TEEN ASTRONOMY Café – To Go!

Teacher Guide for the Backyard Worlds Instant Pack

What objects lie on the fringes of our Solar System just waiting to be discovered? In this Teen Astronomy Café — To Go! Instant Pack, students use patches of the sky to analyze the motion of objects over time. Students then use plots to determine the relationship between star temperature and wavelengths of light. Then they apply their understanding as they explore a citizen science activity and practice identifying brown dwarf candidates using data from telescopes. This activity is conducted in a Python Notebook, a web-based interactive computational environment that contains code, text, and plots.

Learning Objectives

Students will be able to:

- Analyze and interpret the motions of stars on different timescales.
- Analyze data from telescopes to identify brown dwarfs.

NGSS Standards

Building Towards NGSS Performance Expectation:

- HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements.

Disciplinary Core Ideas	**ESS1.A: The Universe and Its Stars** The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
Science and Engineering Practices	**Analyzing and Interpreting Data** Students use models of an area of the sky that represent different time scales to compare and contrast the observed motion of stars over time. Students analyze plots to determine the relationship between star temperatures, colors, and wavelengths of light. Students analyze the motion and characteristics of objects within various fields of view to communicate if an object is a brown dwarf or not.
Cross Cutting Concepts	**Scale, Proportion, and Quantity** Students use models of the sky representing two different time scales to observe patterns of the observed motions of stars.

Suggested Timing:

- Backyard Worlds Phenomenon & Presentation (50 minutes)
- Python intro and how to run a cell (5 minutes)
- Activity 1: Motions of Stars and Brown Dwarfs (10 minutes)
- Activity 2: Colors of Stars and Brown Dwarfs (15 minutes)
- Activity 3: Discover The Brown Dwarfs (30-40 minutes)

Backyard Worlds Presentation

This Teen Astronomy Café — To Go! Instant Pack includes a slideshow presentation that is accompanied by a recorded presentation video. The purpose of the slideshow is to provide the audience with background information on the Sun's neighboring worlds and to excite and motivate learners with the content. A lesson-level phenomenon (below) is suggested to precede the presentation slides and is recommended as a student-driven active learning strategy to initiate curiosity and questioning. Instructions for incorporating the phenomenon are included below.

Backyard Worlds Phenomenon

1. Before class, arrange a Driving Question Board with the lesson-driving question, "How are brown dwarfs discovered?"
2. Start the lesson with a three-dimensional visualization of brown dwarfs in our neighborhood. Explain that astronomers and citizen scientists have been mapping our neighborhood of the Universe and the visualization maps cool brown dwarfs within 65 light-years of the Sun.
    - Note: The video begins with "*the location of the Earth at the center of the view, then zooms out into interstellar space, showing the spatial distribution of the brown dwarfs in multiple ways before returning back to the Solar System and Earth at the end.*" Credits: NASA/Jacqueline Faherty (American Museum of Natural History)/OpenSpace
3. After showing the video, hold a class discussion to find out what students know about brown dwarfs and develop curiosity. Ask students, "*What do you think the neighboring objects (brown dwarfs) are?*" Include prompts such as:
    - "*Do you think brown dwarfs are stars, planets, or something else?* "
    - "*What makes something a star? What about a planet?*"
4. Ask students to record their initial responses to the driving question in their notebooks and reassure students that their responses will likely be modified throughout the lesson. Questions students write about brown dwarfs and their discoveries should be posted on the Driving Question Board to help students drive their learning. The class questions can be organized into categories and revisited throughout the slideshow presentation and/or Python Notebook.
5. Share the article What makes brown dwarfs unique? This article introduces brown dwarfs and explains why they are important to study. After students read the article, provide them with the opportunity to modify their initial response to the driving question.
6. Begin the presentation, followed by the Python Notebook activity. Be sure to revisit the Driving Question Board after these activities to allow students time to develop their responses to the driving question and answer any questions they may have originally posted or ask new questions.

Python Notebook General Information

- Start by going over the operation of a Python notebook: To execute or run a selected cell, click the little play button or hit [Shift + Enter] on your keyboard. Some cells may take a few seconds to render, so be patient!
- If something doesn't seem to be working correctly (e.g., it can't find resources such as tools.ipynb, or the first simulation where students don't have to enter in any values fails), try restarting the notebook (**`Runtime → Restart`**).
- To run all the cells at once, go to the "**`Runtime`**" menu and select the option to "**`Run all`**."

