WISE Identified Young Stellar Objects In BRC 38

Team C-CWEL

(**C**ontinuing **C**ool **W**ISE **E**xp**L**oration of BRC 38)

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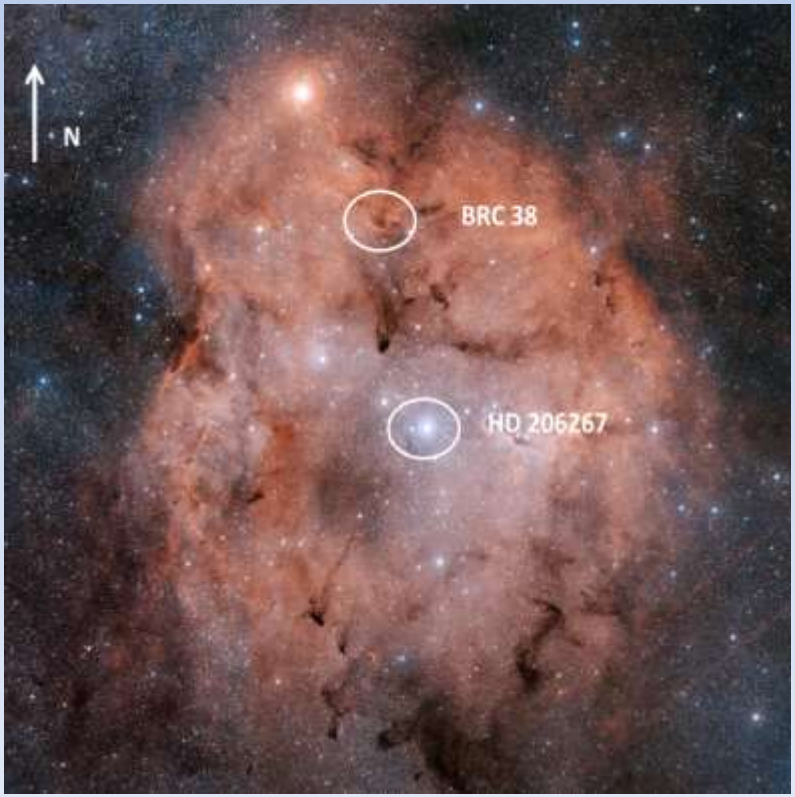
Goal

Use data from the **Wide-field Infrared Survey Explorer (WISE) catalog** to **expand the search for young stellar objects (YSOs)** to a **20 arcminute radius from the center of BRC 38**, located in the north of the **molecular cloud IC1396 at 21:40:42 +58:16:13**.

The **central 5’ x 5’ portion** of this region has been **previously studied** using **Spitzer (IR), Chandra (X-ray), 2MASS (IR), and optical (including Hα)** observations

This study greatly expands the field and uses data from the WISE (IR) catalog



Background – Bright Rimmed Clouds

Bright rimmed clouds (BRCs) are **dense clumps of gas and dust within HII regions at the edges of relatively old (>10 million years) molecular clouds**. While BRCs are dark, their **rims are optically bright due to illumination by nearby O or B stars**.

Many BRCs show **evidence of active star formation, possibly triggered by the ionizing radiation from nearby O or B class stars**. The large molecular cloud **IC 1396 is home to eleven BRCs and star formation is** thought to be driven by **ionizing radiation from HD 206267, a class O6.5V star**

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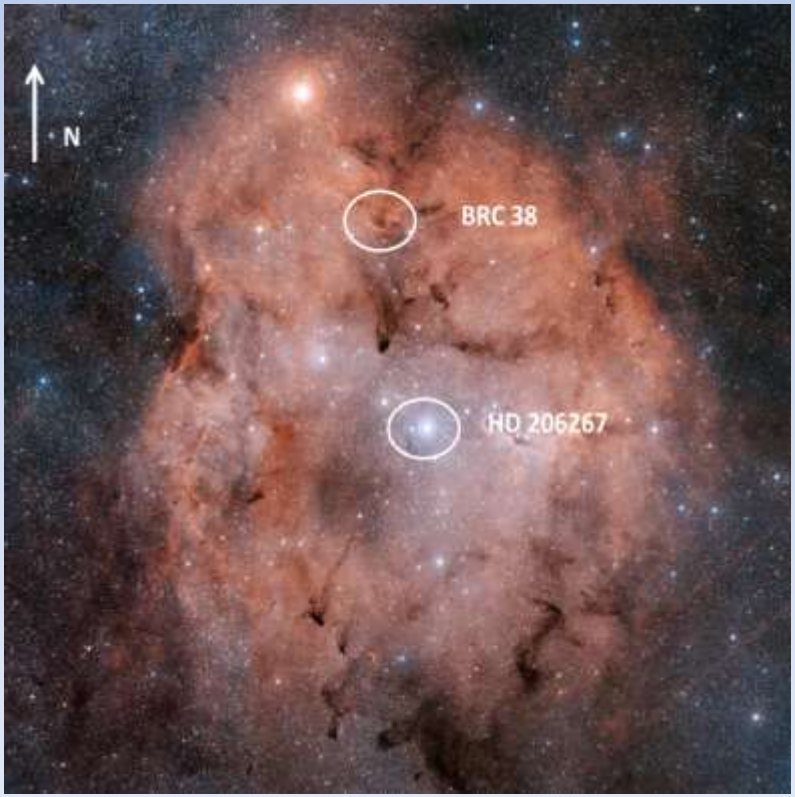
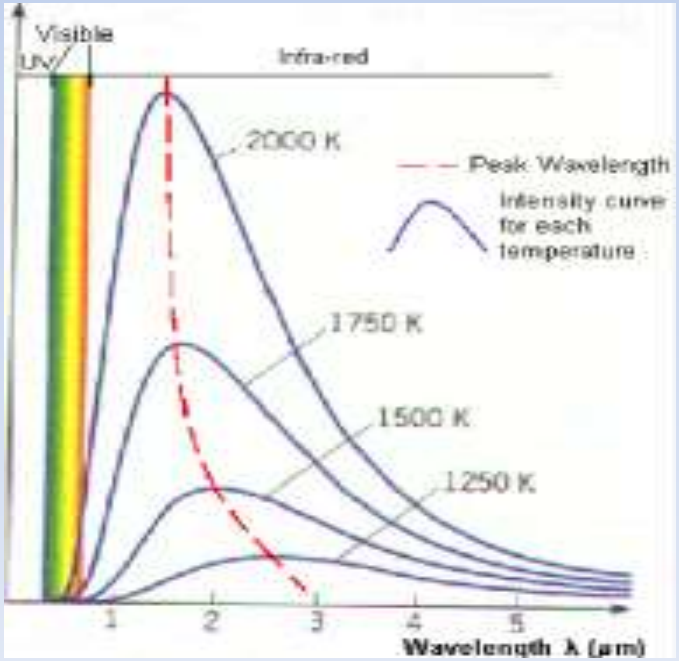


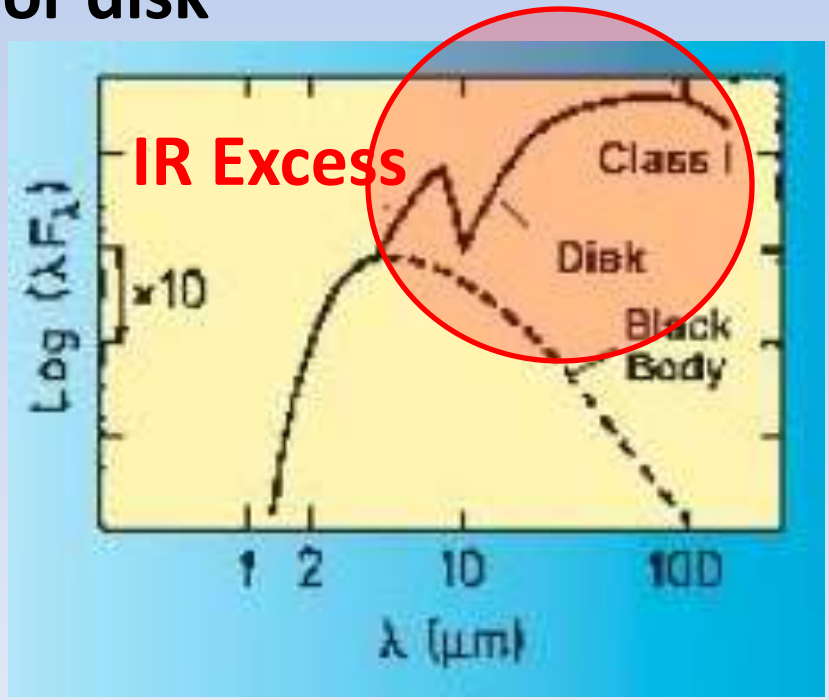
Background – Young Stellar Objects

- **Young stellar object (YSO)** is a collective term for any **stellar object in the early stage of star development**
- **A given BRC may contain YSOs exhibiting a wide range of developmental stages, with YSO ages decreasing with distance from ionizing star**
- **Most radiation emitted by a YSO is absorbed by the surrounding circumstellar dusty cocoon and/or protostellar disk**
- As a result, **YSOs characteristically display excess IR radiation as the dust is warmed by this radiation**
- The **amount and wavelength of the excess IR emissions** is **suggestive of the amount of circumstellar dust, and therefore the stage of development for a given YSO**

