

## Filters and the CCD Camera - An Interactive Model

**Purpose/Overview:** This activity is designed to provide an accessible model of how electromagnetic (EM) radiation interacts with filters and is recorded on a CCD camera. This model demonstrates the wave/particle duality of EM radiation: light emitted by objects in space travels as waves (students in motion) but interacts with matter as photons or particles (foam shapes and push pins).

This model uses a large 3x3 grid to represent the CCD camera. Nine cards with foam shapes of different sizes and colors represent the photons that the object emits. Students represent the wave nature of light by carrying each card to the CCD camera. When the wave reaches the camera, it goes through a “filter.” The information from the “filter” is transmitted to the model CCD pixels which are represented by the 3x3 grid (a large foam board divided into nine sections). There will be four grid boards, each representing one filter: clear, blue, green, and red.

( An **alternative version** for a single student or very small group is to use 4 pieces of cardstock divided into 3x3 grids with Wikki Stixs (or some other tactile type of line). Then use 3x5 notecards with different shape sticky gemstones to represent the photons the object emits. The rest of the instructions are the same).

Filters in astronomy are placed in front of the CCD detector and allow scientists to investigate smaller portions of the electromagnetic spectrum. Precisely manufactured standardized filters allow only photons of specific frequencies to pass through. The standard filters most commonly used are listed below.

Filter	Description	Central Wavelength
u	Allows ultraviolet light to pass through	350 nanometers
g	Allows a combination of green and blue light to pass through	480 nanometers
r	Allows a small portion of red light and yellow light to pass through	625 nanometers
i	Allows longer wavelengths of red light through	770 nanometers
z	Allows a portion of infrared light through	910 nanometers

## Standards Addressed:

[HS-PS4-3](https://www.nextgenscience.org/pe/hs-ps4-3-waves-and-their-applications-technologies-information-transfer) Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other  
<https://www.nextgenscience.org/pe/hs-ps4-3-waves-and-their-applications-technologies-information-transfer>

**Cross Cutting Concept: Systems and System Models**  
 Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-PS4-3)

## Focus Questions:

1. Describe the path of the energy from the object to the CCD camera.
2. Can you identify each element of the model and how each relates to the passage of EM radiation from an object in space to a CCD camera?
3. How is color recorded on the CCD camera?
4. What happens to the photons that are “filtered” out before interacting with the CCD camera?
5. Does all the energy from the object that enters the telescope make it to the camera? Explain.

## Materials:

1. Five foam boards - 16x20 inches; black works well (or five pieces of cardstock if making the small version)
2. One of the foam boards will be cut into nine square pieces (or use nine small notecards)
3. Foam stickers of three different shapes. The different shapes represent the different colors of photons. (Or use small, different shaped sticker gemstones. Make sure you are able to feel the different shapes)
  - a. 29 of the same shape to represent Red
  - b. 16 of the same shape to represent Green
  - c. 10 of the same shape to represent Blue
4. White map pins: short pins with large white heads. (for the smaller version just use a single color gemstone - preferably white or clear)

**In advance:**

1. Using four poster boards, divide each equally into nine tactile grids. The grid represents nine pixels of our model camera. To do this::
  - a. Divide one board into three columns and three rows.
  - b. To make this tactile, attach straws or thick string along the lines of the columns and rows with wide tape (Duct tape works well).
    - i. Or just use the Wikki Stixs on a piece of cardstock for the small version
  - c. Repeat for a total of four boards
2. Cut the remaining foam board into nine equal size pieces. (use nine notecards for the small version). Refer to the master grid [HERE](#)
  - a. Label each of the grid pieces to correspond to a pixel on the CCD grid. For example: A1, A2, A3, B1, B2, B3, C1, C2, C3, with the rows labeled A, B, C and the columns labeled 1, 2, 3. You may also want to label the posterboard.
  - b. Braille/printed stickers for numbers and letters also work well.
  - c. Using the master grid as reference (see below), place the appropriate number of foam stickers of each shape onto the nine squares.

**Procedures:**

1. The following links take you to two videos featuring Dr. Kathryn Williamson. They will help introduce students to the CCD camera.
  - a. [Introducing Dr. Williamson](#)
  - b. [Dr. Williamson Explains CCD Cameras](#)
2. For the large, classroom activity:
  - a. Select nine students to represent nine divisions of space from which energy is collected. Give each student one of the nine grid pieces. These students are carrying photons of different wavelengths (**Photon-carrying Students**).
  - b. Assign four students to play the role of the filters. These students should wear a sleep mask or blindfold (**Filter Students**).
  - c. Assign another four students to be the CCD detector (**CCD Students**). There is a CCD Student for each of the four filters: clear, red, visible light, and blue. The CCD Students should have a supply of white push pins, which represent the electrons that photons are ejecting from each pixel. Each CCD Student stands in front of one CCD poster (the foam board that is divided into nine sections).
  - d. Send the Photon-carrying Students, one at a time, to each of the four CCD Students. The Photon-carrying Students tell/show which card they are carrying (e.g., A1) to the Filter Student and CCD Student.
  - e. Example: At the **clear** CCD poster, a Photon-carrying Student should show the grid piece to the Filter Student, who then counts (by feeling)

the number of foam stickers attached to the square. The Filter Student counts all the photons on the grid square because the clear filter allows all wavelengths to pass through. After counting the photons, the Filter Student tells that number to the CCD Student, who then inserts that number of map pins into the respective section on the CCD poster.

