Light Detectives   (Teacher Guide)
Using NASA's WISE Data to Identify Brown Dwarfs and ULIRGs
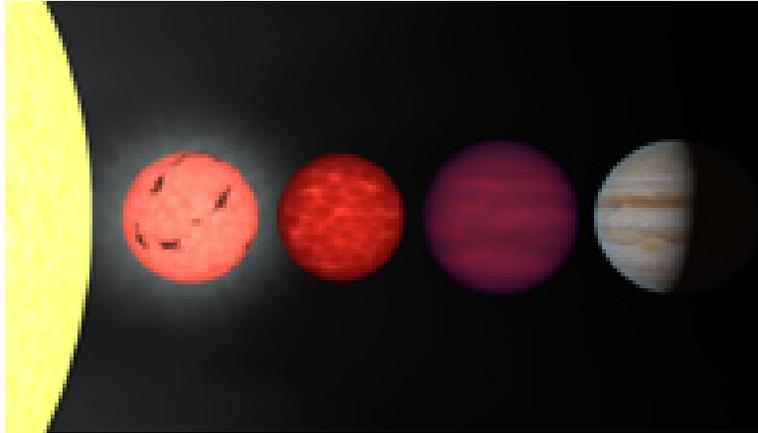
Figure 1: An artist's rendition comparing stars, brown dwarfs, and planets to the same size scale. From left to right is the limb of the Sun, a very low mass star, a pair of brown dwarfs, and the planet Jupiter. These objects have masses ranging from 1000 times that of Jupiter (for the Sun) through 75, 65, 30, and 1 Jupiter mass, respectively.

Overview:
This activity's primary goal is for students to use real NASA data to complete an investigation via the same basic methods that astronomers use. Students use a computer to download data (images) directly from NASA's Wide-field Infrared Survey Explorer (WISE) mission. They then make measurements of those images with the image processing software SalsaJ, and eventually plot and analyze those measurements to find a brown dwarf. In the *Going Further* section, they follow the same process to find an Ultra-luminous Infrared Galaxy, or ULIRG, and then verify it by finding relevant images taken by the Hubble Space Telescope. The teacher engages and guides students along with the help of a slide show and discussion points. There are questions at the end of each section that the students can answer and turn in to be graded.

Grade Levels:
Grades 9-12, recommended for Physics or Astronomy classes

Objectives:
Students will:
- Use real NASA data to complete an investigation via the same basic methods that astronomers use.
- Learn how to find and download images taken by NASA's WISE mission.
- Measure the data in the images using the SalsaJ software.
- Plot and analyze those measurements on paper.
- Learn that observing an object in different wavelengths of light reveals

important information about the properties of the object.
- Understand how an object's color is defined in astronomical contexts: the ratio of two different wavelengths of light.
- Find brown dwarfs and ULIRGs by examining the color of many different objects.
- In the *Going Further* section: verify their finding using images from the Hubble Space Telescope

Time:
Between 50 to 100 minutes (1 to 2 50-minute class sessions):

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Materials (per class):
- A way to show digital slides to the class (i.e. projector or TV screen)

Materials (per student):
- **Computer with internet access and on which SalsaJ (or another FITS-compatible image processing program) is installed**[1]
- Pencil
- Light Detectives Student Guide

Grading:
Please refer to the 'Evaluate' section at the end of this Teacher Guide.

Introductory Reading:
If you have ever looked at the sky through a telescope on a dark night, stars were not the only celestial bodies within your field of view. Space is filled not only with stars, but planets, asteroids, giant clouds of dust and gas (nebulae), white dwarfs, brown dwarfs, and entire galaxies. Astronomers are able to distinguish between objects and learn about their properties by the observing and analyzing the light they emit.

Every type of light, or *electromagnetic radiation*, is associated with a wavelength and energy. The characteristics of the light emitted by an astronomical body can provide clues about things like its composition, temperature, size, mass, and how it interacts with its environment.[2] The goal of NASA's WISE mission is to take a detailed look at space in **infrared** light. In this activity, students will learn to identify a class of objects that have very distinct features when observed in this part of the electromagnetic spectrum: brown dwarfs. In the Going Further section,

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[1] SalsaJ for all computers can be downloaded here:
http://www.euhou.net/index.php/salsaj-software-mainmenu-9/download-mainmenu-10
[2] Visit the following website for a lesson on the nature of light: http://mwmw.gsfc.nasa.gov/

students will extend this knowledge to look for another type of object: Ultra-Luminous Infrared Galaxies (ULIRGs).

