The 2009 RBSE Journal
The RBSE Journal 2009

The RBSE Journal is an annual on-line publication that presents the research of students and teachers who have participated in the Research Based Science Education program RBSE, at the National Optical Astronomy Observatory in Tucson. This program consists of a distance learning course and a summer workshop for high school teachers interested in incorporating astronomical research within their class and school. The RBSE program brings the research experience to the classroom with datasets, materials, support and mentors during the academic year. The journal publishes papers that make use of data from the RBSE program, or from its related programs: TOP, New Mexico Skies, and the SPITZER teacher observing program.

These papers represent a select set of those submitted for publication by students and occasionally RBSE teachers. All papers are reviewed both by the Editor and another astronomer, and the authors are given an opportunity to incorporate these suggestions. More information about both the RBSE and the TOP program can be found on our website, www.noao.edu/education/arbse.

I want to thank numerous individuals: Dr Bill Livingston, Dr. Luise Rebull, Dr. Bill Sherry, Dr. Steve Howell, and Dr. Jennifer Lotz for their generous help in reviewing these papers and working with the young scientists. Special thanks are due to Kathie Coil for her efficient editing of the final copy.

Dr. Katy Garmany
Editor, RBSE Journal
# Table of Contents

## TOP

**Developing a High Quality Color Magnitude Diagram for Estimating Distance to NGC 6694** ................................ 1  
Andrew Hellmund, Elizabeth Mealey, Josiah Smith  
Hartsbrook High School, Hadley, MA  
*Teacher: Charles Weems, ARBSE 2008*

**Measuring the Distance Modulus of M35 with the SDSS Filter System** .................................................. 9  
Ben Greene and Matt Adamczyk  
The Prairie School, Racine WI  
*Teacher: Andrew Vanden Heuvel, ARBSE 2008*

**Galactic Gravitational Distortion as a Measure of Stellar Age** ................................................................. 14  
Laurence LaGuardia, Jr., Dominic M. Robe, Slater Teague  
Sullivan South High School, Kingsport, TN  
*Teacher: Thomas Rutherford, TLRBSE 2005*

## TOP/SPITZER

**Identifying T Tauri Stars Using Small Optical Telescopes** ................................................................. 24  
Jennifer Butchart  
Oil City Area Senior High School, Oil City, PA  
*Teacher: Mr. Tim Spuck TLRBSE 2004*

**Investigating Star Formation in Lynds Cloud 981** ..................................................................................... 33  
Rachele M. Siegel  
Oil City Area Senior High School, Oil City, PA  
*Teacher: Tim Spuck, TLRBSE 2004*

## SPITZER

**Star Formation in Isolated Dark Nebulae: YSOs in LDN 981** ......................................................... 46  
Justin Boerma, Stephen Brock, and Trevor DeWolf  
Chippewa Hills High School, Remus, MI  
*Teacher: Cris DeWolf, TLRBSE 2006*

## SOLAR

**Using Doppler Shifts to Determine the Sizes of Solar Granulation Features** ................................. 57  
*Teacher: Matthew K. Bierer, North Pole High School, North Pole, AK, ARBSE 2008*  
*Teacher: James Elliot, Myers Park High School, Charlotte, NC, ARBSE 2008*  
*Teacher: John W. Fuller, Seacrest Country Day School, Naples, FL, ARBSE 2008*
Developing a High Quality Color Magnitude Diagram for Estimating the Distance to NGC 6694
Andrew Hellmund, Elizabeth Mealey, Josiah Smith
Hartsbrook High School, Hadley, MA
Teacher: Charles Weems, ARBSE 2008

ABSTRACT
In this article we show that analyzing the V and B-V values for a greater number of stars produces a higher quality color magnitude diagram for an open star cluster. This enables us to better determine the values of $m-M$ and $E(B-V)$, from which it is possible to calculate the distance to the cluster, using a standard distance modulus formula. Compared to results of prior surveys we are able to more confidently estimate the distance to the cluster under study. Furthermore, we demonstrate that our technique can be applied by high school students, given access to high resolution B and V images from modern sensors.

INTRODUCTION
The scientific goal of this project was to determine the distance to NGC 6694 (M26) with greater confidence than previous studies using color-magnitude diagrams (CMD). A further goal was to develop a method for estimating the distances to open clusters that can be employed by high school students using freely available software tools, applied to images that can be easily obtained using modern telescopes and CCD cameras.

Given images taken through Johnson B and V filters, of an open star cluster, it is possible to create a CMD that plots B magnitude in relation to B-V. The CMD is then compared to a standard Hertzsprung-Russell (H-R) Zero Age Main Sequence (ZAMS) diagram, with the goal of aligning the main sequence in the CMD to the ZAMS. The degree of shift required for this alignment reveals the absolute magnitude and reddening of the cluster. Using a standard distance modulus formula with these values, we can then compute the distance to the cluster.

To create the CMD for NGC 6694, B and V images were analyzed in ImageJ: an image analysis program with an astronomy plug-in. The images were first adjusted until the stars were both distinct and bright. Next the image was divided into 256 grid squares. We sampled an average of seven stars per square (approximately 10 stars per square near the middle of the cluster, and fewer toward the outer edges, due to the lower density of stars in the outlying areas of the images). We recorded these data (B and V flux values) and imported them into a photometric spreadsheet.

The spreadsheet was used to plot the CMD, expressing the B magnitude with respect to B-V, and also the ZAMS as given by Allen (2000). Based on the $m-M$ and $E(B-V)$ offset, the spreadsheet calculated the distance to the cluster. As a result of plotting 1794 stars in the CMD for NGC 6694, we found a difference between apparent and absolute
magnitude of 13.7, and an excess reddening of 0.7, from which we determined a distance of 2023 pc, which is significantly greater than prior studies.

SUMMARY OF PRIOR RESEARCH
Cuffey (1940) was one of the first to estimate the distance to NGC6694. His goal was to confirm that “the ratio between general and selective absorption” fulfills the ratio: \( \frac{A_r}{(A_b - A_r)} = 2 \). He compared red and blue values as well as a CMD to that of Messier 38. Using 265 stars he calculated a color excess of 0.55 and a distance modulus of 10.1. His corresponding distance to the cluster is 1660 pc (uncorrected), and 1000 pc (corrected for his estimate of 2.0 for the reddening).

To calculate a new value for the constant of galactic rotation, Johnson, et al. (1961) determined the distance to main sequence clusters. Their method included determining the reddening of early type stars and verifying this against late type stars within each cluster. Absorption was calculated from the equation \( A_V = 3.0 \frac{E_B-V}{E_V} \). Using the 129 stars they report in Hoag (1961), they obtained a reddening of 0.58 and a magnitude difference of 10.9 (corrected for \( A_V \) of 3.0, and which would be 12.75 uncorrected, by our calculations) for NGC6694, resulting in a new distance measurement of 1500 pc.

Hoag and Applequist (1965) used photoelectric H\( \lambda \) observations and spectral classifications for 382 stars in 64 galactic cluster fields. For NGC6694, five stars were used. They assigned individual luminosities according to existing calibrations. First by re-determining the modulus using ZAMS to re-examine previous UBV data. Next they selected the clusters that seemed to have their photometric modulus well determined and then compared the modulus estimated from H\( \lambda \) observations and spectrographic observations with the UBV modulus. From the H\( \lambda \) observations they estimate a modulus of 10.3, and spectrographically they report 10.6 with a reddening of 0.51. In their summary, they found that the modulus for NGC6694 was 11 compared to 10.9 for Johnson and Svolopoulos (1961) and 10.8 from Becker (1961).

Using a standard methodology to synthesize U, G, and V fluxes and colors, Battinelli, et al. (1994) applied the methodology to a set of 138 open clusters, which they compared with previous results. Their method enabled them to calibrate a mass-luminosity. They evaluated the mass of approximately 400 open clusters leading them to a well-defined present-day mass function. Their result found that the distance to NGC6694 is 1548pc.

Becker and Fenkart (1971) catalogued 216 galactic star clusters in three colors. They calculated or recalculated the distances using an observed CMD with the zero age main sequence (ZAMS). By using (U-B), V- or (U-G), G- they found more precision. This provided a better separation of the physical members and a more precise determination of the distance modulus, especially for young clusters. They determined that the distance to NGC6694 is 1555pc.
OBSERVATIONS
On July 28, 2005, two images of NGC 6694 were taken using standard Johnson B and V filters. The images are of size 2048 by 2048 and were obtained using the KPNO 0.9-meter WIYN telescope and the S2KB camera. Data was also taken on four absolute standard stars, yielding flux/magnitude scaling factors of 21.6 for V and 21.5 for B. Airmass for the B image was 1.51 and for V it was 1.53. However, no compensation for airmass was included in the scaling factors and they have a formal error range of +/- 0.03.

Because the sensor-telescope combination has a pixel scale of 0.6 arc seconds, the image area is just over 20 by 20 arc minutes, and thus includes the entire central portion of NGC 6694 as well as its outer reaches. Exposure time for the B image was 40 seconds, and for the V image it was 30 seconds. The raw images were reduced by KPNO staff using standard dark, flat and bias data. The resulting images are in the FITS file format, with 32-bits per pixel.

DATA REDUCTION
Image J is used to process the two FITS files—the B and V images. These are first adjusted with brightness and contrast controls to equalize the images. The automatic function is initially used, then the max/min values are fine tuned—these values are manually recorded as they must be re-entered every time image J is opened, and because all of the members of the analysis team must use the same image settings. The goal of this initial image adjustment is to have a large number of visible stars with good contrast.

Next, a grid is laid over the image—this can be adjusted to discretion using the ImageJ Analyze plug-in. For these images we arranged for a 16 x 16 square grid. Each grid square was manually assigned X and Y coordinates for coordination of team members to ensure that there was no duplication of the data.

To process one square we zoom in on it. Next we calibrate against the background using the Seeing Profile tool in the Astronomy plug-in. This tool also estimates an appropriate aperture radius that can be used in the subsequent analysis. We then set the aperture parameters for the Multiaperture tool, and also select the option to display the aperture and other information in an overlay.

Prior to activating the Multiaperture tool we examine the images for candidate stars, choosing those with a round shape and sufficient isolation from adjacent stars. Typically, about 5 to 15 stars are identified. The Multiaperture tool is then activated and the number of candidate stars is entered. We then click on the center of each star to be measured. After the specified number of stars has been measured, a window with the measurements appears, and these are saved using a file naming convention that incorporates the coordinate system of the squares. This process is repeated for the second image for the same stars in the same order. Because the Multiaperture tool displays an aperture circle and sequence number around each measured star, it is easy to ensure this correspondence.
The B and V measurement files are separately imported into the spreadsheet program. From these two spreadsheets the data is copied into the photometry spreadsheet which will convert flux to magnitude using the formulas:

\[
M_v = 21.6 - 2.5 \times \log(\text{flux}_v/30) \\
M_b = 21.5 - 2.5 \times \log(\text{flux}_b/40)
\]

The photometry sheet also computes the difference between \( M_b \) and \( M_v \). The program plots a chart containing a standard ZAMS diagram as a curve and the photometry data as a scatter plot. By overlaying the two and adjusting the placement of the ZAMS curve in the chart it is possible to estimate \( m-M \) and \( E(B-V) \) which can be use to derive the distance to the cluster using the formula:

\[
\text{Distance}_{\text{pc}} = 10^{(m - M - A(V) \times E(B-V) + 5)/5}
\]

Where \( A(V) \) is the absorption due to dust in the interstellar medium. Because our data do not allow us to determine \( A(V) \) specifically for NGC 6694, we use the standard value of 3.1 from Allen(2000).

Figure 1 shows this chart for our data. Following the approach of Cuffey, we divided the stellar data into rings. Ring 1 represents the stars nearest the center of cluster, and Ring 2, contains all of the stars that are more distant. In this case, Ring 1 contains the nearest 500 stars, and Ring 2 holds the other 1294. A distinctive curve can be seen in the scatter plot that corresponds very closely to the ZAMS diagram. These curves have the same scale because their relative apparent magnitudes are proportional to their relative absolute magnitudes. We determined the best fit of the ZAMS curve visually, by adjusting its placement in the chart through entering different values of \( m-M \) and \( E(B-V) \) into the spreadsheet.
Figure 1. CMD for NGC 6694 with ZAMS Corresponding to $m-M = 13.7$ and $E(B-V) = 0.7$
DISCUSSION
Because we used 1794 stars, our CMD has greater density and range than prior studies. We argue that this enables us to determine a better fit of the ZAMS than earlier work that used a much smaller number of stars. Our reddening value is somewhat greater than more recent studies that are based on spectral analysis, and we obtain a modulus that is greater than all of the prior work for which we could find this value, with the exception of Becker (1971). As a result, we find a distance of 2023 pc, which is greater than all prior estimates.

Of course, an accurate distance calculation depends on the value of A(V). Cuffey used $A(V) = 2$ for his "corrected" distance and 0 for the "uncorrected" distance. Johnson used $A(V) = 3$ to obtain a distance of 1500pc. Through back-calculation, Becker seems to have used $A(V) = 3.4$ and Lynga used $A(V) = 3.1$. Adopting Becker's value for A(V) would change our distance estimate to 1837 pc.

Table 1 summarizes our results in comparison to prior studies. We do not include Hagen (1970) in the table because even though she plots a CMD with new data, her summary merely repeats the analysis from Johnson (1961). However, a ZAMS fit to the 101 stars in her CMD is in good agreement with ours.

