A Search for Faint Sources of Infrared Excess in the SEIP Catalog

1. NITARP Team

Mentor Astronomer:

- Dr. Varoujan Gorjian (Caltech, Pasadena, California)

Mentor Educator:

- Vincent Urbanowski (Academy of Information Technology & Engineering, Stamford, Connecticut)

Participant Educators:

- Andrea Galloway (Thomas Jefferson High School, Council Bluffs, Iowa)
- Geoff Holt (Madison Metropolitan School District Planetarium, Madison, Wisconsin)
- Noah Kearns (Mitchell High School, Mitchell, Indiana)

2. Abstract

The Spitzer Enhanced Imaging Products catalog (SEIP) contains millions of sources that have been serendipitously imaged as part of other projects. The SEIP contains the largest sample of sources detected at 24 microns fainter than 8th magnitude, many of which may exhibit an infrared excess at that wavelength. Finding an excess of infrared radiation in a source's spectral energy distribution can indicate the presence of dust, which is often an indicator of an interesting evolutionary phase. The dust grains absorb shorter wavelengths of light, heat up, and reradiate that energy in the infrared. This study will build upon the work of three previous studies of infrared excess sources found in the SEIP while attempting to find fainter objects than those surveys had been able to identify. After using the SEIP to find infrared excesses, the sources will then be manually confirmed, discarding any with a signal-to-noise ratio of less than 5. Then, the sources will be inspected visually using the IPAC/NASA Infrared Science Archive (IRSA) Viewer to ensure that the fluxes of the identified sources are free from contamination by nearby objects. Using the distances from the Gaia archive will allow us to concentrate on Galactic

sources, narrowing the focus of this study. This new catalog of infrared excess sources will provide a rich opportunity for further study by current and future infrared telescopes.

3. Background

Almost all information that we have about astronomical objects such as stars and galaxies comes from analyzing the electromagnetic radiation that is emitted from them. Most astronomical objects behave as blackbodies which emit electromagnetic radiation on a continuum of wavelengths depending on the temperature of the object itself. This gives rise to the distinctive blackbody curves of Planck's law as seen in Figure 1.

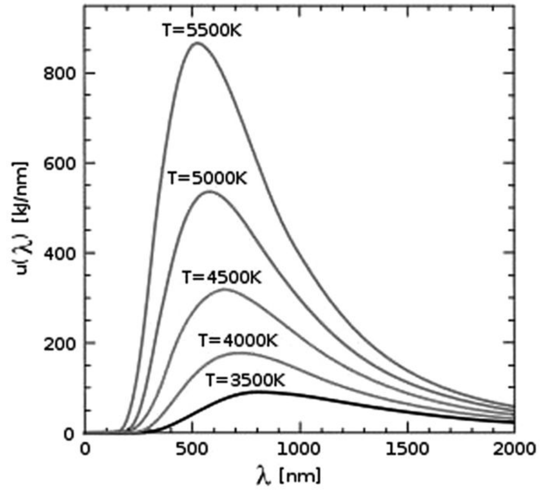


Figure 1: Ideal blackbody radiation curves [Yang, Wei, 2016]

In these curves as the temperature increases there is an increase in the intensity of the light that is emitted and the peak wavelength becomes shorter. It is also important to notice that the Rayleigh-Jeans Tails of the curves in the above plot tend to a horizontal asymptote at longer wavelengths.

This tendency of the curves to flatten is the key to the search for infrared excess. If we observe an astronomical object whose Rayleigh-Jeans Tail region increases instead of decreases, we can infer that the object is not acting as a normal blackbody. This is typical if the shorter wavelength light emitted from the blackbody is absorbed by a dusty envelope surrounding the object which then re-emits the energy in the infrared region. This has the effect of summing multiple blackbody curves which changes the slope in distinctive ways such as those seen in figure 2.

