

# Teacher Guide

## From Molecular Cores to Stars

Grades 9 - 12

### NSES

#### Content Standards 9-12:

**Science as Inquiry:** understanding about scientific inquiry; abilities necessary to do scientific inquiry.

**Physical Science:** conservation of energy and increase in disorder; interactions of energy and matter.

**Science and Technology:** understanding about science and technology.

### Materials and Tools

For each “Dust Hunt” collaborative group:

Graph paper, magnifying glass (2x and 4x lenses), tweezers, cleaning pad (e.g. Swiffer or Grab-it mitts) or paper towel, watercolor brushes, wide clear packing tape, clear metric ruler showing millimeter marks.

Elaborate: Examining Herbig-Haro 46/47

Student guide (one for each student)

One computer, whole class: PowerPoint, video projector, and computer.

Computer lab or mobile laptop lab: two students per computer, with the PowerPoint file loaded on each computer.

### Engage

Dust is everywhere — on the floor, floating in the air, orbiting the Sun in our solar system, and in huge clouds in space like the Eagle Nebula and the Tarantula Nebula. Begin by asking students:

- *What is dust?*
- *What are everyday examples of dust?*
- *Why would an astronomer study dust?*

### Get Ready to Explore

Divide students into science teams of 2-4 members. Ask each group to pick their own physical area of the classroom to investigate, or assign investigation areas (locations) to groups. Tell the groups that their objectives are:

1. Collect dust in your assigned area.
2. Separate out the dust sample into different groups based on physical characteristics.
3. List the properties of the dust you discover.
4. Suggest origins for the dust that you find.
5. Explain how you think that your investigation of dust is related to an astronomer investigating dust in space.

### Explore

Each group uses the cleaning pads or paper towels to collect dust from their chosen place in the classroom. Students place each sample in separate baggie, and label it according to where the dust was collected, the time, date, and science team name.

An alternative dust collection method is to use the clear plastic tape to sample classroom areas. Use the sticky side of the tape to pull dust off surfaces.

### Example investigation:

1. Collect dust samples using the cleaning pad or clear tape.
2. Carefully remove particles from the pad (scrape with the tweezers and gently shake the pad) onto the graph paper. Then sort the contents by features (size, color, shape...) on the graph paper. Clear tape can be used to hold down the samples while students measure the size of the particles — the slightest breath will scatter the particles.
3. Measure the size of the particles. Using the clear plastic metric ruler and magnifying glass at 4×, students can see particles down to 100 micrometers (0.1 mm); but, the limit of their measurement accuracy is half the smallest unit of measurement on the ruler, or 0.5 mm. Prompt groups with questions to guide their investigation, such as:
  - *What range of sizes do you observe?*
  - *What is the largest size that qualifies something as dust?*

Interstellar dust (dust between stars and inside nebulae) is about 1 micrometer or smaller in size. For comparison, one millimeter is 1,000 micrometers. How a massive clump of micrometer size dust particles condenses into a planet thousands of kilometers wide is still a mystery. A planet is about  $10^{12}$  times bigger than the dust particle (one-millionth of a meter) !

4. List the basic properties of dust for each location. Some of the material might not qualify as “dust” (hair, seeds, and string). Many things will be too small to accurately measure, but students can still see them with the magnifying glass.

### Explain

Students explain the origin of the dust based on the results of their investigation. Help students with their explanations with guiding questions such as:

- *Do the observations suggest a relationship between dust and where it was collected?*
- *If so, what are the most likely origins of the dust?*
- *How could you better determine the source of the dust?*

Students should also explain their reasoning behind their dust organization and what evidence helps them support their dust-origin hypothesis. Some guiding questions to ask students are:

- *How did you decide to organize your samples?*
- *What evidence do you see that supports your hypothesis?*

Students may find evidence that does not support their original hypothesis, but instead points toward another explanation. Assure students that they did nothing wrong, they simply didn't find evidence to support their original hypothesis. As a result, they should explain why the evidence does not support their original hypothesis, then offer a better explanation for the origin of the dust based on their evidence.

### Elaborate

Read the following from Spitzer Space Telescope scientist Dr. Neal Evans III. (Students may follow along in their Student Guide.) Relate origins of dust in your classroom to dust in space. Astronomers are asking the same sorts of questions about dust that drive the students' classroom investigations.

