What Color is the Sun?
and other mysteries

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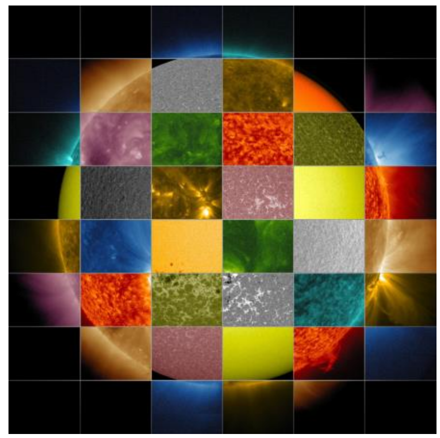
Introduction

Participants use scientific practices[1] to investigate answers to simple questions such as what color is the Sun, why is the sky blue, what causes orange sunsets, and why is the ocean blue. It is as important for them to experience the process as to get the "right" answer.



Collage of solar images taken by NASA's Solar Dynamics Observatory spacecraft

Target audience:	**Goals of activity**:	
Public science events Youth groups & afterschool programs Visitors to NASA centers Libraries Amateur astronomy clubs Parents & general public May be adapted to classroom settings	• Introduce and encourage the use of scientific practices • Explain natural phenomena and address commonly-held misconceptions	**Activity Time:** 30-45 minutes **Age Group:** 8-adult

Materials Needed:

- Clear acrylic or glass container that can hold water (2 quart size or larger)
- Water for box
- Strong flashlight (& extra batteries)
- Liquid milk or powdered creamer (or cedar oil or isopropyl alcohol)
- Pinhole camera or 2 sheets of heavy white paper and a nail (*optional*)
- Sun data sheets (*optional*)
- Color wheels (*optional*)
- LED colored lights (*optional*)
- 2 prisms (*optional*)

[1] As described in the Next Generation Science Standards: http://www.nextgenscience.org/next-generation-science-standards

Scientific Practices:

Science practices are described in the Next Generation Science Standards http://www.nextgenscience.org/next-generation-science-standards. These form the basis for scientific investigation. The steps include the following[2], though are not necessarily linear:

1. Asking questions
2. [Researching what information is already known]
3. Developing and using models
4. Planning and carrying out investigations
5. Analyzing and interpreting data
6. Using math and computational thinking
7. Constructing explanations
8. Engaging in argument from evidence
9. Obtaining, evaluating, and communicating information

In this activity, scientific practices are employed to investigate the answer to simple questions such as what is the color of the Sun. Learning science practices is useful both to students and the general public.

Process:

1. Explain to participants that they are going to be using science practices to solve some problems. Begin by asking participants what color they think the Sun is, or why they think the sky is blue. *(Scientific Practice #1)* Accept all answers. Hopefully, there will be several suggested answers. Then explain the scientific practices, as described above.

2. Explain that when scientists don't know an answer, or think they could be wrong, they investigate. So, let's investigate! Tell your participants they are going to plan and carry out an investigation, based on examining data. Divide your group into teams of 3-4. Or, if you are doing this in a lecture demonstration setting, have participants pair up with a neighbor[3]. Describe to them *Activity #1 - What color is the Sun?* and ask your teams to perform the investigation. *(Scientific Practices #4 & #5)*

3. Once teams/pairs have completed Activity #1, ask them to report their findings to the whole group. If there is not consensus, have teams attempt to convince others, using evidence, of their conclusions. Eventually, the consensus could be reached that the intrinsic color of the Sun is white. But misconceptions are hard to let go of, so don't expect all participants to accept the same conclusion. *(Scientific Practices #7, #8, #9)*

4. The investigation may have turned up the concept that the Sun is evidently a different color at different times and places, leading to the theory that the Sun may be a

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[2] #2 added by author

[3] Think-Pair-Share technique: http://serc.carleton.edu/introgeo/interactive/tpshare.html

number of different colors. So, now participants are going to develop and use a model to explore the possibility that white light is made up of different colors. See *Activity #2 – Do all colors make white?* This activity may be done as an exploration or as a demonstration (*Scientific Practices #1, #3, #4, #5*). If your audience already accepts that white light is made up of all the spectral colors, then you can skip this section.

