Session 4 – Invisible Light

General Description

Discussion and group experimentation with specialized instruments at different stations (visible, infrared, and ultraviolet) allow students to discover that "invisible" light is as real as visible. Students learn that in astronomy, it is important to make observations over a wide range of wavelengths, because the different wavelengths of light in the electromagnetic spectrum give us different pieces of information. This session ties in with Session 5.

Objectives

- To explore several different types of light, both visible and invisible.
- To reflect on the everyday and astronomical applications of light.

Concepts Addressed

- The electromagnetic spectrum
- Applications of visible and invisible types of light

Materials

- The *Electromagnetic Spectrum* handout (black and white version included in Appendix E and color version included in Appendix F)
- Flashlight (with batteries)
- One sheet of plain white paper
- Infrared light (heat lamp)
- Two Alligator jumper clip cables (the colors don't matter) *
- Photocell or solar cell **
- Amplifier/speaker *
- Audio cable *
- 9V battery
- Assortment of one or more remote controls, any kind — TV, VCR, radio, etc.
- Digital camera or camera phone
- Ultraviolet lamp *
- Invisible ink pens (or other items which are sensitive to ultraviolet light, such as ultraviolet reactive beads, glow-in the-dark stars, white powder laundry detergent, credit cards, etc.)
- Visible Light worksheet for program leader (included in Appendix E)
- Invisible Light worksheets, one per student (included in Appendix E)
- Pencils/pens
- Whatever is available in approximately 12″ × 12″ (size is not critical) sheets of material, including some that let light pass through and some that don't — such as, clear plastic,

black plastic, aluminum foil, paper, piece of cloth, wax paper, plastic bag, window screen, etc. You will need 4 sets of these materials, one set for each station.

** Information about where this can be purchased, along with part numbers can be found in Appendix C.*

*** The infrared detection circuit requires an encapsulated solar cell with two wire lead (pictured below). Information about where this can be purchased can be found in Appendix C.*

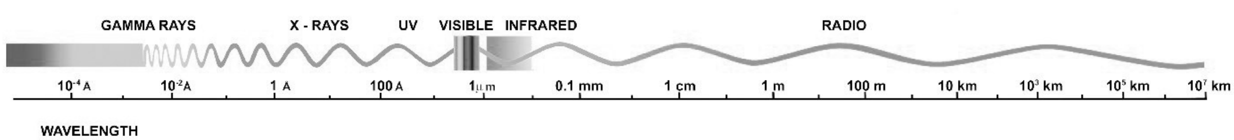
The type of solar cell used for the infrared detection circuit.

Other Requirements

- A room that can be set up with 4 tables or desks that serve as "stations" for working with different types of light.
- Access to a blackboard, whiteboard, flip chart, or large sheet of paper, and chalk or markers.

Background

The electromagnetic (EM) spectrum is made up of all the different wavelengths of light, including visible and ranging from radio waves to gamma rays. Just as our ears can only hear certain frequencies of sound, our eyes can only see visible light, which makes up a tiny portion of the entire spectrum. Remember, scientists use the word "light" for any wavelength of energy, and will use the words 'light' and 'energy' interchangeably at time.



Astronomical objects emit light at various wavelengths depending on their temperature. For example, the material around black holes is very hot and shines very brightly at X-ray wavelengths. Stars that are still forming are too cold to emit light at visible wavelengths, but do so at infrared (IR) wavelengths. Collecting data at different wavelengths is very important in astronomy, to gain a more complete picture. You can think of the fable with the blind men and the elephant:

> A group of blind men is asked to touch an elephant to understand what it looks like. Each one touches a different part, but only one part, such as the trunk, leg, or tail. They then compare notes on what an elephant is, and learn they are in complete disagreement (it is a tree, wall, snake, etc.) about what an elephant looks like. But if they combined all their experiences, they would arrive at a more complete and accurate description of the elephant.

(Long version of this story at http://www.peacecorps.gov/wws/stories/stories.cfm?psid=110)

How the receiver circuit works (for Station 2)
– No need to explain this to students, but here's the information in case of questions:

In the circuit, the photocell receives the IR signal from the flashlight and converts it to an electrical signal that is sent to the amplifier-speaker. This particular photocell is sensitive to light over a range of wavelengths, including visible and infrared light.