<table>
<thead>
<tr>
<th>Source</th>
<th>Stars Used</th>
<th>m-M</th>
<th>E(B-V)</th>
<th>Distance (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuffey (1940)</td>
<td>265</td>
<td>10.0 corrected 11.1 uncorrected</td>
<td>0.55</td>
<td>1000 corrected 1660 uncorrected</td>
</tr>
<tr>
<td>Hoag and Applequist (1965)</td>
<td>5 (spectra)</td>
<td>11</td>
<td>0.51</td>
<td>Not specified</td>
</tr>
<tr>
<td>Becker and Fenkart (1971)</td>
<td>Not specified</td>
<td>13.8</td>
<td>0.83</td>
<td>1555</td>
</tr>
<tr>
<td>Johnson (1961)</td>
<td>129</td>
<td>10.9 corrected 12.75 uncorrected</td>
<td>0.58</td>
<td>1500</td>
</tr>
<tr>
<td>Battinelli (1994)</td>
<td>159, statistical synthesis</td>
<td>Not specified</td>
<td>0.57</td>
<td>1548</td>
</tr>
<tr>
<td>WEBDA (1987) (Lynga Catalog)</td>
<td>Not specified (statistical synthesis)</td>
<td>12.85</td>
<td>0.589</td>
<td>1600</td>
</tr>
<tr>
<td>Karchenko (2005)</td>
<td>Not specified, based on &quot;private communication with Loktin&quot;</td>
<td>12.86</td>
<td>0.6</td>
<td>1582</td>
</tr>
<tr>
<td><strong>This paper</strong></td>
<td><strong>1794</strong></td>
<td><strong>13.7</strong></td>
<td><strong>0.7</strong></td>
<td><strong>2023</strong></td>
</tr>
</tbody>
</table>

Table 1. Summary of Results Comparing Our Data with Prior Studies
POTENTIAL SOURCES OF ERROR
The ImageJ Astronomy plug-in's Multiaperture tool has a fixed diameter for each set of selections, which may not be optimal for the wide range of stellar flux values. Thus, it might overemphasize background flux for fainter stars, and underemphasize actual stellar flux for larger stars. Correcting this error would involve readjusting the aperture for each star or at least for groups of similar stars within each grid square. A tool that automatically adjusted the aperture would be a more reliable alternative.

Because the data from ImageJ must be transferred manually to a separate spreadsheet for analysis, the potential exists for random errors, although these are unlikely to result in a discernable shift in the scatter plot, because of the total number of points plotted. Addressing this error would best be done by extending ImageJ to automatically place all of the data into one database that could then be imported into a spreadsheet or graphical analysis program.

Since the H-R curve must be aligned with the CMD by visual inspection, it is possible that different observers would select slightly different combinations of m-M and E(B-V). Our experience is that the density of the data obtained through our method produces a fairly strong CMD curve. However, there may be bias introduced by the large number of field stars if. This error could be reduced by use of member analysis to reduce the influence of nonmembers on the graph.

The flux/magnitude conversion factors that were computed from the four calibration stars are limited in their accuracy. Using the given formal error in these values, we determined that our E(B-V) value could range from 0.65 to 0.77, resulting in a variation in estimated distance from 2173 pc to 1830 pc. This variance of 343 pc is approximately 15% of our distance estimate. This error could be reduced through the use of additional calibration stars.

SUMMARY
In the course of this study, we have shown that it is possible to produce a higher quality CMD based on data from a larger number of stars, obtained from using readily available software and modern imaging technology. Because our CMD has greater density and extended range we were able to more easily determine the placement of the ZAMS in relation to the main sequence of NGC 6694.

Our measurements also extended farther from the center of the cluster than most prior work, which focused on the inner core. Hagen, for example, looked no further than 4' from the center. From our data it thus appears that there may be considerably more members in NGC6694 than have been identified in prior studies. We also see a correlated grouping at around B-V = 1.75, which could be due to measuring the flux of close binaries at the red end of the spectrum as if they were individual stars.

We conclude that the distance to NGC 6694 is 2023 pc, which is greater than previous studies suggested. Even with error analysis that shows a minimum distance of 1830 pc,
our results are still greater than prior reports, although a greater value for A(V) could yield a distance that is more consistent with earlier work. However, from examination of that work, we believe that it could be biased by the limited magnitude range of their CMDs.

ACKNOWLEDGEMENTS
We would like to thank the staff of KPNO for providing the images, and the RBSE program for providing the opportunity to conduct this research. We would especially like to thank Katy Garmany and Travis Rector for their help in developing our approach and working with the software.

REFERENCES
Measuring the Distance Modulus of M35 with the SDSS Filter System
Ben Greene and Matt Adamczyk
The Prairie School, Racine WI
Teacher: Andrew Vanden Heuvel, ARBSE 2008

ABSTRACT
The photometry of open clusters is a long-standing and well-studied area of astronomical research. Until recently, nearly all such photometry has been performed with the standard UBVRI Johnson/Bessel filters. New filter systems have been developed in recent years, most notably the SDSS filter set comprised of u,g,r,i,z filters. Measurements with new filter systems such as this allow truly independent verification of previously measured open cluster properties. We present the first measurements of the reddening and distance modulus of the open cluster M 35 ever made with the SDSS filter set. We measure a g-r reddening of 0.34 mag and a distance modulus of 10.8 mag corresponding to a measured distance of 2900±200 ly.

INTRODUCTION
Performing photometry of open clusters, groups of stars closely related in composition, relative distance, and age, is important for several reasons. Photometry allows the measurement of the distance modulus of clusters, an essential rung of the distance ladder that reaches out to the farthest galaxies in the universe. Photometry also allows the age of a cluster to be determined quite accurately. Ages of clusters can help put important constraints on the lifecycles of stars and ultimately the age of the universe. In our research, we have set out to measure the distance to the open cluster M35 through photometric techniques.

Since the invention of the Johnson UVBRI filter system in the 1950s-60s, their use in performing astronomical photometry has been ubiquitous. The development and growing use of new filter systems, especially the Sloan Digital Sky Survey (SDSS) filter system (Fukugita 1996), as well as a distributed network of reference stars related to the photometric system has made it possible for the first time to independently verify the measured distances and ages of clusters.

In recent years, astronomers have begun photometric analysis of open clusters using the SDSS filters, but this work has focused primarily on southern targets (Rider et al 2004, Fornal et al 2007). Here, we present the first photometric analysis of the open cluster M 35 (NGC 2168) using SDSS filters. We chose M 35 in part due to convenient observing conditions, but also because it is a unique target due to its notably young age and apparent similarity to the Pleiades (von Hipple et al 2002).

OBSERVATIONS AND DATA REDUCTION
The data was collected on site at Kitt Peak National Observatory near Tucson Arizona. All observations were made using the WIYN consortium’s 0.9-m research observatory
with time given to us through NOAO’s Teacher Observing Program. Images were collected with the S2KB CCD camera. S2KB has a chip size of 2048x2048 pixels.

M35 was imaged on the evening of January 9th, 2009 with 20-second exposures taken through each of the SDSS g, r, and i filters. The raw fits images were then reduced in ImageJ, an open-source java based image analysis program. First bias subtraction and then flat fielding were performed using the astronomy plug-ins available for ImageJ. Dark subtraction was not required since S2KB is cryogenically cooled. A calibrated image of M35 in the SDSS g filter can be seen below.

![Figure 1: A Reduced Image Of M35 In The SDSS G Filter.](image)

**ANALYSIS AND RESULTS**

In order to extract the data from the images, the calibrated photos were aligned and organized into layers of a stack. The use of stacks in ImageJ allows photometry to be measured in multiple images simultaneously. Using the aperture photometry tool in
In order to convert these brightnesses into apparent magnitudes, we also observed several SDSS standard stars (Smith et al. 2002). Following the same data reduction and photometric techniques, we extracted the brightness of the standard stars and then compared this to their known apparent magnitudes in order to determine the proper transformation from counts to magnitude. Averaging the results for our three standard stars, we were able to generate the following equations:

\[
\begin{align*}
g & : 22.16 - 2.5 \cdot \log(\text{counts}/\text{exp\_time}) \\
r & : 22.31 - 2.5 \cdot \log(\text{counts}/\text{exp\_time}) \\
i & : 21.88 - 2.5 \cdot \log(\text{counts}/\text{exp\_time})
\end{align*}
\]

One of the most daunting challenges of a cluster study is identifying which stars are members of the cluster, and which are not. Fortunately, M 35 is a well-studied cluster and we were able to rely on previous proper motion measurements that accurately determined which stars are members (Cudworth 1971). With a map of over 400 member stars, many of which were fainter than our limiting magnitude, we performed photometry on nearly 100 stars of which we estimate 90% are cluster members (the presentation of the data from the proper motion study made it difficult to match every star to a known cluster member).

With the apparent magnitudes of nearly 100 known cluster members, we were able to create a color-magnitude diagram by plotting g vs g-r. The data is presented in the graph below.

![Figure 2](image.png)

**Figure 2**: A CMD of M 35 With A Best-Fit Isochrone.
We compared our CMD to a model isochrone in the SDSS filter system (Girardi et al 2004). We converted the isochrone from absolute magnitude to apparent magnitude by adjusting the distance modulus and reddening until it suitably fit our data. Through χ²-by-eye techniques, we found a distance modulus of 10.8 mag with an estimated uncertainty of 0.2 mag and a reddening of 0.33 mag with an uncertainty of 0.05 mag. This corresponds to a distance to M 35 of 2900±200 ly. This value is in good agreement with numerous other studies (von Hippel et al 2002). WEBDA quotes a distance modulus of 10.37 mag and a reddening of 0.262 mag corresponding to a distance of 2660 ly based on numerous UBVRI photometric studies of the cluster (Paunzen and Mermilliod 2009).

DISCUSSION
It is reassuring to find that the distance of M 35 when measured through the SDSS filter system is nearly identical to the measurements obtained with Johnson filters. While we intended to measure the age of M 35 as well, the absence of a horizontal branch in the CMD, which can be clearly seen as missing in Figure 2, made it impossible for us to compare our data to isochrones of differing ages. For age, we are left to conclude simply that it is a young cluster, which again is in good agreement with other studies. WEBDA quotes a log age of 7.979 indicating a cluster age of just under 100 million years (Paunzen and Mermilliod 2009).

SUMMARY AND ACKNOWLEDGEMENTS
The authors would like to thank Dr. Garmany and the NOAO education and public outreach team for providing us with the opportunity to participate in genuine astronomical research using a world-class observatory.

The authors are more than willing to share their raw data as well as specific details on the data reduction and analysis techniques used. For more information, please contact the authors.

REFERENCE


ABSTRACT
Several Arp galaxies were imaged using the 0.9-meter WIYN telescope located at Kitt Peak, Arizona in late October, 2008. These galaxies were photographed in “B” and “V” light in order to determine whether or not stellar age could be correlated to the amount of gravitational distortion present in the colliding galaxies. Only weak, and in some cases contradictory, evidence of such a correlation was shown.

INTRODUCTION
In the 1960’s, Halton Arp compiled a list of galaxies that were unusual or peculiar. It seemed to him that the newly discovered quasars were in some way related to these strange galaxies, although that does not now seem to be the case (Arp Introduction, 2009).

Today, it is known that these galaxies are the results of pairs of galaxies, or in some cases multiple galaxies, colliding with one another. These collisions result in a great increase in the rate of star-formation. While many of these galaxies have been imaged in the UV part of the spectrum, few of them have been studied in visible wavelengths (Coumins, 2002).

A galaxy can be defined as a large system of gravitationally-bound star systems and their accompanying interstellar dust and gas. It also usually contains a supermassive black hole at its center, around which the elements of the system revolve (Coumins, 2002).

Galaxies can be classified into four groups: elliptical (E), which have an ellipsoidal shape and a very smooth brightness profile, lenticular (OS), which have a disk shape, but lack well-defined spiral arms, spiral (S), which have a rotating disk that contains spiral arm structures and a central bulge area, and irregular (I), which contains few or no features, possibly from gravitational interactions, that allow them to be classified into one of the other groups (Galaxies, 2009).

Most galaxies have enormous masses, on the order of tens to hundreds of billions of solar masses. The average distance between most galaxies is an order of magnitude greater than their diameters, so interactions between them are not frequent, but also not rare. When galaxies approach one another, or even collide, the gravitational forces can pull outlying dust, gas, and even stars from one galaxy to the other, disturbing the structures of both systems in the process. These interactions greatly increase the density of the interstellar dust and gas in one or all of the involved galaxies (Coumins, 2002).
The interstellar gases found in galaxies are very cold, having temperatures between 10K and 20K. At these temperatures, the gases are molecular, which allows them to clump together, forming areas of high density. If this density is high enough, the clouds will collapse under their own gravity, forming several areas of very high density. These high-density areas evolve into protostars, which are the first stage of a star’s life cycle (Schombert, 2002).

The color of a star, or even the color of an area filled with stars, can reveal much information about that star or area. A star’s color depends mostly on the temperature of the star. Bright, blue stars are much hotter than dimmer, red ones. Hotter stars burn through their fuel relatively quickly, meaning that blue stars are often younger stars. This implies that if a particular area of a galaxy is emitting more blue light than other areas, it is either undergoing, or has undergone more star formation recently, because soon after a period of star formation, the bluer, hotter stars begin to die out (Rothstein, 2002).

When galaxies collide, most of their stars do not collide since the distances between stars are vast compared to their sizes. However, interstellar gas is present in far great amounts. The interstellar dust and gases in each galaxy will be disturbed by the collision, resulting in great changes in its density and temperature (Strobel, 2007).

It is proposed that when galaxies get near each other, they should accumulate large amounts of gases from each other through gravitational tides which would increase the density of gas clouds in those galaxies. These dense clouds would then become areas of frequent star formation. The high production should cause a higher number of short-lived blue stars. These increased numbers of blue stars would show up as areas of a galaxy that are bluer than other areas.

OBSERVATIONS AND DATA REDUCTION
Images were taken using the 0.9-meter WIYN telescope at the Kitt Peak National Observatory, located at Kitt Peak, Arizona on the nights of October 21-23, 2008. Two of the three nights proved to be extremely windy, which impacted the data collection.