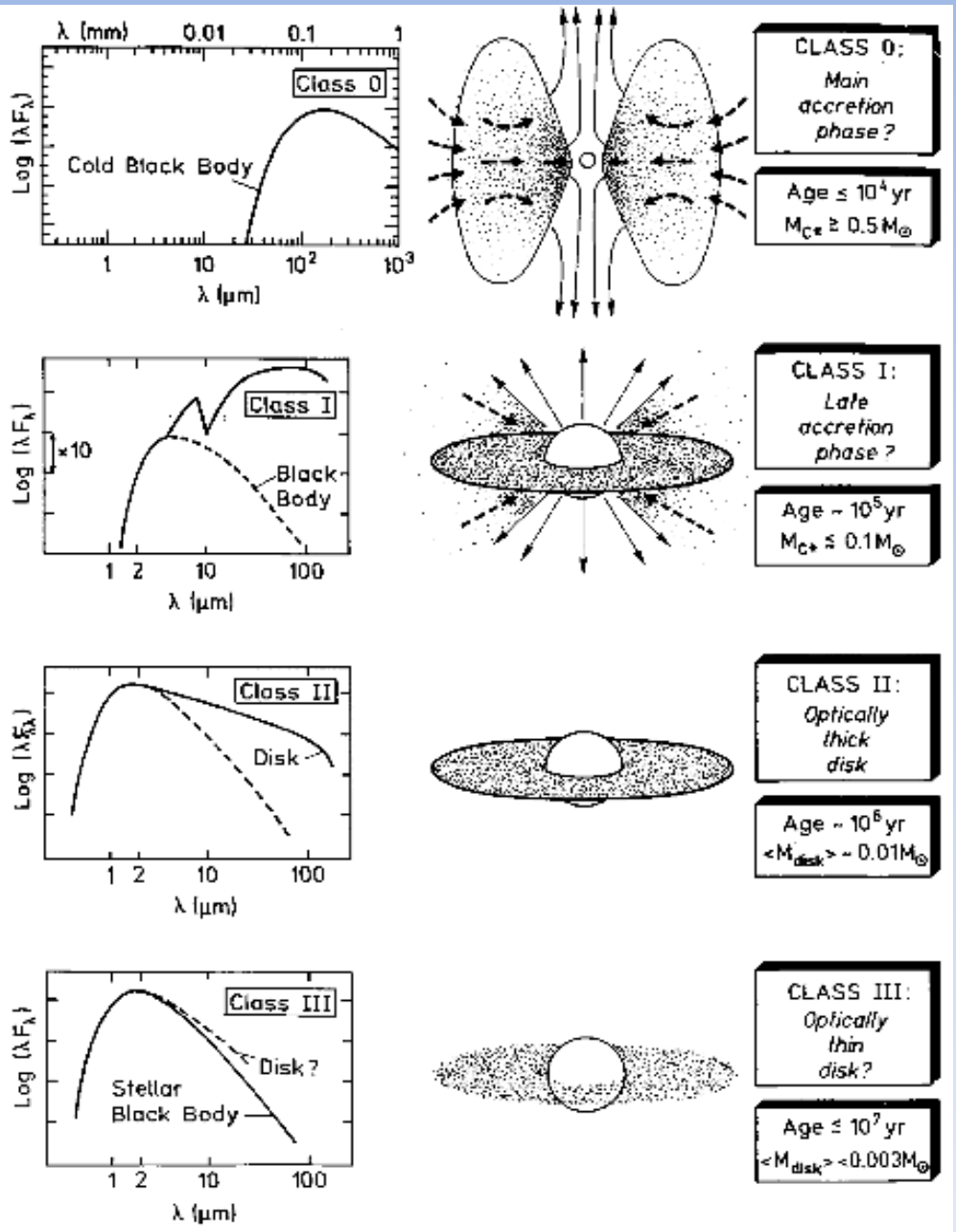
Background – Spectral Energy Distributions

- A **spectral energy distribution (SED) plots energy (y-axis) against wavelength (x-axis)**
- The **SED of a main sequence star is similar to that of a blackbody** according to its surface temperature
- The **SED of a YSO** exhibits an **excess of IR energy (between 2-24 μm) resulting from heat emitted by the surrounding dusty cocoon or disk**



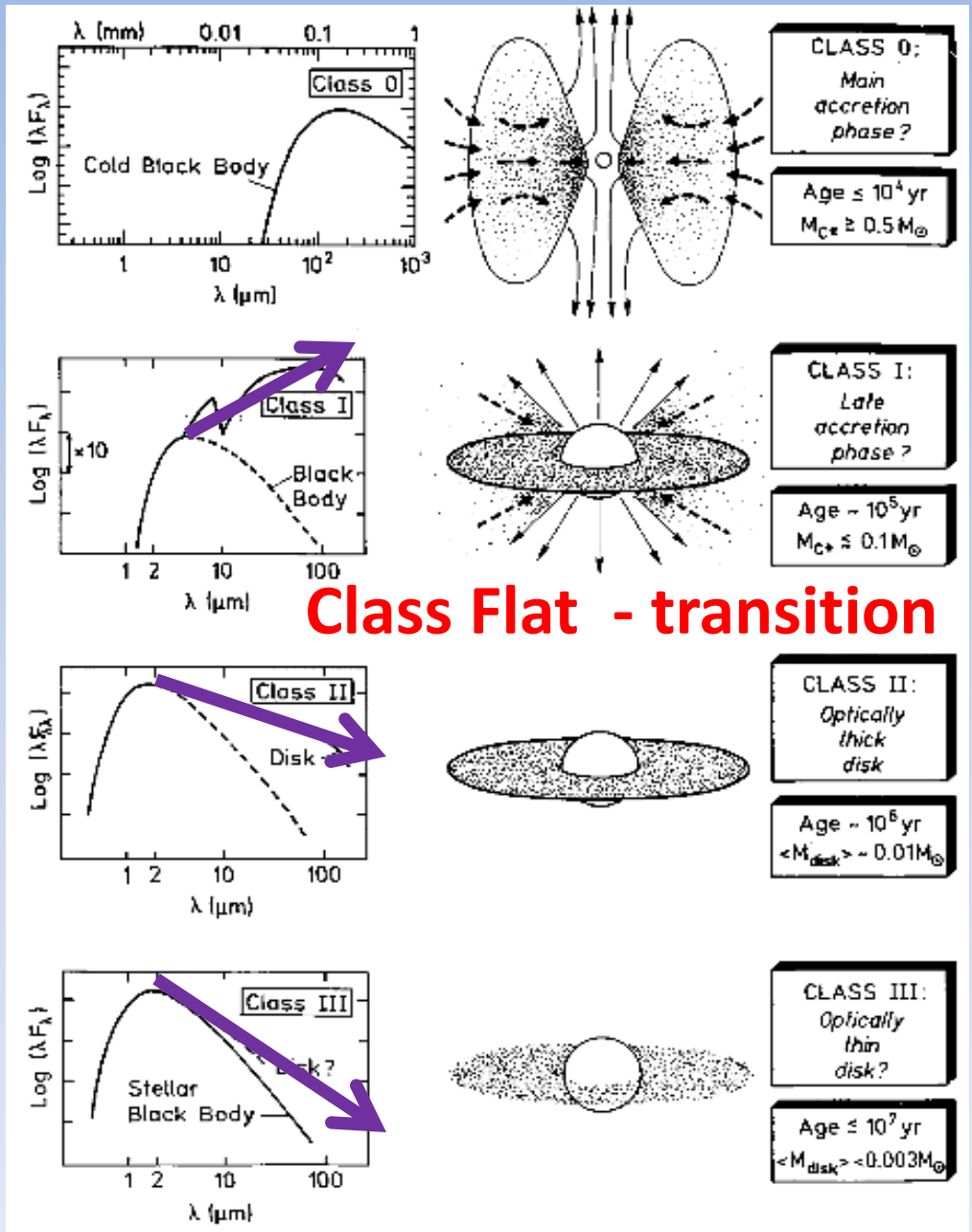


Background – YSO Classes / Development



- The **slope of the excess IR portion of the SED** (2-24 μm) **determines the class** of a low-mass YSO
- The **class** of a low-mass YSO is a **possible indication of its developmental phase**
- **Younger YSOs typically emit more IR radiation** (young YSOs are usually **surrounded by more dust**)
- Eventually the **dust dissipates** and the YSO **emits more like a blackbody**
- **Once H begins to fuse into He, the YSO transitions to a main sequence star**