5. The model in Activity #2 hopefully convinces participants that white light is made up of the spectrum of colors. But their investigation may not have shown how light could behave under conditions of being both white and colored. Participants need some background on the concept of the electromagnetic spectrum and waves. Describe to them the concepts in *Explanation – Light as waves*, and introduce the notions of what causes the sky to be blue and the sunsets to be orange. Using the imagery provided may be helpful. (*Scientific Practice #2*)

6. Participants now perform an experiment to model and explore a possible cause of the blue sky and orange sunsets. See *Activity #3 – Blue sky, Orange sunsets*. This activity is best done as an investigation, but if time is short it could be done as a demonstration. Ask participants to report their findings, and record these on a white board or flip chart. (*Scientific Practices #3,#5, #8, #9*)

7. Participants may still have questions as to why some of their data indicated that the Sun was strange colors (neon green, turquoise, pink, whatever). Participants will explore their questions in *Explanation - Why color the Sun?*. This can either be done as a discussion or an explanation. (*Scientific Practices #2, #7*)

8. In *Activity #4 – Why the misconception?*, participants will be asked to construct explanations as to why the Sun color misconception is so common. Again, you can use the team model or receive suggestions from the floor, perhaps listing them on a white board or flip chart. If this were to be a scientific investigation, participants would need to do a study on why people think the Sun is a certain color. *(Scientific Practices #1 & #7)*

9. Ask participants to summarize what they have discovered. Suggest questions for further study, such as why water appears blue, why is the Moon red during a lunar eclipse, or what color the sunset would be on Mars? Explanations of these phenomena are given with this activity, but you might send participants away without telling them the answers, encouraging them to explore further. *(Scientific Practices #1 & #8)*

Activity #1 – What color is the Sun?

1. Ask teams to plan their investigation by initially brain-storming on how one might determine the color of the Sun. They could come up with ideas such as:

   - Glance up at the Sun in the middle of the day. (Do **not** stare and **never ever look at the Sun through a telescope or binoculars without the proper filters**!)
   - Observe what color the clouds are, or the Moon, since both shine by light from the Sun.
   - Observe sunlight reflecting off the walls of a white building, or a piece of white paper.
   - Collect photographs taken of the Sun, both from Earth and from space.
   - Project an image of the Sun through a pinhole camera[4] or a SunSpotter™[5] telescope.
   - Observe the Sun's corona (atmosphere) during a total solar eclipse.
   - Look at some pictures of the analemma, which show the Sun at the same time of day throughout a year.
   - Look at images of the Sun taken by observatories both on the ground and in space.
   - Google the question.
   - Ask a scientist (though scientists are often subject to the same misconceptions that other people are).
   - *… and so on*

2. After brain-storming, ask the teams to investigate by using some of the techniques they have come up with. If you have time, send them off to do the investigations. If not, at least have participants glance up at the Sun (at mid-day) and/or look at it through a pinhole camera. If your time is very limited, or if you are in a lecture-type setting, or if the Sun is not out, you can provide the set of data following.

3. Ask your teams or pairs to come up with a consensus about the color of the Su, based on examining their data, and report that consensus back to the group. Write their findings onto a white board or flip chart.

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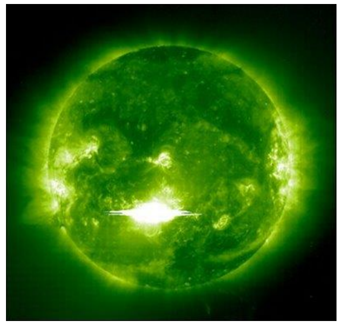
[4] To learn how to make one, go to http://solar-center.stanford.edu/observe/

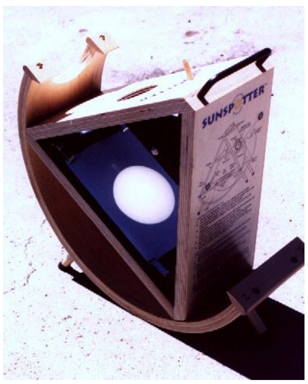
[5] http://www.teachersource.com/product/sunspotter-solar-telescope/astronomy-space

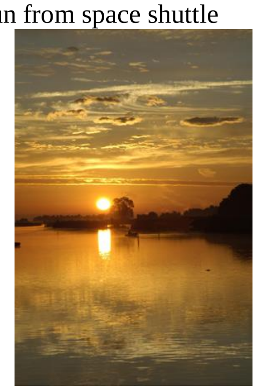
Sample data for investigating the color of the Sun