- f. At each of the other CCD posters, the Filter Student counts only the number of photons (as represented by different shapes of foam sticker) which correspond to the filter being represented. The Filter Student will tell this number to the CCD Student, who again attaches that number of map pins to the section of the CCD poster that corresponds to where the photos came from, ie, (A1, A2 etc).
- g. Each Photon-carrying Student approaches each of the CCDs in turn until all nine Photon-carrying Students have been to all four CCD posters.
- h. Optional - Have students fill in a blank grid on paper with the data the CCD recorded.

When the activity is complete, the number of map pins in each of the sections of the CCD poster will equal the color (shape) of the photons from each corresponding grid piece. The sections of the clear filter CCD will have a number of pins equal to the sums of those in the pixels of the three colored filters.

*For the smaller version, the same procedure is followed, but one person plays all three roles.*

#### **Accessibility Considerations:**

1. If possible allow each BVI student to experience each of the roles in this model.
2. Ask all of the players to talk out loud when they are doing their tasks. For example, they can even be coached to say, "I am a blue filter and I count 5 blue photons in this part of the sky."

#### **CCD Cameras and Filters references:**

A good reference for filters is from the Sloan Digital Sky Survey Voyages site: <http://voyages.sdss.org/filters/>

Another reference on the SDSS Voyages site discusses CCD cameras for telescopes(scroll down the page to the CCD Camera):

<http://voyages.sdss.org/sdss-instruments/>

This link is to the Astronomical Society of South Australia. They do a nice, one page summary of CCD cameras using a farmer with paddock analogy:

<https://www.assa.org.au/resources/astrophotography/how-ccds-work/>

The same site as above has a good basic description of the equipment used for stellar photometry:

<https://www.assa.org.au/resources/astrophotography/stellar-photometry/>

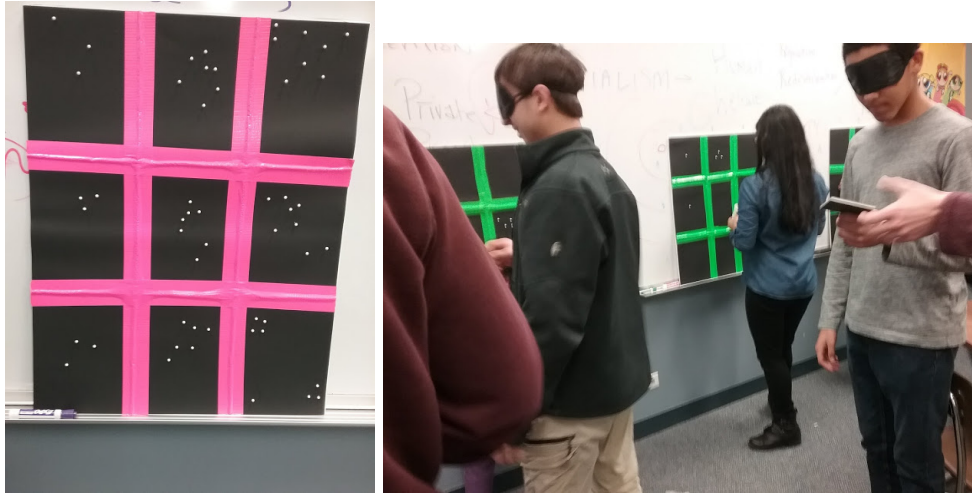
### **3X3 Filled Pixels for the CCD Activity**

R=Red, B=Blue, G=Green

(the number in parenthesis is the total number in that square)

2R (3)	4R (7)	2R (8)
<b>A1</b>	<b>A2</b>	<b>A3</b>
1G 0B	3G 0B	4G 2B
2R (3)	4R (8)	6R (9)
<b>B1</b>	<b>B2</b>	<b>B3</b>
1G 0B	1G 3B	2G 1B
2R (3)	2R (6)	5R (8)
<b>C1</b>	<b>C2</b>	<b>C3</b>
1G 0B	1G 3B	2G 1B

Images of the large, classroom activity:



Credits: **Innovators Developing Accessible Tools for Astronomy (IDATA)**, officially known as *Research Supporting Multisensory Engagement by Blind, Visually Impaired, and Sighted Students to Advance Integrated Learning of Astronomy and Computer Science*, and the resulting curricular resources, Afterglow Access software, and project research were made possible with support from the U.S. National Science Foundation's STEM+C program (Award 1640131). IDATA institutional collaborators include AUI, GLAS Education, Linder Research & Development Inc., Logos Consulting Group, TERC, University of Nevada – Las Vegas, University of North Carolina at Chapel Hill, and Universidad Diego Portales. Individual consultants on the project include Kathy Gustavson and Alexandra Dean Grossi. IDATA Teacher collaborators in the U.S. include Amanda Allen, Jacqueline Barge, Holly Bense, Neal Boys, Tim Fahlberg, Kristin Grender, David Lockett, Matthew McCutcheon, Caroline Odden, Michael Prokosch, Kara Rowbotham, Rick Sanchez, and Barbara Stachelski. IDATA Student collaborators in the U.S. include Evan Blad, Naleah Boys, Ellen Butler, Jayden Dimas, Riley Kappell, Joseph Murphy, Logan Ruby, Alex Scerba, Charlize Sentosa, Meg Sorensen, Remy Streichenberger, Trevor Warren, and others. IDATA Undergraduate Mentors include Tia Bertz, Katya Gozman, Chris Mathews, Kendall Mehling, Andrea Salazar, Ben Shafer, Alex Traub, and Sophia Vlahakis. Special thanks to the IDATA external advisors including Nic Bonne, Al Harper, Sue Ann Heatherly, Russ Laher, Luisa Rebull, Ed Summers, and Kathryn Williamson.