Background – YSO Classes / Development



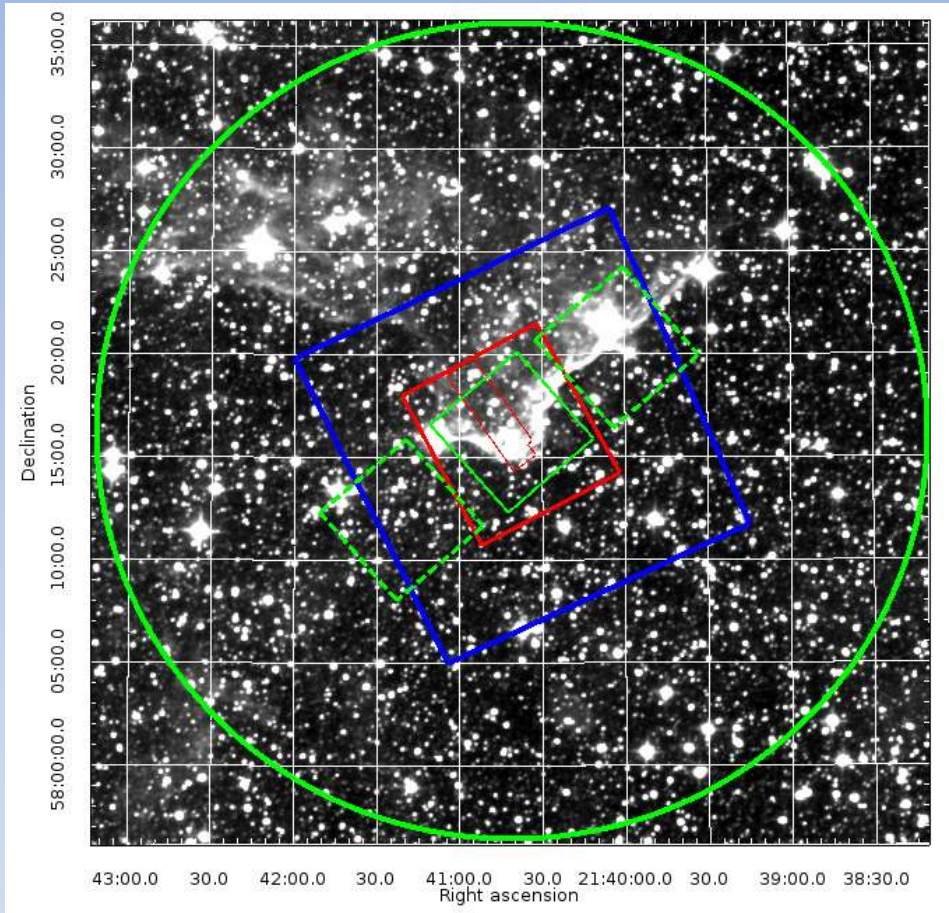
- **Class 0:** main accretion phase - cold blackbody (no IR excess); rare - very, very young (less than 10,000 years)
- **Class I:** slope >+0.3; age ~100,000 years
- **Class Flat:** slope between +0.3 and -0.3
- **Class II (Classical T Tauri):** slope -0.3 to -1.6; age ~1,000,000 years
- **Class III (Weak-lined T Tauri):** slope <-1.6; age ~10,000,000 years

Instruments / Catalogs

1. **WISE (Wide-field Infrared Survey Explorer)**
   - Primary data source
   - WISE 1 [3.4 μm], WISE 2 [4.6 μm], WISE 3 [12 μm], WISE 4 [22 μm]
2. **Spitzer (IR Array Camera and Multiband Imaging Photometer for Spitzer)**
   - IRAC 1 [3.6 μm], IRAC 2 [4.5 μm], IRAC 3 [5.8 μm], IRAC 4 [8 μm]
   - MIPS [24 μm]
3. **2 MASS (Two Micron All Sky Survey)**
   - J [1.25 μm], H [1.65 μm], K_s [2.17 μm]
4. **Isaac Newton Telescope (optical)**
   - r' [0.624 μm], Hα [0.656 μm], i' [0.774 μm]
5. **Other optical**
   - b [0.44 um], v [0.55 um], r [0.71 um], i [0.79 um]

Region of Interest - BRC 38

WISE 22μm image



Region of interest (20’ radius)

Spitzer (4 IRAC bands)

(Left) Spitzer IRAC 2 (4.8μm) & 4 (8 μm)

(Right) Spitzer IRAC 1 (3.6μm) & 3 (5.8 μm)

Spitzer MIPS (24μm)

Spitzer MIPS (70μm)

Chandra (x-ray)

The optical data from Chauhan et al. (2011), Choudhury et al. (2010), Ogura et al. (2002), and the deep JHK data from Beltrán et al. (2009) are largely within the region of IRAC 4-band coverage. The large blue box in the center is the Chandra field of view discussed in Getman et al. (2007).

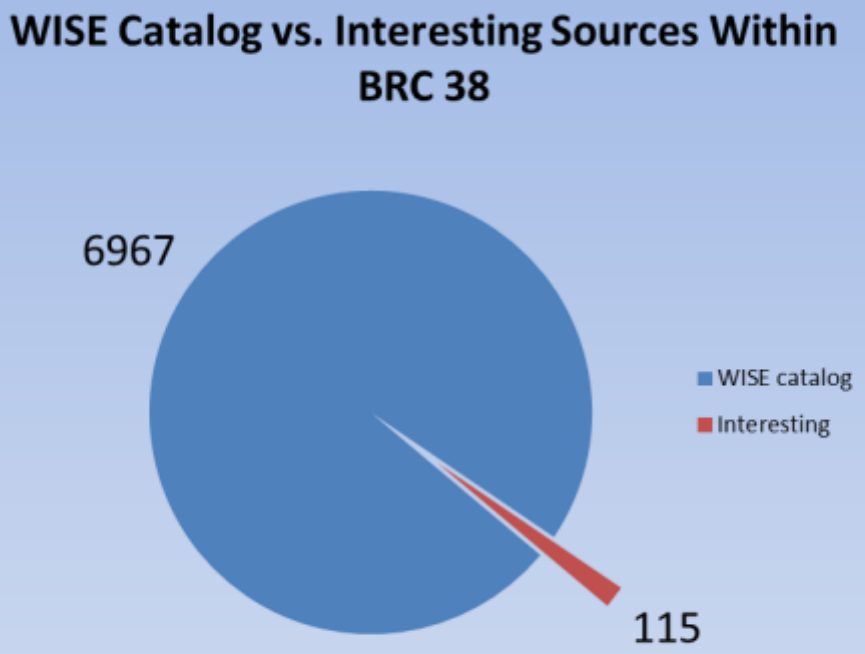
Methodology

1. From a population of nearly 7000 sources within the WISE catalog in the region of interest, we used color cuts to select possible YSOs based on likely IR excess colors
2. Sources previously mentioned in the literature were included within the sample - These sources, together with sources exhibiting IR excess from the WISE catalog, are considered sources of interest
3. The sources were plotted on multiple color-color and color magnitude diagrams
4. We visually inspected images of all sources of interest in POSS, 2MASS, Spitzer and WISE (when available) to determine if they resolve into single sources

Methodology

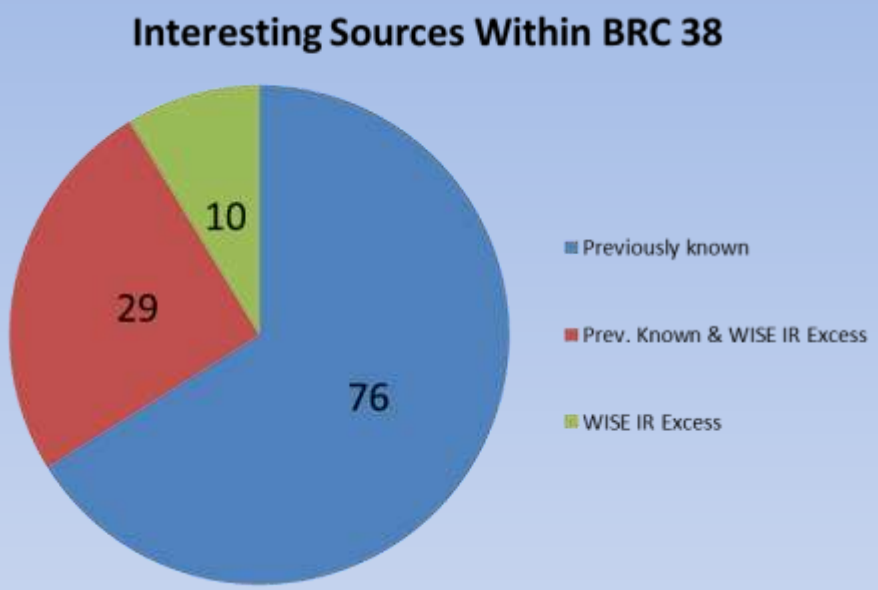
5. We constructed SEDs for each source of interest – catalog magnitudes were generally utilized, however new photometry was done on some sources with Spitzer data
6. Each source of interest was classified based on image inspection, and the slope of the IR excess portion of the corresponding SED - Their positions on color-magnitude and color-color diagrams were used as corroborating evidence
7. All sources were assigned a confidence score based on the quality and quantity of imagery and available data, as well as giving consideration to the types of previous studies done
8. We compared our classifications against those of previously known sources
9. The location of the highest confidence level sources were plotted on an image of BRC 38

Methodology – YSO Selection



Of the nearly 7000 sources within the WISE catalog, 115 exhibited IR colors consistent with those of YSOs and were therefore considered to be of interest:

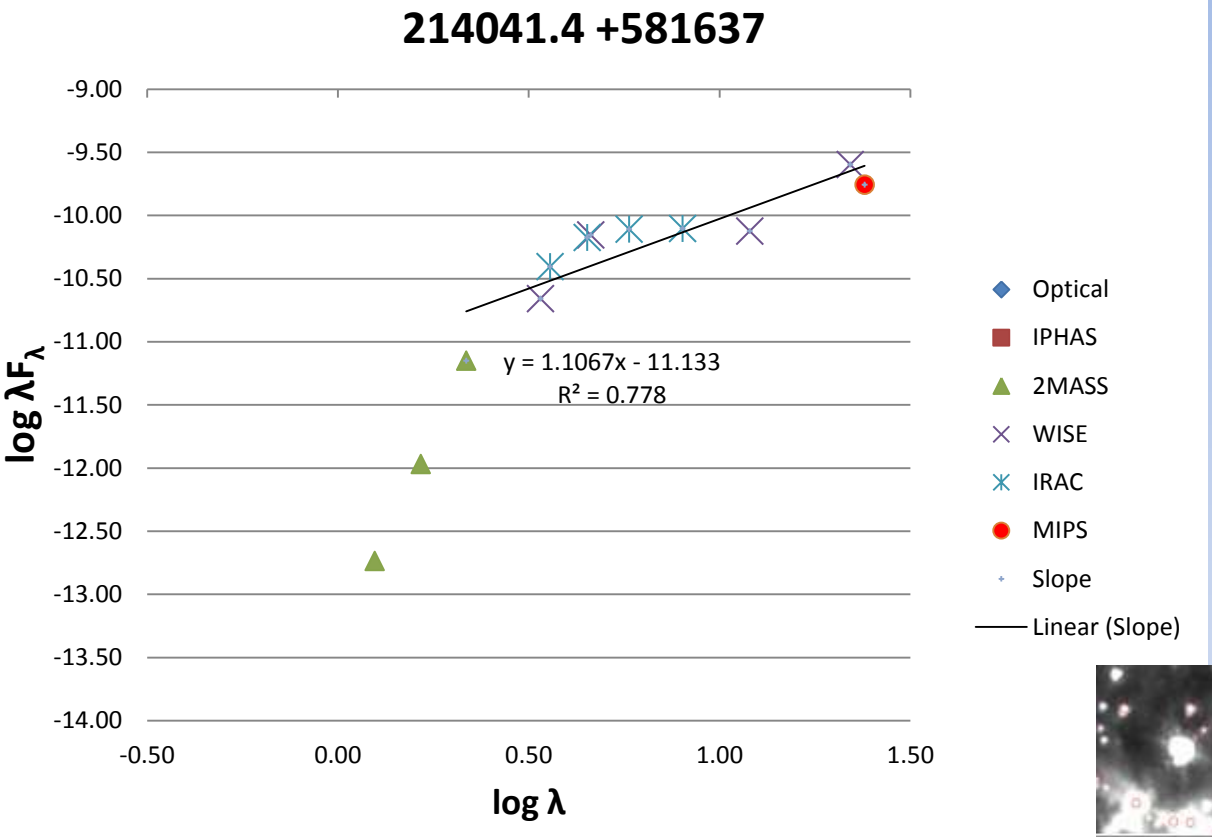
Methodology – YSO Selection

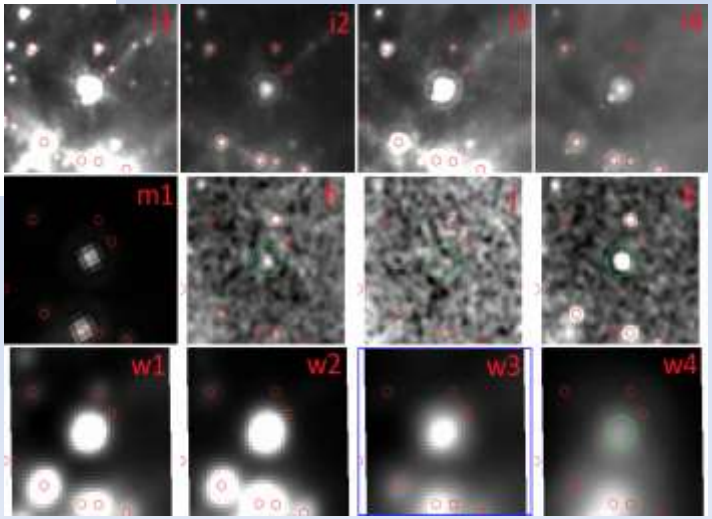


Of the nearly 7000 sources within the WISE catalog, 115 exhibited IR colors consistent with those of YSOs and were therefore considered to be of interest:

- Main sequence stars, active galactic nuclei, shock emission knots, resolved structured PAH emission, and background galaxies were filtered out using an updated version of the IR color selection scheme developed for the WISE catalog by Koenig et al. (2012)
- 105 sources were previously known
- 39 sources exhibited excess IR excess
- 10 sources exhibited IR excess, but were not previously known

