Star Formation in Lynds Dark Nebulae

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Abstract:

1. Project Description & Scientific Merit

a. Goals

Recent research on star formation in large molecular cloud complexes, such as the Cepheus Flare (Kun 1995), Orion, Perseus (Rebull et al. 2007), and Taurus molecular clouds, have included studies of a number of Lynds dark nebulae (LDN). Less attention has been given to isolated Lynds clouds, such as LDN 1616 (Cooksey 2001). Another example of an isolated cloud that may contain young stellar objects (YSOs) is LDN 981, located in Cygnus. This cloud has a linear structure, with several filaments radiating out from a central core, one of which terminates in V1331 Cyg, a known YSO. Quanz et al. (2008) studied this region near V1331 Cyg; it may be a member of a group of YSOs that has recently emerged from this dark nebula.

What could have prompted star formation in this nebula? Scattered supernova remnants can be found at various locations within Cygnus. These include the Cygnus Loop (Veil nebula) and one discovered in 2000 - SNR G069.0+02.7 (Mavromatakis 2002). Cygnus OB associations are members of a group of massive stars – some of which have produced supernovae with resultant shock waves and cavities in the ISM (Plüschke 2002). Could a slightly earlier episode of this have resulted in star formation in LDN 981 that remains as of now undetected?

Another isolated dark nebula is LDN 425. While it is not directly associated with any molecular cloud complex, there is mention of an extended distribution of dust between the main clouds in Chamaeleon, Lupus and Ophiuchus (Sartori 2000). Ophiuchus is another region of active star formation, much of which is localized in a region centered on rhọ Ophiuchi. According to Wilking (1992), the Ophiuchus molecular cloud complex is one of the most prominent areas of star formation for low to intermediate mass stars. Padgett et al. (2008) recently presented Spitzer/MIPS data over a 14.4 square degree map of the entire Ophiuchus molecular cloud, finding more than 300 YSO candidates. Could LDN 425 be part of this "extended dust distribution" and be on the fringes of the Ophiuchus star formation region?

Both LDN 981 and LDN 425 are smaller, more isolated, dark molecular clouds that could contain regions of active star formation within them – they both are associated with IRAS sources, and based on prior shallow surveys, they both have a YSO candidate in the neigborhood. Spitzer observations with IRAC and MIPS will allow us to see deep inside the cloud, deeper than any prior observations could see, and reveal any hidden star formation that is ongoing in these clouds. These clouds have morphological differences. LDN 981 is somewhat linear with filaments extending outward from a central core. LDN 425 is more compact and lacks the filamentary structures. A comparison of star formation in these structurally diverse dark nebulae would be a useful addition to the study of star formation in smaller, more isolated molecular clouds.

b. Data Analysis Methods

Once the data have been collected, the team plans to visit the Spitzer Science Center (SSC) to work with Dr. Rebull in the reduction of the data. The team will use MOPEX to create a mosaic, perform photometry, and generate a list of band-merged 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 possibly 70 micron) fluxes in both magnitudes and Janskys.

The reduced data will 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, 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 high school astronomy students. MaxIm DL is a bit more sophisticated image analysis package that has been tested in the Spitzer IC2118 project, and a method has been developed to acquire fairly accurate fluxes using this software tool. 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 spectral energy distributions (SEDs) with the data to test hypotheses related to using infrared wavelengths to identify and classify young stars. As part of the IC2118 project, we worked with R. Laher to develop an Excel spreadsheet that will generate SEDs, so the software is already in place.

In reaching the stated goals, the mosaics, data tables, and fits images will be shared with our students, as well as other teachers. It is hoped that all participants will assist in the data analysis process. This sharing and analysis will be another component of the education that will be supplemented with a variety of activities.

c. Target Selection

Dust is found everywhere in the universe. It is in our houses and in large areas of our Galaxy and the Universe, dating all the way back to nearly the beginning of time (e.g., Yan et al. 2005). This dust was formed initially from massive short-lived stars such as Cassiopeia A (e.g., Rho 2008). Dust can also be formed from old, dying stars that used to be like our Sun. Dust found in molecular clouds (which have large amounts of gas and dust) is crucial to the star formation process because it allows the gas to cool down enough so that clumps of the cloud can condense into pre-stellar cores under the influence of self-gravity. From there, the cores evolve into YSOs, which will consist of the central protostellar object and a circumstellar disk of dust. The circumstellar disk of dust associated with the YSOs can be used to make planets, and possibly provide the foundation for life itself.