Brown Dwarfs

A brown dwarf is an astronomical object that, when it was formed, did not quite have the mass necessary to become a star. On the inside of stars that are similar in size or bigger than the Sun, hydrogen atoms join together and become helium, releasing energy in the process; hydrogen is the "fuel" that causes stars to shine. This process is called *nuclear fusion*. In brown dwarfs, fusion also occurs, but lithium and deuterium act as the fuel, not hydrogen.

$$^{7}_{3}\text{Li} + ^{2}_{1}\text{H} \rightarrow ^{9}_{4}\text{Be}$$
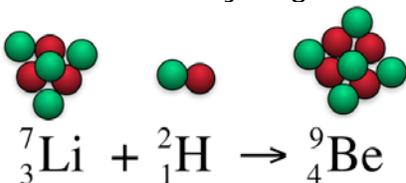
Figure 2: This equation shows how lithium and deuterium (hydrogen with one extra neutron) can fuse to make beryllium.

For most brown dwarfs, fusion does not last for long. After a brown dwarf stops fusion and cools down, it generates energy only through gravitational contraction. The masses of brown dwarfs range from about 13 times the mass of Jupiter to about 80 times the mass of Jupiter. Objects less massive than 13 times the mass of Jupiter would be classified as giant planets; objects more massive than 80 times the mass of Jupiter probably fuse hydrogen and would be called stars. Brown dwarfs are one kind of object that the new WISE mission is searching for.

Activity:
Engage: Astronomers as light detectives
(Areas highlighted in grey refer to the accompanying Student Guide)

1. Start the activity by showing slide #1 – *Light Detectives*

2. Show slide #2 – *Brown dwarfs*: Tell students the definition of a brown dwarf: *A brown dwarf is an astronomical object that, when it was formed, did not quite have the mass necessary to become a star. Brown dwarfs are too large to be planets and too small to be stars.* Slide #2 shows the size of typical brown dwarfs compared to that of typical stars and the planet Jupiter.

3. Show slide #3 – *Where is the brown dwarf?*: Show students the WISE image, and **ask them if they can find the brown dwarf** (they won't be able to) called WISE 1828+2650, the coldest brown dwarf known. Raw data – or the images astronomers receive before they are processed – have lots of information that may be difficult to interpret by eye.

4. Show slide #4 – *How do astronomers know what they know?* (I): One of the ways astronomers identify and learn about celestial objects is to measure their *color*. The characteristic wavelengths of light associated with a star, for instance, depend on the specific physical and chemical processes that take place within and around that star. **_Color_ is the ratio *of two different wavelengths of light associated with a celestial object*.** The WISE mission takes images of the sky in four wavelengths of infrared light: 3.4 µm (microns), 4.6 µm, 12 µm, and 22 µm. We refer to these as the W1, W2, W3, and W4 bands. Light in the W1 band is typically designated blue, the W2 band green, and the W3 band red. Since brown dwarfs are relatively deficient in W1 (3.4 µm) light and relatively bright in W2 (4.6 µm) light, they appear very green in color images.

5. Show slide #5 – *Where is the brown dwarf?*: **The image on this slide is a combined representational-color image of the same part of the sky as the previous slide (#4).** Light in the W1 band is designated blue, the W2 band green, and the W3 band red. Based on this information, as well as the previous slide, ask your students if they can now identify the brown dwarf in the image.

6. Show slide #6 – *Where is the brown dwarf?*: The arrow indicates where the brown dwarf is.

7. Show slide #7 – *Let's find a brown dwarf more scientifically using real NASA data:* In order to find out detailed information about lots of stars and brown dwarfs, astronomers have had to develop techniques for precisely measuring their light. *Photometry* is the technique of measuring a celestial object's *brightness* or *intensity* – the amount of light in a given wavelength. In the following section, students will use the computer program SalsaJ to systematically measure the intensity of stars and brown dwarfs.

