Do Massive Stars Trigger New Waves of Star Formation?
Wyoming NASA Space Grant Proposal

Michael Alexander
Henry A. Kobulnicky (advisor)
Department of Physics and Astronomy, University of Wyoming

Abstract

A new major area of study is how massive stars affect the surrounding gas and dust. My project is to study exactly that using the wealth of NASA *Spitzer Space Telescope* data in the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE). I plan to use the GLIMPSE archive along with numerous other complementary datasets at other wavelengths of light to look for and identify regions of massive star formation. Once these regions have been identified I can then search for possible causes as to what "triggered" the star formation. In recent work I have studied the area around star forming region W51 (Alexander et al. 2009). Early results have shown two major areas of possible triggered star formation in two very different locations in this region and potentially by two different means. This project has four major goals: 1)Identify star forming regions with sizes from a single massive up to dozens of massive stars (such as W51); 2) Idenitfy and classify young stars and get a census of how much star formation is occuring; 3) Look for differences between triggered star formation in small regions and large regions. 4) To determine if triggering increases the level star formation, I will compare triggered star forming regions to control regions that are not believed to be triggered. These steps will offer a greater understanding of the star formation process.

Project Proposal

I. Proposed Research

Stars form in the universe. We know this because we can see thousands of stars in the night sky, and we also orbit the most famous star, our Sun. However, the mechanisms that lead to their formation are still very much unknown. Astronomers also now believe that stars were the first large objects to form in the early universe. Understanding the origins of stars, and thereby the origins of galaxies and also planets, is one of the major contemporary research areas in astrophysics and one of NASA's primary science themes.

Studying star forming regions used to be very difficult. Most telescopes were not able to see through all of the dust and gas that typically surround star forming regions. However, the *Spitzer Space Telescope*[1] has opened a new window to the inner regions of the Milky Way and allowed astronomers to look into these unique areas of our Galaxy. *Spitzer's* landmark mission, the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) in particular, has opened up a new world to astronomers. It has now become possible to pin-point specific objects that may be stars buried by dust and are just beginning to form, or have recently formed.

When stars form, a cloud of gas collapses, heats up, and any small initial rotation becomes magnified. The rotation of the gas flattens it out into a disk, which then slowly falls onto the central forming star. A study by Lada et al. (2006) of a star forming region called IC 348 showed that the newly formed stars could classified by selecting the right colors of infrared light. In doing so, they found two distinct classes of objects: thick-disk stars and thin-disk stars. A star with a thick-disk is still in the process of forming and has not blown away its gas disk. A thin-disk star has evolved further and enough time has passed to allow the star to eject most, but not all, of the surrounding gas disk. Another study by Rho et al. (2006) on a different region took the classification one step further. They were able to identify five distinct categories of objects based on their observed colors, and thus better separate young stars from other types of objects. Figure 1 shows the classification schemes of Lada and Rho. The figure is the first step towards identifying possible young stars as it provides a framework on which to build. Once the general classification is done, we can look at each objects in detail and put them through a more rigorous identification procedure.

As better imaging reveals the structures of star formation regions, it is now possible to see where astronomers have never seen and study processes that created stars. If stars are forming in a region where stars formed in the recent past, it is possible that the star formation was "triggered" by the energy being released by the nearby stars. One method of triggered star formation is the “collect-and-collapse” model, first explored by Elmegreen (1977). In the collect-and-collapse process, the radiation pressure from a massive star pushes gas outwards, where it collides with slower moving gas and collects. The points of highest density will then be able to collapse and form stars. Another form of triggered star formation is called sequential star formation (Fukuda 2000). In this model there is gas cloud that contains thin filaments of material that are denser than the

[1] http://www.nasa.gov/mission_pages/spitzer/main/index.html

overall cloud. When the radiation from a massive star pushes on these filaments, they begin to contract, which creates individual cores of star formation. The cores first form close to the star and form later further from the star.