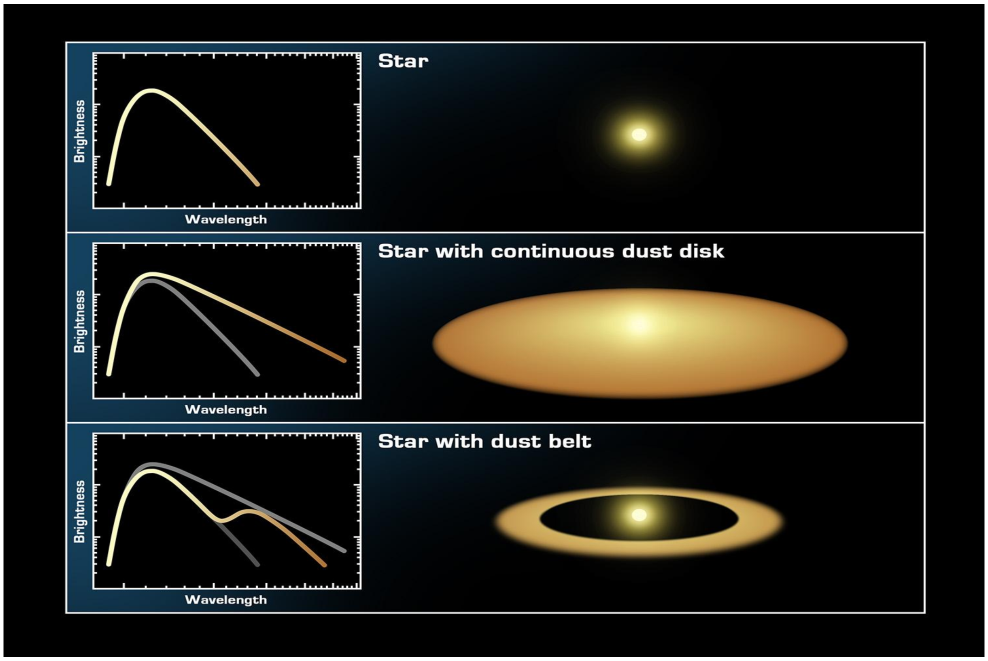


Figure 2: In the top panel, the star follows a typical blackbody curve. In the middle panel, the light coming from the star and disk show an excess of infrared light compared to a perfect blackbody. The bottom panel shows a blackbody curve with an infrared excess as well, but the excess is not uniform due to the gap between the star and the disk. Credit: NASA/JPL-Caltech/T. Pyle (SSC)

3.1 Sources of Infrared Excess

3.1.1 Young Stellar Objects

Dust-shrouded stellar objects are often found in the nebulae in which they formed. This process starts when a nebula begins to collapse after some initial trigger such as radiation pressure from a nearby star or a shock wave from a supernova. As the nebula collapses the core begins to heat up as the gas loses its potential energy. This core is now called a Young Stellar Object or YSO. These YSOs are still surrounded by dust from the nebula that has not yet collapsed. This sets up a situation in which we expect to find infrared excess where the shorter wavelengths emitted by the newly formed star are absorbed and re-emitted at longer wavelengths. Further, the blackbody curves we see for these YSOs depends on the arrangement of dust around them, as shown in Figure 3.