The photocell produces a constant electric current when exposed to light. A constant light source produces a constant current and no sound. You might hear static, if anything.

Speakers require a changing current to produce sound. When the light changes in brightness, the current produced by the photocell changes, and the speaker produces sound. You change the brightness of the light when you move your hand back and forth in front of it, so you hear "pops" each time the light is turned back on. (To the photocell, moving your hand across the beam is the same as turning the light off and on.)

Why a changing current is needed to hear sound from the speaker (for Station 2)
– No need to explain this to students, but here's the information in case of questions:

Inside the speaker, a flexible cone (usually made of paper, plastic, or metal) vibrates rapidly in response to a changing electrical current. As it moves, it pushes the air molecules around it. Those air molecules, in turn, push other air molecules near them, and the vibration is transmitted through the air as a sound wave. Our ears detect the vibration of air molecules and convert them into an electrical signal that our brain interprets as sound.

The cone vibrates because it's attached to a steel frame that receives impulses caused by the changing magnetic field from a magnet behind it. The magnet will only change if there is a change in the current it receives from the photocell. If the current is constant, there's no magnetic field change, so no impulse, no vibration, and no sound.

Session Overview

Students experiment with different types of light (different wavelengths) most of which are not visible to the human eye. Different stations allow them to experience similarities between visible, infrared, and ultraviolet light. Each station has a source of light, a detector, and sheets of material to test as potential "transmitters" or "shields" for the light. By testing various types of light with these shields and transmitters, students discover for themselves that there are types of invisible light that can be detected — but not with our eyes.

Preparation

- On the blackboard, draw the chart (template included at the end of the session) to record observations for your demonstration with visible light. Change the materials listed in your chart to whatever you are using.

- Make copies of the *Invisible Light* worksheet for each student.

- Set up the 4 stations (below) at 4 widely-separated tables with all the supplies listed under each. Label each station with its title, source, and detector(s), as well as the appropriate number. (*For large classes, you can set up two of each of these stations.*)

Demonstration station – Visible light
SOURCE: Flashlight (with batteries)
DETECTOR: Plain white paper
Set out one set of shield and transmitter materials
Set up this station near your blackboard

Station 1 – Infrared light
SOURCE: Infrared light (heat lamp)
DETECTOR: Student's hand
Set out one set of shield and transmitter materials

*** **NOTE: The heat lamp can get extremely hot, and students should handle with care! Do not touch any materials directly to the heat lamp bulb, and keep hands at a reasonable distance to avoid injury. Consider putting the heat lamp inside a "cage," such as a milk crate, to prevent contact.*** ***

Station 2 - Infrared light
SOURCE: Remote controls
DETECTOR: Simple circuit (construction described below)
DETECTOR: Digital camera
Set out one set of shield and transmitter materials

Station 3 – Ultraviolet light
SOURCE: Ultraviolet lamp
DETECTORS: Invisible ink pen
Set out one set of shield and transmitter materials

Step 1: Building the receiver circuit (*diagram below*)

Check our online resources for a video about building this circuit.

The infrared receiver circuit.

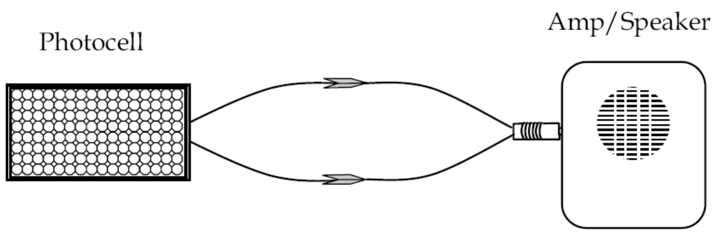
To make the photocell detector, you will use jumper cables and the audio cable to connect the photocell with the amplifier/speaker (which requires a 9V battery).

1. Clip one alligator clip from a jumper cable to one of the wire leads coming from the photocell. Always clip to the exposed (wire) end of the lead.

2. Clip the alligator clip at the other end of the jumper cable to one of the leads coming from the audio cable.

3. In the same way, use a second jumper cable to connect the other lead from the photocell to the other lead of the audio cable.