The telescope was equipped with the S2KB CCD camera. Multiple exposures were taken through “B,” “V,” and “R” photometric filters. The “B” and “V” images were used for data analysis, while the “R” images were reserved for searching for faint “tails” of highly distorted galaxies which might not have been evident through the other two filters. In addition, the “R” filter data will allow color images to be constructed at a later date.

In order to have the least amount of atmospheric extinction and distortion, the observing window was 15 degrees east and west of the telescope’s local meridian (30 degrees wide). The observing window also ran along the local meridian from declination +00d to declination +62d. While the north-south window should also have covered 15 degrees on either side of the local zenith, there were not enough targets passing through this area of the sky to get a reasonable sample size.
Target galaxies were chosen, as available, from the Arp catalogue in order to represent as many apparent magnitudes, sizes, galactic types, and stages of interaction as possible. Two non-interacting galaxies, one spiral and one elliptical, were chosen as control galaxies to compare to the experimental interacting galaxies.

The following procedures were followed:

1) At the beginning of the second night’s observing run, a set of “standard stars” from the Landholt series was imaged. The set of standard stars were located at RA 00:54:41 and Dec +00:41:00. These standard stars would be used to determine atmospheric extinction. At regular intervals throughout the night, the standard stars were imaged with each filter.

2) The first galaxies targeted were those toward the western end of the observing window, since due to pointing limitations, these galaxies would be lost from view first. The 0.9-meter WIYN telescope has a pointing limit of 2 hours of right ascension (30 degrees) to both the east and west of the local meridian. Objects beyond this point cannot be imaged. In addition, objects below Polaris likewise cannot be imaged.

4) Images were taken in order of right ascension, from west to east. This allowed the shortest amount of time to be lost slewing from one target to another, maximizing telescope time.

5) Due to the long readout time of the CCD camera, two exposures were made through each filter and stacked to achieve a high signal to noise ratio, rather than making several shorter ones.

In order to account for the different sensitivities of the imager to different wavelengths, images in the B, V, and R filters were exposed for different lengths of time. The program CCDTime, provided by NOAO, was used to calculate the necessary exposure lengths. Images in the B filter were exposed for 600 seconds, V images for 488 seconds, and R images for 520 seconds.

Once the images were taken, they had to be reduced into useful data. First, the images were calibrated and combined. Flux counts from fifteen dark areas were taken, averaged, and then the averages subtracted from each image. Each galaxy was then divided into squares 25x25 pixels on each side to be measured for color and distortion.

The light from astronomical objects must travel through the Earth’s atmosphere on its journey to the telescope. The particles in the air scatter and extinguish the light. The amount of extinction depends on the altitude of the object as its image is calculated using the following equation:

\[
\text{Magnitude}=\text{Observed Magnitude}-(\text{Extinction Coefficient}\times\text{Airmass}) \quad \text{Equation 1}
\]

A set of standard stars of known apparent magnitude were imaged to calculate the atmospheric extinction coefficient for that location at that elevation with that weather. However, due to underexposure of the standard field the images were unusable, so extinction coefficients in B and V were found using the values provided by Gary (2005).
Kitt Peak is at an elevation of approximately 7000 feet, so the corresponding values of 0.140 Magnitudes/Airmass for V and 0.200 Mag/Airmass in B were used as extinction coefficients.

A common measure of astronomical color known as the B-V color index can be found by taking an image in the visual (V) and the blue (B) filter, and finding the difference in the magnitude of a star or area in them using the following equation (Richmond, 2009).

\[
\text{B Magnitude} - \text{V Magnitude} = \text{Color Index} \quad \text{Equation 2}
\]

The light from distant objects must travel through interstellar dust on its journey to the earth. The amount of dust varies from region to region in the sky, but it has a similar effect, regardless of the location on the starlight that passes through it. Shorter wavelengths of light, such as blue, are absorbed more readily than longer, redder, wavelengths. This has the effect of making stars (and other objects) appear redder than they really are. Also, some of the light is actually absorbed by the dust, making the objects also appear dimmer than they really are-- this process is known as extinction (Swinburne, 2008).

In the case of the studied Arp galaxies, the reddening value varied according to the galaxies’ location on the celestial sphere. The reddening value for each galaxy was taken from the NED website as being the appropriate correction for that galaxy. This value was then subtracted from all measured (B-V) values for each galaxy, giving their true color indices.

Once the reddening factor was known, a correction for extinction could be made. This correction involved taking the reddening factor and multiplying it by 3.2 as is shown by Equation 3 (Clemons, 2007).

\[
\text{AV} = 3.2 \ E(\text{B-V}) \quad \text{Equation 3}
\]

The resulting value was then subtracted from the (V) magnitudes of the galaxies in each galaxy cluster. The result was their true brightness. Once this information was known, then the galaxies’ true color indices could be determined as seen in Table 1 (Washington 2005).
Galaxy | Color Index (B-V) | Extinction Value | Corrected (B-V) |
-------|-----------------|-----------------|----------------|
Arp 278 | -1.17           | 0.066           | -1.24          |
Arp 278 | -0.99           | 0.066           | -1.05          |
Arp 278 | -0.90           | 0.066           | -0.96          |
Arp 278 | -1.05           | 0.066           | -1.11          |
Arp 278 | -1.12           | 0.066           | -1.19          |
Arp 278 | -0.94           | 0.066           | -1.00          |
Arp 278 | -1.04           | 0.066           | -1.10          |

Table 1. Extinction and reddening corrections were made for each measurement of each galaxy. Due to the large amount of data, a complete list is available at http://www.bristolastronomy.org/arpgalaxydata

ANALYSIS AND RESULTS

The first step of analysis was to stack the images of each galaxy. Each Arp galaxy was imaged twice per filter. Bias frames and flat field images were applied to each image. Dark frames were unnecessary since the S2KB camera is cooled with liquid nitrogen.

Some galaxy images could not be used—there were several reasons for this. High wind, which shook the telescope, was an issue when the telescope dome was turned toward the north. Also, some images contained a large number of foreground stars which prevented accurate measurements of those galaxies. The omitted galaxies are shown in Table 2 below.

<table>
<thead>
<tr>
<th>Arp #</th>
<th>Reason for exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>184</td>
<td>Foreground stars</td>
</tr>
<tr>
<td>143</td>
<td>Foreground stars</td>
</tr>
<tr>
<td>46</td>
<td>Foreground stars</td>
</tr>
<tr>
<td>262</td>
<td>Wind</td>
</tr>
<tr>
<td>145</td>
<td>Foreground stars</td>
</tr>
<tr>
<td>20</td>
<td>Foreground stars</td>
</tr>
<tr>
<td>210</td>
<td>Wind</td>
</tr>
<tr>
<td>52</td>
<td>Foreground stars</td>
</tr>
</tbody>
</table>

Table 2. These galaxies were omitted from the study due to the reasons listed.

Each galaxy image was overlain with a 25x25 pixel grid as is shown in image 1. This allowed the different areas of that galaxy to be measured. The amount of distortion for each part of a galaxy was then determined by consensus and categorized into several bins.

The distortion bins were labeled 0 for the undisturbed standard galaxies, 1 for an area of low distortion, 2 for a region of moderate distortion, and 3 an area of high distortion. Some galaxies also exhibited highly disturbed “tails” and “bridges.” These features were assigned to bin 3.
Image 1. Each galaxy was divided up into at least three areas using squares that were 25 pixels x 25 pixels in size. Larger galaxies were divided into more areas.

B-V indices were calculated for each 25x25 pixel square using Microsoft Excel. These indices were then plotted on a graph using the program Graphical Analysis 3. The graph compared the B-V indexes and amount of distortion.
Graph 1: Graph comparing distortion to color of an area. A distortion value of zero represents a standard galaxy. Two means low distortion, three means high, four means tails, and five means areas of overlapping galaxies. The shallow slope shows little correlation between amount of distortion and star age.

When represented this way, a few, large, essentially uniform galaxies create many more data points than the other, smaller, galaxies. In order to counter this flooding of the data, the total flux from each galaxy was added up, and the B-V indexes for the entire galaxies were found. A distortion rating was then given to each galaxy as a whole.
The graph of the individual areas correlates with a negative slope, indicating bluer stars in more distorted areas. However, the graph of the whole galaxies correlates with a positive slope, indicating redder stars in more distorted areas. Neither has a very great slope, the individual area plot had a slope of -0.0023, and the whole galaxy data had a slope of 0.034. Their correlations were also both very low, with a value of .107 for the areas and -.0035 for the galaxies.

**DISCUSSION**
The graph of the 25x25 pixel areas seems to provide evidence for the hypothesis that more distorted areas contain bluer, younger stars. The graph of the galaxies as a whole shows the opposite relationship, in other words, as a galaxy is more distorted, it actually has fewer young, blue stars. The relationship in both cases is slight and questionable, but present nonetheless. This experiment, overall, can be said to show some evidence supporting the hypothesis. The low correlation of the data and the fact that the area numbers and the galaxy numbers conflict with each other makes this a very weak test of the hypothesis. However, the greater correlation and the much greater number of data entries support the individual area graph as the slightly stronger evidence.

There are several issues that could have created errors in the results. One problem is the small sample size of the data. The useable images consisted of only ten objects, for a total of 19 galaxies. Then, there is the effect of foreground stars, which can be removed, but not accurately. There is also the problem of the inherent inaccuracy of this measuring
method. There is no standard method of quantifying the distortion of the structure of a galaxy, so the binning of the areas into “Low”, “Medium”, “High”, and “Standard” is subjective and imprecise.

Another inaccuracy is the fact that, though some distortion is in the form of compressed areas, for every compressed area there is an area that has been pulled apart. This sort of balance of density would cause the observed near-flattening of the color indexes as distortion increases.

In order to draw a stronger conclusion in the future, it is suggested that this experiment or a similar one should be repeated, using the errors made in this run to produce more accurate results. Targets can be chosen more carefully, so as not to flood nearly half of the data with points from just a few large galaxies. Objects can also be chosen which do not have a great number of foreground stars. The measurement system should also be rearranged to be more precise and quantitative.

SUMMARY
This study was performed to test the hypothesis that the distortion of a galaxy can be used to measure the age of the stars in that galaxy. Images were taken of several astronomical objects suspected of being interacting galaxies in B, V, and R filters to determine the B-V color index of areas in those galaxies. The galaxies and their composing areas were classified by their level of distortion, and then scatter plots were made comparing color to distortion of the areas and galaxies. The data obtained from the graphs was weak, contradictory, and largely inconclusive. The experiment could be said to provide evidence for a correlation between distortion of a galaxy and the color of the stars in it, but this alone is not enough evidence to declare the hypothesis correct. More research is needed to clarify the relationship between tidal distortion and star age.

ACKNOWLEDGEMENTS
We would like to deeply and sincerely thank the following people who contributed their time, knowledge, capital, patience, and so much more to the welfare of this project.

Katy Garmany (NOAO & TLRBSE) for giving us the opportunity to conduct our research and for assisting us and remaining cool when the focus ran away.

Dr. Beverley Smith (East Tennessee State University, Johnson City, Tennessee) for advising us on a plethora of topics, proper procedures, and issues.

Mr. Tom Rutherford (Sullivan South High School, Kingsport, Tennessee) for keeping this project on track and for making the trip to Arizona regardless of a very recent and personal loss.
Mrs. Debbie Fink, Mrs. Gerri St. Clair, Ms. Lane Jessie, Ms. Tracey Dishner (Sullivan South High School, Kingsport, Tennessee) for tending to Mr. Rutherford’s classes while he was in Arizona.

Mr. Greg Harvey (Principal, Sullivan South High School, Kingsport, Tennessee) for his support.

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES
“AAVSO: CCD Observing Manual: Camera Skills”. 

“ARP Atlas of Peculiar Galaxies”. 
<http://nedwww.ipac.caltech.edu/level5/Arp/Arp_contents.html>.


"Galaxies." SDSS SkyServer DR7. 01 Apr. 2009 


“Arp Peculiar Galaxy Club Introduction”, 

ABSTRACT
Identifying T Tauri stars can be a challenging process. It typically requires expensive and sophisticated equipment and data analysis techniques. This study used optical data from Kitt Peak National Observatory’s WIYN 0.9-meter telescope and R, I, H-alpha filters to image known T Tauri stars and standard stars. Simple intensity values were measured using MaxIm DL and plotted on an X/Y scatter plot with Log(I-intensity/R-intensity) vs. Log(H-alpha-intensity/R-intensity). There is strong evidence that this simplified data analysis technique termed SBOS (Spuck-Butchart Optical Survey) could be used to identify and classify T-Tauri candidates.

INTRODUCTION
T-Tauri stars, which are starting to blow away the gas and dust surrounding them, are called Young Stellar Objects (YSOs). Current models of these young stars in their early stages of formation contain a hot collapsing core surrounded by a cocoon of gas and dust. As the star matures, the cloud of gas and dust slowly forms into planetary objects or is blown off into space exposing the young star (Rebull et al. 2007).

T Tauri stars are a class of young, low mass (0.1 to 3.0 solar masses) pre-main-sequence stars whose ages are in the range of $10^5$-$10^7$ years (Ghez et al. 1993). T Tauri stars are found in young clusters and nebulae, have low-temperature spectra with strong emission lines and broad absorption lines. (Darling 2009)

Observationally, T Tauri stars are identified by the following characteristics: they are stellar objects often associated with regions of obscuration; their spectra show Balmer lines and Ca, H-alpha and K lines, in emission; and, the photospheric absorption spectra are similar to those of stars with spectral-type later than late F (Appenzeller et al. 1989).