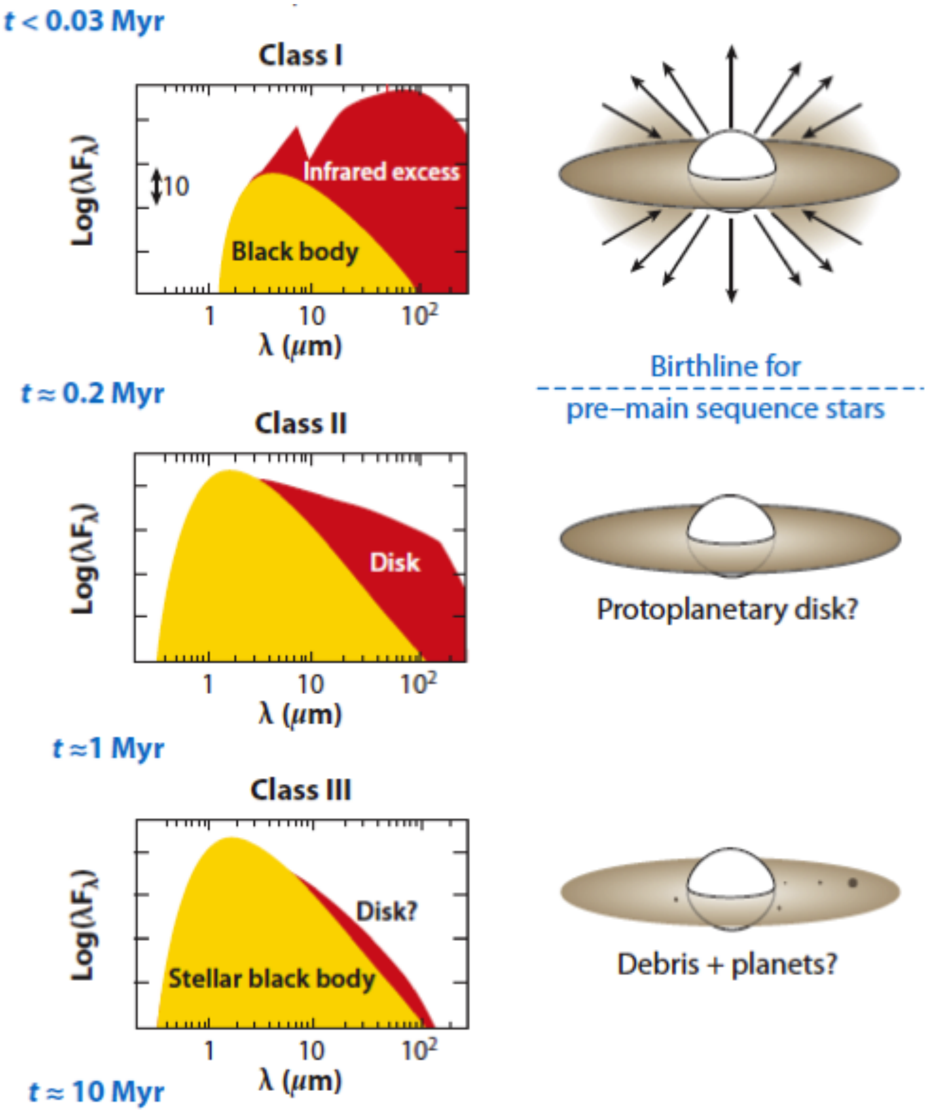


Figure 3: The deviation from the expected SED for each class of star formation is shown above. The red represents the infrared excess exhibited in each stage, and the pictures to the right show what that stage of star formation looks like. [Madison, 2017]

3.1.2 Main Sequence Debris Disks

Star formation is a messy process. Not all of the material in the cloud is accreted into the star. A main sequence star can exhibit infrared excess if a debris disk has formed due to dust released from comet sublimation and asteroid collisions. This dust can absorb radiation from the main sequence star and re-emit it in the infrared. H.H. Aumann et al. [1984] describe the process of using this infrared excess to detect a debris shell of dust around Vega by looking at the infrared photometry taken by IRAS. Su et al. [2005], using *Spitzer* observations, definitively showed that it is a dust disk imaged face-on, since we are looking down at Vega's pole. This is illustrated in figure 4**.**

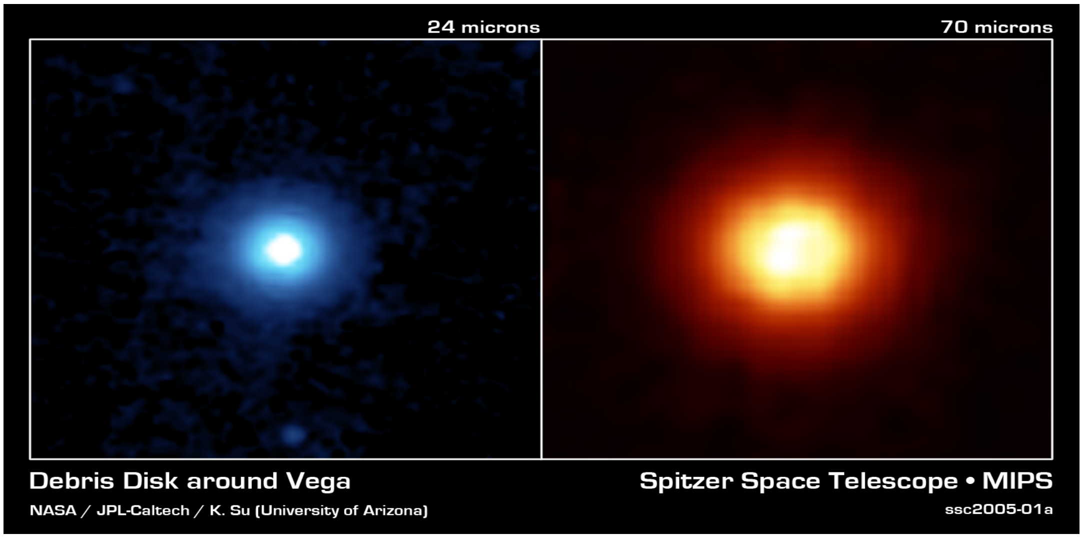


Figure 4: This figure shows two different images of the star Vega, one representing the energy detected at 24 microns and one representing the energy detected at 70 microns. The debris disk around the star is visible in both wavelengths. [Su, 2005]

3.1.3 Evolved Stars

As a star of less than 10 M ☉ evolves off of the main sequence phase, they enter the Asymptotic Giant Branch (AGB) of the Hertzsprung-Russell Diagram, depicted in Figure 5 below.