4. Put audio cable into the jack labeled “input.”



Simplified diagram of the infrared receiver circuit.

Step 2: Testing the receiver circuit

For best results, turn off any overhead fluorescent lights. They will cause the speaker to emit a constant buzz or hum, because the intensity of the light changes.

1. Turn on the amplifier. You will hear static. (The static is noise from the detector and the amplifier themselves, plus some ambient light. Daylight will produce even more noise than indoor light.)

2. Now shine a flashlight on the detector and wave it back and forth or "chop" the light in front of it with your hand. You should hear "pops" in the sound level now (see the explanation for how the receiver circuit works in the background section for why it works this way). This confirms that the photocell reacts to light falling on it. You have confirmed that your circuit works — turn off the amplifier.

Activity

(Adapted from Invisible Universe, developed by the Lawrence Hall of Science with support from NASA's Swift mission.)

I. Discussion and demonstration (15 minutes)

Pass out the electromagnetic spectrum handouts.

1. Base yourself at the demonstration station for this discussion.

Ask the students why astronomers observe the same object in space — like a star — in more than one wavelength? Wait for answers.

Here's a short fable that helps to explain why:

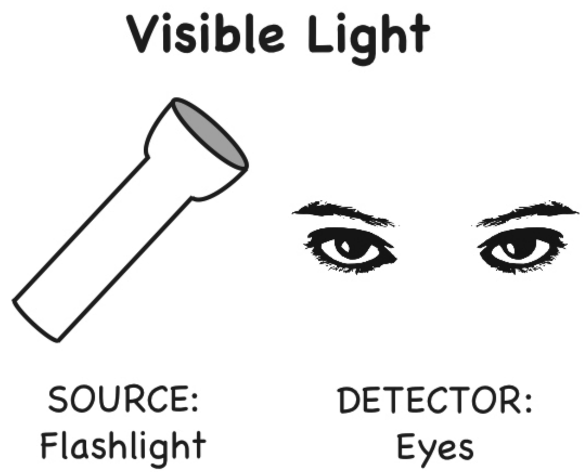
> *A group of blind men is asked to touch an elephant to learn what it is like. Each one touches a different part, but only one part, such as the trunk, leg, or tail. They then compare notes on what an elephant is, and learn they are in complete disagreement (it is a tree, wall, snake, etc.) about what an elephant looks like. But if they combined all their experiences, they would arrive at a more complete description of the elephant and realize its true nature.*

When we look out in the Universe, astronomers play the parts of the blind men. They observe objects like stars in different wavelengths, and then share their information with each other. This allows them to learn much more about what they are looking at than if they worked alone.

2. Tell the students you are going to talk about **sources** and **detectors** of light. Shine the flashlight at the blackboard.

   Tell them that the flashlight is a source of light because it produces its own light. Ask what other sources of light they can see in the room. Allow students to respond. Note that many objects reflect light (like the Moon, a mirror, and even the Earth itself) — they are not the source of light. Sources of light produce the light themselves — a star is a good example.

   Ask them how we know the light is there. Allow students to respond. Lead them to the answer of "with our eyes." Our eyes are detectors of light.

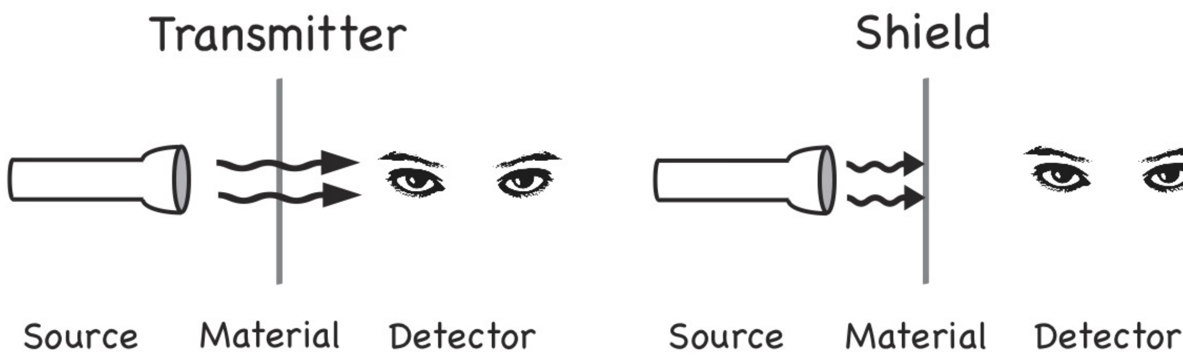


The demonstration station, visible light, and its source and detector.

