Title: Young Stars in IC 2118
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Abstract

IC 2118, the Witch Head Nebula (~210 parsecs), is a region of star formation located near the supergiant star Rigel in the constellation Orion. Last year, we observed the head of the nebula and approximately QUADRUPLED the number of young stars known here. We propose using IRAC and MIPS to continue our investigation by observing the densest part of the rest of the cloud. Our team proposes to use IRAC and MIPS observations to (1) investigate star formation, (2) look for likely cluster member stars with infrared excesses, and characterize this young star population by obtaining their colors and therefore estimates of masses and ages, (3) study the distribution of stars, their relationship to the ISM, and the possibilities of triggered star formation, (4) compare the young star population, distribution, and age to other similar sites of star formation, e.g., IC 1396 and (5) produce a dramatic image of the interstellar medium in the region surrounding IC 2118. Since this region is in the Orion constellation near the bright star Rigel, it provides additional appeal to students and the general public.

I. Project Description

A. Goals

Large dense clouds of gas and dust, molecular clouds in the interstellar medium (ISM), are where stars form. Stellar formation in the cloud is believed to be triggered by a passing shockwave, with the densest regions of the cloud contracting under the pull of their own gravity and eventually fragmenting to form protostars. This group of protostars forms into a cluster or association of stars, given sufficient time (Seeds, 1999).

Protostars begin as large cool objects, but as the fragment collapses the temperature increases. When the core reaches a temperature of 1,000,000 K, hydrogen fusion begins in the core and a star is born. The newly formed star then begins shedding off its cocoon. With these young stars deeply embedded in their cocoons, it is difficult if not impossible to view these objects in the visible light. However, they can easily be detected in the infrared because the longer wavelength photons can escape the surrounding gas and dust. Thus, the Spitzer Space Telescope is an essential tool in unlocking the secrets of these star formation regions.

IC 2118, the Witch Head Nebula (~210 parsecs), is one such region located near the supergiant star Rigel in the constellation Orion. Rigel appears to be responsible for exciting and blowing off a significant portion of the nebula in this region (Kun et al. 2004, A&A, 418, 89). Last year, we obtained time to map a small region near the head of the nebula with IRAC and MIPS. With just a little bit of Spitzer time, we have ***~QUADRUPLED*** the number of suspected young stars in this region! We have taken these results to the January AAS meeting (Spuck et al. 2006, BAAS, 207, 187.07;

Weehler et al. 2006, BAAS, 207, 109.02) and we are preparing a journal article (Rebull et al, 2006 in prep.) We now propose using IRAC and MIPS to map the rest of the nebula.

Previous all-sky surveys, including both IRAS and 2MASS, have included this region, but not to the resolution or the frequencies that Spitzer can provide, and there are few studies of this particular region in the literature. These few existing studies of this region in the literature (summarized in Kun et al. 2004, A&A, 418, 89) have revealed additional potentially interesting objects in the rest of the cloud, so we expect that hunting for young stellar objects elsewhere in the cloud with Spitzer is likely to be as productive as it was in the head of the cloud. Our team proposes to use IRAC and MIPS observations to continue our investigations begun at the head of the nebula: (1) investigate star formation in this region, (2) characterize the young star population in this region, (3) study the relationship between color and age (embeddedness) of young stars in or near ISM (color could be the result of degree of embeddedness in the ISM/natal material or age, see, e.g., Allen et al., 2004, ApJS, 154, 363), (4) study the distribution of stars and the relationship to ISM, and the possibilities of triggered star formation, (5) compare the young star population, distribution, and age to other similar sites of star formation, e.g., IC 1396 (Reach et al., 2004, ApJS, 154, 385) and (6) to produce a dramatic image of the interstellar medium in the region surrounding IC 2118. In addition, since this region is in the Orion constellation near the bright star Rigel, it provides additional appeal to students and the general public.

