A Search to Uncover the Infrared Excess (IRXS) Sources in the Spitzer Enhanced Imaging Products (SEIP) Catalog

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Abstract
The Spitzer Enhanced Imaging Products (SEIP) catalog is a collection of nearly 42 million point sources from approximately 600 sq. degrees of the sky obtained by the Spitzer Space Telescope during its 5+ year cryogenic mission. Strasburger et al. (2015) isolated sources with a signal to noise ratio (SNR) > 10 in five IR wavelength channels (3.6, 4.5, 5.8, 8, and 24 μm) to begin a search for sources with infrared excess (IRXS). They found 76 objects that were never identified as having an IRXS. Based on this success, we intend to dig deeper into the catalog in an attempt to find more IRXS sources; specifically, by lowering the cutoff for the SNR on the 3.6, 4.5, and 24 μm channels. A preliminary filtering of the database at SNR > 5 yielded 186,000 sources. We will examine the results of various SNR cutoffs until we get a large and reliable set of IRXS candidates by plotting color-color diagrams. After verifying the candidates with a visual inspection and cross-referencing them against known sources in existing databases, we will be left with a list of highly reliable IRXS sources. These sources will prove important in the further understanding of galaxy and stellar evolution. Once identified, they will serve as a starting point for closer study by scientists interested in this area of astronomical research.

Background

I. Infrared Excess (IRXS) and its Detection

An object that exhibits infrared excess (IRXS) will have a spectral energy distribution (SED) curve with a slope in the infrared wavelengths that does not match the expected blackbody curve of a source at a particular temperature. Figure 1 shows an example of an IRXS for a star with a dust disk and a dust belt. The shorter wavelength radiation emitted by the star is captured by the dust and re-emitted in the IR wavelengths, which are on the right side of the curve (the Raleigh-Jeans tail).

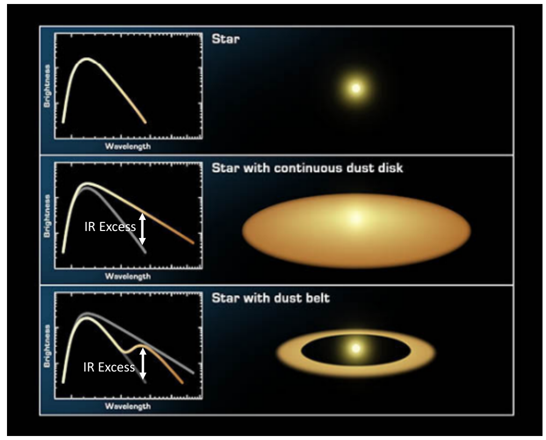

Figure 1 Dust surrounding a hot body results in a Rayleigh_Jeans tail with slope different from that of a single temperature black body. (Artist rendition by T. Pyle (SSC)). IR excess noted with white arrow.

We will primarily use the Spitzer Enhanced Imaging Products (SEIP) (Teplitz et al. 2012) to detect both galactic and extragalactic sources with IRXS. The SEIP contain some 42 million source detections collected during the cryogenic phase of the Spitzer Space Telescope's mission. Spitzer's complement of instruments includes the Infrared Array Camera (IRAC) and the Multiband Imaging Photometer for Spitzer (MIPS). IRAC has four cameras with broadband filters centered at 3.6, 4.5, 5.8, and 8 µm. MIPS has three cameras that image using three broadband filters, centered at 24, 70, and 160 µm. During its cryogenic phase, Spitzer's instrumentation performed at high efficiency and collected data with unprecedented sensitivity. (Werner et al., 2004). The depths to which Spitzer could probe in the infrared were many orders of magnitude greater than any prior astronomical study (Gehrz et al., 2007). The SEIP include Super Mosaics (combining data from multiple programs where appropriate) and a Source List of photometry for compact sources. The primary requirement on the Source List is very high reliability -- with areal coverage, completeness, and limiting depth being secondary considerations. The SEIP include data from the four channels of IRAC (3.6, 4.5, 5.8, 8 µm - designated I1, I2, I3, and 14 respectively) and the 24 µm channel of MIPS (designated as M1).