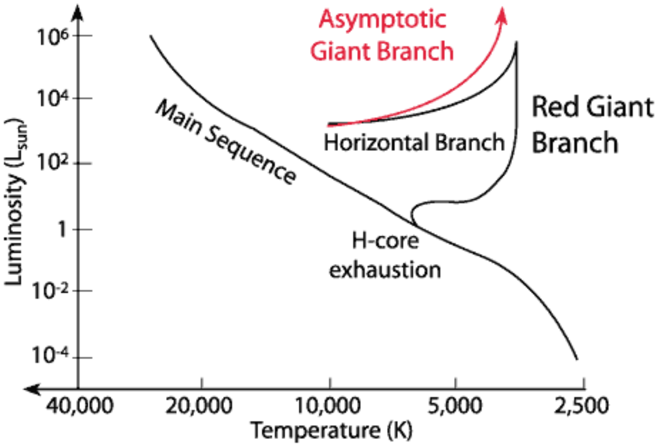
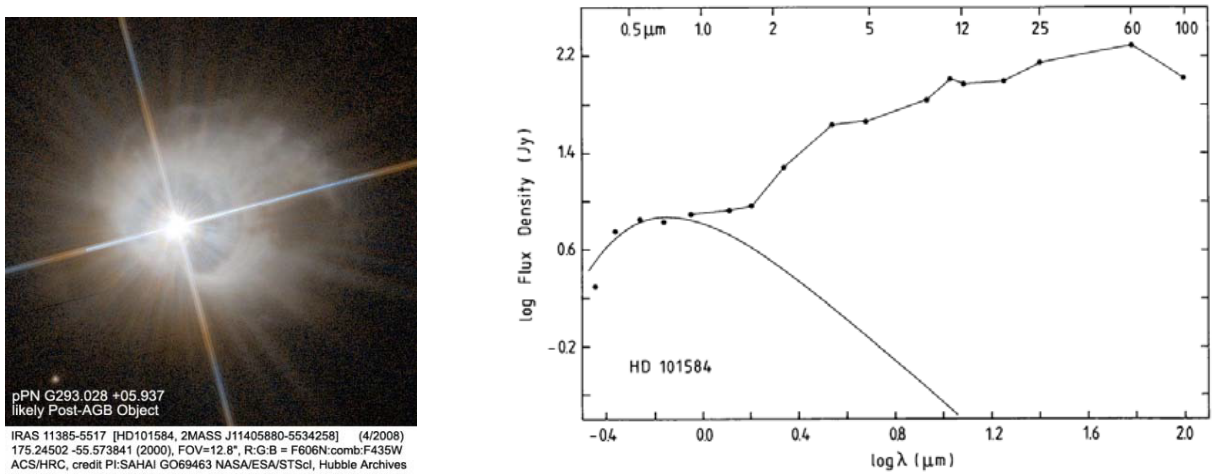


Figure 5: This figure depicts the location of evolved stars on the HR Diagram, referred to as the Asymptotic Giant Branch.
[Isbell, 2003]

During this period the star swells as its core becomes hotter until a superwind phase occurs. Once this happens the star will lose 20 to 80 percent of its mass from the outer layers that are less strongly bound to the core by gravity. As this gas cools, the heavier elements will condense into dust. This provides another situation in which the star will end up with a spectral energy distribution (SED) showing infrared excess. This is well illustrated by the star HD101584 in Figure 6.



IRAS 11385-5517 [HD101584, 2MASS J11405880-5534258] (4/2008)
175.24502 -55.573841 (2000), FOV=12.8", R:G:B = F606N:comb:F435W
ACS/HRC, credit PI:SAHAI GO69463 NASA/ESA/STScI, Hubble Archives

Figure 6: Right: The SED of post AGB star HD101584 [Parthasarathy, Pottasch, 1986]. Left: Hubble image showing the dust cloud enveloping the star.

Of particular interest are post-AGB stars high above the Galactic plane. These objects are intriguing because their distance from star-forming regions within the galactic disk is difficult to reconcile with their age. That is, the time required for stellar evolution from birth to AGB to ultimate collapse is too brief an interval for covering such vast distances without invoking extraordinary velocities that are difficult to explain.

3.1.4 Active Galactic Nuclei

A typical large galaxy has a supermassive black hole in its center. If a large amount of gas is falling toward the supermassive black hole, an accretion disk will form. The gas will become quite hot and will emit radiation, which will be absorbed and then re-emitted by the surrounding dust as infrared radiation. This luminous central region is now known as an active galactic nucleus (AGN). The contribution of the dust emission appears as excess infrared in the SED, which can be distinctive, allowing identification as an AGN on a color-color diagram as discussed by Stern et al. [2005]. Figure 7 shows this color-color diagram.