Life can exist on planets around stars. Stars are organized into galaxies. What is the origin of stars, planets, and galaxies? The origins of all of these are hidden from view if we use visible light. Stars form in clouds of molecules and dust. The dust blocks visible light. Planets form in disks around the forming stars; planets like Earth form FROM the dust itself. The origin of galaxies is intimately related to the origin of the stars within them and again this is often hidden by dust. For distant galaxies, even the fully formed stars are “hidden” because their visible light is shifted to the infrared by the Doppler shift. Clearly, infrared light is the key to understanding the origins of stars and planets. But we need a cold telescope (cooler than the light source) above Earth’s atmosphere to collect and detect infrared light. Once we have this, we can study the light of stars in distant galaxies, study the origin of those stars in the dusty clouds in our own and other galaxies, and study the disks that form planets. We can even trace the nature of the dust as it changes to produce planets, comets, and asteroids. We can learn when the building blocks of life (the icy mantles containing carbon, nitrogen, and oxygen) form on the dust particles. And we can study the end of planets and stars as they create new dust. We can study the cycle from dust to dust.

### Doppler shift and distant galaxies

The universe is expanding all around us. The farther away we look the faster objects (galaxies, quasars, etc.), are moving away. Depending on how fast an object moves away, the wavelength of the light that it emits toward us becomes longer. In the visible part of the spectrum, we perceive the longest wavelengths as the color red. Compared to a spectrum taken in an Earth-bound laboratory, any atomic absorption or emission features in the galaxy’s spectrum will appear at longer wavelengths. The features look as if they shifted to the red end of the spectrum. Astronomers say that these atomic spectral features are “redshifted” from their laboratory-measured wavelengths. Some galaxies are receding so fast that most of the star light is shifted into the infrared wavelengths, hiding them from optical-wavelength telescopes.

Astronomers use the relationship between a galaxy’s distance and redshift to calculate distances to galaxies and quasars. Edwin Hubble was the first astronomer to establish this relationship with the Hale Telescope and a sample of galaxies in the early 20th century. Astronomers continue to refine this relationship today.

In everyday life, highway patrol officers use a “radar gun” (RADio Detection and Ranging) to check the speed of cars. During baseball games, a radar gun checks the speed of the pitch. These radar guns emit microwaves (about 1 cm in wavelength) that bounce off a moving target then travel back to the radar gun. The reflected waves are slightly longer or shorter than the emitted waves due to the relative motion between the target and radar gun. The object’s speed is related to the wavelength difference, or the wavelength shift.

Professor Dr. John Lacy describes interactions between infrared light and dust grains:

Dust grains that are large compared to the wavelength of the light hitting them cast shadows. If the wavelength of the light is larger than the dust grain, then the light can go around it. The basic reason for this is *diffraction*. This means that an astronomer can measure the size of the dust particle using the wavelength of light he/she observes.

### Examining a Young Star: Herbig-Haro 46/47

Students examine both visual and infrared wavelength images of Herbig-Haro 46/47 (HH 46/47). The infrared image of HH 46/47 is a false color image. To make physical inferences from the image, students

must draw on their knowledge of primary and secondary light colors.

**Suggestion: review primary and secondary light colors.**

### Primary light colors: blue, green, and red

- white = blue + green + red.
- Example: Look closely at a television screen to see tiny red, green, and blue cells.

### Secondary light colors: magenta, cyan, yellow

- magenta = blue + red = white – green
- cyan = blue + green = white – red
- yellow = red + green = white – blue
- Example: Watch bubbles floating in the air on a sunlit day to see these secondary colors. Destructive interference of a primary color in the bubble’s thin film causes these secondary colors to appear to our eyes and brain.

### Excellent background information and lesson websites

- <http://micro.magnet.fsu.edu/primer/java/primarycolors/additiveprimaries/>
- <http://www.colorado.edu/physics/2000/tv/colortv.html>
- <http://www.glenbrook.k12.il.us/gbssci/phys/Class/light/u1212d.html>
- NASA: <http://imagers.gsfc.nasa.gov/teachersite/UL.htm>
- Exploratorium Science Snack: Three Little Pig(ments) <http://www.exploratorium.edu/snacks/cymk/index.html>

### What is a Herbig-Haro object?

Herbig-Haro (HH) is the name for a range of odd looking outflows of matter from a forming star or a young star. They look like nebulae, but their spectra show emission features unusual for a nebula due to strong outflows of gas. These outflows can stretch several light-years, and move as fast as 300 kilometers per second. Astronomers have observed HH objects with modern telescopes and instruments, like the Spitzer Space Telescope, to better understand how stars and planets form. HH 46/47 represents the archetype Herbig-Haro object. So studying HH 46/47 will lend insight into other HH objects.

