Star Formation in CG4

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Abstract
We propose to look for new young stellar objects (YSOs) in Cometary Globule 4 (CG4) in Puppis. We will attempt to answer the following questions:

- Will (additional) stars form here?
- What triggers star formation?
- Has a cluster formed?

CG4 is approximately 1300 parsecs/4680 LY away. It is one of about 30 cometary globules in the Gum Nebula (Choudhury and Bhatt 2008), many of which are known to be forming stars. These globules are pointed generally radially outward from the center of the Vela OB2 association, which is also forming stars. CG4 is dramatic in appearance, and that has brought it to the attention of both scientists and the public. Recent visible and visible/infrared mosaics have been featured in *Astronomy Magazine* and *Science News Magazine*.

Our team will use archival Spitzer InfraRed Array Camera (IRAC) and Multiband Imaging Photometer for Spitzer (MIPS) data, 2 Micron All Sky Survey (2MASS) data, and XMM-Newton/ESA x-ray spectroscopy data from that space telescope, as well as optical data obtained by collaborators. We expect to recover the previously known YSOs (Reipurth and Pettersson 1993) and find additional new YSOs in this region. We will primarily use infrared excess to find new YSOs. There may be some non-member CG4 objects in this candidate group; so, along with CG4's YSOs, we may find extragalactic sources (i.e., active galactic nuclei, etc.) and other stars from our Galaxy. We will use all available data to attempt to determine legitimate cluster members, and to separate CG4's YSOs from other objects with similar spectral energy distributions (SEDs).

1. Project Description and Scientific Merit.

a. Goals

We are looking for new YSOs in the cometary nebula CG4, in Puppis. Cometary Globules are isolated, relatively small clouds of gas and dust within the Milky Way. Hawarden (1976) was the first to discover twelve cometary globules in Puppis: YSOs have already been found in many of these globules, including the CG4 region. Additional YSOs we find may reveal added information about cometary globules and conditions within them. We will attempt to perceive the structure in the globule, and that should tell us more about its history and future.

CG4, approximately 1300 parsecs away, is a part of a larger structure in the Milky Way called the Gum Nebula. CG4 is one of a number of cometary globules in the area which point radially away from a common center, possibly the Vela supernova remnant. This nearby, dramatic-looking cometary globule, has a fortunately-placed nearby galaxy, and this creates a dramatic image; shown below in Figure 1. Visible light wavelengths and four filters: blue, green, near IR and H-alpha, were used to create this image. CG4's head is about 1.5 Light Years (LYs) in diameter and its tail is about 8 LYs long. The Cometary Globule contains enough material to make several Sun-sized stars.

Figure 1: CG4 in the optical, from CTIO/Nat. Optic. Astron. Observ.-Tucson. Dark nebulosity can be seen; the galaxy on the left is ESO 257-G 019. Image: T.A. Rector/University of Alaska Anchorage, T. Abbott and NOAO/AURA/NSF (http://www.noao.edu/image_gallery/html/im1000.html).

b. Background.
Stars form from clouds of gas and dust. If there is some sort of triggering event (example of external event; nearby supernova explosion enriches nebula; or internal to the cloud; collision of densest parts of nebula, under the influence of gravity), matter begins to accumulate to form a central mass. If accretion continues, then, due to conservation of angular momentum, matter falls not radially down onto the central mass, but instead onto a disk around the central mass, and from there spirals through the disk onto the central mass. If a sufficient amount of material accretes, a protostar forms. As the mass infall accelerates, concentrating mass near the center, conservation of angular momentum takes over and bipolar outflows (jets) form, ejecting matter from the north and south poles of the protostar. Eventually, the outflows, plus the ongoing accretion onto the protostar, disperse the cocoon of matter surrounding the YSO, allowing the disk+jets+central object to be more easily detected. As matter is gravitationally accumulated onto the protostar, the accretion rate slows, the jets turn off and the disk thins out. Eventually planets, or at least large rocks, form in the circumstellar disk.

Throughout this process, the dusty circumstellar material (the cocoon and the disk) manifests itself as an infrared excess, e.g., more infrared emission will be seen from these objects than is expected from similar objects that do not have circumstellar dust. Spitzer is extremely well suited to finding such infrared excesses. Spitzer, too, easily sees any protostellar outflows in the infrared, due to emission from polycyclic aromatic hydrocarbons (PAHs) which accumulate on the surfaces of gas cloud masses.