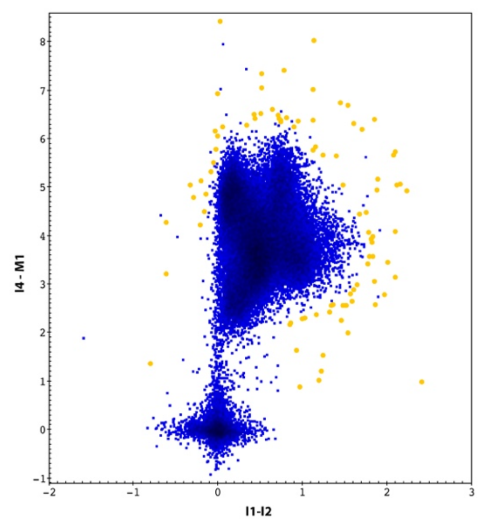

Figure 2 Example of a color-color diagram (Strasberger et al. 2015)

Since Spitzer's cameras cover only infrared (IR) wavelengths, we will not have access to full spectrum data like the graphs in Figure 1. Instead, we will plot color-color diagrams to detect IRXS (see Figure 2). In figure two the yellow dots represent items with extreme IRXS which were tagged for further follow up by Starasberger et al (2015). With an IR color-color diagram, if the location of the object is up and to the right of the origin, then the object has IRXS. For each signal to noise (SNR) value we choose, we will generate color-color diagrams using [I1-I2] values to represent the x axis and [I4-M1] as values on the y axis.

II. Sources of IRXS

Current theory shows several different kinds of objects that emit this IRXS: a) Young Stellar Objects (YSO), b) Debris Disks, c) Evolved Stars (AGB), d) Active Galactic Nuclei (AGN), and e) various luminous infrared galaxies (LIRG's). For each of these categories there are many known examples. The SEIP provides a large potential sample of new discoveries and may provide examples of rare and transitional stages for each of the following classes of IRXS objects. The catalog generated from this project will be the ideal source for future follow-up and identification of these rare stages.

a. Young Stellar Objects

YSO's are stars in the earliest stages of development and may be surrounded by a disc of primordial dust not yet expelled or by a debris field caused by the collision of forming protoplanets. In either case, the surrounding material is heated by the star or protostar and the target will be expected to exhibit IRXS. (Mendoza and Eugenio 1966). (Figure 3)

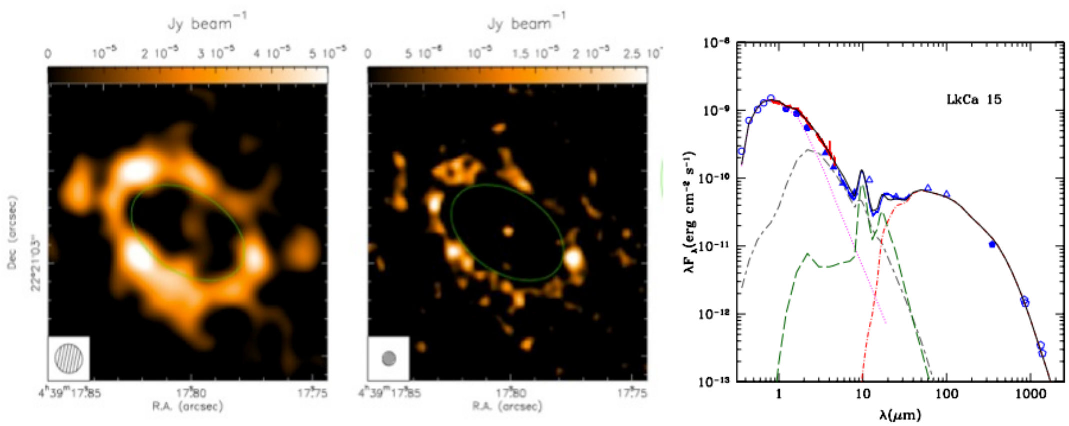

Figure 3 Radio image (left from Isella et al. 2014) and SED for YSO LK Ca 15 IRXS (right) that was used to identify an inner disk separated by a gap from an outer disk. (Espalliat et al. 2010)

b. Debris Disk

Main sequence stars can contain circumstellar debris disks which can be detected as IRXS. IRXS at 24 μm in these debris disks is thought to be a sign that rocky planets, like those in our own solar system may have formed (Morales et al. 2011). The creation and subsequent elimination of debris disks is short lived (in astronomical time scales), and makes this stage hard to find. To date, only 370 debris disks have been identified using 24 μm emission (Figure 4).