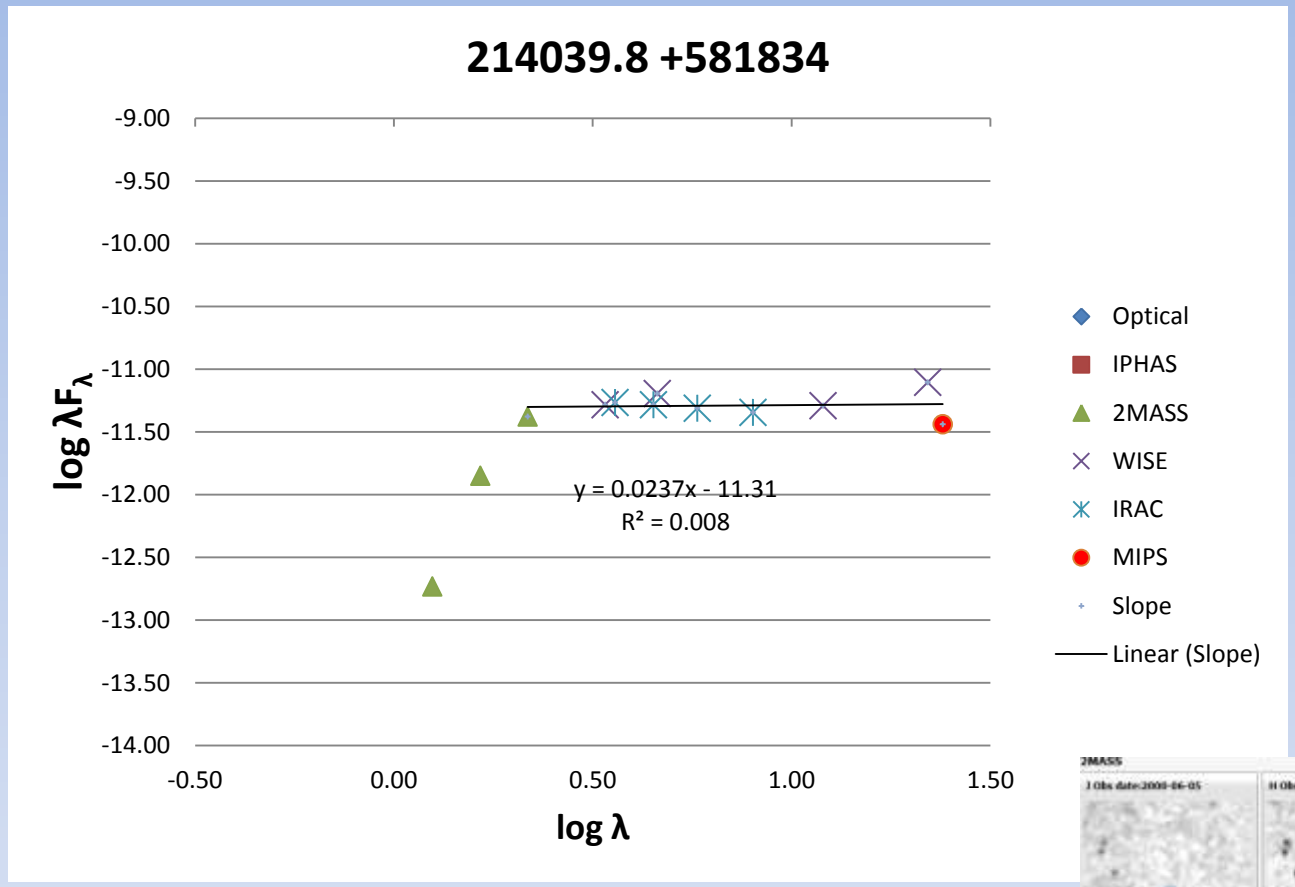
Methodology – Example Classification

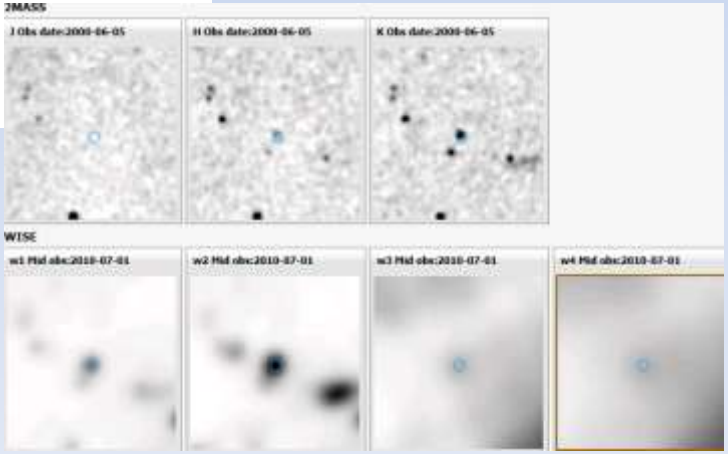




Class I

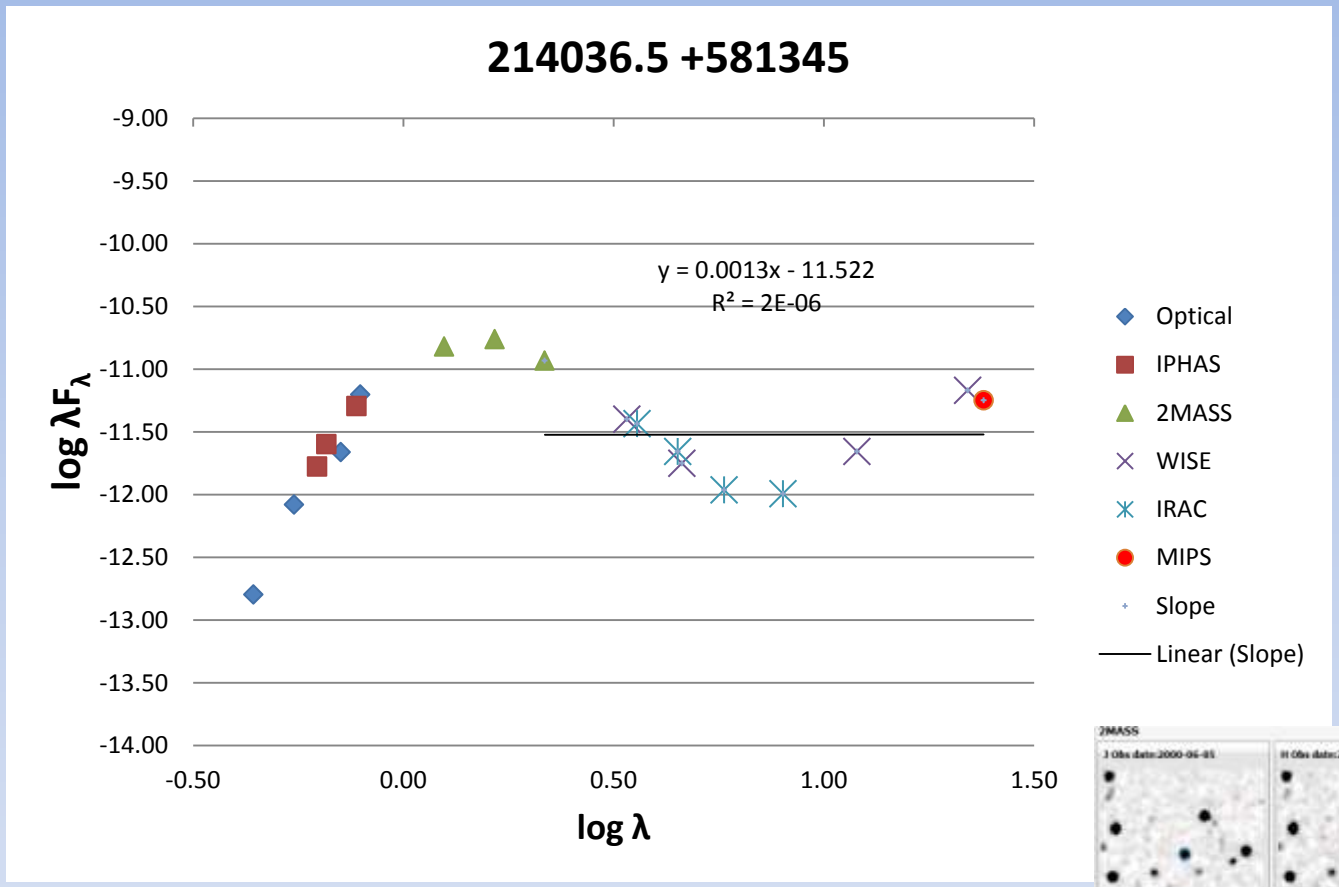
Methodology – Example Classification

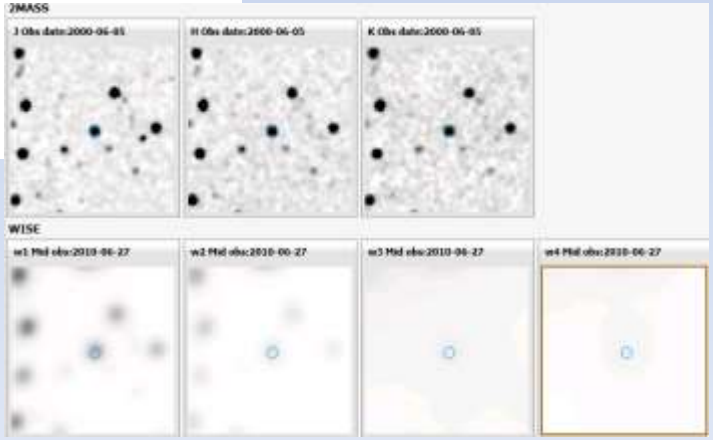




Flat Class

Methodology – Example Classification

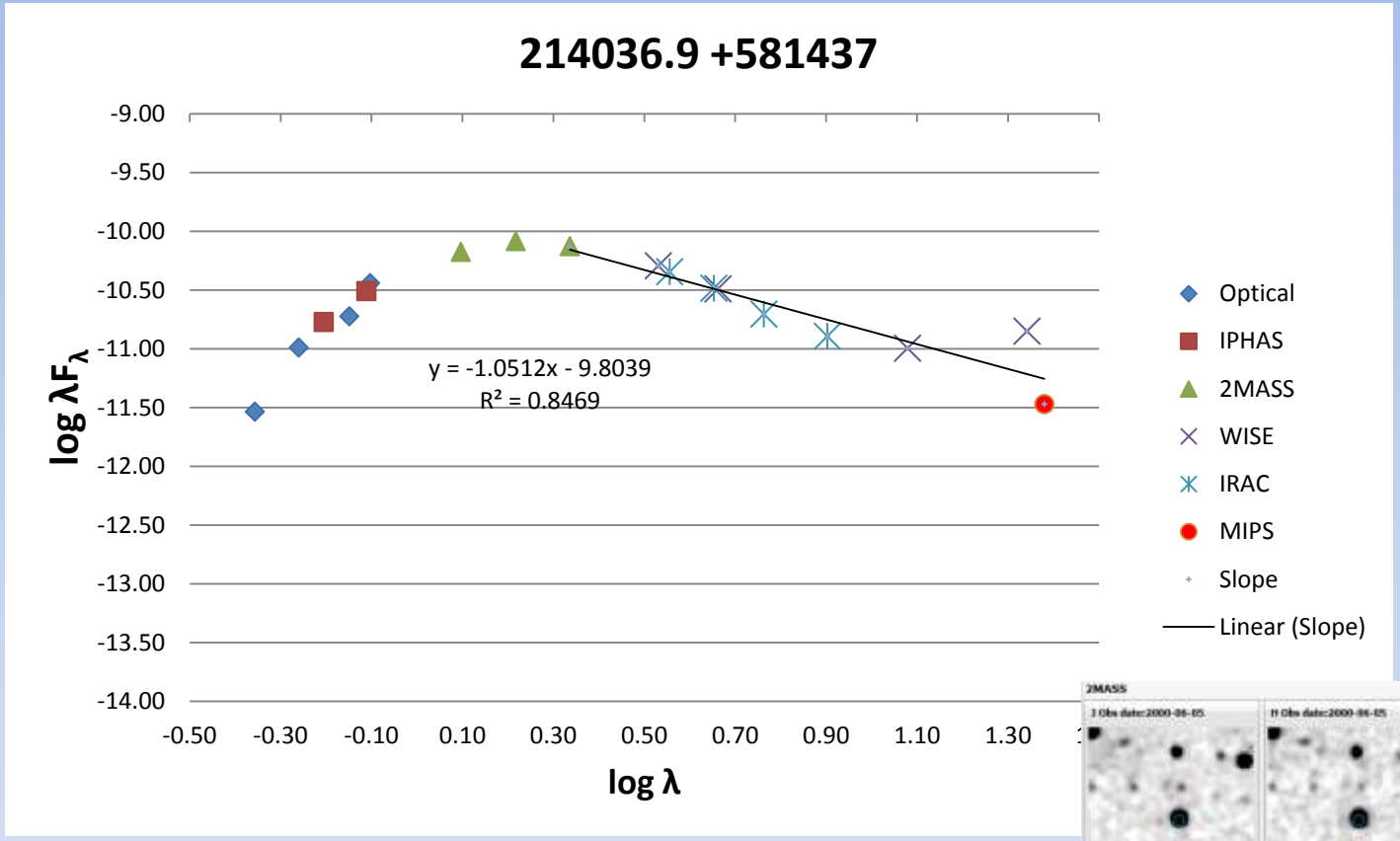


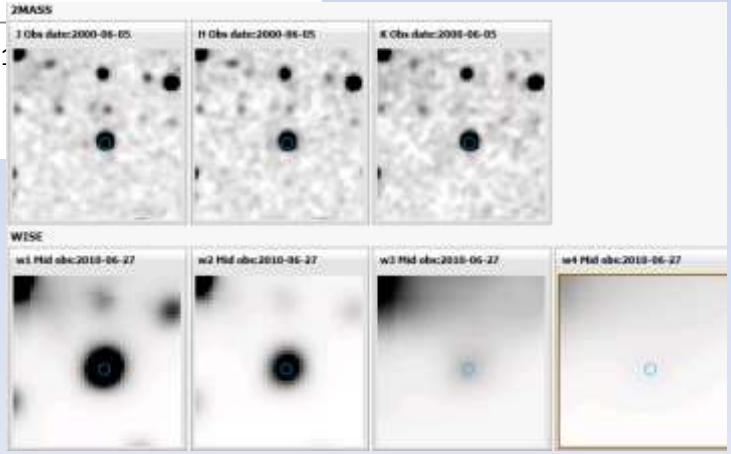


Flat Class

(Pattern of SED suggests a gap in the disk and likely relatively old)