Additionally this pervasive dust collects in large areas all over our galaxy. In 1962, Beverly Lynds (Lynds 1962) undertook a general survey of dark nebulae based on Palomar Schmidt photographs. Lynds determined the approximate RA and DEC of the centers of these cloud and made visual estimates of the opacity of each one. A scale of 1 to 6 was used with the higher number associated with the greater (visual) opacity. For our project, we have picked two of these darker nebulae from Lynds' catalog, LDN 425 and LDN 981.

Our selection process was as follows. We began with the full list of more than 1750 Lynds objects and focused on objects with opacity classes of 5 or 6 to be sure we were selecting the darkest, densest clouds. Next, we determined which objects had already been observed by Spitzer in the GLIMPSE and MIPSGAL surveys – since those surveys cover large segments of the Galactic plane, and most of the Lynds objects are in the plane, we anticipated that many of the Lynds clouds would already be in those surveys. For each of the remaining objects, we used Leopard to search the rest of the Spitzer archive for existing observations with either IRAC or MIPS. There are 270 objects without IRAC or MIPS observations. We used SIMBAD to check and see how many literature references there were for each of the objects. We wanted to find objects that had some supporting data (such as a distance determination, or NIR observations), but not so well-studied that everything was already known about them. One particularly useful paper we used to aid in selecting candidates with dense optical cores was "A Catalog of Optically Selected Cores" (Lee & Myers 1999); there are 9 objects meeting our criteria above that are also listed in Lee & Myers (1999) as having likely star formation. There are 14 more objects with no Spitzer data but more than 10 publications in SIMBAD. At this point, then, we have 23 candidate objects left from a list of over 1750 objects, which is a reasonable list for searching manually. We went and examined the optical images and literature references for these objects, as well as a handful of other clouds we had found by other means, settling on 6 candidates most likely to host star formation. The group discussed the pros and cons of each of the 6 and settled on two, LDN 425 and LDN 981 as our two best candidates to focus on for observation with IRAC and MIPS.

When our group first met, we noticed the variety of morphology of the Lynds clouds. Therefore, as we were sorting the Lynds cloud list finalists, we decided to try to examine clouds of different morphology. LDN 425 has a somewhat globular appearance, and LDN 981 has what seems to be a very linear appearance.

Many Lynds clouds are already in the Spitzer Archive; as of the end of Cycle-4 (prior to the ingestion of Cycle-5 AORs), 191 of the opacity class 5/6 clouds are covered by both IRAC and MIPS, plus 54 more (also opacity class 5/6) covered by either just IRAC or just MIPS. As part of our study, we will also investigate some of these Lynds clouds already in the archive, extending our study of different Lynds cloud morphologies.

2. Targets and AOR construction

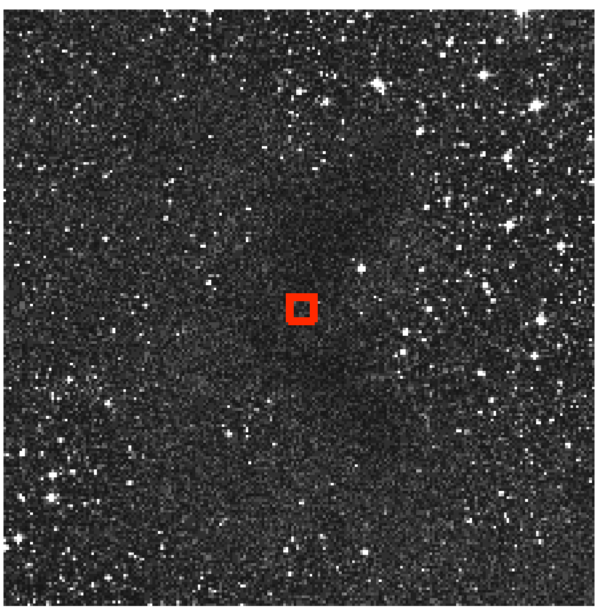


FIGURE 1: LDN 425 from the POSS-red plates, 0.25 degrees on a side. The square indicates the center of our planned observation; see text.

