MID-INFRARED IMAGING OF STAR FORMING REGIONS

Mary Dahm
The University of Denver
Department of Physics and Astronomy
Denver, Colorado

ABSTRACT

Star formation is one of the most widely studied subjects in astronomy today, but many aspects of the star forming process are still not well understood. One aspect of star formation that still needs research involves collective star formation; this is where the formation of stars occurs in a group rather than in isolation. This is now believed to be the most common environment for stellar evolution. When studying collective star forming regions, it is important to understand how massive stars form at the center of star clusters, and influence other stars to form at high efficiencies. One such region that is a good example is the Trapezium, or Ney-Allen Nebula, in the Orion Nebula. Using the University of Denver's Ten aNd Twenty micron CAMera (TNTCAM), the Trapezium nebula was imaged at 7.8, 10.3, 11.6, 12.4, and 18,0 μm. In this wavelength region, known as the mid-infrared, the dust surrounding the region can directly be observed, because it primarily radiates at a temperature from 150 to 300 Kelvin. By studying the arc structure of the dust, astronomers will better understand the triggering mechanisms of star formation in collective star forming regions.

Background

Even though star formation is one of the most well researched topics in astronomy, much of the process is not well understood. There are many star formation theories, but many fall short of fully explaining the process. Observational evidence to support such theories are sparse. Oftentimes observation can produce more questions than it answers.

Star formation is believed to occur in four stages as described by Shu, et al (1987a). First, protostellar cores form in molecular clouds and contract, as magnetic and turbulent support are lost through ambipolar diffusion. Ambipolar diffusion is the drift of neutral particles, relative to charged ions, towards the center of cloud core (Shu, 1982). The charged ions stay with the magnetic field. As the ions move out of the protostellar core, they take the magnetic field with them. The magnetic field is believed to inhibit the collapse of a cloud core into a star. In the second stage, a protostar surrounded by a nebular disk will form at a cloud core center and collapse from the inside out (Shu, et al, 1987a). Once this occurs, in the third stage, a stellar wind will break out causing a bipolar outflow. In the final stage, the infall of material will terminate, and a newly formed star with a circumstellar disk will be revealed.

This model describes isolated star formation well, but is weak in explaining aspects of the collective star formation process. Collective star formation occurs in molecular cloud complexes that are rich in dust and gas (Zinnecker, et al, 1993). Dust and gas are important ingredients for making stars. In collective star formation regions, it is seen that massive OB (very hot and massive) stars form at the center. In turn, these hot stars produce a strong stellar ionizing wind which disrupts the molecular material in the region. These disruptions will, in turn, can cause gravitational instabilities. These instabilities can cause the material in the region to collapse into stars. This is the basic idea behind collective star formation. However, there are many aspects of the collective star formation process that are not well understood.

Ionizing winds from a hot OB star can cause many disrupting effects that can inhibit star formation. Tidal effects in the region can prevent the accretion of material that a star needs to form (Zinnecker, et al, 1993). Even though, tidal effects limit the amount of material available for accretion, it will accelerate the formation of stars with the material available. This would explain why stars on the outer regions the cluster are of lower mass.

Mass segregation can also affect star formation in clusters. The most massive stars will form at the center, because that is where the most material is available (Zinnecker, et al, 1993). Evidence can be seen of this, if all the material near the center is swept away. This means that little or no star formation can occur near the central massive star. At the outer regions, lower mass stars may still form. However, the effects of ionizing winds from the central massive star can still be seen in the form of stellar bow shocks.

Theory Behind Stellar Bow Shocks

Bow shocks occur in regions of molecular clouds where a very hot massive star, an OB star, is moving through the wind at supersonic velocities (Van Buren, et al, 1990). These hot stars have ionization winds emanating from them. Therefore, when moving through a medium, they will act to move the material away from the OB star. However, when another star is in the way of the swept up dust and gas, this will arc around the intervening star(s). This will cause the dust and gas to form a stellar bow shock in the area of the star (see figure 1). This is clearly seen in the mid-infrared images of the Trapezium region.

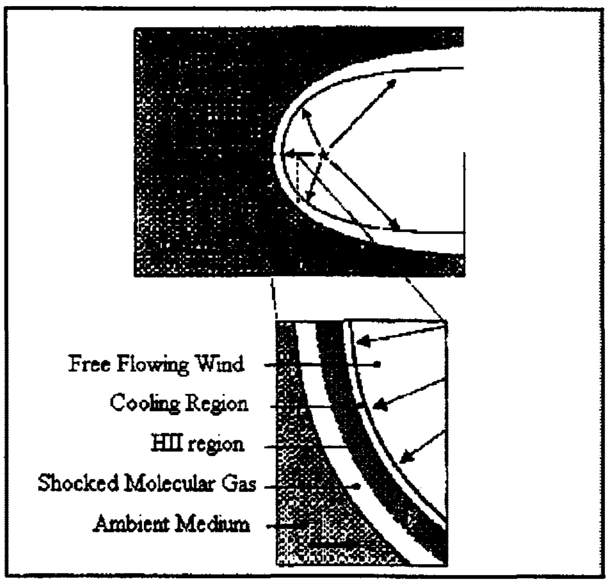

Figure1: Diagram of a stellar bow shock (Van Buren, et al, 1990).