As a result, two pieces of evidence should be apparent in T Tauri candidates. First, due to the relatively warm excess gas and dust around the young star and the accretion disk, the T Tauri star will show infrared excess (IPAC 2008). Classical T Tauri stars should show significantly higher infrared emissions than older, more stable stars, which have matured and shed their accretion disk. Second, since T Tauri stars tend to be very active, they will have a strong H-alpha emission line (Ogura et al. 2002). Stars identified as standard stars are stable and rarely change in brightness. Consequently, they should be relatively inactive and have small H-alpha emissions when compared to more active T Tauri stars (Rebull et al. 2008).

Since T Tauri stars are very young sun-like stars in the early stages of development, astronomers find them crucial to the understanding of planetary development. Additionally, to better understand how our own Sun evolved and how our solar system came to be, astronomers must
study similar stars. T-Tauri stars are similar in mass to that of the sun, and therefore follow a similar evolutionary path (Rebull et al. 2007). As a result, a better understanding of T Tauri stars will lead to a better understanding of how our own Sun and planets evolved to their current state.

Further, astronomical research with small telescopes (20 cm – 40 cm) has traditionally been a challenging problem. The invention of CCD cameras and personal computers has now answered this question and has reduced the need for small telescopes (Goderya et al. 2002). Some of the smaller telescopes at NOAO presently support long-term or survey projects where large aperture is not required but many hours of telescope time are needed (NOAO 2009). It has been made clear by many astronomers that small telescopes have been mothballed and taken offline because of budget cuts and the development of new instruments.

Traditionally YSO’s and T-Tauri stars in particular have been identified by using infrared cameras and the using color-color diagrams (see figure 1) to analyze the data. However, infrared telescopes are expensive and hard to come by. Optical telescopes, on the other hand, are numerous, and if equipped with the proper filter, might work in a similar fashion. I filters on an optical telescope can be used to provide some evidence of infrared excess. H-alpha is a narrow emission line embedded within the R portion of the electromagnetic spectrum. Thus, a ratio of the two measurements should indicate stars with strong H-alpha emissions. As a result, an optical telescope with an I, R, and an H-alpha filter could provide a method of measuring objects which possess both infrared excess and strong H-alpha emissions which are two of the primary characteristics of T-Tauri stars. An extensive literature search and discussions with Dr. Luisa Rebull (a YSO expert) at the Spitzer Science Center confirm the method proposed in this paper has yet to be explored.

**Figure 1:** Color-Color Diagram

![Figure 1: Color-Color Diagram](IPAC 2008)
OBSERVATIONS AND DATA REDUCTION
The WIYN 0.9-meter telescope at Kitt Peak National Observatory in Tucson, Arizona, was used to image all of the target stars from November 14 - 16, 2008. Imaging took place from 6:30 PM – 5:30 AM Mountain Standard Time. Using the S2KB CCD camera at 0.60 arcsec/pixel, the targets were imaged with the I-Harris (625.6 – 1041.0 nm), R-Harris (489.5 – 791.3 nm) and H-alpha (651.8 – 663.6 nm) filters. Prior to the beginning of each observing session bias and flats were acquired. The focus was determined with the initial exposure and reset throughout the evening as necessary.

Standard stars are stars which have been precisely measured over the years and do not change in brightness. This study used selected standard stars from the Landolt UVBRI Standards (Landolt 1992). Known T-Tauri stars were chosen from an extensive literature search of various journal articles and Internet resources.

Figure 2: Target Stars

<table>
<thead>
<tr>
<th>Standard Stars</th>
<th>T-Tauri Stars</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG2331+055A</td>
<td>92 417</td>
</tr>
<tr>
<td>PG2331+055B</td>
<td>92 263</td>
</tr>
<tr>
<td>PG2336+004B</td>
<td>PG2220+132B</td>
</tr>
<tr>
<td>PG2336+004A</td>
<td>PG2220+132</td>
</tr>
<tr>
<td>PG2336+004</td>
<td>PG2220+132A</td>
</tr>
<tr>
<td>92 322</td>
<td>95 98</td>
</tr>
<tr>
<td>92 245</td>
<td>95 100</td>
</tr>
<tr>
<td>92 248</td>
<td>95 101</td>
</tr>
<tr>
<td>92 249</td>
<td>95 102</td>
</tr>
<tr>
<td>92 250</td>
<td>95 190</td>
</tr>
<tr>
<td>92 330</td>
<td>95 105</td>
</tr>
<tr>
<td>92 252</td>
<td>95 107</td>
</tr>
<tr>
<td>92 253</td>
<td>95 106</td>
</tr>
<tr>
<td>92 335</td>
<td>95 115</td>
</tr>
<tr>
<td>92 339</td>
<td>95 132</td>
</tr>
<tr>
<td>92 259</td>
<td>95 137</td>
</tr>
<tr>
<td>92 345</td>
<td>95 139</td>
</tr>
<tr>
<td>92 347</td>
<td>95 227</td>
</tr>
<tr>
<td>92 260</td>
<td>95 142</td>
</tr>
</tbody>
</table>

The exposure times for each object were determined using the estimated R magnitude of the target. Sufficient exposure times were determined to ensure an SNR (Signal-to-Noise Ratio) of 50 or better. The R exposure times were calculated using the exposure calculator at http://www.noao.edu/gateway/ccdtime/. I exposure times were then determined based on the R exposure time and were always two times the R exposure time in both standard and T-Tauri stars. The H-alpha exposure time was ten times the R exposure time in all images.

Data reduction was completed using MaxIm DL and Pinpoint Astrometry. MaxIm DL has a built in automated procedure that averages and calibrates the bias and flat fielded images, then uses these calibration files to calibrate each image.
In order to establish right ascension (RA) and declination (DEC) in the image, the approximate center RA and DEC and the pixel scale of the image was entered into Pinpoint Astrometry. PinPoint Astrometry utilized the USNO-A2 star catalog to identify field stars and calibrate RA and DEC in each image.

The intensity for each target was measured using the aperture tool in MaxIm DL. Since the relative brightness’s through the different filters are being compared, and the ratio for exposure times remained the same for all images, there was no need to determine magnitude using this methodology. Intensity values were sufficient. For each target the result was an intensity value (counts) at R, I, and H-alpha.

**Figure 3:** Aperture Tool in MaxIm DL

![Aperture Tool in MaxIm DL](image)

The intensity values were then inserted into a Microsoft Excel spreadsheet and an X/Y scatter plot was generated. The X-axis displayed the Log(I counts/R counts) and the Y-axis displayed the Log(H-alpha counts/R counts). Because the narrow band H-alpha filter is within the broad band R filter, very active stars (T Tauri stars) should be separated from less active stars.
## ANALYSIS AND RESULTS

**Figure 4:** Intensity Values and Corresponding Log Ratios of Standard Stars

<table>
<thead>
<tr>
<th>Type</th>
<th>ID</th>
<th>R Intensity</th>
<th>I Intensity</th>
<th>H-alpha Intensity</th>
<th>Log (I/R)</th>
<th>(Log H/R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>PG2331+055A</td>
<td>25469.1</td>
<td>41628.2</td>
<td>10155.3</td>
<td>0.213</td>
<td>-0.399</td>
</tr>
<tr>
<td>S</td>
<td>PG2331+055B</td>
<td>5995.2</td>
<td>10176.6</td>
<td>2536.1</td>
<td>0.230</td>
<td>-0.374</td>
</tr>
<tr>
<td>S</td>
<td>PG2336+004B</td>
<td>90923.2</td>
<td>138073.0</td>
<td>37103.7</td>
<td>0.181</td>
<td>-0.389</td>
</tr>
<tr>
<td>S</td>
<td>PG2336+004A</td>
<td>305278.2</td>
<td>484145.7</td>
<td>123566.0</td>
<td>0.200</td>
<td>-0.393</td>
</tr>
<tr>
<td>S</td>
<td>PG2336+004</td>
<td>2815.5</td>
<td>2542.0</td>
<td>1024.1</td>
<td>-0.044</td>
<td>-0.439</td>
</tr>
<tr>
<td>S</td>
<td>92 222</td>
<td>77647.5</td>
<td>115735.7</td>
<td>28418.2</td>
<td>0.173</td>
<td>-0.437</td>
</tr>
<tr>
<td>S</td>
<td>92 245</td>
<td>49282.2</td>
<td>132240.8</td>
<td>21398.4</td>
<td>0.429</td>
<td>-0.362</td>
</tr>
<tr>
<td>S</td>
<td>92 248</td>
<td>9183.9</td>
<td>18673.5</td>
<td>4250.5</td>
<td>0.308</td>
<td>-0.335</td>
</tr>
<tr>
<td>S</td>
<td>92 249</td>
<td>18506.8</td>
<td>31838.5</td>
<td>7041.1</td>
<td>0.236</td>
<td>-0.420</td>
</tr>
<tr>
<td>S</td>
<td>92 250</td>
<td>56641.5</td>
<td>94033.0</td>
<td>22310.5</td>
<td>0.220</td>
<td>-0.405</td>
</tr>
<tr>
<td>S</td>
<td>92 230</td>
<td>9658.3</td>
<td>15237.2</td>
<td>3535.6</td>
<td>0.199</td>
<td>-0.436</td>
</tr>
<tr>
<td>S</td>
<td>92 252</td>
<td>9900.1</td>
<td>15673.5</td>
<td>4129.9</td>
<td>0.200</td>
<td>-0.380</td>
</tr>
<tr>
<td>S</td>
<td>92 253</td>
<td>32938.7</td>
<td>66653.9</td>
<td>13675.4</td>
<td>0.306</td>
<td>-0.382</td>
</tr>
<tr>
<td>S</td>
<td>92 335</td>
<td>39325.8</td>
<td>72171.6</td>
<td>16276.3</td>
<td>0.264</td>
<td>-0.383</td>
</tr>
<tr>
<td>S</td>
<td>92 339</td>
<td>4591.1</td>
<td>8886.6</td>
<td>2251.0</td>
<td>0.287</td>
<td>-0.310</td>
</tr>
<tr>
<td>S</td>
<td>92 259</td>
<td>9345.9</td>
<td>15568.1</td>
<td>4065.2</td>
<td>0.222</td>
<td>-0.362</td>
</tr>
<tr>
<td>S</td>
<td>92 345</td>
<td>4025.1</td>
<td>6205.6</td>
<td>1651.3</td>
<td>0.188</td>
<td>-0.387</td>
</tr>
<tr>
<td>S</td>
<td>92 347</td>
<td>5343.9</td>
<td>7218.5</td>
<td>2194.7</td>
<td>0.131</td>
<td>-0.386</td>
</tr>
<tr>
<td>S</td>
<td>92 260</td>
<td>13050.7</td>
<td>21208.8</td>
<td>4767.4</td>
<td>0.211</td>
<td>-0.437</td>
</tr>
<tr>
<td>S</td>
<td>92 348</td>
<td>134946.9</td>
<td>212105.1</td>
<td>48312.3</td>
<td>0.196</td>
<td>-0.446</td>
</tr>
<tr>
<td>S</td>
<td>92 417</td>
<td>7277.2</td>
<td>13012.6</td>
<td>3035.2</td>
<td>0.252</td>
<td>-0.380</td>
</tr>
<tr>
<td>S</td>
<td>92 263</td>
<td>239097.6</td>
<td>448536.1</td>
<td>97700.5</td>
<td>0.273</td>
<td>-0.389</td>
</tr>
<tr>
<td>S</td>
<td>PG0220+132B</td>
<td>23095.3</td>
<td>42733.8</td>
<td>8276.5</td>
<td>0.267</td>
<td>-0.446</td>
</tr>
<tr>
<td>S</td>
<td>PG0220+132</td>
<td>761.4</td>
<td>7743.9</td>
<td>2052.6</td>
<td>0.007</td>
<td>-0.569</td>
</tr>
<tr>
<td>S</td>
<td>PG0220+132A</td>
<td>5113.9</td>
<td>9891.5</td>
<td>2417.9</td>
<td>0.287</td>
<td>-0.325</td>
</tr>
<tr>
<td>S</td>
<td>95 98</td>
<td>21506.5</td>
<td>28270.5</td>
<td>8842.5</td>
<td>0.126</td>
<td>-0.386</td>
</tr>
<tr>
<td>S</td>
<td>95 100</td>
<td>6337.3</td>
<td>6957.1</td>
<td>2927.6</td>
<td>0.041</td>
<td>-0.335</td>
</tr>
<tr>
<td>S</td>
<td>95 101</td>
<td>87903.5</td>
<td>95168.8</td>
<td>36335.7</td>
<td>0.034</td>
<td>-0.384</td>
</tr>
<tr>
<td>S</td>
<td>95 102</td>
<td>6613.4</td>
<td>7576.7</td>
<td>2688.2</td>
<td>0.059</td>
<td>-0.399</td>
</tr>
<tr>
<td>S</td>
<td>95 190</td>
<td>70494.3</td>
<td>64245.8</td>
<td>25349.9</td>
<td>-0.040</td>
<td>-0.444</td>
</tr>
<tr>
<td>S</td>
<td>95 105</td>
<td>42507.9</td>
<td>49467.1</td>
<td>18596.4</td>
<td>0.066</td>
<td>-0.359</td>
</tr>
<tr>
<td>S</td>
<td>95 107</td>
<td>4232.2</td>
<td>8198.5</td>
<td>1806.6</td>
<td>0.287</td>
<td>-0.349</td>
</tr>
<tr>
<td>S</td>
<td>95 106</td>
<td>8900.9</td>
<td>13722.4</td>
<td>4298.1</td>
<td>0.188</td>
<td>-0.316</td>
</tr>
</tbody>
</table>
Figure 5: Intensity Values and Corresponding Log Ratios of Standard and T-Tauri Stars (Continued)