   Leave this slide up until the students have downloaded their images.

Explore: Finding and downloading the data (images)

8. Instruct the students to begin on pages 2-3 of the Student Guide, where they will use the WISE image service to download their data (images).
If you are pressed for time, you may choose to download the images ahead of time, and have the students begin on page 4 of the Sutdent Guide (using SalsaJ).

   Once all of the students have their images downloaded, have them begin to use SalsaJ starting on page 4.

Searching for Brown Dwarfs using SalsaJ

9. Show slide #8 – *Finder Chart*: Discuss the talking points on the slide. Tell your students that a **finder chart** shows them how to locate the objects they will measure. The numbers are arbitrary. The same targets appear in each of the three images they will analyze.

   Leave this slide up while the students complete the next section...

10. Instruct the students to continue through pages 4-7 in the Student Guide.

   Continue once all of the students have completed their measurements and filled in their Color-Color Diagrams (through page 7).

   Sample measurements and a color-color diagram can be found in Appendix B

Explain: Where are the Brown Dwarfs?

11. Show slide #9 – *How do astronomers know what they know?*: This is the exact same slide as before (#4). **Ask the students to study the slide, especially the ratio of green to blue (W2/W1) and the ratio of red to green (W3/W2)**, and see if they can guess which of 12 objects they plotted is a brown dwarf (only one of them is).

12. Show slide #10 – *Sample color-color diagram for brown dwarf search:* The students color-color diagrams should look *roughly* like this one. **Ask which object has the highest W2/W1 ratio? Which object has the highest W3/W2 ratio?**
...The answer is object #6! That is a brown dwarf!

13. Show slide #11 – *Color-Color Diagram*: Discuss the talking points on the slide and below.

   Slide #11 shows the regions on the color-color diagram where different

classes of objects detected by WISE would fall. Notice that although both brown dwarfs and a class of stars known as <u>asymptotic giant branch (AGB)</u> stars have high W2/W1 ratios, the two classes of objects can be distinguished because we can also compare their W3/W2 ratios. Though the regions have some overlap, AGB stars tend to have much higher W3/W2 ratios than brown dwarfs.

Brown dwarfs are noted for having an *absorption line* near the W1 (3.4 μm) wavelength. That means that due to the chemical composition of the brown dwarf, it absorbs light with wavelengths near 3.4 μm, and the intensity in that wavelength tends to be unusually low. This means that the ratio of the 4.6 μm intensity to the 3.4 μm intensity (W2/W1) will tend to be high in comparison to other objects, which will have smaller values.

However, brown dwarfs are not the only objects that might have 4.6 μm to 3.4 μm (W2/W1) ratios in that high range. Certain giant stars or dusty galaxies may also have similar ratios (or "color" as astronomers use the term). To separate out those objects we can look at the intensity ratio between 12 μm and 4.6 μm (W3/W2). Brown dwarfs and stars will tend to have smaller flux ratios compared to the dusty galaxies and red giant stars.

Thus, brown dwarfs will tend to be higher on the color-color diagram than normal stars. Since dusty galaxies such as ULIRGs emit lots of light in the W3 band due to warm dust, their W3/W2 ratios are high, and they tend to be farther to the right of brown dwarfs on the color-color diagram.

14. Have the students answer the questions in the Student Worksheet (question #s 1-5 on pages 8-10 in the Student Guide) and turn their work in to be graded (grading rubric in Appendix A)

Elaborate:
Discussion Notes:

After finishing the activity, discuss the following questions and talking points with your students.

- What is a brown dwarf?
- What is the difference between a brown dwarf and a star?
- What does the computer software measure when you click on an object?
- What sources of error might there be in this experiment?
- What might the objects be that occupy the lower left-hand corner of the color-color diagram?

Going Further: ULIRGS (optional)

In this extension activity, students will follow the same basic process as before to search for ULIRGs using data from WISE, and then they will make a follow-up verification using data from the Hubble Space Telescope.

ULIRGS
An Ultra-Luminous Infrared Galaxy (ULIRG) is a type of galaxy that is a 100 times more luminous in infrared light than it is in visible light. The key to this excess of infrared light is *dust*, which mostly emits infrared light and which astronomers observe wherever stars are forming. Thus, ULIRGs may be found in merging galaxies whose collisions lead to dust-enshrouded bursts of star formation. WISE will discover ULIRGs all over the sky.

