments from this early embedded stage to the moment they emerge from the parental material.

An effort like this can be done nowadays by obtaining a complete census of the young stellar population using infrared devices, which assure detection of young stars even at high levels of extinction. Then, the properties of the molecular gas environments of these young members can be studied using millimeter wavelength detectors at large antennas to assure sub-cluster beam resolutions. These combinations of near-infrared and millimeter data should help to reveal some of the details of star-gas interaction, leading us to the precise quantification of the star formation *properties* (star forming efficencies, initial mass function and star forming rates) in different regions, essential to reconstruct their histories of star formation.

The Rosette Molecular Cloud (RMC) is an ideal astrophysical laboratory, for a study of this kind. Located at 1600 pc in Monoceros, next to the well known Rosette Nebula, the RMC hosts seven embedded clusters discovered by Phelps & Lada (1997) and located by surveying a region of the cloud that contained several massive dense gas cores which hosted what were thought to be intense IRAS sources (Williams et. al. 1995). The goal of our study is to determine the history of formation of these clusters as well as any distributed population in the RMC by studying the properties of the stars and the cores from which they form. Any differences among the clusters and their enviroments will be helpful toward a global understanding of star formation in our galaxy.

2. OBSERVATIONS

2.1. *FLAMINGOS near-infrared data*

The work we report is part of a major NOAO survey program dedicated to obtaining complete near-infrared imaging and spectroscopic surveys of nearby GMCs. The program has been carried out with the use of the instrument FLAMINGOS, a portable wide field imager and multi-object spectrometer for the 1.1 to 2.2 μm range, built under the direction of Richard Elston at the University of Florida. At a 2m class telescope FLAMINGOS achieves a field of

[1]Astronomy Department, University of Florida.
[2]Institute for Astronomy, University of Hawaii.

view of 20^2 arcmin, which makes it ideal for scanning the areas of entire nearby clouds. In the case of the Rosette, we mapped the area of the Rosette Nebula and the Rosette Molecular Cloud (a total of about 2.2 square degrees) with 24 FLAMINGOS fields at the KPNO 2.1m telescope in J,H and K. The survey has a depth of K=17.5 which is close to the hydrogen burning limit and -for comparison- almost 3 magnitudes deeper than 2MASS.

The main goal of the program is to obtain a significant sample of near-infrared spectra for every cloud, which can be used, for example, to estimate age distributions along the stellar birth places. In the case of the Rosette, more than 400 spectra in 25 multi-object plates that cover the most important regions of formation in the cloud, were observed between December 2003 and January 2004, and are already being processed for further analysis and publication.

Here, we consider it useful to point out the similarities between FLAMINGOS and the instrument EMIR, currently under construction by the COSMOS project (P.I. Francisco Garzón, Instituto de Astrofisica de Canarias).

Table 1 shows a comparison of the characteristics of both instruments, which are remarkably similar. In this sense, EMIR could be used for a similar program at the 10m GTC telescope, with serious advantages.

For example, although the FOV of EMIR is rather small compared with that of FLAMINGOS, the telescope at which it will be located is large enough to extend the study to more distant regions; the study we did at the Rosette, with each field scanning approx. 10×10 pc^2, could be done with EMIR at the GTC with a cloud located 5 times further, redefining the concept of *nearby* molecular cloud to d<10 Kpc.

Another possibility is to take advantage of the better resolution of EMIR and use it to make deeper studies in individual regions. For example, the nebulosities present in many embedded clusters could be resolved out with the higher resolution while achieving photometric depths that will allow the users to have a mass range that includes easily the brown dwarf regime even at the distance of the Rosette (or further). Furthermore, as shown by Elston et. al.(2003),large protoplanetary disks (of the order of 1000 AU) can be detected in regions of cluster formation, a result that could be expanded easily with the EMIR/GTC coupling, with obvious consequences on the global understanding of star and planet formation.