a. LDN 425

(Lynds 1962 reports galactic coordinates L(II)-21.6, B(II)-12.30
RA 17:44.2, DEC -4:40 [1950], Opacity class 5)

LDN 425 is an irregularly shaped Class 5 Dark Cloud; see Figure 1. The possibility of a YSO near the region was speculated by Carballo in 1992 and later confirmed in papers by Connelley (2007) as well as Lee and Myers (1999). Connelley (IRAS source 17441-0433) observed a spatially resolved near-infrared source that suggests a YSO due to its K-band morphology; they think it is a reflection nebula. IRAC observations should reveal the illuminating object.

This area fits the basic criteria for selection of a LDN target (darkness, possible YSO, and IRAS source; it has non-linear structure for the aspect of our study relating to Lynds cloud morphology). The target is viewable from Spitzer from April 12 to May 23, 2008. Should the data appear promising, we will come back later to request additional data at 70µm during its next visibility window from September 21 through November 2, 2008.

The part that is the center of the coordinates given by Lynds (and retrieved by SIMBAD) is offset from the darkest part as seen in POSS. There is not much to the dark cloud north of the image region shown in Figure 1. Therefore, we are adopting the center of our observations to be (in J2000 coordinates) 17:46:55 -04:36:25, the box in Figure 1. (Galactic coordinates 21.26, +12.11, Ecliptic coordinates 266.56, +18.79.) At an ecliptic latitude of +18, we might expect some asteroids to move through our field of view, but we do not require a second epoch of observation to weed out any moving objects; we will use 2MASS observations to remove any asteroids. Figure 2 below shows our proposed IRAC (left) and MIPS-24 (right) observations. In the right below, x's are IRAS sources. IRAC total time is 657 seconds and the MIPS-24 total time is 395 seconds.

TOTAL TIME FOR THIS OBJECT= 0.3 hrs.