Observing an object in different wavelengths of light helps astronomers to more fully understand that object's properties. The various physical and chemical interactions taking place in and around a star, for instance, produce different wavelengths of light; so the star looks different depending on the wavelength in which it is observed.

Engage:

1. Show slide #12 – *ULIRGs*: Tell students what a ULIRG is: ***An Ultra-Luminous Infrared Galaxy (ULIRG) is a type of galaxy that is a 100 times more luminous in infrared light than it is in visible light***.

2. Show slide #13 – *Arp 220*: Compare and discuss the near-infrared and optical images of the ULIRG Arp 220. Much of the infrared light of ULIRGs comes from warm dust associated with star formation (left). However, dust blocks light at optical wavelengths, but stars emit a large part of their energy in the optical, and so in an optical image of Arp 220, the structure of the galaxy's stars and dust lanes are prominent (right).

Explore: Downloading the data searching for ULIRGs

3. Instruct the students to begin on pages 11-13 of the Student Guide, where they will use the WISE image service to download their data (images) again following the same process as before.
If you are pressed for time, you may choose to download the images ahead of time, and have the students begin with the part using SalsaJ (step 2).

4. Show slide #14 – *Finder Chart*
Once all of the students have their images downloaded, have them begin to use SalsaJ starting at step 2, and continue all of way through step 4, and stop there.

During these steps they will find and look at images from the Hubble Space Telescope.

Sample measurements and a color-color diagram can be found in Appendix C

5. Once everyone has completed step 4, ask the class if they think they found a ULIRG. Discuss their results and have them explain their reasoning. ***The correct answer is object #11.***

Explain: Where are the ULIRGs?

6. Show slide #15 – *Sample color-color diagram for ULIRG search*
   Explain and discuss the following with the students. Both brown dwarfs and ULIRGs have similar W2/W1 flux ratios. So to distinguish between the two types of objects, you can compare their W3/W2 ratios, as well. Astronomers have evidence showing that ULIRGs are the likely result of two or more colliding galaxies. A galaxy collision typically triggers huge amounts of star formation, and the resulting energy heats the dust, causing it to "glow" very brightly in 12 μm light (W3). Thus, the W3/W2 flux ratios of ULIRGs are very high, and they tend to be on the far right of the color-color diagram.

7. Show slide #16 – *WISE color image*
   This is a 3-color image, also known as an RGB image, created from the same 3 WISE images that the students just analyzed. W1 was assigned the color blue, W2 green, and W3 red. The images were then stacked on top of each other to create a color image.

8. Show slide #17 – *WISE color image & Hubble image*
   Here is the same WISE image, along with a Hubble image of the ULIRG up close. ***The Hubble image shows that the object is in fact a ULIRG, which is created by two merging galaxies.*** It is one of the images that the students should have seen on the Hubble archive website, called N4GV12010. The image was taken by the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) instrument, which looks at objects in the near-infrared wavelengths between 0.8 μm and 2.5 μm. So this Hubble image is in wavelengths longer than the human eye can see (0.39-0.7 μm), but shorter than what WISE can see (3.4-22 μm).
   The arrows in the Hubble image point north and east.

15. Have the students answer the last two questions in the Student Worksheet (#6 and #7 on page 14 in the Student Guide) and turn their work in to be graded (grading rubric in Appendix A)

Elaborate:
Discussion Notes:

After finishing the activity, discuss the following questions and talking points with your students.

- What is a ULIRG?
- Why do ULIRGs look different in mid-infrared light (as seen in WISE images) and optical light (as seen in Hubble Space Telescope images)?
- Why are ULIRGs to the right of brown dwarfs in the color-color diagram?
- Look at the color-color diagram in Figure 6, and notice how some of the regions overlap. Suppose you wanted to identify an object whose W1/W2 and W2/W3 ratios made it fall in the overlapping brown dwarf-ULIRG region. How could you use the Hubble Space Telescope to tell whether it was a brown dwarf or ULIRG?