<table>
<thead>
<tr>
<th>Type</th>
<th>ID</th>
<th>R Intensity</th>
<th>I Intensity</th>
<th>H-alpha Intensity</th>
<th>Log (I/R)</th>
<th>(Log H/R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>95115</td>
<td>15467.8</td>
<td>19633.0</td>
<td>6517.5</td>
<td>0.104</td>
<td>-0.375</td>
</tr>
<tr>
<td>S</td>
<td>95132</td>
<td>25811.9</td>
<td>39426.2</td>
<td>8817.0</td>
<td>0.184</td>
<td>-0.467</td>
</tr>
<tr>
<td>S</td>
<td>95137</td>
<td>31543.2</td>
<td>55550.6</td>
<td>13144.3</td>
<td>0.246</td>
<td>-0.380</td>
</tr>
<tr>
<td>S</td>
<td>95139</td>
<td>31607.9</td>
<td>56070.8</td>
<td>13100.2</td>
<td>0.249</td>
<td>-0.383</td>
</tr>
<tr>
<td>S</td>
<td>95227</td>
<td>13897.1</td>
<td>22167.4</td>
<td>5233.7</td>
<td>0.203</td>
<td>-0.424</td>
</tr>
<tr>
<td>S</td>
<td>95142</td>
<td>28020.6</td>
<td>46039.1</td>
<td>11413.6</td>
<td>0.216</td>
<td>-0.390</td>
</tr>
<tr>
<td>T-41</td>
<td>LkCa 1</td>
<td>29901.4</td>
<td>80201.2</td>
<td>12776.6</td>
<td>0.428</td>
<td>-0.369</td>
</tr>
<tr>
<td>T-42</td>
<td>FM Tau</td>
<td>96550.7</td>
<td>170089.8</td>
<td>34422.8</td>
<td>0.246</td>
<td>-0.448</td>
</tr>
<tr>
<td>T-43</td>
<td>LkCa 3</td>
<td>56841.9</td>
<td>200979.0</td>
<td>24977.3</td>
<td>0.548</td>
<td>-0.357</td>
</tr>
<tr>
<td>T-44</td>
<td>LkCa 5</td>
<td>11670.3</td>
<td>45141.7</td>
<td>5712.0</td>
<td>0.587</td>
<td>-0.310</td>
</tr>
<tr>
<td>T-45</td>
<td>LkCa 7</td>
<td>36742.5</td>
<td>116930.6</td>
<td>17277.2</td>
<td>0.503</td>
<td>-0.328</td>
</tr>
<tr>
<td>T-46</td>
<td>LkCa 21</td>
<td>16593.1</td>
<td>68210.6</td>
<td>8083.3</td>
<td>0.614</td>
<td>-0.312</td>
</tr>
<tr>
<td>T-47</td>
<td>HL Tau</td>
<td>3207.0</td>
<td>7260.7</td>
<td>1423.9</td>
<td>0.355</td>
<td>-0.353</td>
</tr>
<tr>
<td>T-48</td>
<td>V995 Tau</td>
<td>197144.8</td>
<td>385022.0</td>
<td>82457.2</td>
<td>0.291</td>
<td>-0.379</td>
</tr>
<tr>
<td>T-49</td>
<td>DK Tau</td>
<td>17521.1</td>
<td>61594.9</td>
<td>23623.0</td>
<td>0.546</td>
<td>0.130</td>
</tr>
<tr>
<td>T-50</td>
<td>V827 Tau</td>
<td>26017.0</td>
<td>85224.6</td>
<td>12512.3</td>
<td>0.515</td>
<td>-0.318</td>
</tr>
<tr>
<td>T-51</td>
<td>V928 Tau</td>
<td>9839.4</td>
<td>46003.8</td>
<td>4529.6</td>
<td>0.670</td>
<td>-0.337</td>
</tr>
<tr>
<td>T-52</td>
<td>GG Tau</td>
<td>52578.3</td>
<td>155674.5</td>
<td>38371.8</td>
<td>0.471</td>
<td>-0.137</td>
</tr>
<tr>
<td>T-53</td>
<td>04335+1836</td>
<td>201440.7</td>
<td>315017.7</td>
<td>77170.5</td>
<td>0.191</td>
<td>-0.417</td>
</tr>
<tr>
<td>T-54</td>
<td>DQ Tau</td>
<td>16151.5</td>
<td>56908.5</td>
<td>13529.7</td>
<td>0.547</td>
<td>-0.077</td>
</tr>
<tr>
<td>T-55</td>
<td>GM Aur</td>
<td>40931.6</td>
<td>111338.9</td>
<td>34682.8</td>
<td>0.435</td>
<td>-0.072</td>
</tr>
<tr>
<td>T-56</td>
<td>IC2118-1</td>
<td>244251.3</td>
<td>400702.3</td>
<td>96903.9</td>
<td>0.215</td>
<td>-0.401</td>
</tr>
<tr>
<td>T-57</td>
<td>IC2118-2</td>
<td>318795.8</td>
<td>574872.0</td>
<td>133048.6</td>
<td>0.256</td>
<td>-0.380</td>
</tr>
</tbody>
</table>

Figure 6: The SBOS Method

![SBOS Method Diagram]
DISCUSSION
Figure 6 shows a clear separation of T-Tauri stars and standard stars with over 70% of T-Tauri stars breaking away from their standard counterparts. Figure 3 also provides some preliminary evidence to support the idea that T-Tauri stars themselves may separate out as well based on embeddedness or class. T-49, T-52, T-54, and T-55 are all younger class 2 T-Tauri stars. Other studies using infrared telescope data show similar separation between older main sequence stars and T-Tauri’s as well as further separation based on T-Tauri classification (IPAC 2008). However, this study is the first attempt to measure such separation using optical telescopes and basic R, IR, and H-alpha photometry.

Although other objects in space including galaxies, asteroids, planets, and black holes emit IR excess, and other objects like quasars emit an H-alpha emission line, few produce significant emissions in both the IR and H-alpha (Gregorio-Hetem et al. 1992). Quasars are one of the few examples of objects in space that may emit both the H-alpha emission line and IR excess. However, quasars are such distant objects that they may be sufficiently redshifted that the H-alpha emission line would be outside the narrow range (651.8 – 663.6 nm) of the H-alpha filter (Norman 2009). Future studies including quasars, galaxies, additional standard stars, other main sequence stars, and additional T-Tauri stars are necessary to confirm the results found here, and to refine the SBOS method of identifying potential T-Tauri candidates.

SUMMARY AND ACKNOWLEDGEMENTS
The data presented here provides strong evidence that supports the basic premise of this study. Small telescopes equipped with the proper I, R, and H-alpha filters may provide a new avenue for astronomers studying young stellar objects. Although a broader more enhanced study is now necessary, the SBOS method shows significant merit. In recent years, smaller telescopes have moved off line, and as a result are now available for projects that require a great deal of telescope time. In addition, amateurs and science students throughout the world are gaining more and more small scale telescope time (Spuck 2009). When you consider increases in telescope availability and people-power, and the simplicity of the SBOS method, the implications of this study are significant. It may well lead to a full scale continuous survey of the night sky for active young stellar objects by professional astronomers, and the involvement of many amateurs and science students around the world in the hunt for T-Tauri stars for many years to come.

There are several people deserving recognition in respect to this project. First and foremost, deserving the most thanks and praise is Mr. Timothy Spuck. His continual support and instruction has been a true inspiration. Without him, this project, as a whole, would not have been possible. Also deserving recognition is Katy Garmany, a Senior Science Education Specialist in the Educational Outreach arm of the PAEO department at NOAO. She oversaw the use of the 0.9-meter telescope at Kitt Peak National Observatory. Dr. Luisa Rebull also deserves recognition: without her guidance and time, this project would not be where it stands today. To all of the family members, astronomers, scientists, professors and regional judges: thank you for taking the time to edit and review this paper. Also deserving acknowledgement is Kristen Criado, without her patience and help, this paper would not be where it stands today. Last but not least, my family deserves to be acknowledged: without their help and constant nagging, this paper would never have been completed.
REFERENCES

Espey, B. R., R. F. Carswell, J. A. Bailey, and M. G. Smith. “H-alpha Emission Lines in High-

Watson, K. I. Uchida, B. Sargent, J. D. Green, L. D. Keller, and T. L. Herter. “A Survey and
Analysis Of Spitzer Infrared Spectrograph Spectra.” The Astrophysical Journal Supplement

Genzel, R., R. Schodel, T. Ott, A. Eckart, T. Alexander, F. Lacombe, D. Rouan, and B.
Aschenbach. “Near-infrared flares from accreting gas around the supermassive black hole at the

for T Tauri Stars Based on the IRAS Point Source Catalog. I.” The Astronomical Journal 103

Goderya, Shaukat. “Doing Research On Eclipsing Binary Stars With Small.” Astrophysics and


Kitamura, Yoshimi, Munetake Momose, Sozo Yokogawa, Ryohei Kawabe, Motohide Tamura,
and Shigeru Ida. “Investigation Of The Physical Properties Of Protoplanetary Disks Around T

Landolt, A. U. “UBVRI Photometric Standard Stars in the Magnitude Range 11.5-16.0 Around

NOAO, “NOAO Smal Telescopes Workshop - Preamble to Workshop Discussion Groups.” The


Ogura, Katsuo, Koji Sugitani, and Andrew Pickles. “H-alpha Emission Stars and Herbig- Haro

1 Feb. 2009 <https://coolwiki.ipac.caltech.edu/index.php/Color-Magnitude_and_Color-
Color_plots>.

Rebull, Luisa. “General Background on Young Stars.” The Spitzer Wiki. 11 Dec. 2007. IPAC. 1


Rowan-Robinson, Michael. “A New Model For the Infrared Emission of Quasars.” Monthly


Investigating Star Formation in Lynds Cloud 981
Rachele M. Siegel
Oil City Area Senior High School, Oil City, PA
Teacher: Tim Spuck, TLRBSE 2004

ABSTRACT
Lynds Dark Nebulae 981 is thought to be one of a few limited cases of isolated star formation. Since star formation is usually triggered by supernovae, strong stellar winds or colliding nebulae, isolated star formation is relatively rare. Using observations from the 2MASS Survey, the Spitzer Space Telescope, the WIYN 0.9-meter telescope, and the 14 Inch Tzec Maun Telescope, an in depth study of star formation in LDN 981 was conducted. Data reduction was completed using MOPEX, Maxim DL, and Microsoft Excel. The results indicate additional star formation may be taking place with LDN 981; however it is less than expected.

INTRODUCTION
Star formation is a process that is constantly taking place in space. In addition to the materials, certain conditions must be met for this process to occur. In clouds of gas and dust, also known as interstellar medium, there are typically a few major events which initiate the birth of the millions of stars seen in the Milky Way galaxy (Seeds 2008). Star formation is normally triggered by either supernovae shock waves, stellar winds, or the collision of masses such as galaxies or nebulae (Quanz, Apai, & Henning 2006). In the first occurrence, the supernova shell of gas, or shock wave, passes at a rapid speed through a dense, cool cloud, creating an unstable cloud. Motion in the region and gravity cause the densest parts of the cloud to contract, and among these embedded regions stellar objects form (Seeds 2006). Strong stellar winds from O and B Class stars also trigger the formation of new stars. Preibisch and Zinneker (1999) illustrate the concept that O and B class stars cause regions to collapse, pulling gas and dust toward the core. Furthermore, OB associations and gravitationally unbound clusters are likely to be the dominate birthplace for low-mass field star populations (Garmany 1994). Finally the formation of stars has been observed during the collision of interstellar clouds, nebulae, or galaxies. The impact causes compression at the boundaries of the masses and sets the star up to carry out subsequent star-forming processes (Elmegreen 2002). If the cloud is cool enough, gravity can break the pieces of interstellar medium as they collapse upon themselves, forming protostars. All triggered events lead to the eventual breakup of the cloud and subsequent contraction of the cloud fragments.

Once the star forming process begins, the object follows one of two patterns of existence determined by temperature and mass. If the cloud is too hot, there will be too much pressure and gravity will not be strong enough to overcome it. In all stars, gas and dust falls onto a disk surrounding the star (Miller & Stone 1997). As the matter from the disk gathers in the center, increased friction of the particles causes the temperature to rise. Although all potential stars go through this process the mass of the cloud fragment determines the rate of the collapse. From the collapse, stars proceed into the protostar stage (Rebull 2008). Stellar evolution is broken into two tracks based on the mass of the star after the protostar stage. Henceforth, protostars with a
mass higher than 8 solar masses are considered to be high mass and those less than 8 solar masses are classified as low mass (Seeds 2008).

If and when the temperature in the core reaches 10,000,000 degrees Kelvin, hydrogen fusion begins in the protostar and a star is formed. Additionally, a high enough density at the core must exist (Rebull 2007). In high-mass protostars, the gravity is stronger therefore the star contracts faster. From a star’s mass, deductions can be made hypothesizing how long it will take the star to reach the main sequence, or become fully developed (Seeds 2008). Further explanation of the high-mass phenomenon by Seeds details the protostar’s contraction and conversion of gravitational energy to thermal energy. Half of this thermal energy radiates into space, but the remaining half raises the internal temperature. When the center gets hot enough, nuclear reactions begin generating energy, the protostar halts its contraction, and, having blown away its cocoon of gas and dust, it becomes a stable, main sequence star (Seeds 2006).

There are equally diverse developments for lower mass counterparts too. Comins and Kaufmann (2001) testify that low mass protostellar objects, equivalent or less than 0.08 solar masses are too small to ignite hydrogen fusion. Known as brown dwarfs, these objects slowly contract, convert their gravitational energy into thermal energy, and radiate it away. Brown dwarfs have temperatures of 1000 K therefore designating them the only masses originating as protostars in which stars are not formed (Seeds 2008).