Sunrise


ESA/NASA SOHO image in EUV

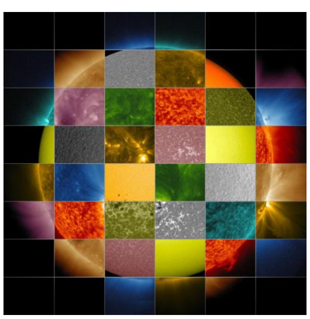
Sun from space shuttle

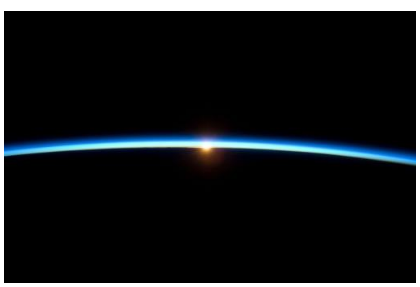

SunSpotter™ image

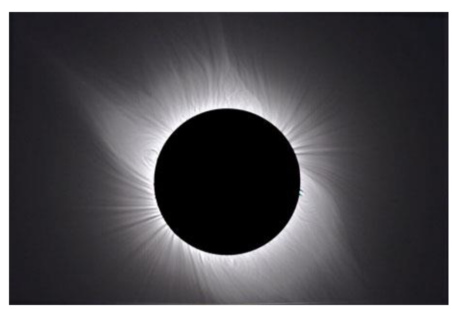

Sunset


Sunset

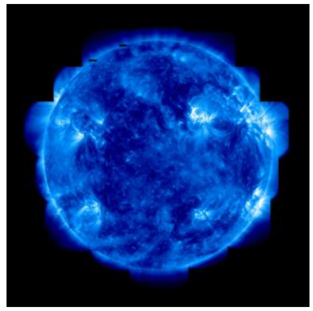
Analemma


NASA SDO composite images


Sunrise seen through Earth's atmosphere

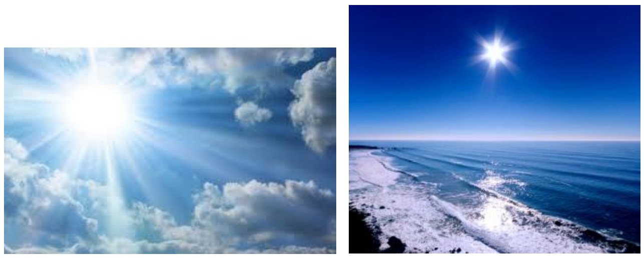

Total solar eclipse

Sun from space

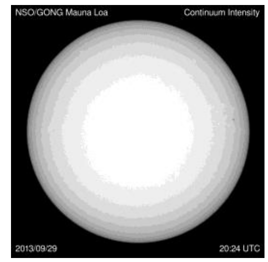


Sun from SDO/AIA, in EUV

Annular eclipse through a filter



Sun at mid-day



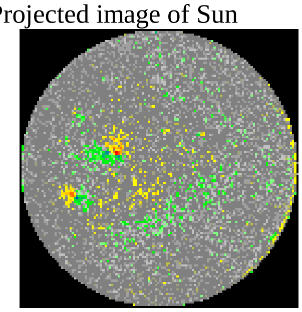
Solar image in visible light from GONG, a ground-based telescope

The Green Flash

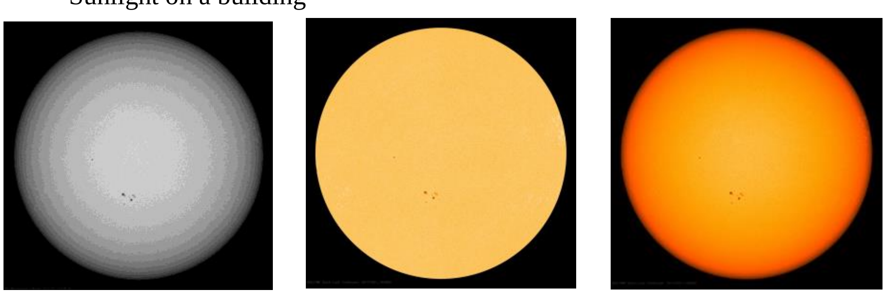
Projected image of Sun

Sunlight on a building

Composite solar image taken in EUV from SDO/AIA



NASA SDO/HMI magnetogram (colorized)



NASA SDO/HMI Visible light images (all)

Activity #2 -- Do All Colors Make White?