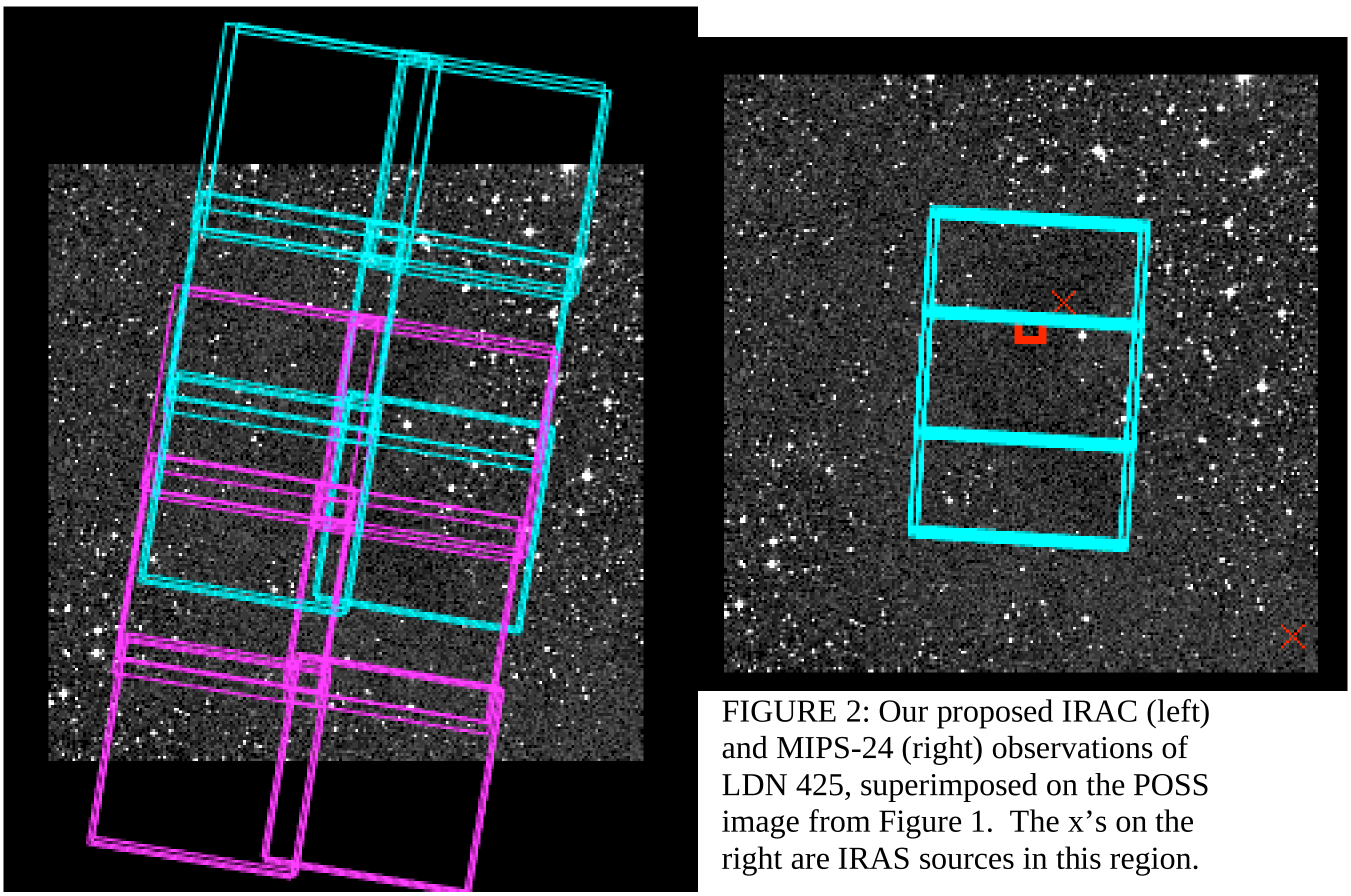


FIGURE 2: Our proposed IRAC (left) and MIPS-24 (right) observations of LDN 425, superimposed on the POSS image from Figure 1. The x's on the right are IRAS sources in this region.

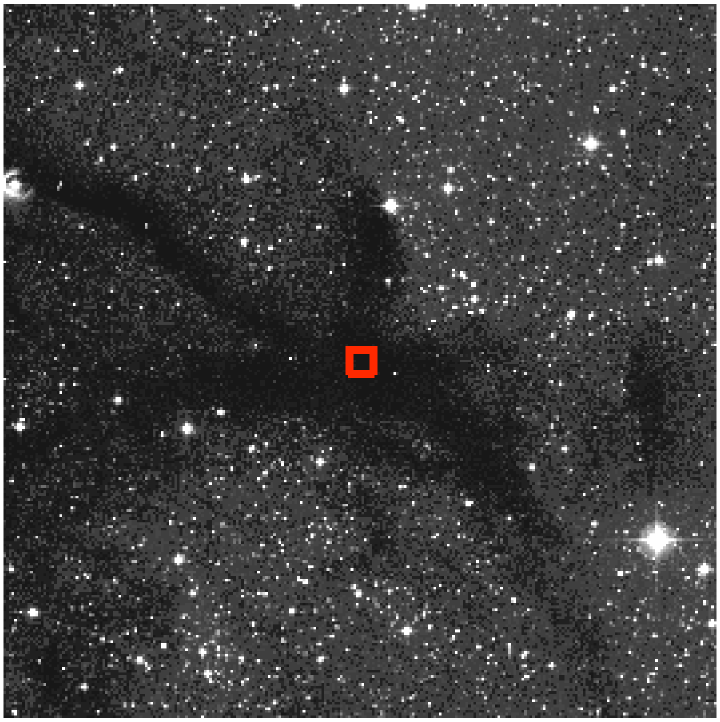


FIGURE 3: LDN 981 from the POSS-red plates, 0.3 degrees on a side. The square indicates the center of our planned observation, and the object with the ring around it at the far left is V1331 Cyg; see text.