Appendix A: Grading Rubric:
Evaluate:

There are 5 questions on the Student Worksheet that students can answer after they have finished the Brown Dwarf activity, and another 2 additional questions at the end of the *Going Further* ULIRG activity.

If the students only answer the first 5 questions, then each should be worth 20%. If they answer all 7, then each one is worth 14% (with a free extra 2% added on).

1. Photometry:
In this activity, you measured the amount of light coming from each star in the finder chart. This is called *photometry*. Explain why the images you open on your computer (W1, W2, and W3) look slightly different from one another. In other words, why do you measure three <u>different</u> numbers (W1, W2, and W3) for the <u>same</u> star?

Answer: Students should mention something about each image being taken in a different wavelength, and that each wavelength reveals different properties of each object.

2. Helpful clues for a light detective. Part 1:
Brown dwarfs are expected to emit <u>less</u> W1 (3.4 µm) light than normal stars, so they have <u>lower</u> values of W1. But this is not enough to tell you whether an object is a brown dwarf or not. Why? (Hint: The objects in the finder chart are at different distances. Do you expect W1 to increase or decrease as an object moves farther away?)

Answer: Students should mention that lower (decreased) values of W1 might be due to an object being further away.

3. Helpful clues for a light detective. Part 2:
Brown dwarfs are expected to have <u>higher</u> W2/W1 ratios than normal stars, but this is still not enough information to tell you whether or not an object is a brown dwarf. Why not? Why do you also need to know the ratio W3/W2? (Hint: Remember the color-color diagram in the slide show [Slide #11] that included galaxies, ULIRGS, and AGB stars)

Answer: Students should mention that other objects besides brown dwarfs also have high W2/W1 values, and that they can be differentiated form each other by comparing their W3/W2 ratios as well.

4. A WISE detective:
The wavelength of light at which an object shines most brightly depends on how hot that object is. If you know the object's temperature (*T*), you can find that wavelength, using this equation:

$$\text{wavelength} = \frac{2900}{T}$$

(a)   The surface temperature of a brown dwarf is about 1000 degrees Kelvin (1000 K). Use the equation to calculate the corresponding wavelength of light. Your answer will be in units of µm (microns).

Answer: wavelength = 2.9 µm

(b)   The temperature at the surface of the Sun is about 5800 K.   What is the corresponding wavelength?

Answer: wavelength = 0.5 µm

5. Why Infrared?:

The human eye can see light having wavelengths between 0.39 µm and 0.7 µm. Explain why we cannot see brown dwarfs with the naked eye, and why a telescope like WISE can help us to detect brown dwarfs.

Answer: students should mention that most of the light emitted by brown dwarfs corresponds to wavelengths longer than the human eye can see. WISE detects light in the infrared part of the electromagnetic spectrum, where brown dwarfs emit a lot of their light.

6. ULIRGs:

Why are ULIRGs to the right of brown dwarfs in the color-color diagram?

Answer: students should mention that ULIRGs emit even more light than brown dwarfs at the lower infrared wavelengths shown in W3. In other words they are relatively much brighter in W3 (12 µm) compared to W2 (4.6 µm) than brown dwarfs.

7. ULIRGs:

Why does the ULIRG look different in the WISE images compared to the in Hubble Space Telescope images?

Answer: students should mention something about resolution differences and-or magnification differences between the two telescopes. (WISE was designed to look at the entire sky, while HST was designed to focus in on very small areas).

Appendix B: Example Data and Graphs - Brown Dwarf

TABLE 1 Brown Dwarf							
Finder chart #	X	Y	W1 [DN]	W2 [DN]	W3 [DN]	W2 / W1	W3 / W2
1	212	70	11576	4554	1145	0.393	0.251
2	450	125	134459	76949	17364	0.572	0.226
3	88	24	26333	10610	2145	0.403	0.202
4	900	197	24519	9537	2055	0.389	0.215
5	507	318	7688	2974	635	0.387	0.214
6	335	421	1940	1373	447	0.708	0.326
7	66	368	71829	27496	5880	0.383	0.214
8	411	534	3182	1281	268	0.403	0.209
9	586	632	2914	1449	442	0.497	0.305
10	432	777	8597	3212	838	0.374	0.261
11	319	777	7781	2857	476	0.367	0.167
12	455	846	4338	1430	141	0.330	0.099