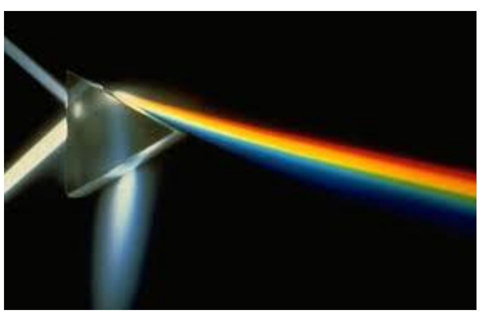
A modeling experiment

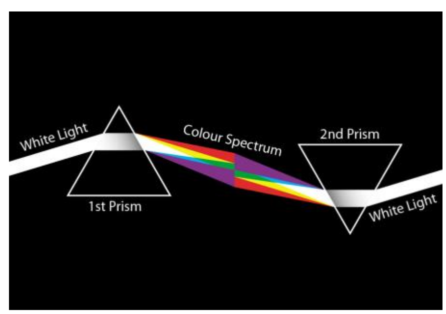
It is a common misconception that the Sun is yellow, or orange or even red. However, the Sun is essentially all spectral colors mixed together, which appear to human eyes as **white**. This is a function of the ways our eyes evolved, of course, so the perception of all wavelengths of visible light as white is as much a human phenomenon as it is a physical one.

It is easy to see the Sun is white in pictures taken from space. However, it is sometimes difficult for people, especially young people, to accept the "all colors equals white" phenomenon. Here are some models and demonstrations to help them understand.

To begin the experiment, ask your audience "Where do the colors in a rainbow come from?" Accept all answers. Then continue with the models.

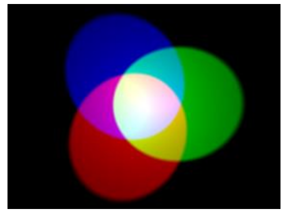
If you have prisms, ask participants to experiment shining a light through one. What do they see? If you have 2 prisms, ask participants to try Newton's experiment of lining up 2 prisms to see if sending the colors back through a 2nd prism reproduces the original white light.





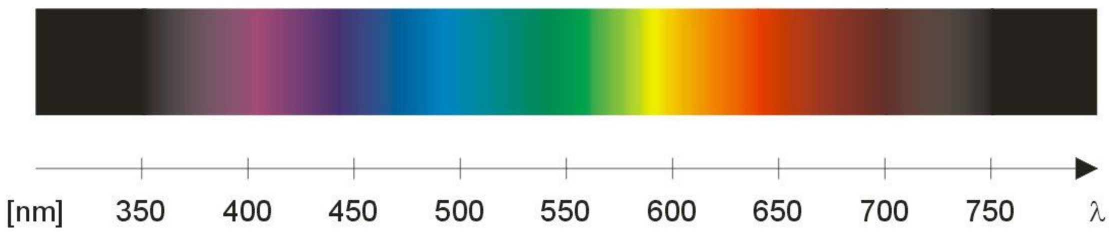
Ask participants what would happen if they spun a color wheel very fast. Let them experiment by coloring one then spinning the colored wheel around. What do they see? Color wheels can also be purchased on the web.

Another experiment would be to point 3 differently-colored LEDs at the same spot on a piece of white paper.



A bit about spectral colors:

A **spectral color** is a color that is evoked by a single wavelength of light in the visible spectrum, or by a relatively narrow band of wavelengths. Every wavelength of light is perceived as a spectral color in a continuous spectrum. The colors of sufficiently close wavelengths are indistinguishable.



The spectrum is often divided up into named colors, though any division is somewhat arbitrary since the spectrum is continuous. Commonly used colors include red, orange, yellow, green, blue, and violet. The color table should not be interpreted as a definitive list – the pure spectral colors form a continuous spectrum, and how it is divided into distinct colors linguistically is a matter of culture and history.

In the 17th century, the explanations of the optical spectrum came from Isaac Newton, when he wrote his book *Opticks*. Newton chose seven colors out of a belief, derived from the ancient Greek sophists, that there was a connection between the colors, the 7 musical tones of a scale, the 7 known objects in the solar system, and the 7 days of the week. The division used by Newton in his color wheel was red, orange, yellow, green, blue, indigo, and violet (Roy G Biv).

There are colors perceived by the human eye that are not a single wavelength, as the spectral colors are. Most of these are combinations of colors. As an example, violet is a spectral color but brown (a combination of many colors) is not. Black is not a color but rather the absence of color. Likewise, white is not a spectral color, but a combination of spectral colors. Many colors can be created by the use of pigment and electronic devices. Thus the term “all the colors of the rainbow” only encompasses the spectral colors, not necessarily all colors perceived by the human eye. But all colors are combinations of one or more spectral colors.