Activity 1: Motions of Stars and Brown Dwarfs

Activity 1 focuses on observing the proper motions of brown dwarfs across the sky. Proper motion is simply how fast an object appears to move across the sky and is a two-dimensional measurement (motion toward or away from Earth is not included). Proper motion is measured in units of arcseconds per year. An arc second is a unit of measurement equal to 1/3600 of a degree. For reference, a dime seen from 4 kilometers (2.4 miles) away would have a diameter of 1 arcsecond.

Several factors determine the proper motion of a star: the distance to the star, the speed of the star, and the direction of the star's motion. Stars closer to Earth will appear to have a larger proper motion than those farther away. Likewise, stars that move faster will appear to have a larger proper motion than stars that move slower. Finally, stars that move perpendicular to our line of sight will have a larger proper motion than stars that move closer to parallel to our line of sight (and stars that move directly toward or away from Earth will have no proper motion!).

The first animation highlights Barnard's Star, the star that currently has the largest known proper motion. Barnard's star moves 10.4 arcseconds every year. Telescopes can easily detect this motion over a short period of time (weeks to months).

The activity gives a proportional relationship between the star's proper motion, its transverse velocity (velocity perpendicular to the line of sight), and its distance from Earth. Mathematically, the proper motion of a star is calculated from $\mu = v_{tan}/(k*d)$ where μ is the proper motion,v_{tan} is the transverse velocity of the star, k is a constant (depending on units) and d is the distance to the star from Earth. The most common units used for proper motion are arcseconds/year. In this case, v_{tan} is measured in km/s, d is measured in parsecs, and the value of the constant is 4.74.

Advanced students may know that stars also exhibit parallax as Earth orbits the Sun. Stars appear to move back and forth slightly depending on where Earth is located in its orbit around the Sun. This phenomenon is known as stellar parallax. The closest known star to Earth, Proxima Centauri, has a stellar parallax of 0.76813 arcseconds. Since stellar parallax is cyclical, it can be measured and subtracted from a star's apparent motion to reveal the star's proper motion.

The second animation shows a much wider view of the vicinity of Barnard's star over 100 years. The field of view is about 0.7 degrees. Students can step through the animation in intervals of one year or click on the slider and hold down the right or left arrow to create a movie of the stars' motion. Given this much larger field of view, Barnard's star is visible for the entire 100 year duration. Some of the stars have visible motions over 100 years but some have such small proper motions that they do not appear to move appreciably over 100 years at this resolution.

The third animation contains the same field of view as the second but projects the star's motions over 10,000 years. Students step through in 100 year intervals. Given the previous animation, Barnard's star leaves this field of view after the first interval — you can find it at 0 years and 100 years if you look carefully! During the 10,000-year interval, all of the stars exhibit some motion and some stars leave the field of view entirely! The number of stars visible decreases as stars leave the field of view. This animation does NOT include stars that start outside the field of view that would move into the field of view during the 10,000-year timeframe.

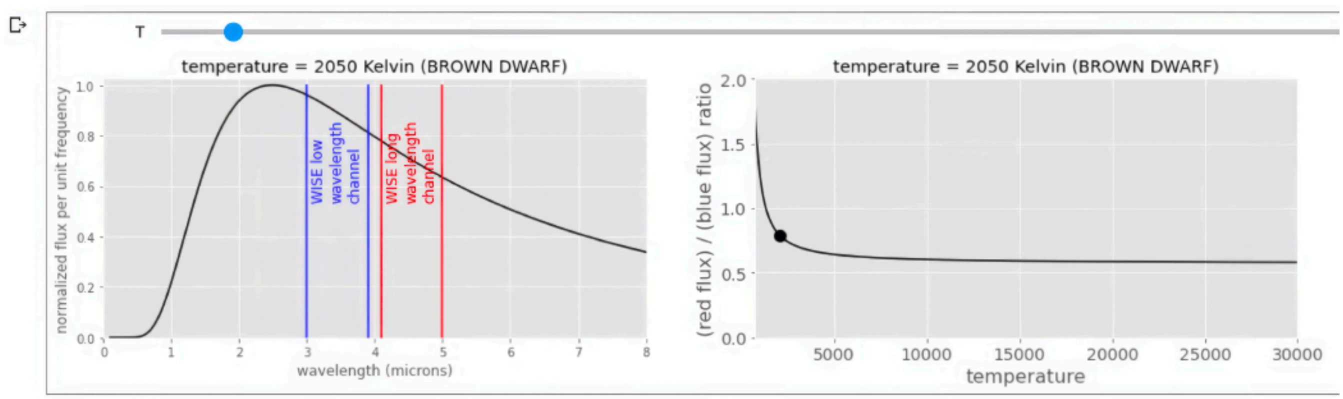
Activity 2: Colors of Stars and Brown Dwarfs