Why Mid-Infrared Imaging?

Mid-infrared imaging is a good way to study bow shocks because they are composed of primarily dust and gas that radiates at a temperature of 150 to 300 Kelvin. This means the bow shocks primarily emit in the wavelength range from 10 to 20 μm. In comparison, interstellar dust is at a temperature of ~10 Kelvin, which means it radiates at the far-infrared wavelengths of 50 μm or more. On the other side of the spectrum, there are stars at a temperature of ~30,000 Kelvin. At this temperature, they predominantly emit radiation at ultraviolet wavelengths. By studying the Trapezium region in the mid-infrared wavelengths, astronomers can learn more about the structure and the temperature of the dust in the region, which are important to understanding the physics involved in creating bow shocks.

The Instrument

The University of Denver is currently operating a mid-infrared camera, dubbed TNTCAM (Ten aNd Twenty micron CAMera) (Klebe, Dahm, Stencel. 1995). Using this camera, we have acquired mid-infrared images of the Trapezium region in the Orion Nebula. In this section, I will discuss the camera's construction, and the filters that are used.

TNTCAM incorporates a compact optical design. The entrance aperture is placed at the rotation axis of the filter wheel (Klebe, Dahm, and Stencel, 1995) (see figure 2). In this design, the off-axis angles from the spherical collimating and reimaging mirrors are minimized. The filters are located at the Lyot stop, which minimizes the effects due to inhomogeneities in the filters on photometry results. The collimating and reimaging optics are housed in separate compartments, which shields the imaging array from unwanted radiation.

The imaging array in TNTCAM is a Rockwell International HF-16 Si:As 128 x 128 Blocked Impurity Band focal plane array. It is designed to detect infrared radiation from 5 to 26 μm. The camera is housed in a liquid Helium/Nitrogen dewar, since the array will only efficiently work at a temperature of 10 Kelvin or less. Optimally, the array should be at a temperature of 6 Kelvin to minimize the dark current noise.

TNTCAM is capable of accommodating eight filters at time. One is a cold blank for taking dark frames. Currently, there are a total of 11 filters to choose from. The first set is the standard OCLI filter set. This set includes a 10.3 μm and 11.6 μm filter, with bandpasses 1.03 μm and 1.16 μm respectively. The other set is newly developed narrow band filter set designed to work in the atmospheric windows from 17 to 26 μm (Klebe, et al, 1994). The filters are presented in table 1. The other filters available are a 7.8 μm and 12μm. Currently, in use are the following filters: 7.8, 10.3, 11.6, 17.93, 20.82, and 24.48μm.

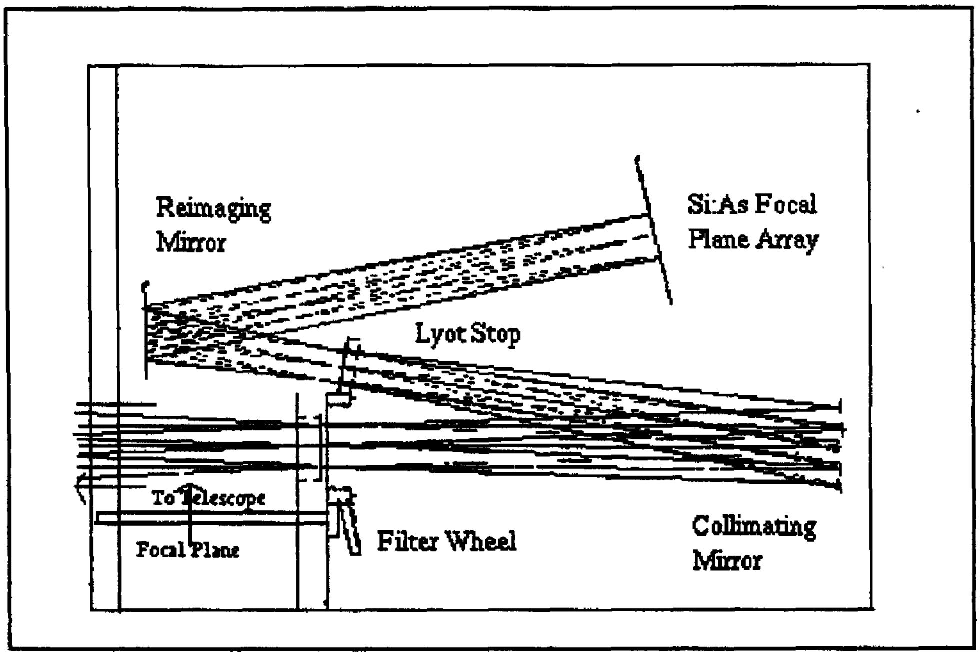

Figure 2: Schematic of TNTCAM (Klebe, Dahm, and Stencel, 1995).