Activity #3 – Model blue sky and orange sunset

Materials Needed:

Clear plastic or glass container (can be spherical or box-shaped

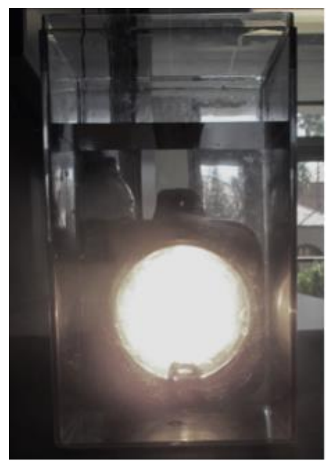
Water

Strong flashlight

Milk or powdered creamer (cedar oil or isopropyl alcohol can also be used)

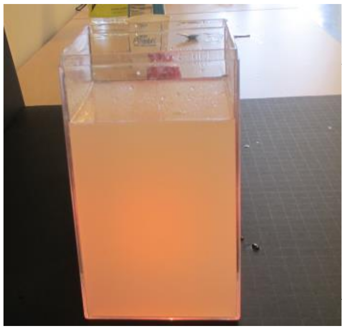
Process:

1. Fill the container with water. The water simulates a clear, small amount of atmosphere. Shine a strong (white light) flashlight through it. What do participants see? [The image should exit the water as white.]



Hence, with a small amount of clear water, all the wavelengths making up white light pass straight through, and no separation of color is observed.

2. Add a small amount of milk or powdered cream to your water and stir until dissolved. The milk particles simulate molecules in the Earth's atmosphere. Have participants look through the water both directly towards the light and also on the side of the container. What do they see?



← When white light is passed through the suspension, the light is observed to be yellow-orange.

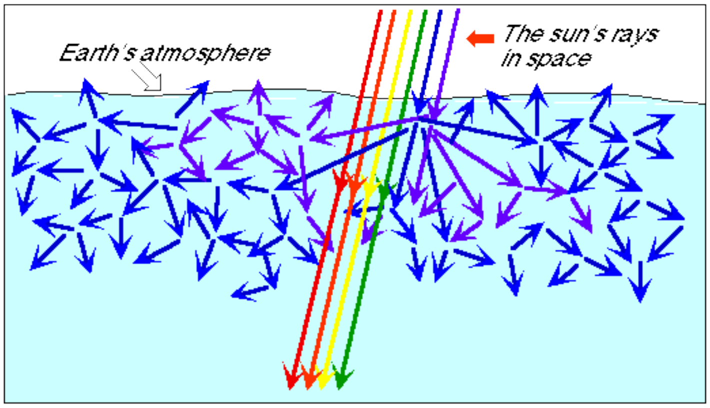
Light of a blue color is observed to come from the side of the container. →

Photo doesn't accurately represent the blue.

The orange color models sunrises and sunsets, when sunlight must travel a much greater distance through the atmosphere than when the Sun is overhead. This results in a greater amount of scattering which removes more and more of the shorter-wavelength colors, leaving reds, oranges, and yellows.

The scattered blue light models the Earth's sky, where short wavelength blue colors have been scattered by air molecules (oxygen and nitrogen, primarily). This is called Rayleigh scattering.

For the setting or rising Sun to be red, small foreign particles must be present in the atmosphere to scatter light along with the atmospheric molecules. This frequently happens during times of fire or volcanic eruptions.



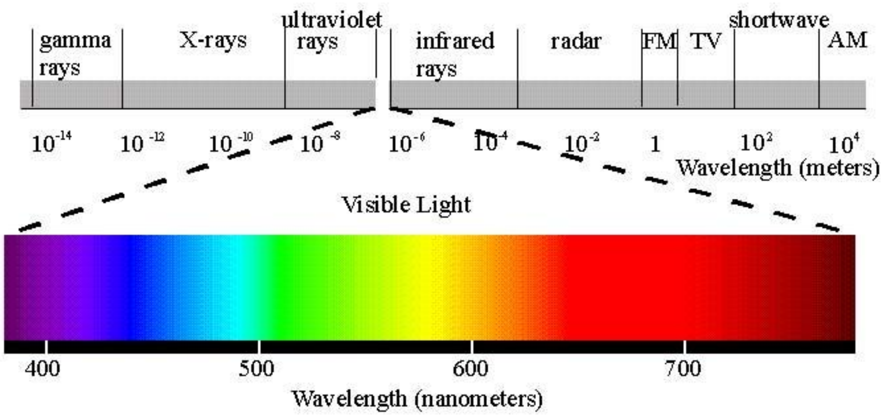
See also:

- http://www.physicscurriculum.com/light.htm
- https://www.youtube.com/watch?v=gUgDtWANJ18
- http://www.esrl.noaa.gov/gmd/grad/about/redsky/
- Wonder what is happening with the milk and water (fat and proteins). Hint: Mie scattering is involved: http://en.wikipedia.org/wiki/Mie_scattering

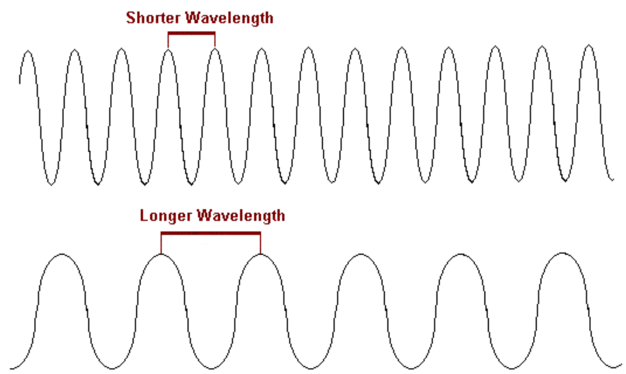
Explanation – Light as Waves

Blue Sky and Orange Sunsets

Light is a form of energy. All forms of light are part of the same phenomena: the electromagnetic spectrum. Our eyes can detect only a small amount of this energy, that portion we call "visible light." Radio waves, X-rays, microwaves, gamma rays, and the rest all have longer or shorter wavelengths than visible light, but otherwise are the same phenomena.

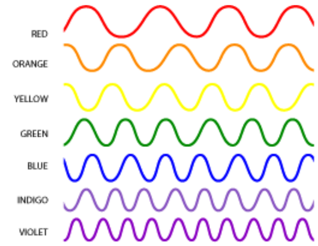


All forms of electromagnetic radiation make characteristic patterns as they travel through space. Each wave has a certain shape and length. The distance between peaks (high points) is called wavelength. The shorter the wavelength, the greater the energy in the smallest possible "chunk" (i.e. photon) of light at that wavelength. The longer the wavelength, the lower the energy.



The colors in our sky come from the Sun. The Sun's light is white, but sometimes the colors can be separated out, as in a rainbow. To help understand this, think of light as waves.

Colors have wavelengths. Just like waves at the beach[6] can be large or small, different colors have different wavelengths that can be large or small -- or anything in between.

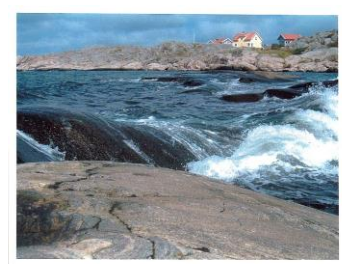


short wavelength ←-----------------------------→ long wavelength

Like these big ocean waves, the colors red and orange have long wavelengths.

Like these small ocean waves, the colors blue and violet have short wavelengths.

When little ocean waves hit big rocks, they get scattered in all directions.

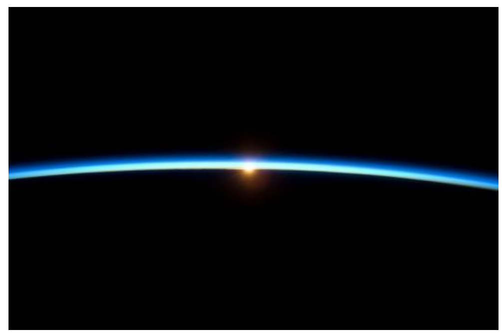


When big ocean waves reach the same rocks, they roll right over them.

[6] Ocean waves are a good way to describe light waves to younger children. However, the analogy is not complete.

When sunlight hits the Earth's atmosphere, the air molecules act similarly to the rocks. When the Sun is high in the sky, some of the short wavelength light (blue & violet) gets scattered out, like the small ocean waves, leaving some blue light bouncing around in the upper atmosphere. The other colors have long enough wavelengths that they slide past the molecules in our air and reach the ground. **Hence our sky appears blue!**[7]

The sunset is orange for a similar reason to why the sky is blue. Sunlight at mid-day goes through very little atmosphere (about 30 km), hence most colors (other than some of the blue and violet) get through and the Sun looks white. However, at sunrise or sunset, sunlight must go through a great deal of the Earth's atmosphere (about 320 km). Many of the colors are scattered away and mostly the red, orange, and yellow (long wavelengths) get through.