TABLE 1

INSTRUMENT CHARACTERISTICS

Characteristic	FLAMINGOS	EMIR
Detector	Hawaii -2	same
Array size	2048×2048	same
Resolution[a]	$0''\!.6$/pix	$0''\!.2$/pix
FOV[a]	$20'\times20'$	$6'\times4'$
$\Delta\lambda/\lambda$	1300 JH,HK	4000 J,H,K

[a]FLAMINGOS at KPNO 2.1m (f/7), EMIR at GTC

2.2. *IRAM molecular emission maps*

For our project we also constructed maps of high critical density molecular gas emission in the seven known cluster regions (see Román-Zúniga et.al 2003 and 2004, for details). The data, obtained at the IRAM 30m telescope facilities had an average beam size of 10 arcsec, i.e about 0.08 pc at the distance of the cloud. Given the typical cluster radius of approx. 1 pc, we were able to tell the morphology of the high critical density gas emission at sub-cluster resolutions.

These kind of observations are an important counterpart to our near-infrared data, because they are essential for understanding the early evolution of clusters in terms of the interaction between recently formed clusters and the remnants of their parental material. Particularly, we estimate star formation efficiencies (SFE) by combining detailed source counts inside countours of stellar density and then calculating the ratio $M_\star/(M_\star+M_{gas})$.

The SFE, along with the timescale for gas dispersal are the basic parameters that determine the evolution of a cluster once it emerges from a the molecular cloud (see Lada & Lada 2003). If the gas is removed too quickly before the cluster reaches a critical SFE, then the cluster will not remain bound. The range of SFE values we observed in the Rosette varies from roughly 0.05 ± 0.02 to 0.55 ± 0.15 depending on which molecular tracer we use, and the higher values correspond to those cluster that present evidence of partial gas removal (see below), which seems to confirm that during the evolution of an embedded cluster the SFE will increase until it reaches a maximum value (possibly below 50%) before it emerges.

3. RESULTS: CLUSTER FORMATION IN THE RMC

We found that some of the clusters are already emerging from the cloud and are probably dispersing to form a distributed population as they reached a critical efficency combined with a rapid gas removal: in those clusters with the higher SFEs, a fraction of the stars appears to be already separated from the gas core (in fact some of these emerged members can be detected in optical images), which suggests that these are more evolved groups.

Opposite from this situation, other clumps show a much more localized emission around the clusters, and have evidence of gas outflows and infalls. As these are the clusters with smaller SFE, then these groups are possibly in earlier stages of evolution.

Using models from Muench et.al. (2000), we made rough estimates of cluster ages by comparing their K-band luminosity functions (KLF) with those of artificial clusters made of coeval populations that have a Trapezium-like IMF at the distance of the Rosette. These experiments suggest that those clusters with evidence of gas dispersal could be in fact up to 0.5-1.5 Myr older than those which are still deeply embedded in their parental cores (which could be as young as few hundred thousand years). Although this result cannot be confirmed until detailed stellar age estimations are completed using the spectroscopic data, it is for the moment suggestive of a possible age dispersion among the Rosette clusters.

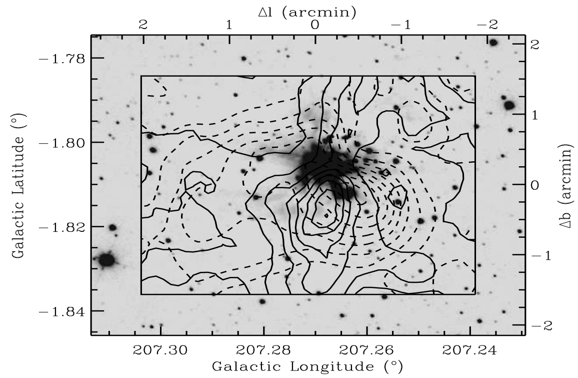
In figure 1 we show how the molecular data also hints for a possible evolutionary sequence among the embedded clusters in the RMC:

Cluster No. 6 in figure 1a. (whose KLF shows a better agreement with a 0.5 Myr population) is deeply embedded and has the highest exinction among the group. Our data shows a broad bulk outflow in CO(2-1) while the cluster appears to be still deeply embedded in the CS(2-1) core.

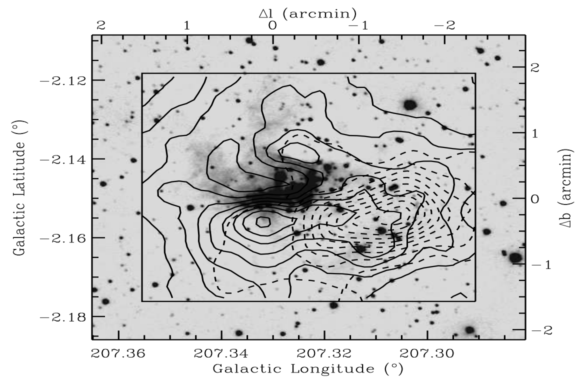
Cluster No. 3 in figure 1b. (with a KLF similar to that of a 1.0 Myr population) shows evidence of gas removal in the morphology of the CO(2-1) countours, and shows how the CS(2-1) emission is no longer located at the cluster but at a closer offset region which contains several very red sources.