b. LDN 981

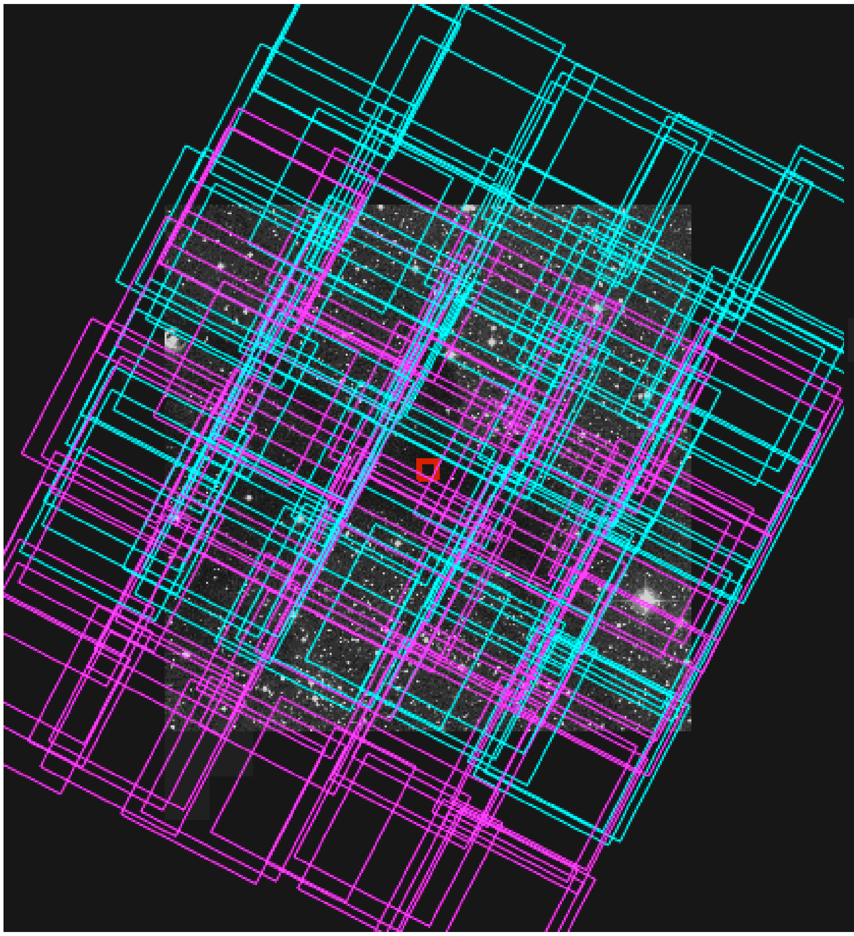
(Lynds 1962 reports galactic coordinates L(II)-89.92, B(II)-2.87 RA 20:58.0, DEC +50:0 [1950], Opacity class 6)

LDN 981 is described as a “roughly elliptical core with five elongated dark filaments” (referred to as F1-F5), where, located at end of one finger, about 8’ long, is V1331 (Quanz et al. 2007). LDN 981 has a distance of 700 pc (Lee and Myers 1999). V1331 Cyg, which seems to be associated with LDN 981, has distances reported from 694 pc (Chavarria 1981) to 550 pc (Shevchenko et al. 1991). With V1331 Cyg having two rings of dust, it is suggested to be a pre-outburst FU Ori candidate (Quanz et al. 2007). Since a known YSO is associated with LDN 981, there might be other YSOs and so we consider this a worthy target; it has a very linear structure for the aspect of our study relating to Lynds cloud morphology. The target is viewable from Spitzer from June 26, 2008 to February 3, 2009.

The center of our planned map is at 21:00:14.88, +50:17:16.8 (J2000), which is Galactic coordinates 90.16, +2.74, and Ecliptic coordinates 346.56, +62.29. At these ecliptic latitudes, asteroids are not a concern, but field rotation as Spitzer moves in its orbit is a concern. We wish to cover as much of the filamentary structure as possible, and we wish to make our map large enough that it requires only the loosest possible constraints to observe the region of interest. Our proposed IRAC and MIPS maps appear in Figure 4. Some existing MIPS data are in the Archive to the east and north of this region, which we will add in to our final maps. The IRAC total time is 2152 sec, and the MIPS-24 total time is 1191 sec. In order to make the AORs cover the minimum area of interest but still absorb a limited amount of time, the IRAC observations need to be completed before Sep 15, and the MIPS observations need to be completed before Sep 1. This window is large enough that it should not unduly stress the scheduling system.