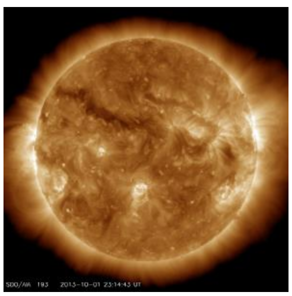
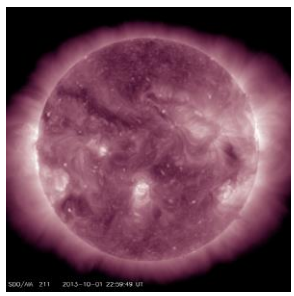
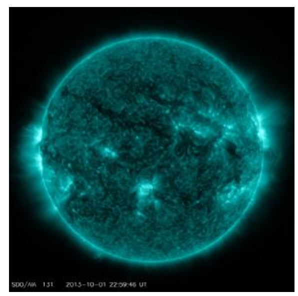
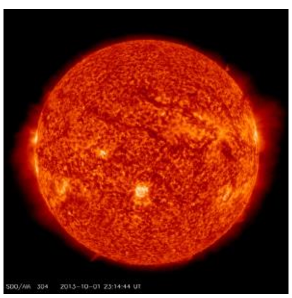
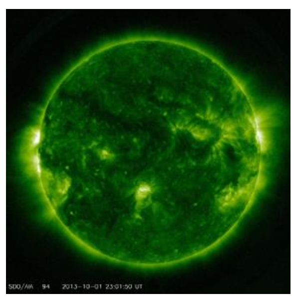
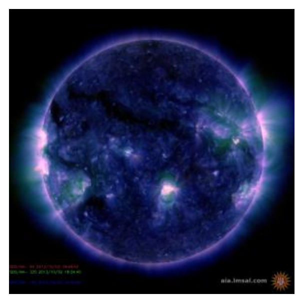


[7] Though violet is even a shorter wavelength than blue, our eyes are not very sensitive to violet, so the blue overwhelms it.

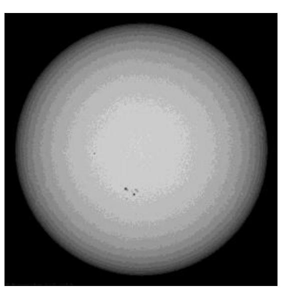
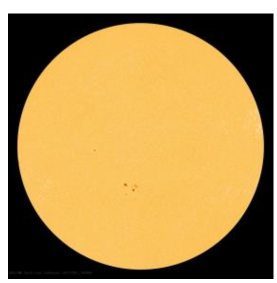
Explanation – Why color the Sun?

If the Sun is white, why are solar images taken by scientific instruments often neon green, or turquoise, or pink, or red, or other interesting colors? Ask your participants to offer explanations. Below are some examples. Can they suggest more?

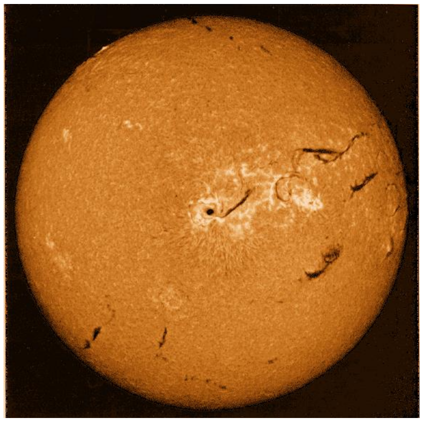
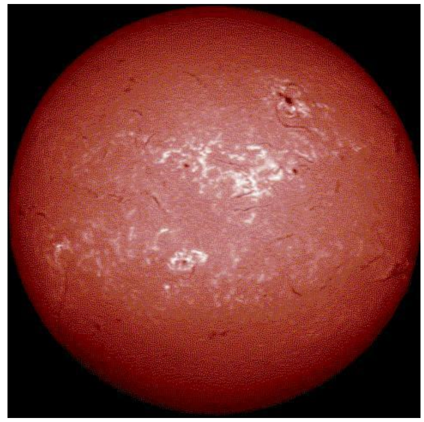
1. Scientific instruments can often detect ranges of the EM spectrum that human eyes cannot. When scientists want to look at those, say, X-ray or ultraviolet images, they need to color them something that eyes can detect. So the scientists pick some bright color, a color that would never be confused with viewing the Sun in white light. That way, we know from seeing a picture of a neon green or bright red Sun that the image was actually taken in some non-seeable version of light such as extreme ultraviolet (EUV) or X-rays. Below are sample images from NASA's Solar Dynamics Observatory (SDO), taken by the AIA instrument in EUV.