### Who are Herbig and Haro?

George H. Herbig (American) and Guillermo Haro (Mexican) are astronomers who first discovered and described these objects in the *Astrophysical Journal* in the early 1950s.

### Set up

#### IT assistance

You may wish to contact your IT specialist for help setting up computers and uploading the PowerPoint and movie files.

#### Computer set up:

##### One computer + projector

- You lead students through the investigation. Each team responds on their student guides.

##### Mobile computer lab (COW) or computer lab

- Each team uses their own computer, progresses at their own pace, and responds on their student guides.

### Student set up

Break students up into teams of two. Pass out the “Examining Herbig-Haro 46/47” student guide to each student.

### Facilitating the investigation

In the Student Guide, “Examining Herbig-Haro 46/47” contains information, suggested guiding questions, and possible student responses for each frame.

### One computer + video projector, whole class

- Make sure the video image on the screen is bright and large.
- Lead students through the investigation using your teacher guide.
- Students work in pairs and write their responses on their student guides.

### Mobile computer lab (COW) or computer lab

- Make sure that the PowerPoint file and movie file are loaded on each computer.
- Circulate from team to team to guide them through their investigation.
- Students work in pairs and write their responses on their student guides.
- Each pair may progress at their own pace.

### **Herbig-Haro 46/47**

These are two images of the same object at the same scale. One is an infrared image, while the other is an image of the visible light (the light our eyes see). The object is composed of gas and dust.

#### **1. 10 Points Which part of the electromagnetic spectrum do you think you see in these images?**

i. Which image is an infrared image?  
a. right side                      b. left side

ii. Which image is a visible image?  
a. right side                      b. left side

iii. What evidence supports your decisions?

#### **More evidence:**

The big clue is that the IR image is “false color.”

Few stars appear near the middle of the image because their light is absorbed or scattered away by dust. It is okay to assume that the background star distribution is uniform.

The nearly opaque cloud in the visible image disappears in the IR image.

Some stars appear dimmer while others appear brighter in the IR image compared to the visible image. The hottest stars will look dimmer in the IR image, while the cooler stars will look brighter in the IR image.

Why: IR wavelengths are longer (1 to 1000 micrometers) than visible-light wavelengths (0.4 to 0.7 micrometers). The hotter stars emit most of their energy in short wavelengths, while the cooler stars emit most of their energy in longer wavelengths.

iv. Is the following evidence for the visible image? Stars at the edge of the dust cloud look red.

a. Yes. The dust in the cloud scatters short wavelength light (blue, green) and is more transparent at longer wavelengths (red and infrared).

The dust is small enough that it is transparent to infrared light (wavelength > size of dust grain), but scatters shorter wavelength light (wavelength < size of dust grain).

b. No. The stars are red because they are hotter than the other stars.

The stars are red because the dust has scattered away the short wavelength (blue and green) light, leaving longer wavelength light (red and infrared) to pass through.

c. Yes. All the stars around the edge of the nebula are inside the nebula, and are hot so they look red.

Most of the stars are background stars, further away than HH 46/47. If they were in the dust cloud they would appear red due to the short wavelength scatter effect of the dust grains.

d. No. All the stars around the edge of the dust cloud are inside HH 46/47 and are emitting more infrared light than the other background stars.

**Note: Before going on, you may want to review light and color: primary and secondary colors of light.**

#### **2. 15 Points Examine the infrared image of HH 46/47**

i. Which false colors in the infrared image represent the material with the highest temperature? The lowest?

a. red      b. yellow      c. green      d. blue      e. white

The blue false color represents the shortest (smallest) wavelength of the infrared channels. White is not a color, nor does it represent a single infrared wavelength channel.

**Note:** the Spitzer Space Telescope sees the intensity of the IR light in four wavelength channels (8, 5.8, 4.5, and 3.6 micrometers).

Hottest: blue – it is assigned to the shortest IR wavelengths.

Coollest: red – it is assigned to the longest IR wavelengths.

**Note:** some IR false color images reverse this color order.

We commonly associate blue with cool and red with hot. This is not physically true with respect to blackbody radiation.

Remind students about the properties of a black body and how the peak color (wavelength) changes with temperature.

Ask students what colors they do not see

magenta = (blue + red) = (white – green).