Because some of these stars will be like our Sun, and some of these stars form planets, some of these planets may ultimately be Earth-like. Studying young stars gives us insight into how our own planet-system formed. On a more grand scale, understanding the formation and evolution of different types of stars gives us insight into the gas and dust and chemical composition of galaxies, which are the structural components of the universe.

We have selected the CG4 - Gum Nebula environment because the area is visually dense with star-forming material. CG4 (α 07^h 32^m 45^s, δ -46° 47′ 48″) and its environs appear to be actively forming stars. Using this locale, we will investigate the previously known objects and look for new YSOs, using infrared excesses. We will also attempt to characterize this young star population by obtaining colors and therefore estimates of masses and ages. We propose to find ages by using color-color plots, and if the ages of localized YSOs are the same then probably they are all members of the same group/cluster. Finally, we will study the distribution of stars, and compare the young star population, distribution, and age to other similar sites of star formation.

We will also attempt to determine whether this is triggered star formation, which will help to determine the local star formation efficiency. The presence of O & B superstars which are copious UV and gamma emitters, and supernova remnants, indicating violent interstellar explosions, suggest an energetic nebular environment in the larger Gum Nebula. We have conducted a preliminary investigation of this region by examining multi-wavelength images of it. Skyview (from Goddard) shows images at all wavelengths, of excited gas/dust in the selected region. In addition, O & B Stars, as well as supernova remnants of their cousin stars, reside in the nearby Vela Nebula. A supernova in Vela may have triggered the stars that are forming in the CG4 region and environs.

One of the largest issues we will face is visual contamination from non-cluster members: easily confused foreground/background stars or background galaxies whose images are superimposed on actual cluster member images. The types of data listed below help to determine cluster membership because all are characteristic of new YSOs, and objects which do not display these qualities are likely to be non-cluster-members: possessing IR excess (from circumstellar disc of protostars), flaring in x-ray or radio (from convection and rapid rotation), polar outflows, emission/absorption lines, variability (determine to 0.1 magnitude accuracy), fast rotation rate (determine by Doppler shifts on emission spectra), UV emission (due to violent mass accretion), spatial location of candidates close together, and spatial motion which would indicate the movement of a cluster of YSO traveling in a unit, due to being gravitationally bound. We will investigate the properties of all our YSO candidates using: infrared excess, apparent age (if all of them are the same age, it is likely they are all members of the same cluster), bright and/or flaring in X-rays (from our XMM data), bipolar outflows (if present), UV excess, spatial location, and association with nebulosity

In this region, there are two kinds of previously investigated objects: InfraRed Astronomy Satellite (IRAS) sources and H-alpha sources. We will compare these sources and images to the Spitzer sources and images in this region. Some of the IRAS sources are likely to resolve into nebulosity (e.g., Rebull et al 2007), others will end up being background galaxies, but some may be YSOs. Reipurth and Pettersson (1993) have discovered nine Hα sources in this region; see Table 1. These objects are confirmed young stars. We will determine if they have infrared excesses.

Table 1. H-alpha Emission Stars in Puppis region.

Star	RA (J2000)	Dec (J2000)	V	(B-V)	(U-B)	Region
CG-Hα 1	07 30 37.77	-47 25 07.21	> 17	--	--	Sa 101
CG-Hα 2	07 30 57.63	-46 56 12.50	> 17	--	--	Sa 101
CG-Hα 3	07 31 10.89	-47 00 33.40	14.99	1.60	0.91	Sa 101
CG-Hα 4	07 31 21.92	-46 59 45.14	14.59	1.40	0.92	Sa 101
CG-Hα 5	07 31 36.65	-47 00 14.13	15.25	1.26	0.23	Sa 101
CG-Hα 6	07 31 37.45	-47 00 22.19	14.21	1.42	0.90	Sa 101
CG-Hα 7	07 33 26.92	-46 48 43.51	13.97	1.19	0.84	CG 4
CG-Hα 8	07 15 40.86	-48 31 27.16	15.33	1.39	0.13	CG 13
PHα 92	08 28 40.73	-33 46 23.17	13.38	1.27	0.91	CG 22