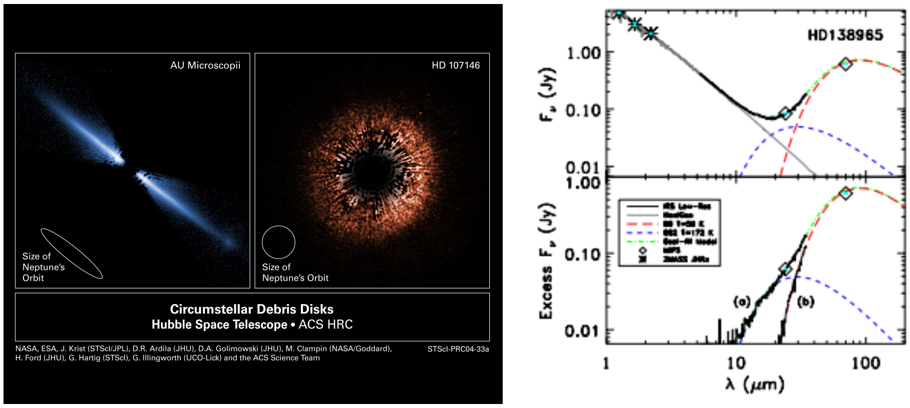

Figure 4 Visible image (left) of two debris disks around sun-like stars AU Microscopii and HD 107146 (Hubble Press release 2004-33) and SED of debris system HD138965 (right); Top: Photosphere plus IRXS and bottom) photosphere subtracted with a fit for two component warm dust emission (Morales et al. 2011)

c. *Evolved Stars (AGB)*

While making a transition off of the asymptotic giant branch (AGB) of a typical H-R diagram, aging stars enter a superwind phase where a large amount of their mass is blown off. Dust, which forms in the ejecta, absorbs the optical light from the star and then will re-emit infrared radiation. (Wallerstein and Knapp 1998) resulting in an IRXS. (Figure 5)

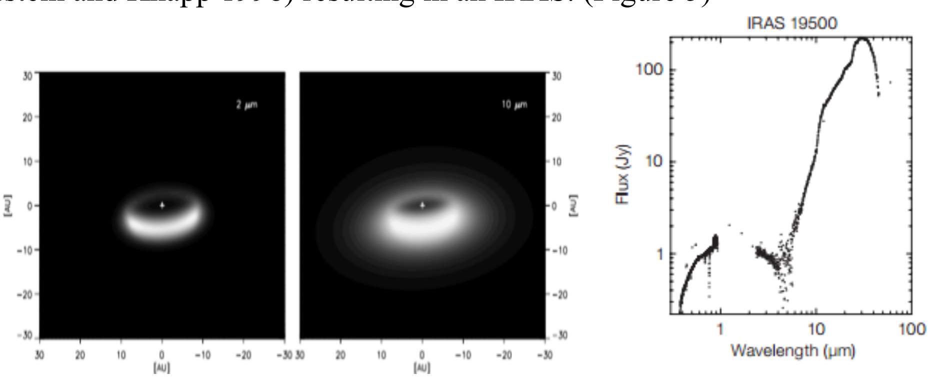

Figure 5 The circumbinary disc of the post-AGB star IRAS 08544-4431 (left) with image constructed from interferomteric observations at 2 and 10 microns (Deroo et al. 2007) and the SED for a post-AGB object (right) with a detached shell and elliptical morphology. Note the high IRXS (Lagadec et al. 2011)