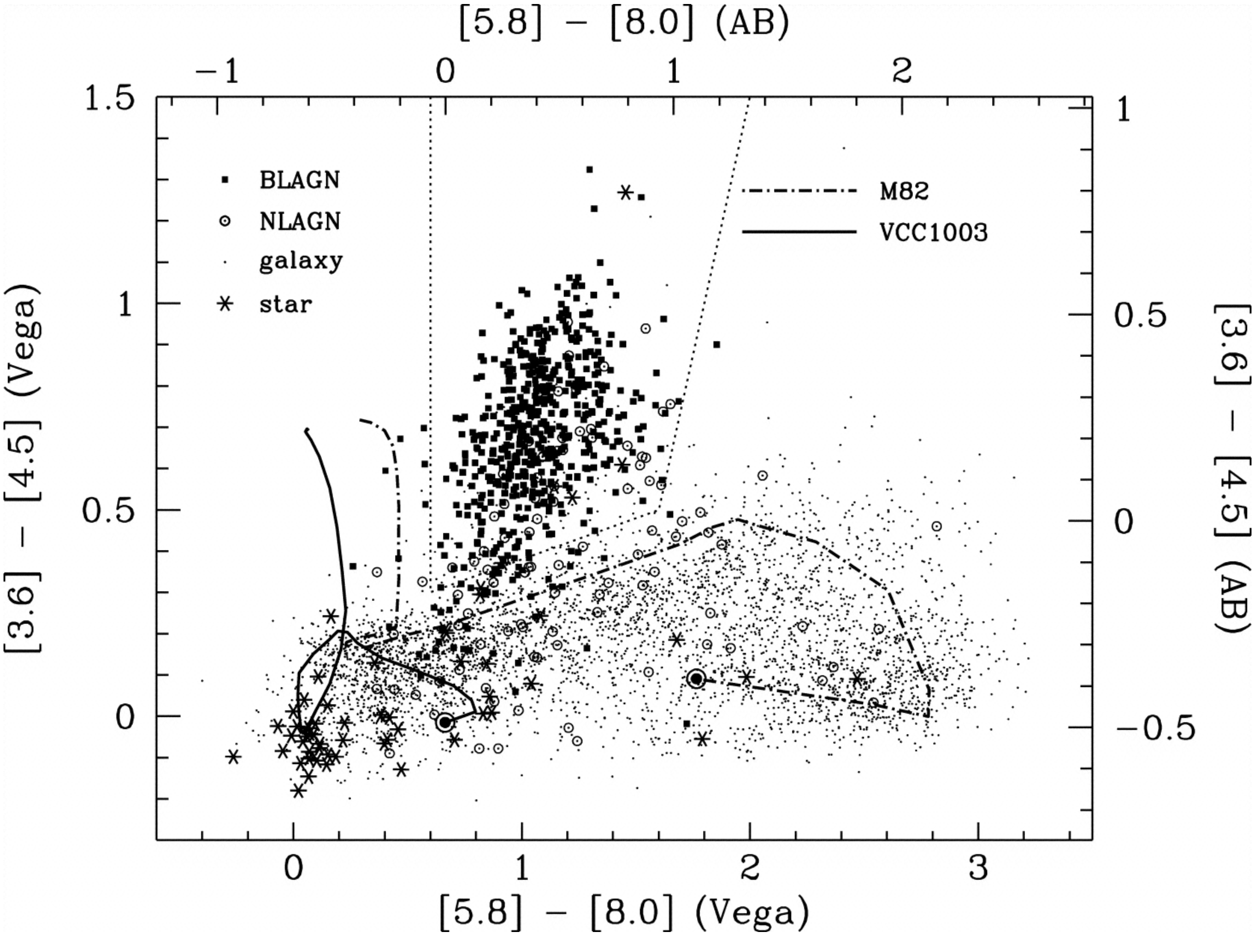


Figure 7: Colors of sources spectroscopically identified from the AGES survey of the Boötes field. Axes are labeled for both the Vega and AB magnitude systems. The dotted line in the top half separates active galaxies from quiescent galaxies and Galactic stars. BLAGN - broad line; NLAGN - narrow line. [Stern, 2005]

3.1.5 Luminous Infrared Galaxies

The gravitational pull between galaxies causes them to interact, collide, and combine. Galaxies not only contain billions of stars, but also large quantities of gas and dust. Galaxy interactions disrupt these clouds of gas and dust, sparking a high rate of star formation (starburst), and can cause large volumes of gas to be funneled in toward the center of the galaxies, resulting in the central cores becoming AGN. Both of these phenomena cause dust to be heated, making them luminous infrared galaxies (LIRGs) or ultraluminous infrared galaxies (ULIRGs), producing an infrared excess [Sanders et al 2009]. See Figure 7 above.