Table1: Narrow Q Band Filter Set
(Klebe, et al, 1994)

Filter Name	Wavelength(μm)	Bandpass(μm)
Qo	17.24	0.42
Q1	17.93	0.43
Q2	18.67	0.47
Q3	20.82	1.53
Q4	22.79	1.12
Q5	24.48	0.64
Q6	25.67	0.30

Data Acquisition

Data on the Trapezium region was acquired in three observing runs this year. The first runs were done in January and March 1996 at the Wyoming Infrared Observatory (WIRO), which is located 30 miles southwest of Laramie, Wyoming. The third run was in April 1996. Data from this run was taken at the Mount Lemmon Observing Facility located north of Tuscon, Arizona.

Data taken at WIRO was done using a nod mode. This is where the telescope is physically moved on and off source. Images of the source and sky frame need to be taken at frequent time intervals and together as a pair, because the atmospheric backgrounds are so high in the mid-infrared. A sky frame must be subtracted from a source frame in order to view the astronomical object. At Mt. Lemmon, a nod mode was, also, used.

The Trapezium nebula was imaged at 11.6 μm in January 1996. It was imaged at 10.3, 11.6, and 18.0 μm during the March 1996 run. During the April 1996 run, it was imaged at 7.8, 11.6, and 12 μm. In the next section I will discuss the data reduction scheme.

Data Reduction

Image processing was carried out using the program IRAF (Image Reduction and Analysis Facility) distributed by the National Optical Astronomy Observatories in Arizona. The image processing scheme involves subtracting the sky from the source to eliminate the atmospheric background. Next, the source frame needs to divided by a flat field to eliminate the unevenness of the response in the chip. To eliminate any other noises from the images, image filtering techniques need to be considered.

Data Analysis

The data analysis phase of this research is still in its early stages. One subject of interest will be the arc structure seen in these images (see figure 3 & 4). The bow shock structure is the most prominent feature. By measuring the flux intensity, the values of the temperature and the mass/density can be found. This may present other information about the properties of the bow shocks, such as the velocity of the ionization wind. The data analysis is still an ongoing part of this research. Results are forthcoming.

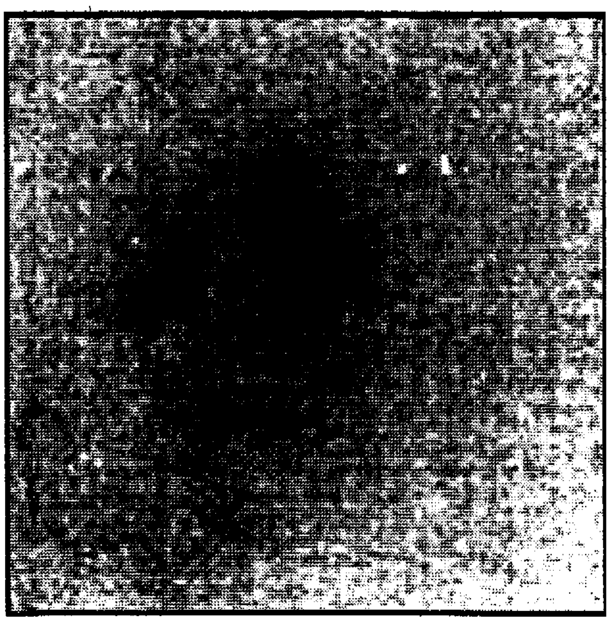

Figure 3: 10 micron image of the Trapezium region in the Orion Nebula taken on March 3, 1996 at WIRO with TNTCAM.

Figure4: 11 micron image of the Trapezium region in the Orion Nebula taken March 3, 1996 at WIRO with TNTCAM.

Conclusions

Doing mid-infrared imaging of starforming regions, such as the Trapezium, can be a valuable tool in studying the dust and gas in the region. Dust and gas are important materials needed for stars to form. However, there must be some triggering mechanisms to perturb the material to collapse into stars.

In general, it is found that most stars form in groups, or collectively, rather than in isolation. Many aspects of collective star formation are not fully understood, such as the effect of stellar bow shocks in the region. By studying the structure of the dust and gas in the bow shocks, using mid-infrared images, I hope to be able to better explain the cause of the bow shocks in the region.

Acknowledgements

This research was supported in part by the Rocky Mountain Graduated Consortium funded by NASA through Utah State University. A special thanks to Dr. Robert Stencel, Dr. Dimitri Klebe, and Michelle Creech-Eakman for help in acquiring the data. A special thanks also to the Wyoming Infrared Observatory and Dr. Robert Howell. Also to the University of Minnesota, Mt Lemmon Observing Facility for allowing us the use of their facilities.

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