d. *Active Galactic Nuclei (AGN)*

At the center of each galaxy there is a supermassive black hole. IRXS has been demonstrated as a successful technique for identifying active galactic nuclei. Gas from the galaxy forms an accretion disk enshrouded by a dusty torus which also originates from the galaxy. (Antonucci 1993). When the SED is examined for the AGN, this torus will show an IRXS due to the energy being radiated by the heated dust.(Figure 6)

e. *Various Luminous Infra-Red Galaxies (LIRG)*

Within the realm of extragalactic sources that could show an IRXS, the most significant contributions may lie in the discovery of hyper luminous IR galaxies (HyLIRG's) and ultra-luminous IR galaxies (ULIRG's). The extremely high luminosities of ULIRG's are believed to be produced by high rates of star formation coupled with Active Galactic Nuclei (AGN) activity which serves to significantly heat dust within these sources. These highly luminous galaxies are believed to be an early stage of galactic collision during which new star formation occurs at a high rate. In addition, during accelerated star formation, large amounts of gas accrete onto the supermassive black hole generating massive amounts of energy that heats the surrounding dust resulting in a HyLIRG. Such activity is believed to be short-lived as evidenced by the relatively small number of sources being identified as HyLIRG's (Wu, et al., 2012) by the Wide-Field Infrared Survey Explorer (WISE) all sky survey (Wright, et al., 2010). HyLIRGs are identified by their SEDs which are hotter than other dust obscured galaxies (DOGs) and so are called Hot DOGs. The SEDs of ULIRGs and the more common luminous infrared galaxies (LIRGs) often fall into the DOG category as identified by Dey et al. (2008). (Figure 6)

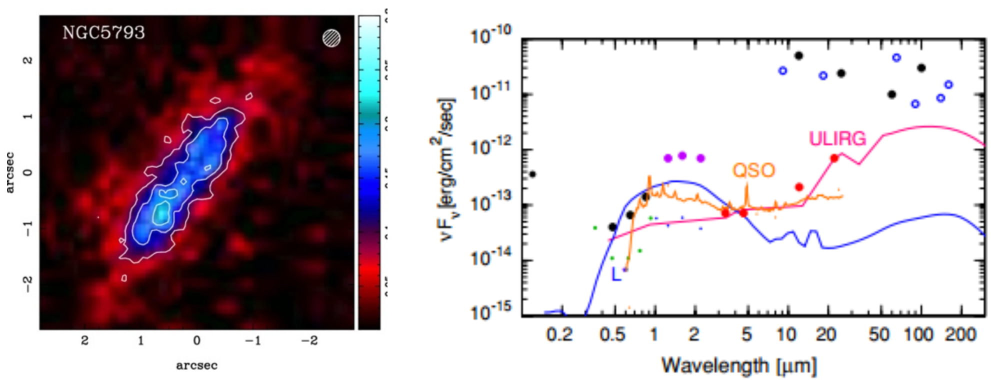

Figure 6 Mid-IR image of AGN NGC 5793 (left, Alonso-Herrero et al. 2016) and SED (right) for a ULIRG (red) and an AGN (orange, QSO) showing the preponderance of radiation in the infrared as compared to an L galaxy (blue) (Wright et al. 2010).*

Scientific Goals

1. Sort the SEIP catalog by using SNR > 5 for the most sensitive IRAC channels I1, I2, and the most sensitive channel from MIPs , M1. (Exclude data from previous surveys and sources close to the galactic plane.
2. Generate color-color diagrams for these sources and identify sources with IRXS.
3. Insure the validity of sources showing IRXS at the M1 channel by visually inspecting these sources using the higher resolution of the I1 and I2 channels.
4. Categorize the remaining sources as Galactic or Extragalactic based on their brightness where *as a general rule* the brighter sources will be Galactic (I1<14 mag)(YSO, Debris Discs, Evolved Stars), and the fainter sources will be extragalactic (I1>14 mag)(LIRGs, Ulirgs, Hylirgs and AGN). (Strasberger et al 2015)
5. Identify new sources of IRXS by filtering out known sources using the Two Micron All Sky Survey (2MASS), the Set of Identifications, Measurements, and Bibliography for Astronomical Data (SIMBAD), and the Palomar Observatory Sky Survey (POSS).