Activity 2 explores the relationship between the colors of stars and their temperatures. Every object in the Universe emits radiation over a range of wavelengths depending on its temperature. Cooler objects emit longer-wavelength (redder) radiation than warmer objects which emit shorter-wavelength radiation (toward the blue end of the spectrum). Although objects emit radiation over a range of wavelengths, there will be a peak wavelength where the intensity of radiation is highest.

A graph of the spectral radiance versus wavelength can be created using Planck's Law.

The WISE spacecraft is using two filters. Since the filters are at different wavelengths, they will each see different fluxes of light passing through them, depending on the exact shape of the spectral radiance curve. The ratio of these two wavelengths can be used to determine the temperature of the star.

The interactive plot allows students to observe the shape of the spectrum as the temperature changes (left graph) as well as the ratio of the red flux to the blue flux (right graph) observed by WISE. The left graph also labels the object as a brown dwarf or star depending on its temperature.



It should be noted that this graph does NOT show the absolute intensity of the spectrum as the y-axis is normalized to a maximum value of one. In reality, the intensity of the flux increases rapidly as the temperature increases. There are interactive elements on other websites that can be used to explore this phenomenon.

Activity 2: Going Further

Of course, real spectra are not perfect black body curves. The atmospheres of stars contain a variety of atoms and molecules that can form depending on the temperature of the star. These atoms and molecules produce absorption lines in the spectra that can make it look very different from a pure blackbody spectrum. Computers can analyze these spectra and calculate where the peak of the black body radiation curve is located and the temperature of the brown dwarf. Some of the most common absorption features in brown dwarfs are water vapor and methane.

Activity 2.1: Looking For Brown Dwarfs Based On Color And Motion

Backyard Worlds citizen scientists analyze WISE images to find brown dwarf candidates that are difficult to detect by computer algorithms. Students will try to find brown dwarf candidates in a series of images that are being blinked to create animations. The WISE observations have a 10-year baseline between the first and last observations, allowing the detection of brown dwarf candidates that are moving as slowly as 0.275 arcseconds per year!

Brown dwarfs frequently have a red/orange color that also stands out from the surrounding field stars. Looking at the graph of the ratio of red flux to blue flux above, the graph is very steep for cool stars but flattens out very quickly for warmer stars. Since warmer stars have about the same ratio of red flux to blue flux, they will all have a very similar color and only the coolest stars will have the red/orange color.