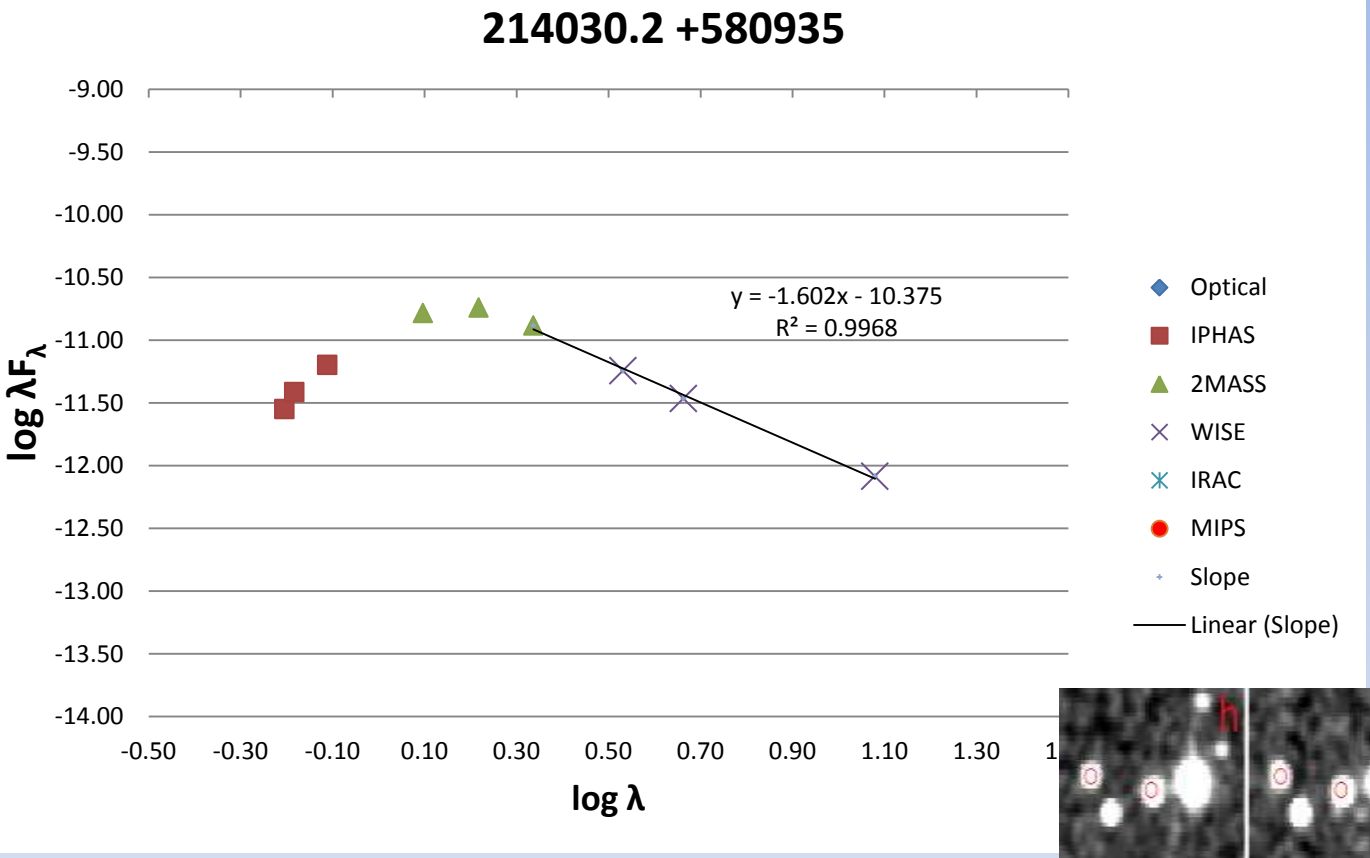
Methodology – Example Classification

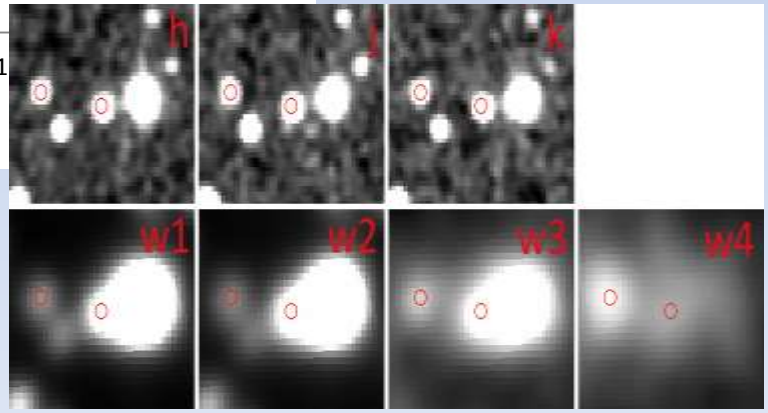




Class II

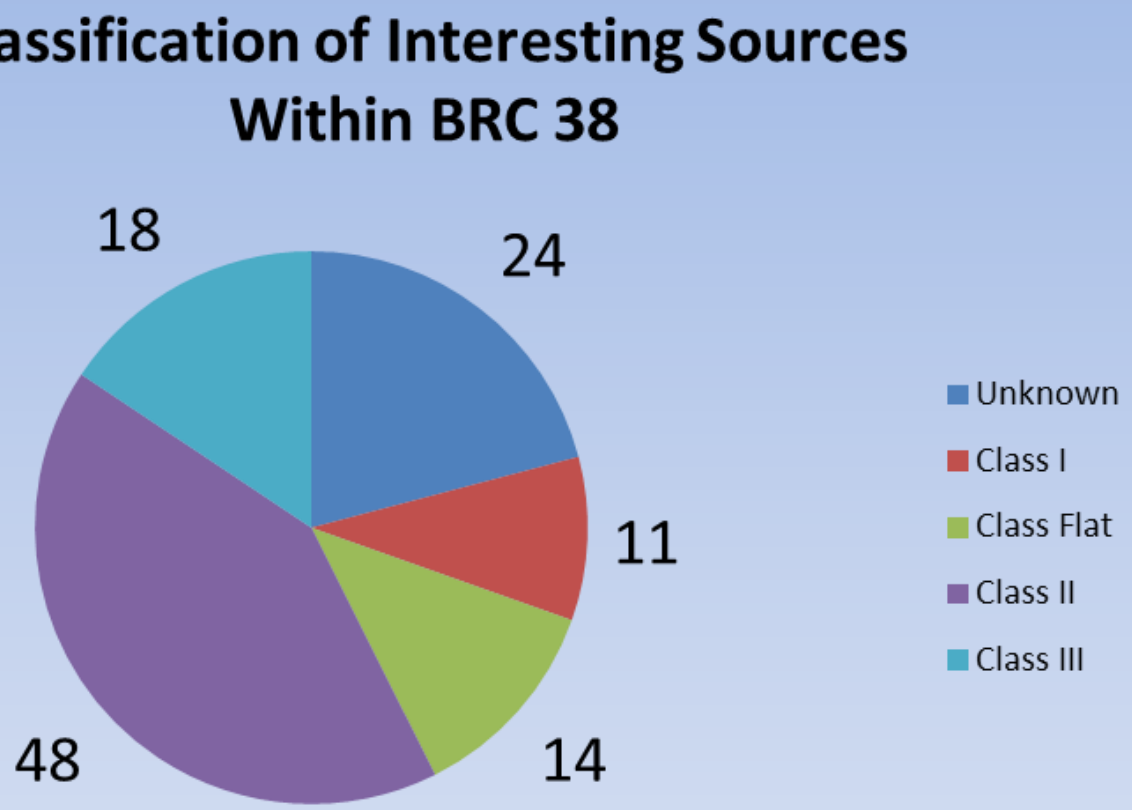
Methodology – Example Classification





Class III

Results - Classifications

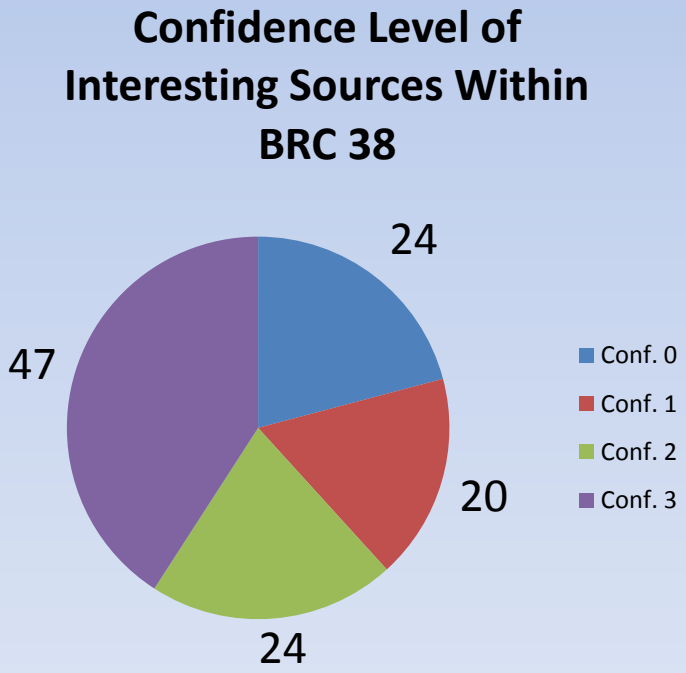


- 25 sources (22%) were Class I or Flat
- 66 sources (57%) were classified as Class II or III
- 24 sources (21%) were unclassified due to poor or insufficient data