Magenta would indicate that the green color-coded wavelengths were missing. Since the stars emit light like a blackbody (continuous spectrum, with a little bit of absorption) we don't see magenta in the false-color IR image.

ii. In the infrared image, why do you think the stars surrounding HH 46/47 are false blue and white?

a. They have the lowest temperatures because blue means cold.

b. They have the lowest temperatures because they emit the shortest wavelengths of infrared light.

c. The density of dust is low, so most all the star's light passes through.

The blue-white colors of these stars indicate that the short-wavelength IR light is getting through and into the telescope. If dust is present, it will scatter and absorb light at the shorter IR wavelengths. Most likely, the density of dust decreases away from HH 46/47, allowing the shorter IR wavelengths to pass through.

d. They are the stars with the highest temperatures because they are the brightest.

The brightest stars do not necessarily have the highest photosphere (the layer we see) temperatures. A star is just

a specific case of an object that behaves like a black body. In general, bright objects do not necessarily have to be extremely hot. A large surface area at a low temperature can radiate as much energy as a small surface area at a high temperature.

iii. If a feature appears white in the infrared image, what does that indicate about the energy distribution over the infrared wavelengths?

- a. All the colors are mixed evenly.
- b. The energy of the light at each wavelength is nearly the same.**  
White = blue + green + red. White colors indicate an even intensity, and even energy distribution over these IR wavelengths.
- c. They are the hottest objects.  
The hottest objects would appear blue in the false-color infrared image.
- d. They radiate the most energy.

The question is about the energy distribution across the wavelengths, not about how much energy the star radiates.

**3. 15 Points Examine the visible-light image of HH 46/47**

i. What is the dark blob (centered at E4) in the visible-light image? Explain.

A cloud of dust and gas. This cloud is enormous, about 3 light-years across, but nearly a vacuum. (Our solar system on the order of light-hours across. Light from the Sun takes about five and one half hours (332 minutes) to reach Pluto.) This cloud's average density is between  $10^3$  to  $10^9$  molecules per cubic meter. For comparison, air at STP contains about  $2.7 \times 10^{25}$  molecules per cubic meter.

ii. What are the points of light surrounding the dark blob in the visible-light image? Explain.

These are background stars. Some you can see near the edge of the cloud. The dust is scattering away the short-wavelength light (blue) and is more transparent for long-wavelength light (red and infrared).

**4. 25 Points Compare and contrast the two images: List the prominent features of each image, and how you think they are related.**

| Feature Coordinate | IR image feature                   | Visible image feature                     | Relationship                                                                                                |
|--------------------|------------------------------------|-------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| F-3                | Bright spot upper right of F-3     | Bright spot upper right of F-3            | Light from the forming star, part of the gas jet. There could be a hole in the dust cloud in F-3.           |
| F-3                | Bright spot upper right of F-3     | Dim, reddish patch near the center of F-3 | Light from the forming star. The dust and gas are blocking the visible light.                               |
| G-3, G-4, and F-3  | Bright ribbon in orange/red        | Edge of the dust cloud                    | The outflow from the nearby star core is heating the dust near the edge of the dust cloud.                  |
| E2, E3, F3, and G4 | Loop of bright green (false color) | None                                      | Outflow from the forming star creates a shock wave that glows in the wavelengths coded (false color) green. |

**5. 10 Points The tube-shaped “smoke ring” in the infrared image (E2, E3, F3, G4) is an outflow of gas and dust from the forming star (F3). The gas is moving rapidly, with maximum speeds approaching 100 kilometers per second. Include supporting evidence in your explanation.**

Why do you think the gas and dust are emitting infrared light?

- a. Strong microwave-wavelength light from the star is heating the dust and making it glow.  
The wavelength of microwave light (centimeters) is longer than infrared (micrometers), and much bigger than the dust grains. The dust is transparent to microwaves, so such radiation would not heat the dust.

b. The out flowing gas is expanding so fast (near the speed of light) that it emits light.

The speed of light is 300,000 kilometers per second. The speed of the outflow material is related to its kinetic energy.

**c. The outflowing gas collides with the surrounding dust in the nebula, which heats it up.**

d. Magnetic fields generated by the star are stirring up the dust and heating it up.

There is no evidence in this image of magnetic fields. Although this happens near stars and near our Sun (for instance, in the corona), the effect in the image extends

over one light-year, which is very far away from the star. The magnetic field strength at this distance is not strong enough to cause the dust to emit infrared radiation.