Recent studies of small and medium sized star forming regions (Watson et al. 2008; Deharveng et al. 2008) have provided strong evidence for triggered star formation. Deharveng et al (2008) found evidence for two stage sequential star formation, whereby a region with several massive stars lead to the formation of a smaller region that only contains a single massive star. This secondary region is thought to host several young stars on its boundaries and be the third generation of star formation in the region. Watson et al (2008) studied smaller regions that appear to have a single massive star at their centers, which are surrounded by a "bubble" of gas glowing brightly in the infrared. They have identified numerous young stars on the boundaries of these bubble and the massive stars that may be responsible for the energy needed to create the bubbles. Both of these papers are evidence that triggered star formation occurs all over the Galaxy in some form, but further study is needed to see what effects the size of the region has on its environment.

The region I am currently studying, W51, is a major star forming region. It is estimated to be in the top 1% of gas clouds by size (Carpenter 1998). Many of the densest regions inside W51 are believed to harbor significant numbers of massive stars making it a prime candidate to search triggered star formation at its periphery. Figure 2 shows one of the regions, which I have identified as a star forming region, possibly triggered by the energy coming from W51.

The W51 region was targeted because of its sheer size, which made it an ideal candidate to search for triggered star formation. This project will expand on my current research by encompassing many different sizes of star forming regions. After identifying the regions, I will use well-established methods to classify young star candidates to determine how much star formation is taking place. Then I will get use the amount of radiation given off the region to get an estimate of how many massive stars it would take to produce enough energy to "light up" the region. By comparing at the number of exciting stars and the number of young stars, I can make judgements on how efficient the star formation is and how that changes with region size.

II. Relationship to NASA Goals

The *Spitzer Space Telescope* mission operates under the "Cosmic Origins" program. The program is designed to answer questions about birth; birth of the universe, birth of galaxies, and finally, birth of stars. As mentioned earlier, one of the key *Spitzer* projects, GLIMSPE, was designed to peer through our Galaxy to never before seen regions and investigate how stars form and, just as important, where they form. My project is a direct descendent of GLIMPSE goals, as well as *Spitzer* and NASA goals as we intend to find direct evidence for triggered star formation by massive stars. By finding star forming regions and the dynamics of the surrounding gas, and dust, I hope to give a deeper understanding of what drives star formation.

III. Papers and Presentations

I have already begun a paper in which I have located two particularly interesting regions around outskirts of the main W51 star forming region (Alexander et al. 2009). The paper describes, in detail, these two regions, the possibility that they may have been triggered by W51, and which mode of collapse they appear to have taken. In doing so, we have identified 120+ possible young stars. In September 2008, I presented my work on W51 as a poster at the National Radio Astronomy Observatory conference, "The Birth and Feedback of Massive Stars, Within and Beyond the Galaxy".

The wealth of information available from the *Spitzer* archive and other data archives, provides a unique opportunity to study previously unknown or unstudied regions. An untold number of projects are possible, producing a wide variety of information. While working on the W51 region, I stumbled across an unknown cluster of massive stars, each more than 6-8 times the Sun (Alexander et al 2009). So this data may not only provide information towards my thesis work, but may also be mined for other important aspects of our Galaxy.

IV. Timeline

Summer 2009 – Finalize data analysis; edit, rewrite, and submit Paper I; Search through archive data and identify new, possibly unstudied star forming regions; Identify potential thesis topic

Fall 2009 – Paper I revised and accepted; Begin study on new star forming regions and Identifying young stars) and new paper; Submit telescope proposals (WIRO for in-depth study on star forming regions (possibly W51); Work on thesis proposal (read, write, think)

Spring 2010 – Continue work on second paper; Get observations from WIRO with new infrared camera; Defend thesis proposal

Summer 2010 – Submit second paper; Begin work on third paper; Work on thesis

V. References

Alexander, M. J., Kobulnicky, H. A., and Clemens, D. C. 2009 (submitted to The Astronomical Journal)

Alexander, M. J., Kobulnicky, H. A., Kerton, C., and Arvidsson, K. 2009 (in prep.)