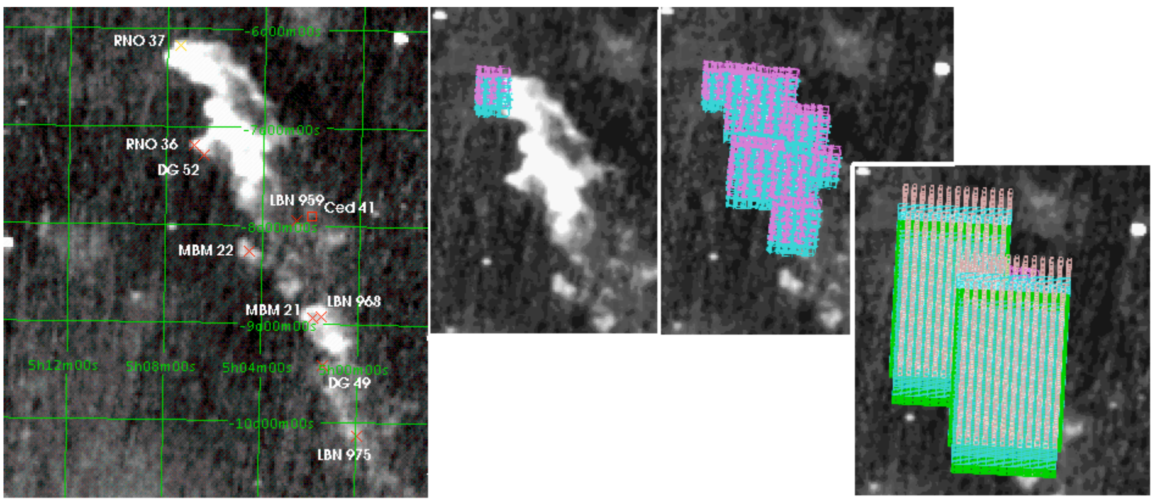
To support this search for young stellar objects in this cluster, we are working to obtain additional optical data of this region. We are working in parallel on several fronts. Through educational collaborations (more on this below), we are obtaining observations of this region with Perth Observatory, New Mexico Skies, Oil Region Astronomical Observatory, and the Faulkes 2-Meter Telescope. We are working to obtain both calibrated magnitudes and monitoring studies (to look for variability as another indication of youth and therefore cluster membership). We have initiated a collaboration with B. Penprase (Pomona) and students to obtain optical data of this region; R. Paterno-Mahler has completed a semester-long project to obtain optical data of several of the stars in our initial “head of the cloud” observation from last year. Finally, we will be applying for Palomar 200-inch time through the SSC to obtain classification spectra.

We would like to bring the teachers and any interested students back to the SSC for a whole week this summer to work on these data. If additional funds permit, and if the Palomar time is granted, we would like to bring at least one of the teachers to Palomar for the observing run.

We submitted a proposal to complete the mapping of the cloud as part of Cycle 2. This collaboration included a proposed study of the structure in the ISM in this region (led by J. Ingalls, SSC), and an additional offer to obtain optical supporting spectra and photometry (led by D. Barrado y Navascues, LAEFF, Spain). If this proposal is granted, it is our intent to continue to work with these collaborators to pursue these goals.

II. Target

The figure below shows the region of IC 2118 (in IRAS 25 microns) selected for observation by IRAC and MIPS (with the proposed observations overlaid). The left panel contains an indication of the previously catalogued objects in this region. The second panel of the Figure shows the IRAC coverage from last year. The next panel includes the proposed IRAC coverage (optimized for scheduling near Mar 26, the union of the visibilities and the current BIC), and the right panel shows the proposed MIPS coverage (optimized for scheduling near Mar 31, again the union of the visibilities and the current BIC). Our observations last year included the region near (but not completely encompassing) RNO37. "RNO" objects come from Cohen (1980, AJ, 85, 29) and are groupings of "red nebulous objects"; 4 of the new Kun et al. (2004) TTauri stars are part of RNO 37, and we observed 3 of these last year. LBN numbers are from Lynds (1965, ApJS, 12, 163) Bright Nebulae, MBM numbers are from Magnani et al. (1985, ApJ, 295, 402). There is another new Kun et al. (2004) TTauri star near MBM 21/LBN 968. DG points are bright nebulae from Dorschner & Guertler (1967, Astron. Nachr., 287, 258). There are IRAS point sources throughout this nebula.