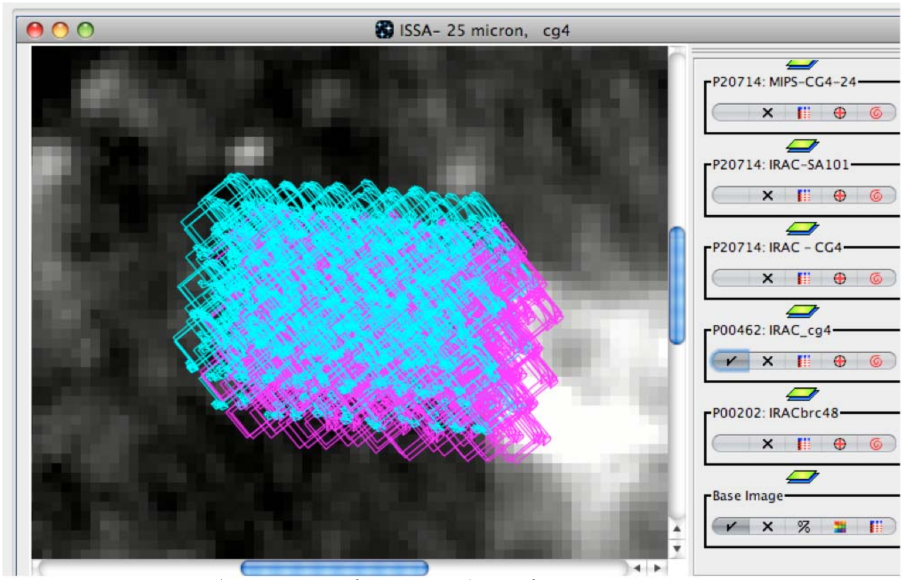

Figure 2. Visualization of IRAC data from program 462 on a 25-micron view of this region. The entire nebulous region plus the galaxy seen in Figure 1 is included in the IRAC data.

c. Data Analysis Methods.

We will use primarily archival Spitzer, IRAC and MIPS data (from programs 202, 462, 20714), as well as 2MASS data; see Figure 2 for a Spot visualization of program 462's IRAC data. Via collaboration with J.S. Kim (Univ. of Arizona), we have access to already-reduced data in two wavelength regimes covering this region: X-ray data from XMM and optical data in BVRI filters from the CTIO 0.9-m. These data cover a roughly 40'x40' region including CG4 and the nearby SA101 (which includes previously-known YSOs). We will combine all of these available data to examine the properties of the previously known YSOs (Reipurth and Pettersson 1993) and look for new YSOs in this region. The primary property of YSOs that we will use to find new ones is the near- and mid-infrared excess emission coming from the matter around a newly forming star. Spitzer data is especially well suited to finding these excesses, as well as any bipolar outflows that may be present. We will construct and examine color-color diagrams, color-magnitude diagrams, and spectral energy distributions (SEDs), looking for objects with infrared excesses.

We will use MOPEX-Mosaics from Photometry data (Makovoz & Marleau 2005) to create the mosaics and then Aperture Photometry Tool (APT) (Laher et al. 2010) to obtain photometry. These reduced data will also be accessible by programs available on our home institutions' computers. We plan to use software such as Hands-On Universe Image Processing (HOU-IP), MaxIm DL Optical Photometry program, and MOPEX to view the fits files and generate color-composite images. HOU-IP is a user-friendly data analysis tool that runs in both Windows and Mac operating systems, and is currently used by many of our high school astronomy students. MaxIm DL is a more sophisticated image analysis package. It has been tested in the Spitzer IC2118 project. Although it may not be possible to extract extremely accurate flux values using HOU-IP and MaxIm DL, these tools can be effectively used for basic flux studies, visual observation, and spatial analysis within the images. The resultant data tables will also be imported into spreadsheet programs such as MS Excel. Within Excel, students can generate color-color plots and SEDs with the data to test hypotheses related to using infrared wavelengths to identify and classify young stars.

2. Education / Public Outreach Merit

The four, widely diverse educator team members working on CG4, reflect four different scholastic scenarios: urban to rural high schools, an undergraduate institution, and an outreach educator at an observatory. Consequently, students involved in the CG4 project will range from high school to college age, and vary in abilities and talents. Of particular note is the inclusion of blind/low vision and deaf/hard of hearing students (BLV/DHH). Each of the educators involved is exceptional in dedication to their students and in commitment to involving students in authentic research.

Science Education Objectives and Performance Expectations: Through archival data gathered for this CG4 project, students and other teachers will learn about the physical properties of light, such as wavelength and flux, emission and absorption. They will gain experience in measuring size and distance and dealing with astronomical quantities. Students will be able to compare the images obtained by IRAC, MIPS, and IRAS to learn about spatial resolution. Evidence will be presented to help students understand how the universe is changing, how stars and planets are forming, and how stars evolve from birth to eventual death. Combining images at different wavelengths, students will be able to produce false-color images that enhance the features of young stellar objects and the interstellar medium (ISM) composition and structures.