Benjamin, R.A. et al. 2003, Publications of the Astronomical Society of the Pacific, 115:953—964

Carpenter, J.M. & Sanders, D.B. 1998, Astronomical Journal, 116:1856—1867

Deharveng, L., et al. 2008, Astronomy and Astrophysics, 482, 585

Elmegreen B.G. & Lada, C.J. 1977, Astrophysical Journal, 214,725

Fukuda, N. & Hanawa, T. 2000, Astrophysical Journal, 533, 911

Lada, C. et al. 2006, Astronomical Journal, 131:1574—1607

Rho, J. et al. 2006, Astrophysical Journal, 643:695—977

Watson, C., et al. 2008, The Astrophysical Journal, 681, 1341

VI. Appendix

Figure 1 is a color diagram of the area shown in Figure 2. This figure compares the different intensities at four different wavelengths of infrared light. The graph is the classification of objectsby Rho (2006). What is seen in this diagram is that thick objects can be seperated from thin disk stars, and all of the regions are not young stars at all and they can be discarded.

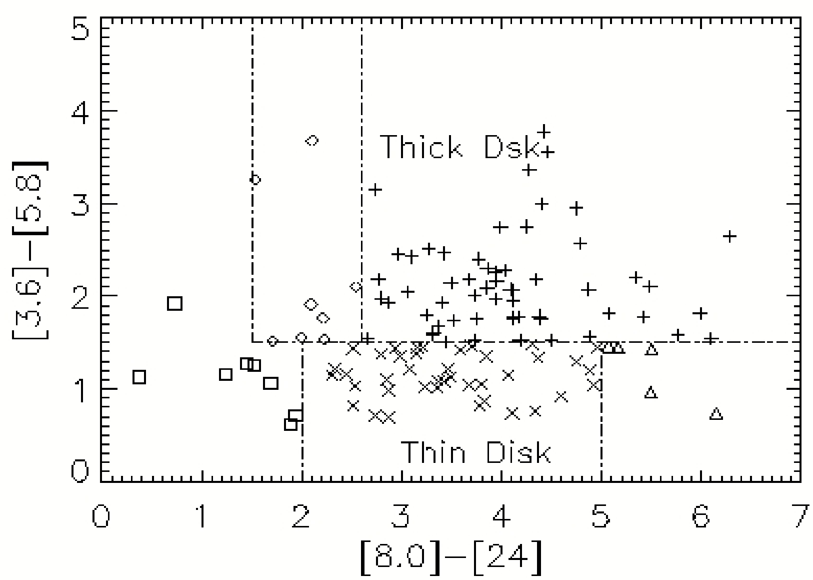
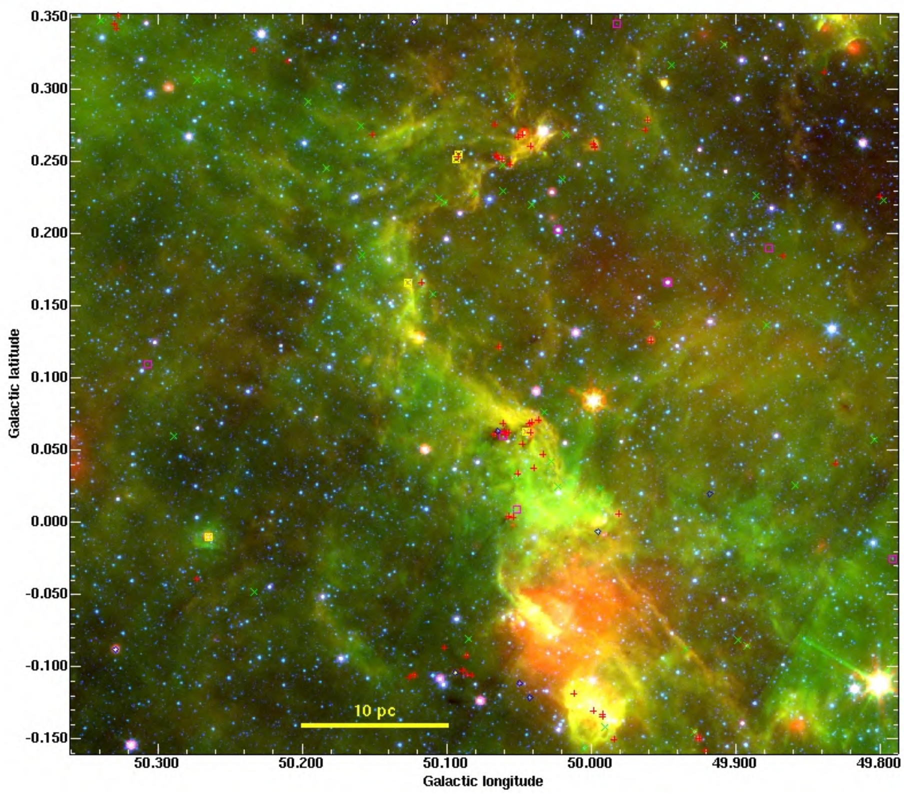