T-Tauri stars, whose masses range from .75 to 3 solar masses, are young, hot, and violent stars deeply imbedded in gas and dust (Weehler et al. 2005). Interestingly, their matter does not fall into the core; instead particles surround the center while a disk develops (Rebull 2007). This accretion disk gives off gas and dust through bipolar outflows causing the star itself to emit in the infrared wavelength (Beck, Turner, & Gorjian 2001). T-Tauri stars are also widely variable indicating a fast rotation rate of two to seven days which is perhaps an effect of instabilities in the disk (Rebull 2007). These stars which range in age from 100,000 to 3,000,000 years (Rebull 2008) represent the phase between a protostar and low-mass main sequence star (Schroeder, Stano, & Kozak 2007). Sun-like T-Tauri stars are excellent indicators of star-formation occurrences in the region in which they reside.

There are four different classes of T-Tauri stars categorized by how deeply imbedded they are in a gaseous nebulae (Lehtinen et. al 2000). The classes range from 0 to 3 with class 0s and 1s being the most deeply imbedded and class 2s and 3s becoming less imbedded and moving toward the main sequence.
Discoveries of T-Tauri stars and other evidence of star formation is pertinent to scientists’ and the general public’s knowledge of the world beyond. Because T-Tauris are theorized to be similar to the sun, understanding star formation includes understanding how planets form, including planets like Earth (DeWolf et al. 2008). The characteristics of T-Tauri stars and their environments lead scientists to conclude that star formation is taking place in a particular region.

Particularly, nebulae rich in gas and dust, called Lynds Clouds, are of interest to astronomers studying star formation. Recent research on star formation in large molecular cloud complexes, such as the Cepheus Flare (Kun 1995), Orion, Perseus (Jørgensen et al. 2007), and Taurus molecular clouds, have included studies of a number of LDN. Less attention has been given to isolated Lynds clouds, such as LDN 1616 (Cooksey et al. 2001) and LDN 981, located in Cygnus. LDN 981 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. (2006) 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). However, according to Quanz et al. (2006) there appears to be no supernovae remnant in the vicinity of V1331 Cyg, nor is there any evidence of stellar winds from O B class stars or of colliding masses. Since there is no evidence of traditional star formation, it would appear one of two things must be happening. Either V1331 Cyg is a case of isolated star formation, which tends to be fairly uncommon, or previous studies lacked the sensitivity or the breadth to identify additional YSOs in LDN 981.
OBSERVATIONS AND DATA REDUCTION
A limited study of Lynds Dark Nebulae (LDN) 981, a cloud with a rough elliptical core and five dark filaments, suggests that only one case of isolated star formation has erupted (Quanz et al. 2008). They suggest that LDN 981 is undergoing a collapse and additional stars could form along the filaments in the future (2006).

At the time of the Quanz study, Spitzer data was not available. Circumstances lead one to believe additional star formation is likely taking place in Lynds Cloud 981.

Identification of YSOs and subsequent T-Tauri require the existence of several important pieces of evidence. First and foremost an envelope of gas and dust will exist around a young star. This gas and dust absorbs energy from the star and reemits it at the longer infrared wavelengths. The Spitzer space telescope was used to acquire images of LDN 981 at 3.6, 4.5, 5.8, 8, and 24 microns. The Multiband Imaging Photometer for Spitzer (MIPS) was used to image LDN 981 at 24 microns on June 27, 2008 at 12:27:40.7 UT, and Spitzer’s Infrared Array Camera (IRAC) was used to image LDN 981 at 3.6, 4.5, 5.8, and 8.0 microns on July 18, 2008, at 18:30:52.8 UT (Spitzer’s Telescope 2008). Both observations were centered at center RA: 21h00m14.88s, DEC: +50°17’16.8” J2000, and the combined observations took the Spitzer Space Telescope approximately 20 minutes total time to complete.

Figure 3 - A color composite image of IC2118 generated by MOPEX demonstrates the method of finding potential YSO candidates (Weehler et al. 2005).

A technique commonly used with Spitzer Telescope data was then employed to identify potential young stellar objects (YSOs). Since YSOs and subcategory T-Tauri stars possess significant gas and dust, they will emit significantly more energy at longer wavelengths. In addition MIPS has a lower resolution than IRAC and as a result when the MIPS image is “stretched out” to match the IRAC image a blurring of the MIPS sources takes place. Therefore if a color composite image is created assigning 24 micron data as red, 8 micron data as green, and 4.5 micron data as blue, point sources with red rings indicate possible YSOs. Spitzer’s MOPEX data analysis software was used to make a similar color composite image of LDN 981.

From the color composite image 24 potential YSOs were identified. MaxIm DL data analysis software was used to identify intensity values for each of the 24 candidates at 3.6, 4.5, 5.8, 8.0,
and 24 microns. These intensity values where then converted to flux and magnitude values using Microsoft Excel. In addition infrared data from the 2MASS survey was acquired using the 2MASS All-Sky Point Source Catalog available on line at http://irsa.ipac.caltech.edu/applications/Gator/. 2MASS J (1.25 microns), H (1.65 microns), and K (2.17 microns) band magnitudes and flux values were acquired for potential targets. The Spitzer IRAC and MIPS, and 2MASS data was used to generate spectral energy distributions for each of the targets and to plot the targets on a color-color diagram. The spectral energy distribution will show excess infrared emissions if they are present, and the color-color diagram is a comparative analysis of a stars magnitude at various wavelengths. Both are valuable tools in the hunt for young stellar objects.

However, one of the dangers of using infrared excess alone to identify YSOs is the fact that other objects like background galaxies tend to have significant IR emissions. Because of this, additional information is needed to distinguish these stars from galaxies and other objects in space.

Another characteristic of YSOs, particularly Class 0 and 1 T-Tauri stars, is outflows. Bi-polar jets or outflows are easily identifiable in the event they exist and if the jet is in the proper orientation to be seen. In addition, since stars form from clouds of gas and dust in space, YSOs and the subclass T-Tauri stars should be located within an area of high nebulosity (Division of Theoretical Astronomy 2006). MOPEX and MaxIm DL were used to inspect IR and optical images for outflows as well as nebulosity.

Young stars and particularly T-Tauri stars also tend to be very active and have fast rotational rates between two to seven days. When stars are active they give off strong H-alpha emissions, and contain large “starspot” regions. As a result H-alpha optical data can be used to determine activity levels, and light curves will demonstrate variability. If variability exists in them, then the period of the variability (caused by the “starspots”) was used to calculate rotation rates. The WIYN 0.9-meter telescope at Kitt Peak National Observatory was used to image YSO candidates in LDN 981 in B, V, R, I and H-alpha from November 14 - 16, 2008. Imaging took place from 6:30 PM – 8:30 PM Mountain Standard Time. Additionally, LDN 981 was observed from 7:00 PM - 8:00 PM MST on the evenings of December 5, 6, 7, 10, and 11, 2008 with Tzec Maun Observatory 14 inch telescope in New Mexico. MaxIm DL was used to reduce the data and make photometric measurements. All images were biased and flat fielded, and the Tzec Maun data was additionally dark subtracted. A comparative method between reference stars and potential YSOs was used to generate the light curves. A total of ten reference stars were measured in order to get an accurate reference average to compare against the potential YSOs. However in a comparative analysis for each individual reference stars two were discarded because they appeared to be fluctuating in brightness, leaving eight reference stars. In addition, only two potential YSOs could be identified in the optical data from Tzec Maun. This may have been due to the remaining objects being embedded.
ANALYSIS AND RESULTS

Table 1: (left) displays the Right Ascension and Declination of twenty-seven identified targets in LDN 981.

Figure 4: (below) is a color composite of LDN 981. The base image for this plot was MIPS 24 microns, shown in red. IRAC channel 4 (8 microns) is green and IRAC channel 1 (3.6 microns) is shown in blue.

<table>
<thead>
<tr>
<th>#</th>
<th>RA</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21h 00m 17.35s</td>
<td>+50d 19m 41.5s</td>
</tr>
<tr>
<td>2</td>
<td>21h 00m 25.58s</td>
<td>+50d 28m 01.2s</td>
</tr>
<tr>
<td>3</td>
<td>21h 00m 34.30s</td>
<td>+50d 24m 03.6s</td>
</tr>
<tr>
<td>4</td>
<td>21h 00m 20.33s</td>
<td>+50d 20m 21.2s</td>
</tr>
<tr>
<td>5</td>
<td>21h 01m 09.34s</td>
<td>+50d 21m 44.3s</td>
</tr>
<tr>
<td>6</td>
<td>21h 01m 03.13s</td>
<td>+50d 21m 29.7s</td>
</tr>
<tr>
<td>7</td>
<td>21h 01m 04.15s</td>
<td>+50d 17m 48.8s</td>
</tr>
<tr>
<td>8</td>
<td>21h 00m 44.30s</td>
<td>+50d 19m 39.4s</td>
</tr>
<tr>
<td>9</td>
<td>21h 00m 49.73s</td>
<td>+50d 15m 45.0s</td>
</tr>
<tr>
<td>10</td>
<td>21h 00m 39.10s</td>
<td>+50d 16m 20.9s</td>
</tr>
<tr>
<td>11</td>
<td>20h 59m 38.51s</td>
<td>+50d 15m 39.4s</td>
</tr>
<tr>
<td>12</td>
<td>20h 59m 33.02s</td>
<td>+50d 12m 02.0s</td>
</tr>
<tr>
<td>13</td>
<td>20h 59m 19.42s</td>
<td>+50d 12m 39.6s</td>
</tr>
<tr>
<td>14</td>
<td>21h 00m 36.58s</td>
<td>+50d 13m 33.6s</td>
</tr>
<tr>
<td>15</td>
<td>21h 00m 17.62s</td>
<td>+50d 12m 31.3s</td>
</tr>
<tr>
<td>16</td>
<td>21h 00m 06.67s</td>
<td>+50d 12m 15.5s</td>
</tr>
<tr>
<td>17</td>
<td>20h 59m 56.11s</td>
<td>+50d 09m 37.8s</td>
</tr>
<tr>
<td>18</td>
<td>21h 00m 05.21s</td>
<td>+50d 10m 37.9s</td>
</tr>
<tr>
<td>19</td>
<td>20h 59m 54.89s</td>
<td>+50d 05m 55.3s</td>
</tr>
<tr>
<td>20</td>
<td>21h 00m 30.53s</td>
<td>+50d 17m 24.7s</td>
</tr>
<tr>
<td>21</td>
<td>21h 00m 34.89s</td>
<td>+50d 18m 12.6s</td>
</tr>
<tr>
<td>22</td>
<td>21h 00m 37.27s</td>
<td>+50d 21m 01.3s</td>
</tr>
<tr>
<td>23</td>
<td>20h 59m 19.24s</td>
<td>+50d 16m 06.2s</td>
</tr>
<tr>
<td>24</td>
<td>21h 59m 40.74s</td>
<td>+50d 18m 21.9s</td>
</tr>
<tr>
<td>25</td>
<td>20h 59m 43.99s</td>
<td>+50d 17m 56.0s</td>
</tr>
<tr>
<td>26</td>
<td>20h 59m 24.21s</td>
<td>+50d 13m 59.0s</td>
</tr>
<tr>
<td>27</td>
<td>21h 00m 26.64s</td>
<td>+50d 15m 00.0s</td>
</tr>
</tbody>
</table>

Each target is represented by its respective candidate number in Figure 4. For reference, V1331 Cyg is candidate number 5. Because the 24 micron image was assigned the color red, objects with excess gas and dust will appear to have a red ring around them. A total of 27 red ringed objects can be seen, which may be potential YSO’s.
Figure 5: Shows the color-color plot (CCP) for fifteen of the identified Lynds candidates.

Magnitude at all 4 IRAC channels was necessary for a candidate to be plotted on the color-color diagram. The Galaxies tend to cluster along the x axis, photospheres near the 0,0 point, and YSOs indicated by the red numbers up and to the right of the 0,0 point.

Figure 6: (above and left) Show spectral energy distributions using 2MASS, IRAC, and MIPS data. Spectral energy distributions were created for all targets, however the five presented here correspond to the five possible YSO targets identified in Figure 5.
Figure 7: Inverse image from the 0.9 meter telescope at Kitt Peak National Observatory (KPNO) using the I filter. Image taken by the author November 14, 2008.

Light curves (Figure 8 above) were generated for two of the possible YSOs using the Tzec Maun 14 inch telescope in New Mexico. Using MaxIm DL an average intensity of 8 image reference stars was compared to the intensity of the possible YSO candidates. The light curve was plotted using MS Excel.
DISCUSSION

This study used both infrared and optical telescopes to conduct an in-depth study of star formation in LDN 981. The results indicate there is likely some additional star formation taking place in this region, however exactly to what extent remains a bit of a question.

The 24 micron, 8 micron, and 3.6 micron color composite image (see Figure 4 and Table 1) showed 27 red-ringed objects. The red ring resulting from the “stretched MIPS image indicates objects with significant IR excess at 24 microns. However there are other objects in space that display such a quality (i.e. galaxies).

Of the 27 targets identified in the color composite image, IRAC data at all 4 wavelengths (3.6, 4.5, 5.7, and 8 microns) could be acquired for only 15 of the 27 targets. It would be necessary to re-image the objects with longer IRAC exposure times, or to implement a different data analysis.
technique to acquire IRAC values for other targets. It is however important to note that just because IRAC values were not measurable does not mean these objects are not YSOs. It may be that the objects where simply too embedded in their cocoons of gas and dust to emit sufficient energy at 3.6 or 4.5 microns. Using the IRAC data a color plot (Figure 5) was generated in Excel. Magnitude values at 5.8-8.0 microns were plotted on the x-axis and magnitude values at 3.6-4.5 on the y-axis. Using the color-color plot the candidate list was narrowed down to five potential YSOs or T-Tauri stars. In the color-color plot galaxies tend to fall along the x-axis, and photospheres (stars on or near main sequence) fall around the 0,0 point, and YSOs are located up and to the right of the 0,0 point (Marston et al. 2004). He farther a YSO’s is from the 0,0 point, the younger it is. The single previously identified YSO did appear in figure 5 where one would expect it to be.