IRAC will in general detect stars in this region, and MIPS will in general be more sensitive to the ISM. By using IRAC and MIPS-24, we will be able to identify more young stars via infrared excesses than by using IRAC alone (see, e.g., Allen et al, 2004, ApJS, 154, 363 and Muzerolle et al, 2004, ApJS, 154, 379). Spectral Energy Distributions (SEDs) constructed using IRAC+MIPS (combined with 2MASS and ground-based optical data that we will obtain) will enable us to discriminate between cluster members and background extragalactic objects. MIPS-70 will largely reveal the structure of the ISM, though it will also help with identifying cluster members because it will enable us to identify young stars with large mid-IR excesses. Although data may be obtained at 160 um with MIPS, we do not require it; any ancillary data obtained at MIPS-160 will further enhance our understanding of the interstellar medium in this region.

With IRAC we will make a map at 3.6, 4.5, 5.8, and 8.0 microns with 3 dithers (cycling dither pattern) in the high dynamic range mode, each exposure 12s. This will cover the entire cloud. The total duration for IRAC will be 5.8 hrs.

With MIPS we will do a fast scan, obtaining data at least at 24 and 70 microns and perhaps (if it is not a MIPS-warm campaign) 160 microns. Each of the scan legs steps by half an array compared to the previous scan leg to ensure complete coverage at 70 microns. We have designed our coverage to overlap as much as possible between IRAC and MIPS. The total duration for MIPS will be 5.8 hrs.

The total project time is 11.6 hrs. Because we are tiling across the cloud with multiple AORs, we have enacted a loose "group-within" constraint to limit the gaps between the tiles. Because we would like to have the data in time to meet this summer with students at the SSC (see below), we have also enacted a timing constraint to have these AORs scheduled in the late March visibility window.

Once the data have been collected, the team plans to come back to the Spitzer Science Center (SSC) (with a new group of students) for up to a week to work with Dr. Rebull in the reduction of the data. As last year, the team will use MOPEX to create a mosaics and a list of bandmerged sources. The source list data table will include 2MASS (J, H, and K band), IRAC (3.6, 4.5, 5.8, 8 μm), and MIPS (24 and 70 μm) fluxes in both magnitudes and Janskys.

The reduced data will be accessible by programs available on our home institutions' computers. We plan to section the images into fits files suitable for use with the Hands-On Universe Image Processing (HOU-IP) software. HOU-IP is a user-friendly data analysis tool that runs in both Windows and Mac operating systems, and is currently used by many high school astronomy students. Although it may not be possible to extract accurate flux values using HOU-IP, it can be used for visual observation and spatial analysis within the images. The data tables can be imported into spreadsheet programs, such as Excel, and students can generate color-color plots with the data to test hypotheses related to how infrared wavelengths can be used to classify young stars.

III. Scientific Merit

This study will characterize the young star population in a region of IC 2118 never before studied at the wavelengths and resolution proposed. With the exceptional spatial resolution of Spitzer and the sensitivity of IRAC and MIPS, we anticipate that it will be possible to classify hundreds of young members of the association. In our project last year, we have already ***~QUADRUPLED*** the number of suspected young stars in the region. We will use IR color-color diagrams as tools to classify the age of stars (see, e.g., Allen et al., 2004, ApJS, 154, 363; Reach et al., 2004, ApJS, 154, 385). Our findings will enable us to characterize the process of pre-main-sequence stellar evolution in this cluster, examine the influence of the density of the molecular cloud on this process, and compare it to processes in other clusters also being studied with the Spitzer Space Telescope.