#### Explanation and evidence:

C is the best answer. At 100 kilometers per second, the outflowing gas crashes into the surrounding gas and dust in the nebula. The collisions heat the gas and excite dust molecules into vibration modes. In accordance with the conservation of energy, the excited and vibrating molecules emit photons at IR wavelengths. The evidence is the bright band in E2, E3, F3, and G4. This infrared emission is from the dust molecules that are excited by the collisions, which then de-excite and radiate light.

Astronomers can analyze the infrared spectrum of HH 46/47 to determine what is radiating the infrared light. In the case of HH 46/47, astronomers see complex emission features of molecules, not of individual atoms, in the infrared spectrum. The spectrum indicates that the molecules are vibrating like a network of balls connected with springs. The molecules will emit light at wavelengths that correspond to the energy of the molecule's vibration modes, similar to the mode of a simple mass on a spring.

experiences tremendous tidal forces. The resulting shear maintains Io's volcanic activity. In addition, the star's intense radiation would vaporize dust very close to the star. Around the edge of the disk, the density of dust decreases. There is not enough dust per unit volume to collapse into a planet.

#### Evaluation Rubric

##### THE "DUST HUNT"

##### Engagement: 0-20 points

- Students actively engage in the activity, with each member contributing to the investigation objectives.

##### Methodology: 0-40 Points

###### Planning 0-10 points

- Simple thoughtful plan for collecting the dust and organizing the samples.

###### Collection 0-10 points

- Consistent collection method and care taken to preserve the dust samples in their labeled plastic baggies.

###### Measurement: 0-10 points

- Consistent measurement technique and reasonable particle size estimates. Shows understanding of accuracy and precision.

###### Organization: 0-10 points

- Dust samples are clearly marked and organized by the particles' physical properties. The organization helps students see relationships between the particles and their possible origin.

##### Synthesis: 0-40 points

- Clear relationship between the dust investigation and the astronomer's research. Student supports claims with relevant examples and evidence from the dust investigation.

##### Total: 100 points

#### Elaborate: Examining Herbig-Haro 46/47

1. **10 Points** Which part of the electromagnetic spectrum do you think you see in these images?
2. **15 Points** Examine the infrared image of HH 46/47
3. **15 Points** Examine the visible-light image of HH 46/47
4. **25 Points** Compare and contrast the two images
5. **10 Points** The tube-shaped "smoke ring" in the infrared image (E2, E3, F3, G4) is an outflow of gas and dust from the forming star (F3). The gas is moving rapidly, with maximum speeds approaching 100 kilometers per second. Include supporting evidence in your explanation.

#### Why do you think the gas and dust are emitting infrared light?

6. **25 Points** These are visible-wavelength images of an object in the Orion Nebula taken with Hubble Space Telescope. These objects represent a stage of star and planet formation that happens after the stage represented by HH 46/47. The colors in images **A** and **B** come from the gas in the nebula emitting light at different wavelengths. These images are small regions of the entire Orion Nebula, 1,500 light-years away. The Orion Nebula is huge. It is several light-years in diameter.
  - i. What is the bright spot in the center of image **A**?
  - ii. What about the dark oval in image **A** and the disk in image **B**?
  - iii. Where do you think planets would form?

##### Total: 100 points

**6. 25 Points** These are visible-wavelength images of an object in the Orion Nebula taken with Hubble Space Telescope. These objects represent a stage of star and planet formation that happens after the stage represented by HH 46/47. The colors in images **A** and **B** come from the gas in the nebula emitting light at different wavelengths. These images are small regions of the entire Orion Nebula, 1,500 light-years away. The Orion Nebula is huge. It is several light-years in diameter.

Image **B** is a side view of an object like the one in image **A**.

- i. What is the bright spot in the center of image **A**?
  - a. a planet
  - b. a star

*Evidence: The object in the image is extremely bright, and about 1,500 light-years away, so it must be very large (in diameter and surface area to radiate light) and luminous (power). A planet does not radiate nor reflect enough light to be seen at this distance with Hubble Space Telescope. A planet is just too small.*

- ii. What about the dark oval in image **A** and the disk in image **B**?
  - a. a planet
  - b. a star
  - c. dust orbiting the star
  - d. a black hole in the nebula

*Evidence: The dust is blocking background light, so it appears as a dark disk with the star in the middle.*

- iii. Where do you think planets would form?
  - a. close to the star
  - b. in the disk of dust
  - c. outer edge of the disk of dust

*Explanation: Planets would most likely form in the disk where dust could collapse into a spherical mass. Gravitational tidal forces would shear a forming planet near the star. For instance, Jupiter's moon Io orbits close to Jupiter and*