The spectral energy distributions provided further evidence the candidates 5, 7, 9, 12, and 23 were all young stellar objects. All of the candidates have a significant slope that increases as wavelength increases. This again is evidence of a possible envelope of gas and dust. Candidate 23 is of particular interest since no 2MASS values could be found for the target. This may indicate that the 2MASS sensitivity was not good enough to see what may well be a young highly embedded star.

Although no evidence of jets or outflows was identified, there is significant nebulosity in the region (see figure 7), and there was evidence active stellar objects. Due to sensitivity limits light curves could only be generated for two of the five objects, and H-alpha data was acquired for only one of the targets. The light curve for target 5 (V1331 Cyg) showed evidence of variability and an approximate 5-day rotation rate (see table 2, table 3, and figure 8). This is within the expected two to seven day rotation rate of T-Tauri stars. Candidate 9 also showed some evidence of variability; however it was small and inconclusive. Additional observations using longer exposure times are necessary.

**SUMMARY AND ACKNOWLEDGEMENTS**

It does appear from the evidence presented here that there is some additional star formation taking place in LDN 981 beyond V1331 Cyg. As stated previously, isolated star formation is not a common event in space. Although there is evidence of additional star formation, it appears to be somewhat more limited than expected, and more than likely would remain classified as an isolated star formation event. The question is why? What is different about the environment in LDN 981 that makes it such a mystery?

Rather than closing the door on LDN 981, this study has pushed it opened a fair bit more than it was. If we are to understand the nature of star formation in LDN 981, additional IR observations from Spitzer or other IR telescopes using significantly longer exposure times is necessary. In addition larger aperture optical telescopes and longer exposure times will be necessary to detect H-alpha emissions and generate light curves for all 27 candidates. Ideally spectroscopy on the 27 candidates identified in LDN 981 would provide some of the most conclusive evidence of their physical properties.
There are so many wonderful people who have been involved on this project for almost a year now, all of whom should be recognized. Foremost, I would like to not only acknowledge but thank Tim Spuck, who has supported not only this project, but all of my hopes and aspirations from the beginning. He is not only a great teacher, but a remarkable mentor. Had it not been for lead Spitzer Space Center scientist, Dr. Luisa Rebull, who took on this massive project, I would not stand where I am today, not only with this paper, but with even the tiniest understanding of the universe and genuine thirst to learn more. I am forever grateful for your countless e-mails chalked full of advice and know-how. I would like to recognize all of the teachers and students who started out on the original “Lynds Cloud Project” last summer in Pasadena and those who presented at Long Beach. New Yorkers, Minnesotans, Montanans, Michigianians, and fellow Pennsylvanians- you are the best. I’d like to extend my appreciation to all the Spitzer Research Team members: Matt, Alix, Samantha, Shana, and Jennifer who have both motivated me and shared in successes throughout the year. I graciously acknowledge Oil City High School, comprised of the most helpful and supportive faculty, staff, and students. Gratitude and thanks to Clarion University (Science in Motion), the National Optical Astronomy Observatorv and Katy Garmany, Spitzer Science Center, and the Spitzer Space Telescope Research Program for Teachers and Students for not only funding a project but cultivating a single idea into something tangible and amazing. Most notably, thank you Aron, Jeremy, and Mom. I would not be half the person I am today without you.
REFERENCES


Rebull, D. L. (26, November 2008). E-mail Interview.


Star Formation in Isolated Dark Nebulae: YSOs in LDN 981
Justin Boerma, Stephen Brock, and Trevor DeWolf
Chippewa Hills High School, Remus, MI
Teacher: Cris DeWolf, TLRBSE 2006

ABSTRACT
Do small isolated dark nebulae still have the ability to form stars? This study endeavors to answer this question. Using the Spitzer Space Telescope, data were obtained of a small Lynds Dark Nebula, LDN 981, using the Multiband Imaging Photometer for Spitzer (MIPS) and Infrared Array Camera (IRAC) instruments, which detect a range of infrared wavelengths from 3.6 to 160 microns. With MIPS, only the 24-micron band was used in this study. These data were reduced using APT (Aperture Photometry Tool), a software package available as freeware from the Spitzer Science Center, to provide photometric information about infrared (IR) sources in this dark cloud. The photometry data were used to create spectral energy distribution charts with Excel. These were compared with spectral energy distribution (SED) plots from known objects in an attempt to classify the IR sources found in this study. From seven identified sources of excess infrared emission, 2 potential Class I Protostars were found.

INTRODUCTION
The universe is a large and ever expanding space where the birth and death of stars continuously changes its beauty in the slow crawl of time. Many studies have focused on star formation in large molecular clouds—like those found in Orion, Taurus and Cepheus—but where else in the dark depths of space might young stellar objects (YSOs) be forming? Star Formation in Isolated Dark Nebulae: YSOs in LDN 981 focuses on a select, isolated Lynds Dark Nebula (LDN 981) in order to determine the extent of star formation within an isolated cloud.

Star formation (while slow) is not that complex. Within all interstellar clouds, (including dark nebulae) there is gas and dust including hydrogen gas and silicate dust. When disturbances such as shock waves from nearby supernovae occur localized regions of higher density develop and begin drawing in more of the mass of the nearby cloud by gravitational attraction. Slowly growing, as the mass increases its gravitational pull also increases therefore the central mass accretes material even faster.

As the central mass continues to grow, the pressure at its center increases raising the temperature and eventually triggering fusion; the fusing of hydrogen, and the mark of a star.

In the case of dark nebulae, the cloud is so dense that it obscures or completely blocks light (disregarding infrared light) from sources in its background. These nebulae are the densest part of a molecular cloud. The closely set dust grains within it either absorb or scatter light wavelengths. This is different for infrared light. Infrared light has a longer...
wavelength. IR sources found in LDN 981 show IR excess due to heating by their embedded protostars.

The target of this research, LDN 981, is a dark nebula because of its low temperature (5-15K). It is so dense and thick with dust and gas that visible wavelengths of light from objects inside it and behind it cannot pass through it. Details of the internal structure of these objects can be investigated using longer wavelengths of EM radiation including infrared. This object was selected from a larger set of potential targets based on its opacity.

Beverly Lynds developed a method for estimation of visual opacity in her catalog of dark nebulae using the National Geographic Society-Palomar Observatory Sky Survey (POSS) plates. She outlined clouds on each plate and ranked them 1-6, with 6 being the darkest clouds, based on her visual estimates of cloud density. Her catalog was the basis for a search conducted by astronomy students at Chippewa Hills High School to help find suitable targets for this study. Nebulae with Lynds visual opacities of 5 and 6 were scrutinized in two ways. First, Leopard, a software tool used to query the Spitzer Science Center’s archival data, was used to see what, if any, studies had been done on a potential target. Next, NASA-ADS was used to see what other studies may have been done on the target. An ideal target would have had no studies involving Spitzer data and have at least some other information available in the literature. LDN 981 fit these criteria.

Dark nebulae are often associated with giant molecular clouds such as those found in Taurus, Ophiuchus, Cygnus, and Orion. Research done by Dobashi, et.al. (ApJS 1994) suggests LDN 981 is associated with a molecular cloud in Cygnus. This cloud, 090.5+02.4 - Number 71 in their catalog of clouds in Cygnus, is roughly 800 parsecs away. If LDN 981 is indeed associated with this cloud, then it may also be around 800 parsecs away. In order to verify this distance estimate other research must be done.

Common methods used to determine the distance to dark nebulae and molecular clouds include photometry, distance of stars or fields associated with the cloud, using CO velocities to obtain kinetic distances, and measuring polarized light from background stars. These methods are discussed in the paper *Distance measurements of Lynds galactic dark nebulae* by Hilton and Labulla (A&AS 1995). Spectroscopy is an alternative method that is currently being investigated by another team researching star formation in Lynds dark nebulae from Oil City Area Senior High School in Pennsylvania.

The Spitzer Science Center (SSC) and the National Optical Astronomy Observatory (NOAO) created the Spitzer Research Program for Teachers and Students, which allowed access to the resources needed to accomplish this goal. With the help of the Spitzer Research Program for Teachers and Students time on the Spitzer Space Telescope was granted to look deep into the heart of LDN (Lynds Dark Nebulae) 981. Using infrared light, the warm glow of young stellar objects (YSOs) would hopefully be found.

For this research, five separate IR wavelengths were compared and analyzed in the search for Young Stellar Objects: 3.6, 4.5, 5.8, 8, and 24 microns. The hypothesis in *Star
Formation in Isolated Dark Nebulae: YSOs in LDN 981 is that if a sufficient gas and dust density exists in a LDN with a Lynds visual opacity of 6 then it is likely that low mass star formation could occur in this object and be detectable with these wavelengths.

OBSERVATIONS
The Director of the Spitzer Science Center has time available on the Spitzer Space telescope that he is able to grant to research proposals from advanced high school students at his discretion. The research presented here is part of a larger project that was awarded time in 2008. Astronomy classes at the 5 schools participating in the Lynds nebulae project of the Spitzer Research Program for Teachers and Students identified potential target LDNs. Program teachers and the lead scientist from the Spitzer Science Center, Dr. Luisa Rebull, selected the final two LDNs, including LDN 981, for further study.

The data run was scheduled using Spot – another software package from the Spitzer Science Center, by Dr. Rebull and the project teachers. The scheduled dates for obtaining the data used for this study (and their release dates) were as follows:

- IRAC mapping: Scheduled--2008-05-21 (Release--2008-08-05)

The schedule was not delayed so data were obtained on the dates indicated. Release dates refer to the time needed for transfer and processing of the raw data through the Spitzer pipeline. All data used in this project were post BCD data from the Spitzer archives.

DATA REDUCTION
Post BCD data from the Spitzer pipeline for LDN 981 were processed further using Spot (or Leopard) to create color-color composite image stacks. In a color-color composite, images taken with different wavelengths are represented using false color to show separate characteristics only visible to a certain wavelength. The longest of the wavelengths, 24 microns, was always assigned to red. A color-color composite was created by assigning red to 24 microns, green to 8 microns, and blue to 3.6 microns. Objects with IR excess would appear in the resulting image to be surrounded by a red ring. This could indicate large amounts of dust surrounding an embedded object. Large amounts of dust around a source could point to an YSO, around which dust would be plentiful.

Within the composite, the images WITH the underlying MIPS band are compared to the images WITHOUT the MIPS band. Objects surrounded by a red ring can be indicative of IR excess and could be potential YSOs.
Within LDN 981, seven potential YSOs were found and recorded, respectively named CHHS 1-7. Their coordinates (Eq-J2000 [degrees]) are as follows:

<table>
<thead>
<tr>
<th>IR Source</th>
<th>RA</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHHS 1</td>
<td>315.0721</td>
<td>50.3278</td>
</tr>
<tr>
<td>CHHS 2</td>
<td>315.085</td>
<td>50.3388</td>
</tr>
<tr>
<td>CHHS 3</td>
<td>315.1517</td>
<td>50.2258</td>
</tr>
<tr>
<td>CHHS 4</td>
<td>314.885</td>
<td>50.2006</td>
</tr>
<tr>
<td>CHHS 5</td>
<td>314.831</td>
<td>50.2618</td>
</tr>
<tr>
<td>CHHS 6</td>
<td>315.2065</td>
<td>50.2618</td>
</tr>
<tr>
<td>CHHS 7</td>
<td>315.2661</td>
<td>50.2961</td>
</tr>
</tbody>
</table>

**Figure 1:** LDN 981 Color-Color Composite Red (MIPS-24), Green (IRAC-5.8), Blue (IRAC-3.6)

**Figure 2:** IR Source Coordinates
Photometric data reduction using APT (Aperture Photometry Tool) was done on the objects found at these coordinates to calculate the flux of each source with the Sky-Intensity subtracted. The aperture and annulus settings varied with the size of the source in each image. APT is a freely available software package from the Spitzer Science Center that can used to do photometric data reduction of any Spitzer archival data.

<table>
<thead>
<tr>
<th>IR Source</th>
<th>Wavelength (microns)</th>
<th>Flux (uJy/pixel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHHS 1</td>
<td>3.6</td>
<td>2.18E+04</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>1.92E+04</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>1.87E+04</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.01E+04</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>2.48E+04</td>
</tr>
<tr>
<td>CHHS 2</td>
<td>3.6</td>
<td>8.25E+02</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>3.78E+02</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>3.20E+02</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>4.80E+01</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>1.80E+03</td>
</tr>
<tr>
<td>CHHS 3</td>
<td>3.6</td>
<td>4.65E+02</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>3.08E+02</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>3.49E+02</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.45E+03</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>8.08E+03</td>
</tr>
<tr>
<td>CHHS 4</td>
<td>3.6</td>
<td>5.93E+02</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>9.32E+02</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>1.77E+03</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.34E+03</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>7.26E+03</td>
</tr>
<tr>
<td>CHHS 5</td>
<td>3.6</td>
<td>4.98E+02</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>7.64E+02</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>1.16E+03</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.04E+03</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>2.30E+03</td>
</tr>
<tr>
<td>CHHS 6</td>
<td>3.6</td>
<td>2.04E+03</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>2.21E+03</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>1.92E+03</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.05E+03</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>5.52E+03</td>
</tr>
<tr>
<td>CHHS 7</td>
<td>3.6</td>
<td>4.68E+02</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>3.93E+02</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>8.63E+02</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>8.58E+02</td>
</tr>
<tr>
<td></td>
<td>23.7</td>
<td>6.46E+03</td>
</tr>
</tbody>
</table>

Figure 3: Source Flux From APT
DATA ANALYSIS
Flux values obtained from a photometric analysis of the IR sources in LDN 981 were converted from MJy/pixel to μJy/pixel and inserted into “Teachers_v2.2_Mac.xls”, a tool created for student research with Spitzer Space Telescope data by Russ Laher from the Spitzer Science Center. Embedded macros within this tool calculated $\lambda F_\lambda$ values that were then entered into a separate Excel sheet to construct SEDs for each of the IR sources identified in this study.