   Ask what other types of detectors they can think of. Common examples are cameras and video cameras. Hold up a blank sheet of white paper. Explain that it reflects the visible light from the room lights or daylight, which is why we can see it. So the white paper might be considered a detector, but our eyes are the *real* detector.

3. Say that we'll next try out some **transmitters** and **shields**. Explain that some materials let light through and are called "transmitters" of light. Other materials do not let any of the light through; they block it. These are called light "shields." Ask students for examples of materials that let light through and materials that don't.

   One at a time, hold up the shield materials you have. Ask students to predict whether the flashlight's light will shine through — but don't try it yet! As students offer their predictions, have a volunteer go to the blackboard and write down the predictions for each material in that part of the table. Transmit (or partially transmit) can be recorded as "T" and shield as "S." Then hold each material in front of the flashlight (at a distance of 3–4 inches) and ask them to tell you what they see. Have the volunteer record the observed results in that part of the table.



A transmitter allows light through and a shield stops it.

4. Ask if they can think of any sources for the invisible light. They should be familiar with TV remotes. Ask if they know how TV remotes "talk" to the TV.

   Remind them to look at the handout to see the range of different types of light. Tell them they will be experimenting with some types of invisible light today, and they will see how TV remotes work.

II. Activity (20 minutes)

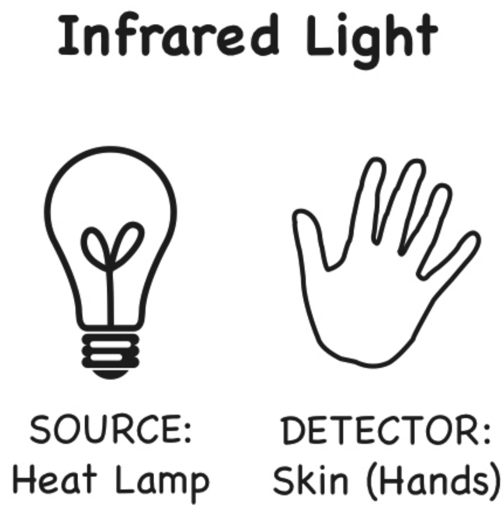
Check our online resources for a video overview of these stations and procedures.

Now we're going to "see" some invisible light for ourselves.

Explain that the 3 stations around the room (besides the demo station) each have a source of "invisible" light, a detector, and a set of materials that may be shields or transmitters for the light. Replace the flashlight at Station 1, and walk around to the 3 stations, pointing out the sources (IR lamp, remote control, and UV lamp) and their respective detectors, and briefly explaining what to do at each station — especially station 2.

Station 1 – Infrared Heat Lamp:

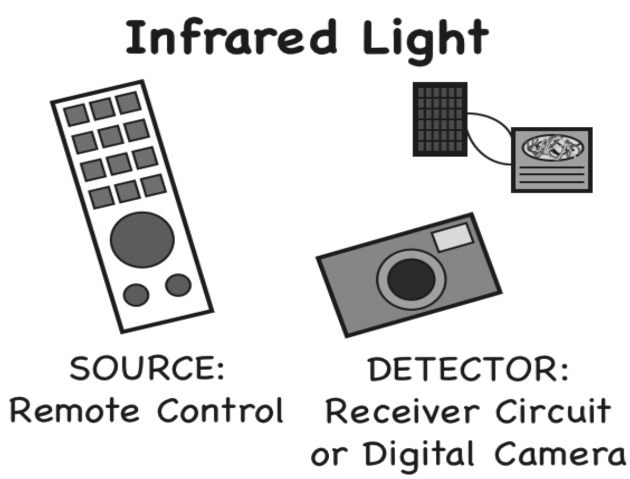
Turn on the infrared lamp and place your hand near it. Students should just feel the heat from the lamp and ignore the small amount of visible light being emitted by the bulb (the part you can see is visible light, the heat is the infrared light). The skin on their hands is the detector here. If it were not dangerous, we would blindfold them so they would not have the chance to be confused by visual input, but this is impractical for safety reasons.