Sample color-color diagram for brown dwarf search W2/W1 vs W3/W2
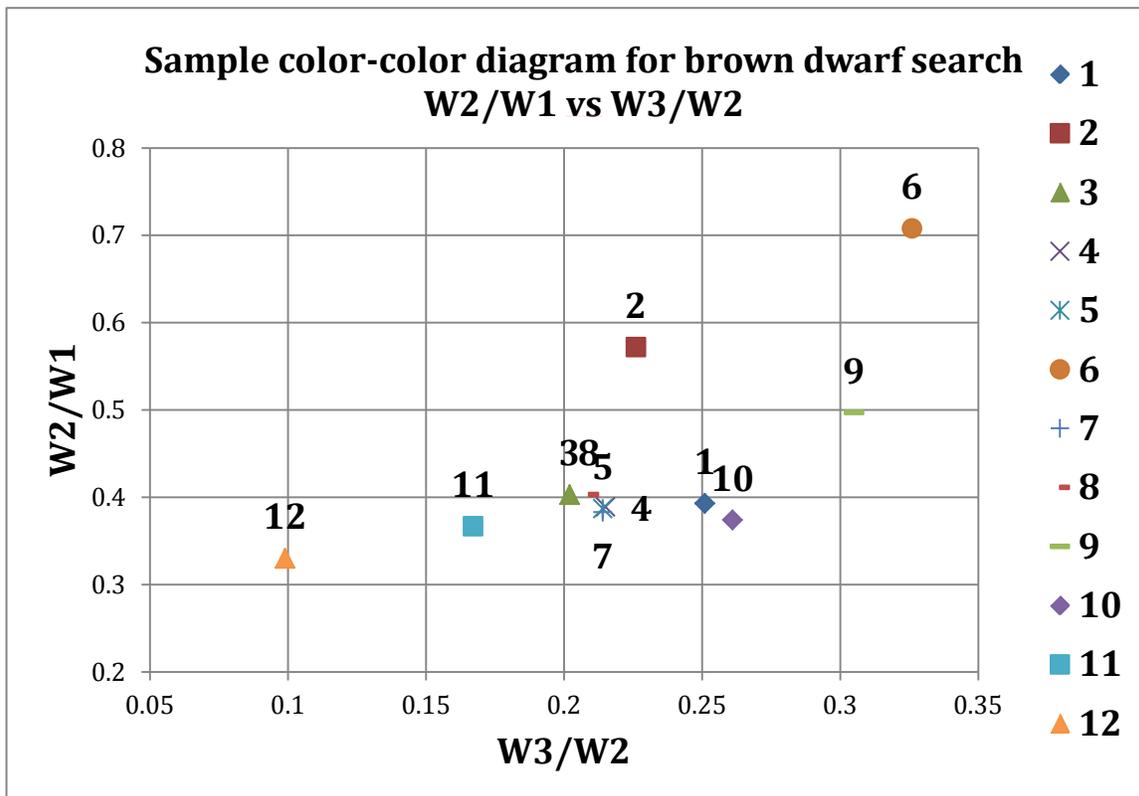
Appendix C: Example Data and Graphs - ULIRG

Finder chart #	X	Y	W1 [DN]	W2 [DN]	W3 [DN]	W2 / W1	W3 / W2
TABLE 2 Ultra-Luminous Infrared Galaxy (ULIRG)							
1	**193**	**63**	6512	2286	363	0.351	0.159
2	**707**	**154**	2198	817	98	0.372	0.120
3	**879**	**457**	724	283	105	0.391	0.371
4	**953**	**773**	14684	5234	856	0.356	0.164
5	**572**	**862**	6003	2231	328	0.372	0.147
6	**249**	**831**	4705	1655	253	0.352	0.153
7	**89**	**605**	3637	1351	198	0.371	0.147
8	**153**	**586**	1536	555	77	0.361	0.139
9	**199**	**405**	2176	779	149	0.358	0.191
10	**578**	**327**	7253	2629	442	0.362	0.168
11	**467**	**468**	1540	1696	9302	1.101	5.485
12	**473**	**539**	3854	1427	189	0.370	0.132

Sample color-color diagram for ULIRG search
W2/W1 vs W3/W2