Last, in figure 1c., cluster No. 5 (similar to a 1.5 Myr group) is mostly located to the NE of its molecular gas emission: both CO(2-1) and CS(2-1) contours seem to peak at a more obscured region located to the SW of the main cluster, with little or no emission near the center of stellar density.

a) Cluster No. 6



b) Cluster No. 3



c) Cluster No. 5

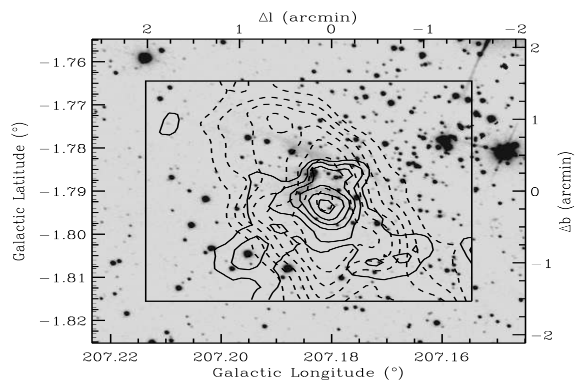


Fig. 1. From top to bottom, figures (a) to (c), we show FLAMINGOS images of clusters 6,3 and 5 with overlayed contours of CO(2-1) (solid line) and CS(2-1) (dotted line). Contour levels in this figures are arbitrary. See text for a more detailed description.

4. CONCLUSIONS

Multi-wavelength studies of star forming regions in nearby molecular clouds are of capital importance for the understanding of star formation. Near-infrared detectors are ideal for the detection and census of embedded clusters, but adding millimeter radio data to these studies has the advantage of allowing for a detailed investigation of the interaction between young stars and their local environments.

The study we are doing in the Rosette Molecular Cloud using FLAMINGOS and IRAM data seems to show how this region formed this group of clusters which seem to be emerging from the gas in a time scale of 1-2 Myr. As we can see, we can use the properties of the gas in combination with our near infrared source detections to create a rough but usable astrophysical clock to test the early evolution of clusters.

With the construction of EMIR, a near infrared detector of similar characteristics to those of FLAMINGOS, and with its use at the Gran Canario telescope, studies like this could be improved in at least two major directions: on one hand similar studies could be done in more distant regions, but also it will be possible to greatly increase the detail at which these studies are done in nearby molecular clouds.

Carlos Román-Zúñiga want to thank CONACYT for a fellowship for graduate studies at the University of Florida.

Elizabeth A. Lada acknowledges support from a Research Corporation Award and Presidential Early Career Award for Scientists and Engineers (NSF 9733367) to the University of Florida.

FLAMINGOS was built by Dr. Richard Elston at the University of Florida under the NSF project grant AST-9731180.

REFERENCES

Elston, R. J., Lada E. A., Alves, J., Ferreira, B., Lada C. J., Levine, J., Muench, A. A., Raines, S. N., Rashkind, N., & Roman-Zuniga, C., 2003, AAS, 202, 28.09

Muench, A. A., Lada, E. A., & Lada, C. J. 2000, ApJ, 553, 358

Phelps R. & Lada, E. A. 1997, ApJ, 447, 176

Román-Zúñiga, C. G., Williams, J. P., & Lada, E. A. 2003, RevMexAA Ser. Conf., 15, 206

Román-Zúñiga , C. G., Williams, J. P., & Lada, E. A. 2004, ApJ, to be submitted

Williams, J. P., Blitz, L., & Stark, A. A. 1995, ApJ, 451, 252

Carlos Román-Zúñiga and Elizabeth Lada: Astronomy Department, University of Florida, 211 Bryant Space Sciences Center, Gainesville, FL 32603, USA (carlos, lada@astro.ufl.edu).

Jonathan Williams: Institute for Astronomy, 2680 Woodland Dr., Honolulu, HI 96822, USA (jpw@ifa.hawaii.edu).