The source and detector for station 1.

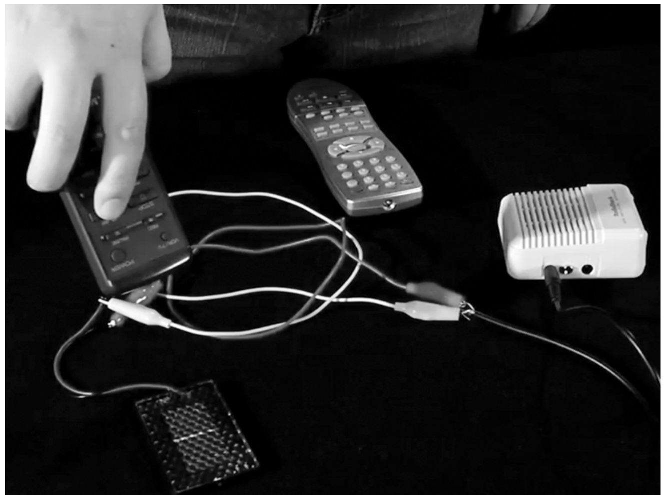
***** NOTE: The heat lamp can get extremely hot, and students should handle with care! Do not touch any materials directly to the heat lamp bulb, and keep hands at a reasonable distance to avoid injury. The plastic bags in particular melt very easily. Consider putting the heat lamp inside a "cage," such as a milk crate, to prevent contact. The best detector in the room for this is the smoke detector, but we hope to not use that one! ****

Station 2 – Infrared Remote Control:



The source and detector for station 2.

Turn on the amplifier. Students should shine one or more remote controls at the photocell in the simple circuit (it may be helpful to label the photocell at the station). The photocell will pick up the light and relay it to the amplifier, which converts it into sound. In this set-up, they can "hear" the IR light even though they can't see it.



Pointing a remote at the solar cell will make sound come out of the amplifier/speaker.

Turn on the digital camera. Have students point a remote control at the camera and push a button on the remote. Depending on the remote control, they will either see a bright beam of light or flashes of light coming out of the remote control when they push a button and watch the screen of the camera. The camera is sensitive to IR light and can see the signal from the remote control, even though we can't.

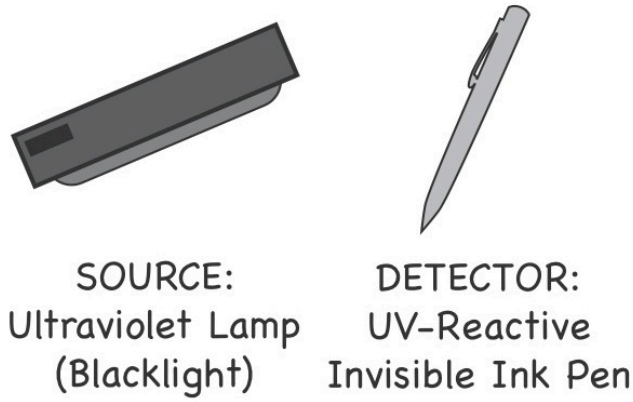
Many digital cameras can see IR light.

If there is time, students can do their tests with both the camera and the circuit and compare their results. It could be interesting to see if the results are the same.

Station 3 – Ultraviolet Light:

Write a message on a piece of plain white paper with the invisible ink pen. Turn on the ultraviolet lamp. If you hold the light over the paper, you should see the message glowing brightly. When you test various materials during the activity, you'll be looking for the message to appear. If you see a message, the ultraviolet light has been transmitted through the material. No message, and the ultraviolet light is being shielded.

Ultraviolet Light



The source and detector for station 3.

There are many other materials that react to ultraviolet light that you could use at this station, though we specifically suggest the invisible ink pen for this activity (see the Suggestions and Misconceptions for further discussion). This station is frequently the one where participants linger the longest, as there are many fun things to explore in the ultraviolet!