SEDs plot each sources energy output versus 3.6, 4.5, 5.8, 8, and 24-micron wavelengths. The energy output was calculated by the spreadsheet tool in terms of $\lambda F_\lambda$ (erg/s/cm²). These SEDs are shown below. Data were plotted as a scatter-plot with connecting lines so that any absorption dips would be more prominent.
DISCUSSION
The SEDs of the CHHS IR sources in LDN 981 were compared to example SEDs from the Coolwiki website (https://coolwiki.ipac.caltech.edu/index.php/Main_Page) to determine their evolutionary stage of development. These example SEDs represent known objects of Classes 0, I, II, and III. A Class 0 SED would represent a black body emission. Class I represents a young protostar, Class II represents T-Tauri stars, and Class III represents a main sequence star. The Spitzer Coolwiki is a website that was established by teachers and students to communicate and share data during their research projects. It is also a source of information that others can tap into to construct their own projects.

The SEDs of the CHHS IR sources did not include any data from 2MASS in the J, H, and K bands. The IR sources identified in both the MIPS and IRAC data are simply to faint to be visible in the bands used for the earlier Two Micron All Sky Survey. Sources detected with MIPS and IRAC wavelengths were not observable with the shorter 2MASS wavelengths. This “missing data” may be a reason for the difficulty presented with matching project SEDs with SEDs of known objects. A possibility for the faintness of the sources identified in this study is that they are extremely distant objects – galaxies in the background, behind the nebula. This would also explain the difficulty with matching SEDs from the study with SEDs of known objects.

While acknowledging the possibility that the sources found by this study may indeed be galaxies in the background, the fact that CHHS IR Sources 2 and 7 show absorption “dips” around 10 microns makes them possible Class I Protostars. Based on comparisons of SEDs, CHHS IR Sources 3 and 4 are probable main sequence stars.
The initial selection of objects from LDN 981 was based on red rings surrounding them in color-color composites that included the 24-micron band from MIPS. The selection was based on the assumption that the brightness of these objects was due to IR excess produced via absorption of radiation by silicate dust. According to Fabbri, et al (MmSAI, 2008), warm dust, warmed by emission of an embedded protostar, would emit more strongly at IRAC wavelengths between 3.6 and 8 microns. The assumption of this study, awaiting confirmation, is that this is indeed the case. Of course, dust in the spiral arms of background galaxies could also account for the absorption features in these SEDs. Distances to the sources must be determined to make final determination of their nature.

SUMMARY & AKNOWLEDGEMENTS

It appears based on the data presented in this paper that star formation may occur in isolated dark nebulae in the same manner in which it occurs in larger molecular clouds. SEDs for IR sources shared features in common with YSOs found in these larger clouds.

Of the candidate IR sources identified two have SEDs that indicate possible absorption of radiation from a central YSO and the presence of a circumstellar disk. This is due to an absorption feature found at approximately 10 microns, typically indicating the presence of silicate dust. The other IR sources may be background stars or strong IR sources in galaxies beyond our own Milky Way galaxy.

Further work should be done to determine distances to the IR sources associated with LDN 981. This would enable a more positive determination of the nature of these IR sources.
Our sincere thanks are extended to:

- Our teacher, Cris DeWolf, for the patience and knowledge that helped us get this far.
- Our fellow students in spring 2008 Astronomy who helped in target selection.
- Tim Spuck, the lead teacher on our team who pointed the way, and
- Dr. Luisa Rebull, and all the others behind the scenes at the Spitzer Science Center who helped make this project possible.

REFERENCES


<http://www.ipac.caltech.edu/Outreach/Edu/sform.html>.


Laher, Russ, “Russ Laher’s Spitzer-Science-Center Webpage”


Using Doppler Shifts to Determine the Sizes of Solar Granulation Features

Teacher: Matthew K. Bierer, North Pole High School, North Pole, AK, ARBSE 2008
Teacher: James Elliot, Myers Park High School, Charlotte, NC, ARBSE 2008
Teacher: John W. Fuller, Seacrest Country Day School, Naples, FL, ARBSE 2008

ABSTRACT
Doppler shifts in the 1579nm Fe absorption line were analyzed to determine the characteristic sizes of solar granulation features. The results indicate the diameters of the most typical granulation features are 1,000 to 2,500 km, 8,000 km, 15,000 km, 25,000 km, and 33,000 km. With the exception of the 15,000-km size, these values correspond well with published values for the diameters of granules, mesogranules, and supergranules.

INTRODUCTION
The surface of the Sun has a mottled appearance due to numerous bright, polygonal regions surrounded by darker edges. These regions are called granules. Solar granules are a visible result of convection currents in the photosphere. Hot gas rises, spreads radially outwards across the photosphere, cools, and sinks below the surface. The typical granule structure is, then, a hot upwelling region bounded by cooler sinking gases. [Seeds, 2007]. Granules generally grow to a diameter of about 2 arcsec during a lifetime of 6-16 minutes. Mesogranules may be collections of granules with a common velocity pattern. They have diameters of about 10 arcsec and last for about two hours. Supergranules are a manifestation of large-scale photospheric convection currents, reaching diameters of about 48 arcsec and persisting for several hours to a day [Bhatnagar and Livingston, 2005].

Solar granules spread tangentially across the photosphere, while the gases are simultaneously moving radially in and out from the surface. The motion of the granules results in the Doppler-shifting of the spectral lines. However, only the radial component of motion can be detected. The portion of the absorption line crossing rising granule centers is blue-shifted and the portion at the sinking granule edges is red-shifted. Thus, pictorially, the absorption line is no longer straight, but shifts back and forth as the scan crosses the granules and their boundaries. In 1949, at the Mount Wilson Observatory, R.A. Richardson may have been the first researcher to notice a zig-zag pattern in the Fraunhofer lines [Bhatnagar and Livingston, 2005]. In the 1960s, John Evans and Robert Leighton began analyzing the “wiggly line spectra” to study gas velocities at different altitudes, granule sizes, and solar oscillation patterns [Zirker, 2003].

During the summer of 2008, the authors independently rediscovered this concept and applied it to a slightly different purpose. Rather than use the magnitudes of the Doppler shifts to determine granule velocities, the locations of changes in Doppler shift were used to determine granule sizes. The distances between the centers of red-shifted sections of the absorption line correspond to the diameters of the granules.

There are other ways to measure granule sizes, but most rely on examining variations in granule brightness. Using the Doppler shifts in an absorption line is advantageous because granule boundaries correspond to the motion of gases, not the brightness of gases. Granules will change
brightness over time. So, a darker granule might be indistinguishable from a boundary region. Also, granule brightness refers to the photosphere emission continuum, which is formed 100-200 km deeper than the Doppler shifts in the absorption lines [Bhatnagar and Livingston, 2005].

OBSERVATIONS AND DATA REDUCTION
Using the McMath-Pierce Solar Telescope, infrared light from the granules was measured at a wavelength of 1579nm. That line was chosen because it is well-separated from the nearest neighboring absorption lines. The scanning took place in randomly selected locations near the center of the solar disk, through a slit that was oriented with its long axis lying east-to-west. At the center of the disk, radial granule motion is best aligned with the line of sight of the spectrometer, which improves resolution of any Doppler shifting of the spectral lines [Plymate, 2008].

For the purposes of this project, the magnitude of the Doppler shifting is unimportant because the goal is only to determine the locations of the changes in shift and, thereby, the sizes of the granules. Finding these locations requires intensity profiles along the red and blue edges of the chosen absorption line. If the intensities along the two profiles vary oppositely, it means the line is shifting to the side with the higher intensity. If the intensities along the profiles vary similarly, it means the line as a whole is getting more or less intense, rather than shifting to one side or the other.

Two types of data were collected: space-varying and time-varying. The space-varying data consisted of scans made across the solar disk in 0.25- or 0.5-arcsecond-wide stripes taken every 200 milliseconds. This type of data shows how the granule positions vary spatially. The time-varying data consists of 200-millisecond scans made at the same location on the solar disk separated by 1.5 seconds. This type of data shows how the granule boundaries vary over time. The two types of data were analyzed in the same way to improve the confidence level of the results.

In both types of data, the spectral lines were recorded at a slight angle to the image pixels. To correct for this rotation, the intensity profiles were collected along lines parallel to the absorption line, which turns out to be diagonal to the image pixels. Since it is not possible to draw the profiles exactly parallel to the absorption line or to each other, it is necessary to compensate for the undesired rotation. Linear lines of best fit were found for each intensity profile. See figure 1. The linear components were subtracted from the original intensity profiles. Had this not been done, the relative rotations of the red- and blue-shifted intensity profiles would give the appearance of a Doppler shift increasing steadily across the spatial direction in the image. See figure 2.

On a graph of the corrected intensity profiles, places where the lines move in opposite directions indicate locations of increased Doppler shift. Places where the lines move in the same direction indicate changes in brightness of the absorption line. To reduce noise and emphasize the locations of Doppler shift changes, the blue-shifted intensity profile was subtracted from the red-shifted profile. It doesn’t matter which is subtracted from the other because the magnitudes of the shifts are unimportant. Only the locations of the changes in Doppler shift are needed.
The analysis of the two types of data differed only in that the time-varying data was averaged over five scans (six seconds in time) before the red and blue profiles were taken, whereas two scans of the space-varying data were averaged after the profile subtractions. The averages were taken for the purpose of noise reduction.

**Figure 1**: An example of the intensity profiles of the red- and blue-shifted edges of the absorption line. Superimposed are the linear lines of best fit for each.

**Figure 2**: An example of the intensity profiles of the red- and blue-shifted edges of the absorption line after the linear components have been subtracted.
In both cases, the result is a plot showing how the Doppler shift varies along the length of the slit. Knowing the angular size of the slit and the number of pixels in the scan, the length of the slit can be represented in terms of physical size on the photosphere, allowing us to see the physical sizes of the Doppler-shifted regions. See figure 3.

![Figure 3](image)

**Figure 3:** An example of the average difference between the corrected red- and blue-shifted intensity profiles, scaled in km.

For several reasons, it was impossible to visually determine the sizes of granules by examining the intensity waveforms. The scan lines captured granules in all stages of evolution and crossed them in all places. The boundaries of granules are approximately one-tenth the size of the granules. Granules occur in a range of sizes, and there are solar features that vary on other sizes scales. And, lastly, not all granules rise or fall at the same speed.

Since a visual measurement of granule sizes was impossible, a fast Fourier transformation was used to determine the relative contributions of the different scale sizes to the composite waveform. The outcomes of fast Fourier transforms of several sets of data were visually compared to look for similar-sized features. The most obvious similarities were matched with the sizes of solar granulation types found in relevant references.

**DISCUSSION**

The authors were encouraged to hear that the scans were made during periods of unusually good seeing, in which the measurements were limited only by diffraction [Plymate, 2008], but were concerned that the sample size was too small for the results to be meaningful. Later consultation with an authority in the field led them to believe it was not a problem [Livingston, 2008].
The results of the research are summarized in table 1. The accepted values are from Bhatnagar and Livingston [2005]. They have been converted from arcseconds to kilometers for comparison with the authors’ results.

The results for granule diameters match perfectly. The results for mesogranules match nicely, but for the difference that we find two separate values, rather than a range of values. The authors feel, though, that an increased sample size might resolve that issue. At present, no solar granulation feature has been found in the literature corresponding to the 15,000-km scale size found in our results. However, since it is an obvious multiple of 5,000 km and is not far from being a multiple of 8,000 km, it may simply be the result of the scan line crossing mesogranules with poorly-resolved boundaries.

<table>
<thead>
<tr>
<th>Solar Feature</th>
<th>Accepted Value (km)</th>
<th>Our Value (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granule</td>
<td>1,000 to 2,500</td>
<td>1,000 to 2,500</td>
</tr>
<tr>
<td>Mesogranule</td>
<td>5,000 to 10,000</td>
<td>5,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15,000</td>
</tr>
<tr>
<td>Supergranule</td>
<td>25,000 to 85,000</td>
<td>25,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33,000</td>
</tr>
</tbody>
</table>

Table 1: A comparison of the authors’ results with values found in the literature.

The results for supergranule diameters are also quite similar to published values. Again, we find two distinct values, rather than a range. In this case, though, our value of 33,000 km matches nicely with the stated average value of 35,000 km [Bhatnagar and Livingston, 2005]. That figure was arrived at by dividing the surface area of the Sun by the typical number of supergranules, 2500, to find the mean cell size and, subsequently, the average center-to-center distance.

In conclusion, the results indicate that this experimental method and data analysis technique are appropriate and effective in achieving the goal of determining the typical sizes of solar granulation features.

**ACKNOWLEDGEMENTS**

The authors are grateful for the opportunity to participate in the Astronomy Research-Based Science Education program in 2008. It has made a significant impact on our understanding of the astronomy research methods.

We thank Dr. Constance Walker of the National Optical Astronomy Observatory for sharing her knowledge of solar physics and her enthusiasm for research.

We thank Claude Plymate of the Kitt Peak National Observatory for his instruction and advice on the possibilities and practicalities of using the McMath-Pierce solar telescope.
Lastly, the authors are grateful to Dr. William Livingston of the National Optical Astronomy Observatory for taking time to discuss our research method and our findings. It was a wonderful experience to share our work with an author of our primary reference book.

REFERENCES
Livingston, William. Discussion of the authors’ research method and findings. 2008.