Activity 3: Discover The Brown Dwarf Candidates

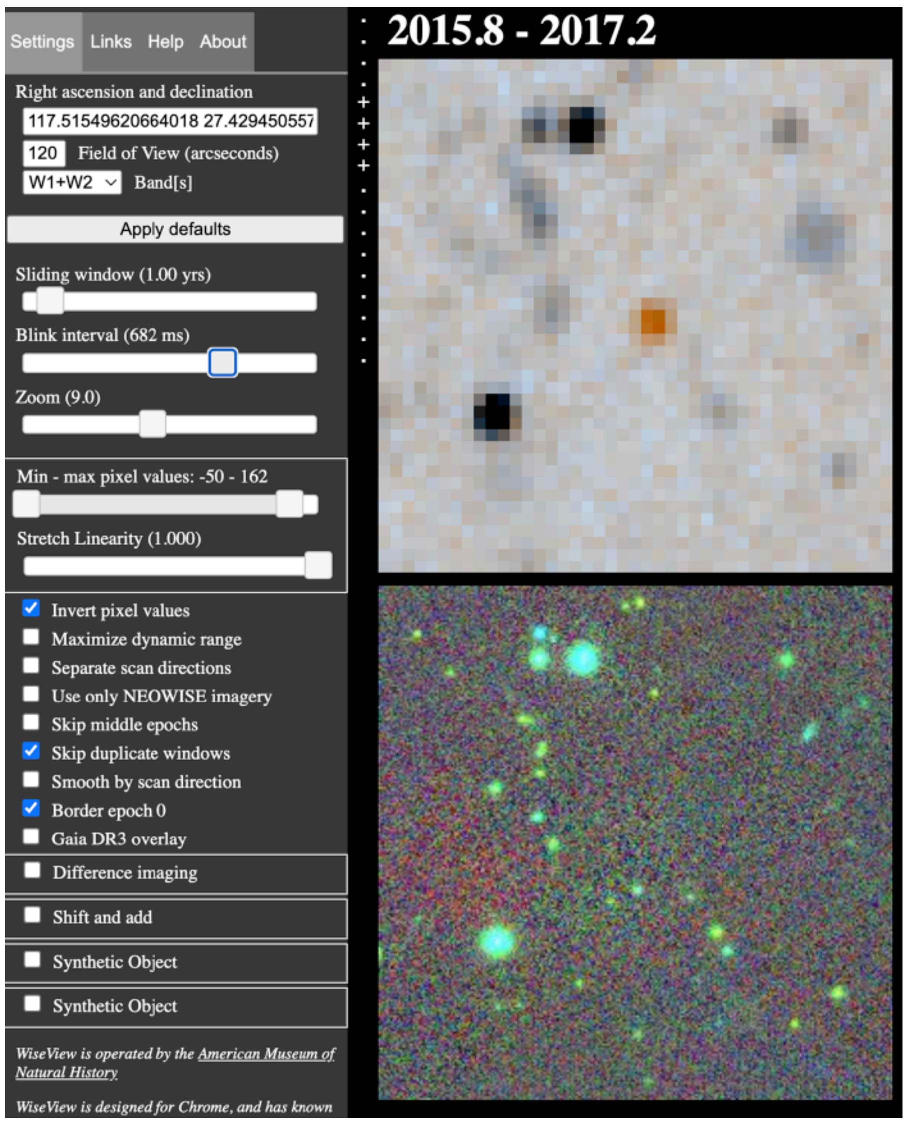
In this section, students look at some brown dwarf candidates from Backyard Worlds and attempt to determine which of the images contain a brown dwarf. The candidate is always near the center of the field of view but it can still be difficult to determine which images contain brown dwarfs.

The Settings Panel on the left side of the screen gives students options to change the animation to help determine if the candidate is a red dwarf. Students should feel free to change the settings and experiment to find the best combination of settings for each candidate. If the students change something and want to get back to the original settings, simply click the Default Settings button.

You can find a video tutorial for the WISEView tool here.

The most important settings are:

- Right Ascension and Declination: These are the coordinates you are looking at on the sky. Students should not change these or they will not be looking at the candidate brown dwarf!
- Field of View: How big an area of sky is being viewed. 120 arcseconds is good for most of the images.
- Bands: You can select to view the W1 image (blue), W2 image (red), or both images combined (W1+W2). Students should leave this in W1+W2 to get color images where the brown dwarf could have a red/orange tint.
- Sliding Interval: Changes the width of the sliding window used for coadding time.
- Blink Interval: The time between frames. This can be used to speed up or slow down the animation.



- Zoom: Makes the image larger or smaller (but does not add any additional information to the image).

- Min-Max Pixel Values: These set the maximum and minimum values that will be displayed. Any pixels with a value less than the Min will show as black and any pixels with a value greater than Max will be white.

- Stretch Linearity: 'Linear=1.0' applies a purely linear normalization to the image, which has no effect. Lower values highlight lower intensity pixels, which is useful for observing faint sources, or those obscured by other, brighter, sources.

- All the checkboxes should be left in their default values.

Some of these fields have brown dwarfs that are easy to identify while others are much more difficult and some may not have a brown dwarf at all! Backyard World has many users analyze each field which reduces the number of false positives and negatives.