3.2 Identifying Infrared Excess

To find sources with infrared excess deviations from a blackbody curve, we will create color-color diagrams from the photometric data taken by the Spitzer Space Telescope. For this project we will use the relative magnitudes of sources taken with Infrared Array Camera (IRAC) at 3.6 and 4.5 µm, as well as Multi-band Imager and Photometer for Spitzer (MIPS) at 24 µm as they are among the most sensitive channels for *Spitzer*.

In order to create a color-color diagram, we will determine the ratios of the magnitudes of sources in various channels. Since these magnitudes are given as logarithms, the ratios can be found as the difference of the magnitudes. If for instance, as in Figure 8, we calculate [3.6]-[4.5] and [4.5]-[24] and plot the results as an (x,y) graph we would expect all blackbody sources to cluster near the origin (0,0). Sources significantly far from the origin in a positive direction show an infrared excess. Sources with infrared excess that are outside the main set of points will be selected for further investigation, including visual inspections. We will also be able to differentiate, based on the location of the object on this color-color diagram, whether the dust is hot or cool depending on which way the object falls relative to the origin.

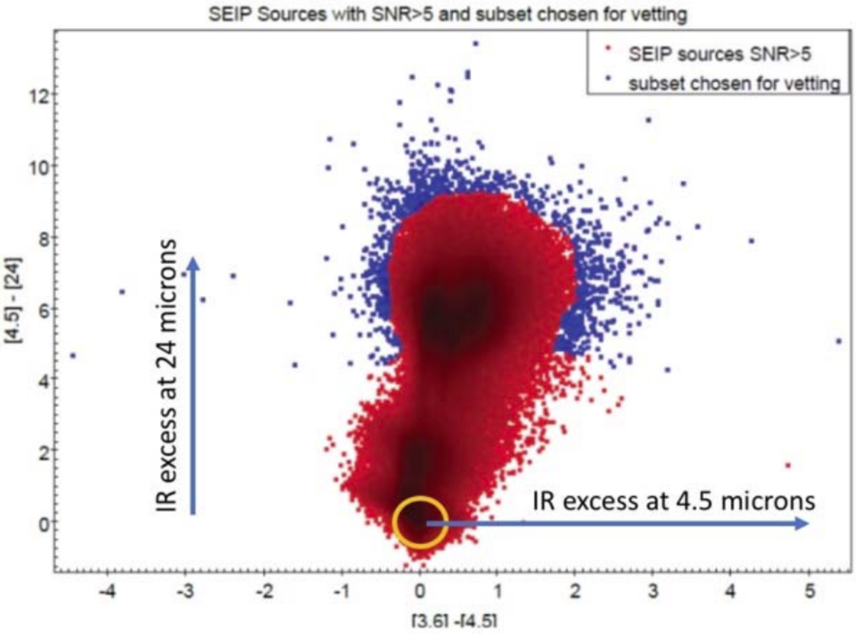


Figure 8: A color-color diagram created by Rowe et al. [2018]. The blue colored sources will be selected for visual inspection because they separate the most from the main set of infrared excess points. The circle indicates the origin.

3.3 Spitzer Enhanced Imaging Products Catalog

The Spitzer Enhanced Imaging Products Catalog (SEIP) catalog is a collection of all the images taken during the Spitzer Space Telescope's cryogenic mission. It includes data from the Infrared Array Camera (IRAC) at 3.6, 4.5, 5.8, and 8 μm as well as the Multiband Imager and Photometer for Spitzer (MIPS) at 24 μm. Overall the SEIP contains data for approximately 42 million sources, most of which were incidental to the intended target and have thus never been studied. Using data from the SEIP catalog has advantages over using data from other sources, such as the Wide-field Infrared Survey Explorer (WISE) mission for instance. The primary advantage is that there are many sources in the SEIP that are fainter than the WISE mission was able to detect.

4. Science

4.1 Objectives

As described above, this project will continue and refine the work done by Strasburger et al. (2015), Rowe et al. (2017) and Goeldi et al (2018). with the basic science goal of identifying sources of IR excess fainter than magnitude 8 in the MIPS 24 μm channel. This restriction is to avoid duplicate detection by teams using the WISE data. We will use the same method as described by Goeldi et al. In addition to identifying sources of infrared excess using the *Spitzer* data, this project will attempt to cross-check sources with data from Gaia. In the Goeldi et al study, many of the sources had to be removed from the final catalog because the reliability of their flux couldn't be verified visually. Our work will benefit from their efforts to identify a bug in the IRSA viewer, which has now been fixed. Using the Gaia archive, the distances to these objects can be determined, which allows this team to determine the luminosities of the Galactic subset of these objects.