In addition to the image datasets, students will also have the extracted data tables of sources and fluxes at each wavelength. Using spreadsheet and graphing programs, students will be able to generate color-color plots with these authentic data. They will access other datasets available in the Spitzer archive to compare these observations with those from similar clusters. Students will also be able to test their own ideas for color-color plots that could be useful in determining stellar properties. All activities will be adapted to be age-appropriate, and shared with other teachers.

Using archival Spitzer data is a prime example of authentic research and the process of scientific inquiry. Students can assume an active role in the process of project development, teamwork, data collection and analysis, interpretation of results, and formal scientific presentations. They will learn about the instrumentation used in infrared astronomy and the necessity of space-based telescopes. These experiences will help teachers and students meet the goals outlined in state/national science and technology standards. Content topics related to the science standards addressed in this project include: electromagnetic spectrum, temperature, structure and properties of matter, interactions of energy and matter, the origin and evolution of young stars and planetary systems, data analysis, and technological design.

The false-color images that this group will produce will be useful in public presentations. Dramatic illustrations of YSOs and star-forming regions will be shared with other teachers via workshops, publication of developed articles, adapted educational lessons and released images in various magazines like National Science Teachers' Association (NSTA), local papers, presentations and the coolwiki web site as described below.

Lessons that address Science, Technology, Engineering, and Math (STEM) skills and concepts will be developed by this NASA IPAC Teachers Archive Research Project (NITARP) teacher group and disseminated to teachers nationwide. These workshops and lessons will promote inquiry-based learning and interest in science, technology, and space research.

Education and public outreach can be accomplished through a resource developed in past NITARP (then Spitzer Teacher project) programs to enhance communication under "distance-learning" conditions. The *Cool Wiki* http://coolwiki.ipac.caltech.edu/) is designed to provide a place for teachers, students, and scientists to interact and share the materials they've developed, work on new materials, and work on current projects. The wiki also provides a resource for other teachers to learn how to use the materials we've developed. The wiki is a dynamic place, constantly changing and growing! We also will use the Cool Wiki to maintain contact among teachers and students while working on the project.

Education component at Yerkes Observatory (V. Hoette). Students will emphasize multi-sensory approach, by including teachers and students from the Wisconsin Center for the Blind and Visually Impaired and the Wisconsin School for the Deaf. Teachers and administrators from both schools have identified students who have previously participated in Yerkes programs and who are blind/ low vision (BLV) or deaf or hard of hearing (DHH). BLV and DHH students challenge us to include strategies that address abilities in a multi-sensory manner rather than limit opportunity because of perceived disabilities. These students are often at a disadvantage when studying science because materials are not generally made available in formats accessible to them (Beck-Winchatz, Hoette, & Grice, 2003). Addressing the needs of BLV and DHH students can also help address the diverse abilities and learning needs of other students (Center for Applied Special Technology, n.d.; Story, Mueller, & Mace, 1998).

Education component at Pierce College (C. Mallory). Students will be recruited by in-class announcements and through (large, inclusive) Pierce College Astronomy Society, which reaches a student body of 26,000. The application process will ensure that students have the skills and interest to complete the project. One of the major objectives for students on this team is for them to be able to take data and extract meaning from it. Students will have to plan their own data gathering, organization, and analysis, to answer specific questions. They'll have to be able to revise methods if the selected actions don't yield unambiguous answers, and use teamwork in data collection and analysis, and in reaching conclusions. Students will have to be able to explain and defend their conclusions. Practice in scientific presentation skills will give a big education and career boost to these students, most of whom desire to become Astronomers.

Education component at Oak Park and River Forest High School (K. McCarron). Selected students will become proficient in publishing scientific research. The students at OPRFHS will be selected on a competitive basis. They will learn the basics of doing scientific research and then publishing that research. They will then teach other students how to do that research in the future. Students will learn the basics of doing a literature search, gathering and analyzing data, then communicating this to others.

The lessons learned from the research will be used in regular education classes. Topics will include the electromagnetic spectrum, space telescopes, cometary globules and stellar evolution. Specific lessons will include the Active Astronomy Kit of Infrared Astronomy, using data archives, presenting findings and using image processors to make scientific measurements. These will enhance science skills in Astronomy, Integrated Lab Science, and Physical Science.

Team Spitzer at Breck School (C. Johnson). Working on weekends for the past 14 months, nine students have been investigating Lynds Dark Nebulae near the Galactic Equator in hopes of finding YSOs. As soon as this project is completed, three additional students will be added to that current team of students to join the CG4 efforts.

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