Students test a UV light with alternate detectors.

Explain that even though they may be able to see red light from the heat lamp and purple light from the UV lamp, this is not the invisible light that we are detecting. This is visible light that is too close to the UV and IR light to be filtered out, but they should ignore it for their experiment. We care about the invisible portion of the light, not the part you can see. If you can see it, it's not invisible!

If helpful, you can draw a comparison to neopolitan ice cream — even if all you want is the vanilla, it is close enough to the chocolate and strawberry that you will probably get some of them as well. Clearly demonstrate what they are actually looking for in each case. Show how the detectors react to visible light, and how that is different from their reaction to the invisible light. Demonstrate these issues clearly before they get to the stations for themselves.

Distribute the Invisible Light worksheets to each student, and split the class into 3 groups.

Have students pick one person in their group who will report their results at the 3 stations.

Have the students make their predictions for whether each material will be a transmitter or shield for each type of light before they get to the given station, and record these predictions (T or S) on their worksheet. You can have them make them all before they start to avoid the temptation to just wait and see what the answer is so that they get it "right." The goal here is not to get everything right, but rather to get used to the process of making predictions and then carrying out an experimental procedure to test those predictions.

They should also come up with a consistent experimental procedure for each of the stations. This is an important aspect of real science, too. Changes with regards to who holds what, distances between items, etc. can introduce error into their results, and should be discussed in the case of inconsistent results. When they get to the stations, let them see if their results change if they change their experimental procedure.

Participants test materials at the heat lamp station.

At each station, students try the "flashlight experiment" themselves, but using the station light source instead of the flashlight. They should shine the light source at each of the materials and experiment to answer these questions:

- *Can they see any light directly with their eyes?* (They shouldn't be able to see much, if they even see anything. **Make sure that the students do not shine the light directly into their eyes, but shine it at the materials you have laid out.**)
- *What can see it?* (The detector.)
- *Which materials block the light from reaching the detector?* For this, we specifically mean the invisible portion of the light, not the red or purple light that they can see with their eyes.

Have them record their results (T or S) on the Invisible Light worksheet. Have them try to explain the results and record their thoughts on the back of the worksheet. They will have 5 minutes (or longer if you have the time) at each station. When time is up, have the students rotate to the next station in order until everyone has been to all 3. Don't let two groups simply switch with each other, because this will leave the third group out of that rotation and they will be behind. If students complete their experimentation at a station before time is up, encourage them to explore other materials on hand to determine if they are transmitters or shields.

The leader should circulate around the room throughout this rotation to answer questions about proper set up and procedure.

III. Sharing results (15 minutes)

Bring the class back together and have each "reporter" present their summary and explanations. After each report is presented, encourage others to ask questions of the reporting group (not just the reporter). Ask students in the reporting group if they have any questions (record any that arise on the blackboard).

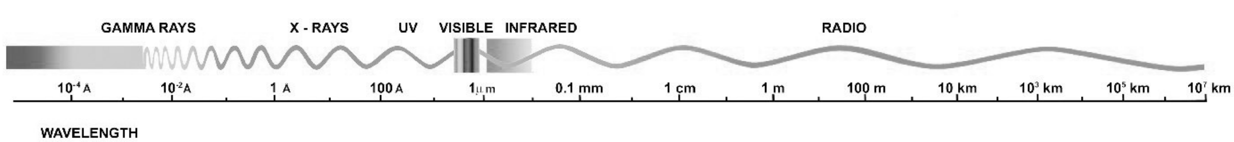
Some questions that you can pose to the reporter are:

- What did you find out?
- What was the source?
- What was the detector?
- What blocked the source?
- What let the invisible light through?
- Did anything surprise you?
- What variables could affect whether something was a transmitter or shield (thickness of material, distance from source, etc.)?

The last of these questions is especially good to discuss when groups disagree or have inconsistent results.

Summarize the class experiences on the blackboard. The leader should now explain what was going on at each station.

Go back to the spectrum handouts. Have a student point out again where visible light falls into the larger electromagnetic spectrum, then the radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, and gamma rays.