4.2 Methods

The analytical method employed by this effort is described below to identify possible sources:

1. Filter the SEIP catalog sources using the following criteria:
    a. S/N ≥ 5 for IRAC I1 (3.6 μm), I2 (4.5 μm), and MIPS M1 (24 μm)
    b. *FluxFlag = 0 for IRAC channels I1 and I2 (minimizes number of sources whose flux density in the IRAC bands may be affected by nearby saturated or extended objects)
    c. *M1_BrtFrac < 0.5 and *M1_ExtFrac < 0.5 (minimizes number of sources whose flux density in the MIPS M1 band may be affected by nearby saturated or extended objects)
    d. MIPS M1 magnitude ≥ 8
2. Generate [I2−M1] vs [I1−I2] color−color diagrams (CCD) from the approximately 360,000 available sources identified in Step 1. The color−color diagrams will be used to identify sources with infrared excess.
3. Ensure the validity of sources showing MIPS M1 infrared excess by visually inspecting the associated IRAC I1, I2, and M1 images. This is required due to the potential presence of image artifacts or saturation, and because the SEIP catalog may not have accurate source matching across wavelengths leading to incorrect matches between the lower resolution M1 24 um and the higher resolution I1 and I2 images.
4. Check for possible Galactic sources with the Gaia satellite data.

5. Identify new sources of infrared excess by eliminating any objects which have already been identified as sources of infrared excess in the Set of Identifications, Measurements, and Bibliography for Astronomical Data (SIMBAD).
6. Produce a final catalog of infrared excess objects for follow−up analyses and observations.

4.3 Expected Outcomes

Previous studies have already begun the process of identifying new infrared excess objects, and this study looks to refine that work in order to build a catalog of verified sources of infrared excess. Filtering the search through the SEIP catalog will result in more accurate results, and utilizing the *Spitzer* 24 micron channel, which is the most sensitive camera at that wavelength flown to date, will help detect fainter sources compared to previous studies. Then, the results will be categorized as either galactic or extragalactic. More can be learned about these sources by finding their distances from Earth in the Gaia database. Further analysis can then be completed by follow-up spectroscopy.

4.4 Data and Tools

- SEIP Catalog (Spitzer Enhanced Imaging Products) - The SEIP includes photometric data from the four channels of IRAC (3.6, 4.5, 5.8, 8 microns) and the 24 micron channel of MIPS on the Spitzer Space Telescope during the cryogenic phase of the mission.
- SIMBAD (Set of Identifications, Measurements, and Bibliography for Astronomical Data) - Used to remove any sources of infrared excess that have been previously identified
- 2MASS (2 Micron All-Sky Survey) - Used to gather additional infrared photometry data and contains over 300 million sources
- NED (NASA/IPAC Extragalactic Database) - Used to cross-correlate astronomical information on extragalactic objects
- DSS (Digitized Sky Survey) - database of optical images used for source identification

- SDSS (Sloan Digital Sky Survey) - Photometric and spectroscopic data to be used for source identification and further investigation
- TOPCAT - Computer program used to process the data that are collected
- IRSA (NASA/IPAC Infrared Science Archive) - Used for visual inspection of the identified infrared excess sources
- Gaia database - Used to find the distances to the Galactic sources

5. Educational Outreach

Andrea Galloway

- Create and supervise an astronomy club at Thomas Jefferson High School.
- Explore the possibility of creating an astronomy-related elective for the science department at Thomas Jefferson High School.
- Provide professional development opportunities for fellow science teachers at Council Bluffs Community Schools' Summer Academy .
- Share findings with my colleagues at Thomas Jefferson High School.

Geoff Holt (Madison Metropolitan School District Planetarium, Madison, Wisconsin)

- Authentic research experiences are rare for high school students, but would be very valuable. Throughout this process, ways to implement student research using archive data will be sought.
- Outreach
  1. Workshops: share the experience with teachers attending in-district science workshops related to the Next Generation Science Standards.
  2. High School Astronomy Club: share the experience with the students in the club throughout the project. Mentor any students who choose to participate.
  3. High School Astronomy Class: share the experience with the students in the class throughout the project. Mentor any students who choose to participate.

4. Great Lakes Planetarium Association: present a paper at a conference sharing the NITARP experience.
5. Wisconsin-Iowa-Minnesota Planetarium Society: share the experience through a presentation at the spring meeting.

Noah Kearns (Mitchell High School, Mitchell, Indiana)

- Bring NITARP students to yearly festival to set up a telescope and talk to festival goers about astronomy and their experiences.
- Present to local science teachers about involving students in authentic research at the Mitchell Public Library.
- Take part in a local radio interview with NITARP students about our research experiences.
- Present to the Mitchell Community School Board about the importance of doing authentic research in schools.
- Bring what I learn about accessing astronomy data and calculation tools to bear in the astronomy classes I teach at Mitchell High School.