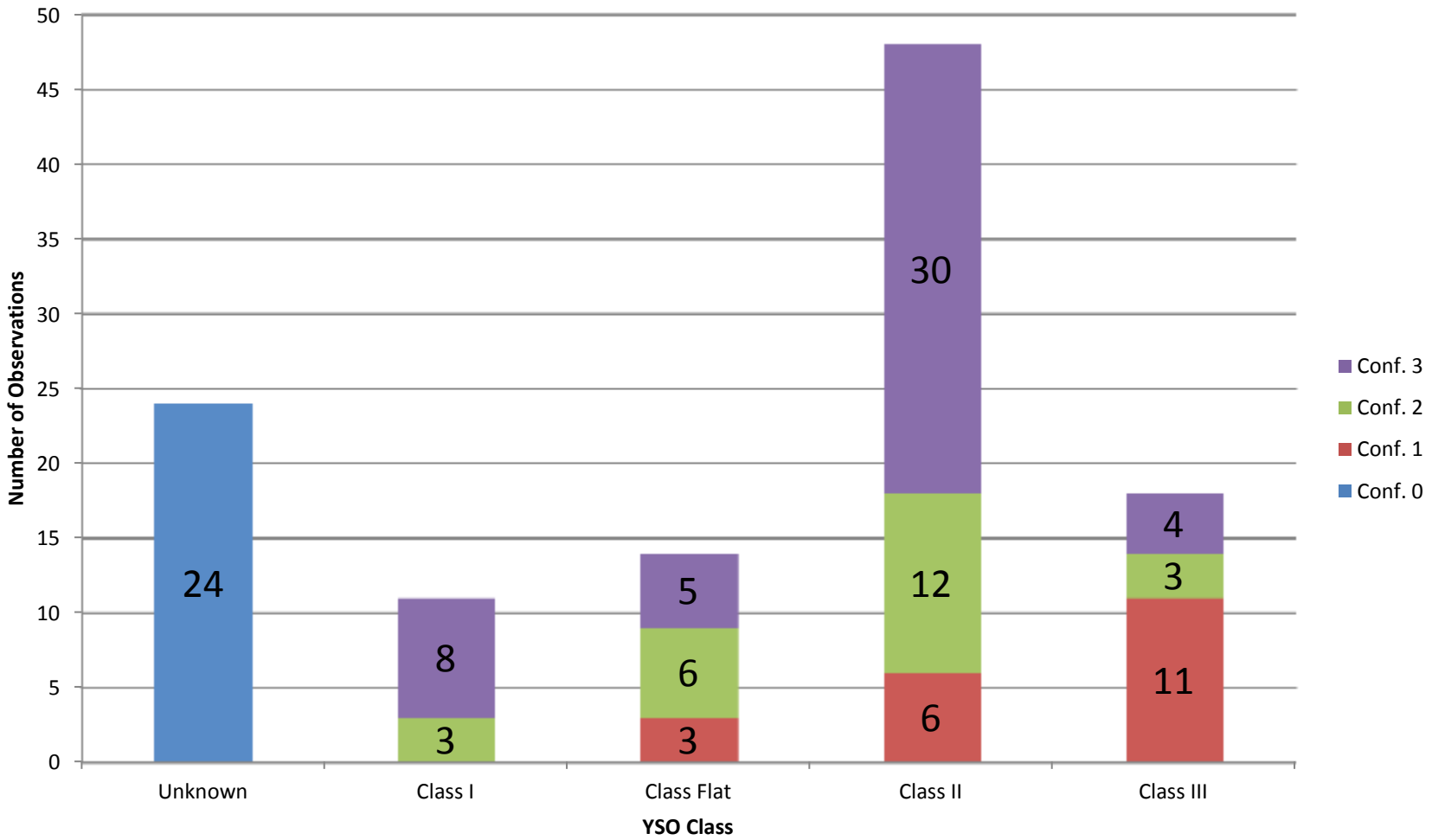
Results – Confidence Level

All sources were assigned a confidence score (0,1,2,3) based on the quality and quantity of imagery and available data, as well as giving consideration to the types of previous studies done – 41% were assigned the highest confidence level (3), 38% were assigned lower confidence levels (2 and 1), while the remainder were unclassifiable

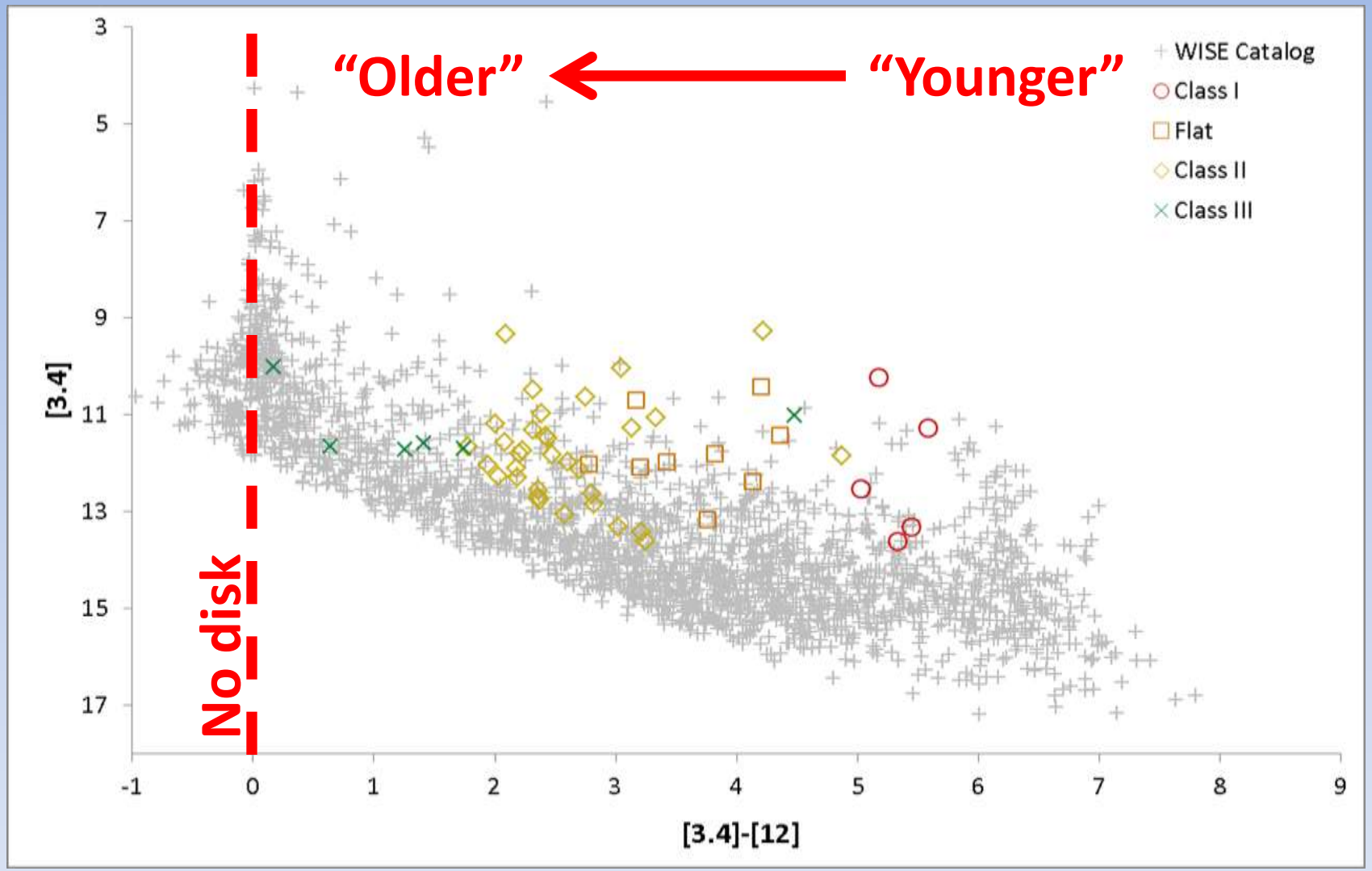
0	Insufficient or very poor data, or classification cannot be determined from the data
1	Worry / lower confidence - poor data, little data, concern after visual inspection
2	Worry / higher confidence - better, but some flaws in data; typically previously known by multiple authors
3	Keep - good data, good images