TOTAL TIME FOR THIS OBJECT= 0.9 hrs.

TOTAL TIME REQUESTED BY THE TEAM FOR BOTH OBJECTS: 1.2 hrs



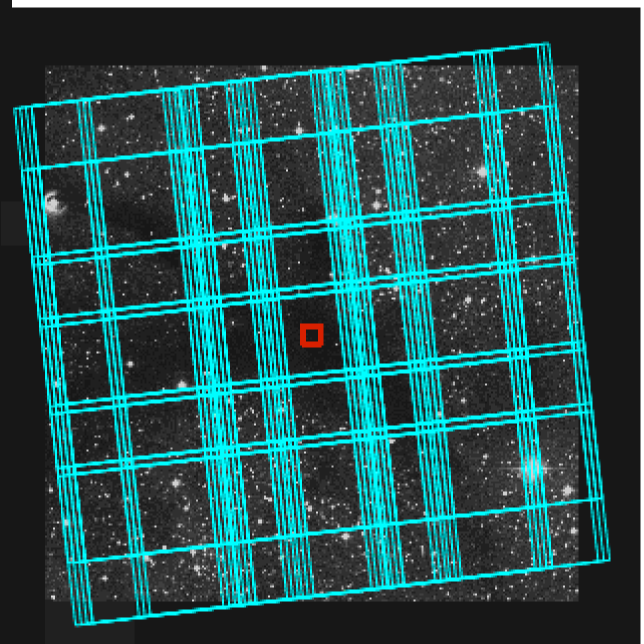


FIGURE 4: Our proposed IRAC (left) and MIPS-24 (right) observations of LDN 981, superimposed on the POSS image from Figure 3.

3. Educational/ Public Outreach Merit

Through observations gathered from this 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 ISM composition and structures.

In addition to the image data sets, 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 be able to access the data sets already available in the Spitzer archive to compare these observations with those from other clusters and Lynds clouds. 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 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. The national science standards addressed in this project are; astronomical observations, small bodies, interplanetary dust, electromagnetic spectrum, temperatures, the structure and properties of matter, interactions of energy and matter, the origin and evolution of the Earth/Planet/Solar systems, data analysis and the abilities and utilization of 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 NSTA, local papers, presentations and the coolwiki web site as described below. Additionally, the team will work to develop three specific activities which will expose both their students and other teachers and their students to the infrared part of the electromagnetic spectrum. The first activity will involve measuring infrared radiation using the classic Newton experiment published in 1672 when he split white light into its rainbow colors. If measurements are made outside the refracted visible color band, one can “see” infrared. William Herschel in 1800 measured the temperature of the different colors from the prism’s rainbow and found the hottest part of the spectrum was outside the color band. The second activity will use the Leslie’s cube developed by Sir John Leslie in the early 1800’s. The cube is made with the four main sides with different characteristics. One side is painted black; one side is painted white; one is polished metal; and one is a dull metal. The cube will show what makes a good radiator of infared radiation. The third activity will involve using a modern infrared thermometer to measure and identify IR sources in an enclosed box.

Lessons that address STEM skills and concepts will be developed by this Spitzer teacher group and disseminated to teachers nationwide. These workshops and lessons will promote inquiry-based learning and interest in science, technology, and space research.

If we don’t find anything in these clouds, it will also be useful – the scientific inquiry process can by its nature be surprising. We might find lots of interesting things, or we might not find anything. This is the nature of science.

Educational and public outreach can be accomplished through a resource recently developed to enhance communication under “distance-learning” conditions. “The Cool Wiki (https://coolwiki.ipac.caltech.edu/) is a resource developed by teachers and scientists involved in the Spitzer Space Telescope Research Program, primarily those from the IC2118 team. It 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 use the Cool Wiki to maintain contact among the teachers and students while working on the project.

4. References

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