Notice the relationship between the infrared, visible, and ultraviolet on the spectrum handout. Discuss why the ultraviolet lamp and heat lamp may have also had some visible "glow" – this is because of each source's overlap with the visible. In each lamp, there is small amount of visible light along with the invisible light that required a special detector.

Remind them that different wavelengths of light tell us different things – light with shorter wavelengths than the visible range (ultraviolet, X-rays, and gamma rays) tell us where the really hot things are.

Light with longer wavelengths (infrared, microwave, and radio) show us where the cooler ones are. Some examples:

- X-rays show us where the black holes are located in a galaxy.
- Ultraviolet light shows us where the really hot stars are.
- Infrared light shows us where the really cold stars and dust in the galaxy are.

Suggestions for Running this Session

- Test the detectors at each station to verify that sources and detectors are functional and that you understand them.

- There are many materials which react to ultraviolet light, many of which we've experimented with during the development and pilot-testing of this session. Glow in the dark stars or other items will glow in UV light. Ultraviolet-reactive beads will change color when exposed to the lamp. Laundry detergent reacts to the UV light by shining very brightly (quite differently from the simple reflection of visible light). Many financial items such as credit cards and currency have ultraviolet-based security measures that react to the presence of ultraviolet light. There are numerous other substances and materials in the world around us that can be detected with an ultraviolet light - even some scorpions glow in the ultraviolet!

  These alternate materials have never worked as well for us in this activity as the invisible ink pen. Some are messy, expensive, or difficult to use. Some only work well in complete darkness, which is impractical in many settings. And some of them get "charged up" by the ultraviolet light (like the glow in the dark items or reactive beads), which means that once you've tested them once, it'll be a while before you can use them again. The reaction of the invisible ink pens is usually the most dramatic, as it has no reaction at all to visible light. It causes the fewest logistical difficulties, as there is no way to mistake the reaction, and it does not retain its glow beyond the test.

- Test your digital camera with your remote control before providing it to the students. Some of the newer cameras have a much better IR-blocking feature, which defeats their use for this activity.

- Try to avoid a remote control with any visible light output (buttons, indicator light, or the LED itself). The existence of both visible and IR in the remote confuses participants about what they should be looking for. We also recommend using a "universal" remote that's programmed for multiple devices, or a few different remote controls, so you can show how the IR output is different for different electronics.

- When you're not using the various sources and detectors in this activity, remove the batteries in each component - especially if it's going to be a while before you use them again. We've seen these items sit around for so long that the batteries inside leak, and that's not a fun thing to clean up!

Misconceptions

- Even though students may be able to see red light from the heat lamp and purple light from the UV lamp, this is not the invisible light that we are detecting. This is visible light that is too close to the UV and IR light to be filtered out, but they should ignore it for their experiment. We care about the invisible portion of the light, not the part you can see. If helpful, you can draw a comparison to neopolitan ice cream — even if all you want is the vanilla, it is close enough to the chocolate and strawberry that you will probably get some of them as well. Clearly demonstrate what they are actually looking for in each case. Show how the detectors react to visible light, and how that is different from their reaction to the invisible light. Demonstrate these issues clearly before they get to the stations for themselves.

Useful websites for background or activity extension

- **The Electromagnetic Spectrum**
  Two sites that provide a good introduction to the electromagnetic spectrum

  – http://science.hq.nasa.gov/kids/imagers/ems/ems.html
  – http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

- **SOFIA Infrared Observatory**

  – This site has several activities for learning about infrared light
  http://www.sofia.usra.edu/Edu/materials/activeAstronomy/activeAstronomy.html

  – Explanation of how the electronics work in the infrared activity
  http://www.sofia.usra.edu/Edu/materials/activeAstronomy/section3.pdf

- **Health in Space — UV Man**!
  This activity explores ultraviolet light coming from the Sun. Students build a detector for UV light and explore the protection/shielding offered by various household materials.
  http://www.lpi.usra.edu/education/explore/space_health/space_radiation/activity_1.shtml

- **The Spitzer Space Observatory**

  – Pictures of animals at infrared wavelengths
  http://coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/index.html

  – Gallery of objects at different wavelengths from the Spitzer Infrared telescope
  http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_astronomy/