Vin Urbanowski

- Develop mathematics curriculum addressing Common Core State Standards via astronomy applications.
- Identify math prerequisites/obstacles for success with college astronomy and develop math lessons in context to address these and improve STEM (Science, Technology, Engineering & Math) college readiness for high school students.
- Share/co-develop the above with science and math teacher colleagues in my school.
- Share the above with the math & science community in my school district.
- Develop “portable” astronomy/data projects that can be implemented by teachers on their own.

- Share the above in presentations at AAPT (American Association of Physics Teachers), NSTA (National Science Teachers Association) and NCTM (National Council of Teachers of Mathematics) regional and national conferences.
- Use new learning and resources from NITARP (NASA/IPAC Teacher Archive Research Program) participation within my current teaching portfolio.

References

Aumann, H.H., Gillett, F.F., Beichman, C.A., DeJong, T., Houch, J.R., Low, F.J., Neugebauer, G., Walker, RG, Wesselius, P.R. 1984. Discovery of a Shell Around Alpha Lyrae. \apj 278:L23-L27

Goeldi N., Friedlander-Holm D., Gorjian, V., Nowinski, M., Rutherford, T., Sperling, A., 2018, A Search for Faint Sources of Infrared Excess in the Spitzer Enhanced Imaging Products Catalog Presented at the American Astronomical Society, AAS Meeting #233, id.#162.02

Isbell, Douglas. 2003. NOAO Press Release 03-07: Astronomers Identify Source of Major Class of Supernova Explosions.
Retrieved from https://www.noao.edu/outreach/press/pr03/sb0307.html

Maddison, S., 2017. Astronomy Online- Classifying YSO's. Retrieved from:
http://astronomy.swin.edu.au/~smaddiso/teaching/yso.html

Parthasarathy, M., Pottasch, S.R., 1986. The far−infrared (IRAS) excess in HD 161796 and related stars. \aap 154, L16–L19.

Rowe, J.L., Duranko, G., Gorjian, V., Lineberger, H., Orr, L., Adewole, A., Bradford, E., Douglas, A., Kohl, S., Larson, L., Lascola, G., Orr, Q., Scott, M., Walston, J., Wang, X., 2017. A Search to Uncover the Infrared Excess (IRXS) Sources in the Spitzer Enhanced Imaging Products (SEIP) Catalog. Presented at the American Astronomical Society Meeting Abstracts #231, p. #151.02.

Sanders, D. B.; Kartaltepe, J. S.; Kewley, L. J.; U, Vivian; Yuan, T.; Evans, A. S.; Armus, L.; Mazzarella, J. M., 2009. Luminous Infrared Galaxies and the “Starburst-AGN Connection". 2009ASPC..408....3S http://adsabs.harvard.edu/abs/2009ASPC..408....3S

Stern, D., Eisenhardt, P., Gorjian, V., Kochanek, C., Caldwell, N., Eisenstein, D., Brodwin, M., Brown, M.J.I., Cool, R., Dey, A., Green, P., Jannuzi, B., Murray, S., Pahre, M.A., Willner, S.P., 2005, Mid-Infrared Selection of Active Galaxies. \apj 631:163-168

Strasburger, D., Gorjian, V., Burke, T., Childs, L., Odden, C., Tambara, K., Abate, A., Akhtar, N., Beach, S., Bhojwani, I., Brown, C., Dear, A., Dumont, T., Harden, O., Joli−Coeur, L., Nahirny, R., Nakahira, A., Nix, S., Orgul, S., Parry, J., Picken, J., Taylor, I., Toner, E., Turner, A., Xu, J., Zhu, E., 2015. Identification and Classification of Infrared Excess Sources in the Spitzer Enhanced Imaging Products (SEIP) Catalog. Presented at the American Astronomical Society Meeting Abstracts #225, p. 336.26.

Yang, X. and Wei, B. Exact research on the theory of the blackbody thermal radiation. Sci. Rep. 6, 37214; doi: 10.1038/srep37214 (2016).

Links

2MASS: https://www.ipac.caltech.edu/2mass/

POSS: http://cas.sdss.org/dr7/en/proj/advanced/skysurveys/poss.asp

SDSS: http://www.sdss.org/

SEIP: https://irsa.ipac.caltech.edu/data/SPITZER/Enhanced/SEIP

SIMBAD: http://simbad.u−strasbg.fr/simbad/

TopCat: http://www.star.bris.ac.uk/~mbt/topcat/

IRSA Viewer: https://irsa.ipac.caltech.edu/irsaviewer/