Expected Outcomes

Like the original 2014 SIRXS survey, our goal is to identify a significant number of previously unknown sources of IRXS in the SEIP catalog. We expect to find IRXS objects that were not detected by Strasburger et al (2015), due to their high SNR cutoff. By using the lower SNR, we expect to find objects that are further away, fainter, or both. The final version of the infrared excess sources will then be available for follow-up study. Some new sources will certainly be found to represent previously identified objects. Some known sources will be re-characterized as having previously unknown IR excesses. Finally, some sources will be possible candidates for IRXS objects not previously known. These newly categorized sources could have a great significance for target selection for future observations by any telescope, including the James Webb Space Telescope (JWST).

Archived data/Instruments

This project will rely primarily on data in the SEIP catalog. We will also utilize 2MASS, SIMBAD, the NASA/IPAC Extragalactic Database (NED) and Palomar Optical Sky Survey (POSS). It may be necessary to include additional shorter wavelength photometric data to properly graph the hotter component of the SED for some objects, which is necessary before an IRXS deviation can be determined. In such instances, we will use data at 2 µm from 2MASS which is included for each source in the SEIP catalog. This whole sky survey concluded collecting data in 2003, which it did from ground based telescopes at two locations, Mt. Hopkins, Arizona for the Northern Hemisphere and Cerro Tololo InterAmerican Observatory, Chile, for the Southern Hemisphere. We may also need to confirm data by referencing images taken at 0.893 µm from the tenth major data release, or DR10, of the Sloan Digital Sky Survey (SDSS), a large ground based sky survey at the Apache Point Observatory in New Mexico.

References

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Education Goals

Gary Duranko, Salem High School:

- Present our work/advertise this program at the 2017 New England Fall Astronomy Festival (NEFAF)
- Revise the Salem High School Astronomy curriculum and research component to reflect the NITARP experience. This will include not only our team research topic, but other learned subjects such as variable stars, and neglected double stars.

- Present our work at a SHS department meeting, with the idea that teachers of other subjects might find similar programs to engage their students in experiential learning opportunities.

Howard Lineberger: Durham Academy, North Carolina

- Presentation of NITARP activities to Durham Academy students, local astronomy clubs and at state, regional, and perhaps national level NSTA meetings
- Training sessions covering techniques learned during NITARP with colleagues at local public schools and at the North Carolina School of Science and Math
- Follow-up our SIRXS catalogue findings with further astronomical research with Durham Academy students.
- Using IPAC and other archived data to do a variety of space science projects.
- Establishment of a summertime, high school level astronomy and planetary science outreach opportunity at Durham Academy
- Apply for funding for unique, high quality science opportunities for high school students all over the Raleigh/Durham, Chapel Hill area of NC in partnership with either astrophysics faculty at Duke University and/or UNC-Chapel Hill, and/or with the educational outreach program at the Morehead Planetarium, to develop a free Space Studies program available to all interested high school students in our area

Jamie Rowe: Bethlehem Central High School, Delmar, NY

- I intend to report to my science research students at regular intervals about the progress of our research.
- I intend to report to the whole student body of BCHS upon completion of the NITARP experience via one of the High Schools regularly scheduled Science Today Lecture s.
- I plan to make a presentation to our school board about the experience.
- I will also offer to speak for other groups such as the local rotary clubs.
- I would like to use this experience to become a mentor myself to students in our Science Research courses to encourage more of our students to pursue research in astronomy.
- I would also like to offer professional development to other teachers to expose them to the databases and authentic science data that is available to them from IPAC.

Laura Orr: Ukiah School, Ukiah, Oregon

- Outreach and presentation of work will be shared at the annual Oregon Science Teacher Association convention, with local school boards, the regional Educational Service District board, and members of the greater Oregon GOSTEM Hub.
- Throughout the study, Mrs. Orr intends to look into the effects of the program on teacher work, future aspirations, and influence on teaching style in all classes.
- Will be tracking student efforts and views of the topic, process, and science career aspiration throughout the project focusing on the questions of how effective the long term study and level of work with this type is with students – does it really work for motivations and interest in the science process and field or perhaps discourage and frustrate?