IV. Educational/ Public Outreach Merit

Students will have access to the image files in four IRAC and three MIPS wavelengths as well as three 2MASS, three (lower spatial resolution) IRAS wavelengths, and B, V, R, and I images using existing optical surveys (i.e. POSS2), and available optical telescopes (in real time) including Perth Observatory, New Mexico Skies, Pomona College Observatory, Oil Region Astronomical Observatory, and the Faulkes 2-Meter Telescope. Students will be able to combine images at different wavelengths to produce pseudo-color images that enhance the features of young stars and the interstellar cloud. Through these tasks, students will learn about the physical properties of light such as wavelength, intensity, emission, and absorption. Students will gain experience in measuring size and distance. They will be able to compare the images obtained by IRAC, MIPS, and IRAS to learn about spatial resolution. Students will also view evidence that the universe is changing, learn about the current models of stellar evolution, and learn that new stars and planets are still forming.

In addition to the image data sets, students will also have the extracted data tables of sources and fluxes at each wavelength. For the optical data, participating students, in some cases, will be extracting the magnitudes themselves. Using spreadsheet (i.e. Excel) and graphing programs (i.e. Excel, PSI-Plot), students will be able to make color plots and spectral energy distribution plots with this authentic numerical data. They will be able to access the data sets already available in the Spitzer archive to compare the plots of this cluster with other clusters. Students will also be able to test their own ideas for color plots that could be useful in determining stellar age.

This follow-up proposal will attempt to expand the student audience to include additional high school students and teachers, as well as a small group of undergraduate college students (at Pomona, contact Bryan Penprase). There participation will broaden the scope of those being exposed to the process of authentic scientific inquiry. They will be part of the process of developing ideas, working in teams, collecting and analyzing data, and interpreting and presenting results. They will learn about the instrumentation used in IR astronomy, controlling a space telescope, and the value of having a telescope in space. These experiences will help teachers and students meet the goals outlined in state/national science and technology standards. Specifically, this project is aligned with teaching standards to support inquiry-based work, working in teams, and providing resources for authentic inquiry. The content standards addressed are the structure and properties of matter, interactions of energy and matter, the origin and evolution of the Earth system, and the abilities of technological design.

Furthering the scientific and educational impact of the follow-up proposal to observe the entire IC 2118 cloud, it is our goal to work in conjunction with the American Association of Variable Star Observers (AAVSO). Using AAVSO web-based resources, we will establish a monitoring program of all T-Tauri candidates identified in the original and the follow-up observing proposal. The AAVSO has worked for years to establish a web-based data collection framework to monitor fluctuations in brightness of variable stars, and produce up to date light curves for these objects. Such an interactive and ongoing program would greatly enhance the long-term impact of this follow-up proposal. Students and educators throughout the US would first identify the T-Tauri candidates using Spitzer data, and then monitor the candidates in V, R, and I using various optical instruments, including those at Perth Observatory, New Mexico Skies Observatory, Pomona College Observatory, Oil Region Astronomical Observatory, and the Faulkes 2-Meter Telescope. This sort of program further establishes the need and usefulness of multi-wavelength astronomy and space-based telescopes.

Finally, if sufficient resources are made available, our team plans to develop a student/teacher activities series that although will be specific to the IC 2118 Spitzer Project, could be easily transferred to other Spitzer data sets. These publishable materials, along with the data sets, would be made available on CD to teachers and students attending workshops. Initially we see the development of three basic units, 1) Image analysis and processing, 2) Interpretation of data plots (i.e. color plots and SEDs), and 3) Follow-up observing. Although a great deal of material is currently available on these topics, it fails to exist in easily usable units. Our goal is to bring the existing resources together, and to develop additional resources as needed, as we produce a user-friendly educational resource package. We hope to be able to integrate at least some of our materials into the Hands On Universe (HOU; contact Vivian Hoette) program.

The dramatic images that will be produced by this group and their students will be excellent vehicles for gaining public and administrative interest and support for science and educational initiatives. The data and experiences collected by this group of Spitzer teachers will be shared with other teachers via workshops and presentations. The lessons developed by the Spitzer teachers will address science and math skills and concepts with current scientific problems and original data. They will promote inquiry-based learning and disseminate interest in science, technology, and space research.

References

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