Figure 2 is 3-color infrared image of one of the regions that I am currently studying on the outskirts of star forming region W51. The colors each highlight different physcial objects. Blue shows stars, green represents warm gas, and red picks out warm dust. The image shows a clear, "ear-shaped" ridge of gas, and each of the small symbols represents a possible young star formed by the collect-and-collapse model. The bar at the bottom of the image shows the scale of 10 parsecs, or 32 light years. While we are still investigating the cause of this ridge, the W51 star forming region (not pictured) lies to the lower right of this region and is a prime candidate for the source of energy that produced it.



Award Request

Project Title: Do Massive Stars Trigger New Waves of Star Formation?
Student Applicant: Michael Alexander
Faculty Advisor: Henry A. Kobulnicky

1. Labor:
Total Student Stipend…………………………………………………… $20,000.00

2. Other Costs:
Supplies……………………………………………………………………$0.00
Travel………………………………………………………………………$0.00
Other………………………………………………………………………$0.00

3. Amount Requested from Space Grant……………………………………$20,000.00

4. Cost Sharing
Approx. Non-federal cost sharing………………………………………$15000.00

Budget Narrative:

I am requesting the total stipend amount of $20,000 for labor for the academic year 2009/2010. Funding for observations in addition to archived data, will be requested from the other institutions (NOAO, NRAO, etc).

Statement of Cost Share:

This project will make use of approximately 10 nights with the infrared camera at the Wyoming Infrared Observatory (WIRO) where time is valued at $1000 per night. Supervisor Prof. Kobulnicky also commits 1 month to participating in and supervising Michael's project, valued at $5000. Michael already has a computer and other resources, purchased earlier with federal funds, needed to complete this project. Prof. Kobulnicky also commits funding from one of the two active federal grants listed below for publication of these results and Michael's observing travel, estimated at $3000 and $1500 respectively.

Current and Pending Support for Prof. Kobulnicky

"Upgrading the Wyoming Infrared Observatory Telescope", 7/1/07 - 6/30/12, National Science Foundation, $412,000. Most of this money is committed to hardware upgrades for the telescope and an observing support scientist to conduct observations for the astronomical community.

"A Census of Intermediate-Mass Star forming Regions" 6/1/08 – 5/30/10, NASA, $27,000. PI Kobulnicky will commit some of this funding for Michael's observing travel, publication charges and miscellaneous expenses.

Pending: "Characterizing the Companions of Massive Stars", NSF, 2009-2013, $400,000. Unrelated project.