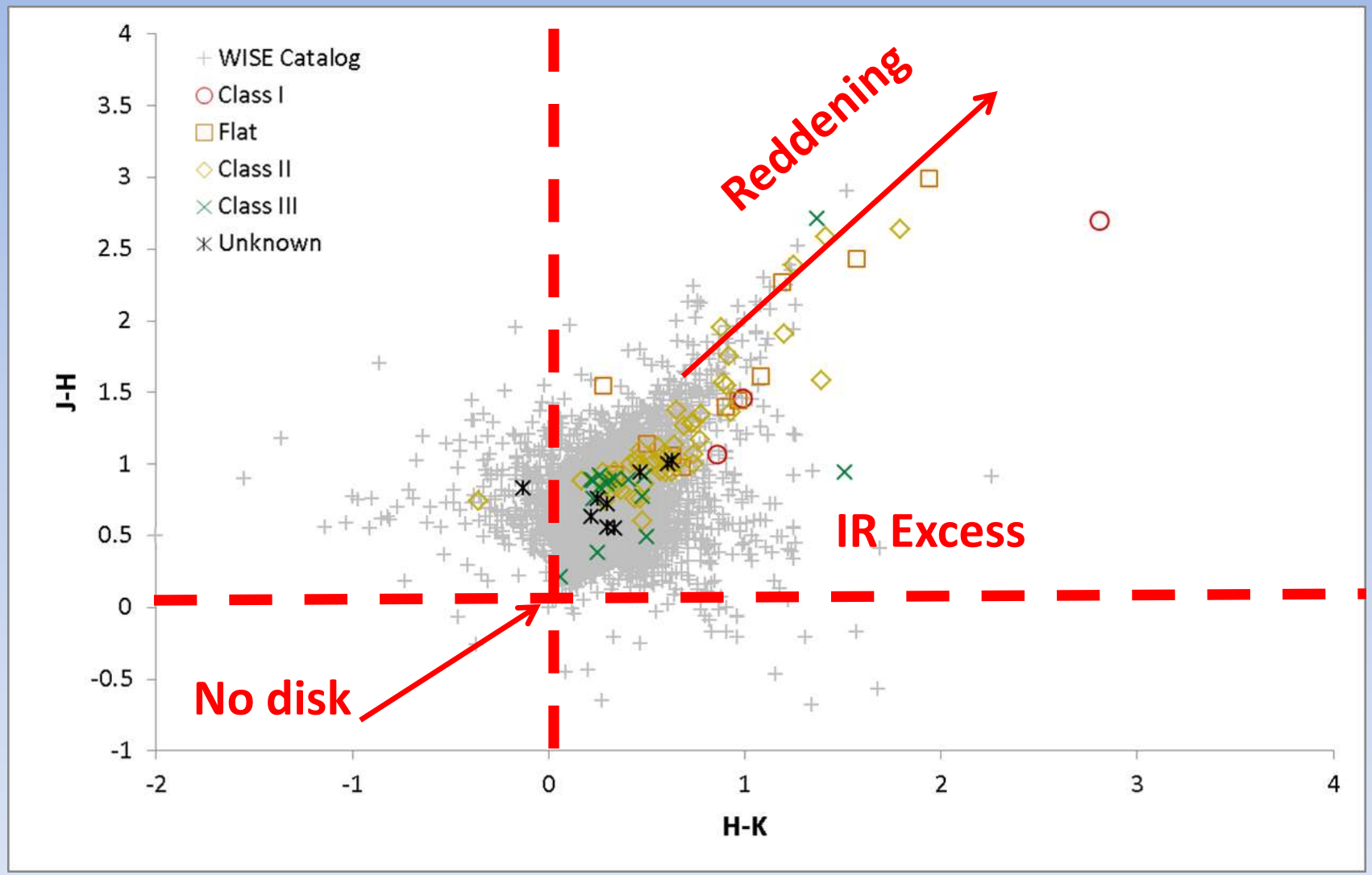
Results – Summary Classifications



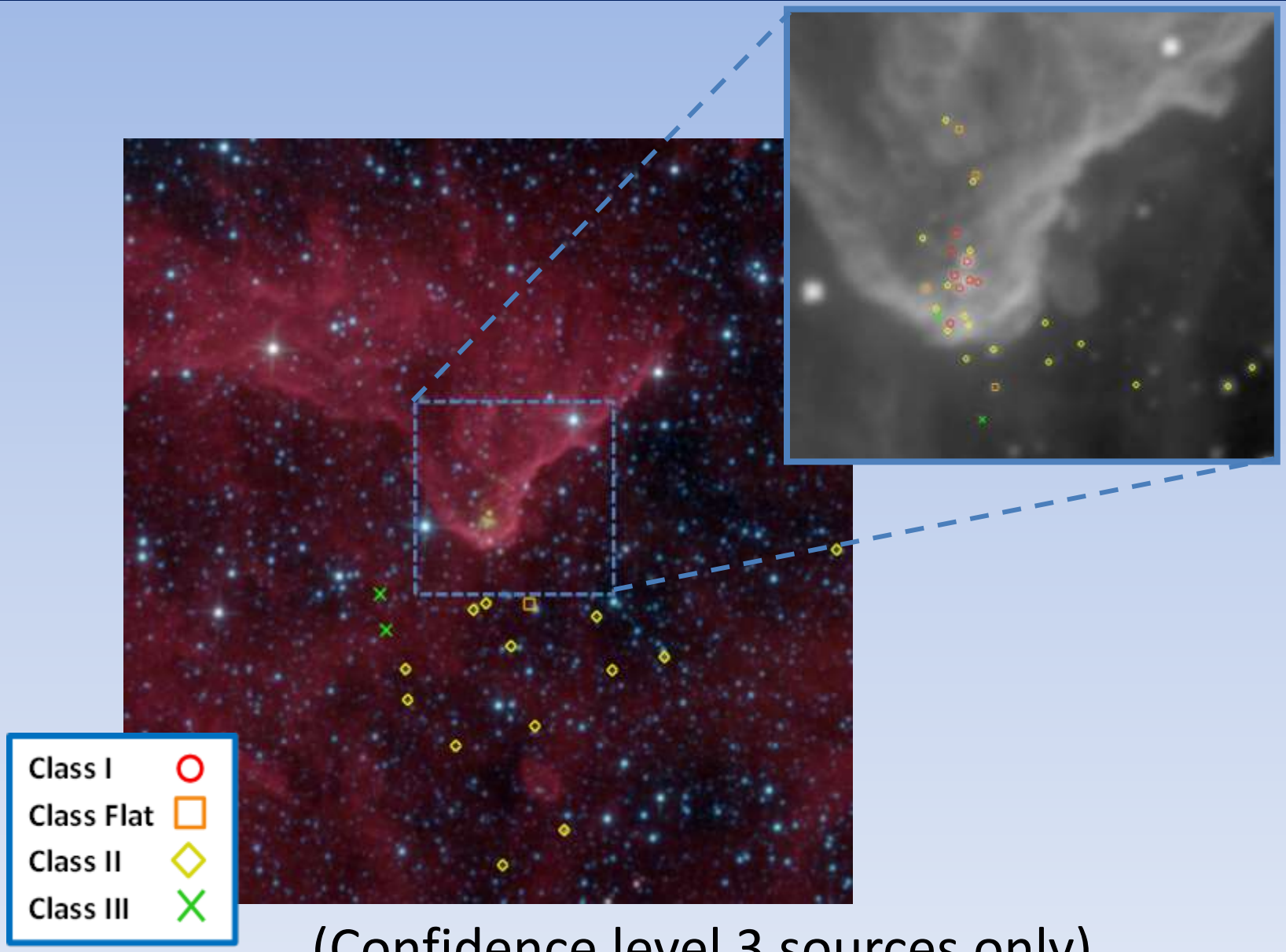
Results – Color Magnitude Diagram



Results – Color Color Diagram



Results – Location of Sources within BRC 38



(Confidence level 3 sources only)

Results – BRC 38 vs. BRC 34

Our results were reasonably consistent with a similar study of YSO candidates in BRC 34 (particularly Class II), another bright rimmed cloud in IC 1396

RATIOS OF YSO CLASSES IN BRC 38 AND BRC 34					
	Class I	Class Flat	Class II	Class III	Total
BRC 38 (Conf. level 3)	8 (~17%)	5 (~11%)	30 (~64%)	4 (~9%)	47
BRC 34 High confidence L. M. Rebull et al. (2013, AJ, 145, 15)	1 (~7%)	1 (~7%)	8 (~57%)	4 (~29%)	14

Conclusions

- Our analysis identified 47 sources within and near BRC 38 as candidate YSOs with confidence level 3:
  - 8 Class I, 5 Class Flat, 30 Class II, and 4 Class III
  - 5 confidence level 3 sources were previously unknown
- 44 additional sources were identified with lower confidence levels
- Ten previously unknown sources were determined to have an IR excess (five with high confidence) and are thus identified as candidate YSOs:
  - Class I (1 confidence 3, 1 confidence 2)
  - Class Flat (1 confidence 3, 1 confidence 2)
  - Class II (3 confidence 3, 2 confidence 2, 1 confidence 1)
- IR excesses were determined using WISE data for 39 previously known candidate YSOs
- Ratios of YSO classes within BRC 38 are consistent with ratios found in BRC 34, also located in IC 1396
- We looked for evidence of triggered star formation in BRC 38, but are limited in our conclusions by small-number statistics

Acknowledgements

Support for this study was provided by the **NASA/IPAC Teacher Archive Research Program (NITARP)**, which receives funding from the NASA ADP program and the IPAC archives.

Team C-CWEL also thanks the Spitzer Science Center, the California Institute of Technology, and the Jet Propulsion Laboratory for their support of NITARP.