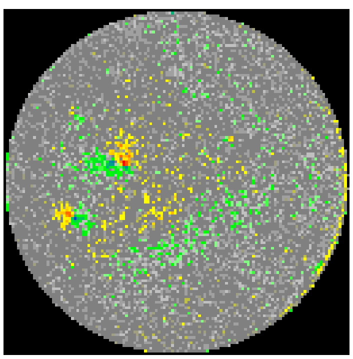
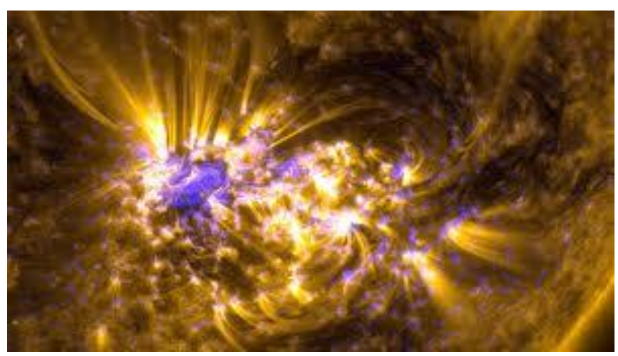
2. Sometimes scientists color their images to enhance detail. The image on the left was taken in visible light by the HMI instrument aboard NASA's SDO. The image on the right is the same image but colored to enhance contrast and visibility.

3. Many scientific images of the Sun are taken through filters. These were taken from telescopes on the ground using a red filter called H-alpha[8].

4. Scientific images may be the result of data that are visualized. Both images below were taken by NASA's SDO. The image on the left is a magnetogram, essentially a map of the magnetic fields on the Sun, taken by the HMI instrument. The image has been rendered in color to make the data visible. The image on the right is from the AIA instrument, taken in extreme ultraviolet light, and has also been colorized to highlight details for investigation.

5. Some scientists are subject to the misconception and actually color their white solar images orange or yellow.

6. Can you think of other reasons why scientists might color their data from the Sun?

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[8] http://en.wikipedia.org/wiki/H-alpha

Activity #4 – Why the misconception?

We see the Sun almost every day. By glancing up at mid-day (**never stare at the Sun!**), one can see that it is white. Why do you think many people have the misconception that the Sun is yellow or orange or red? Ask your participants to report their ideas, perhaps writing them on a white board or flip chart.

Here are some explanations we have heard (whether valid or not):

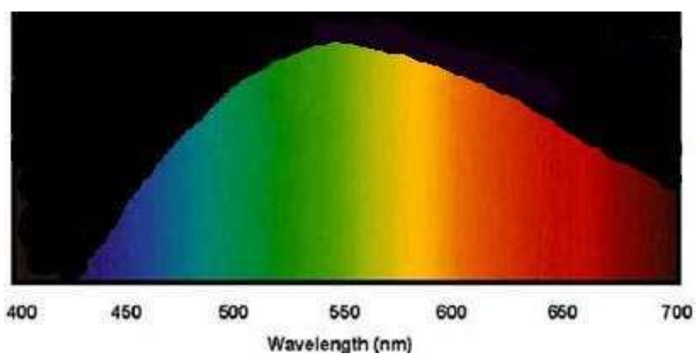
- People most frequently see the Sun at sunrise and sunset.

- People are [correctly] told not to look at the Sun.

- People believe what they are told, and never thought about why the clouds or Moon are white.

- They have heard that the Sun is formally classified as a "yellow dwarf".
  The Sun is classified as a G-type main-sequence star (G2V), based on spectral characteristics. It is informally designated as a yellow dwarf[9] (for historical reasons as well as its placement on the HR[10] diagram) though it is white in color and larger than 85% of the stars in our galaxy.

- They believe the Sun's light peaks in the yellow spectrum.
  Actually, the Sun's emission peaks in the green. Wein's displacement law says the peak wavelength is 2900/5600 = 0.518 um = 518 nm, which is very much within the green range of ~490-560.



- Children are taught to color the Sun yellow when young (white crayon does not show up on white paper).

- People have never looked up in the middle of the day.

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[9] http://en.wikipedia.org/wiki/Dwarf_star
[10] http://en.wikipedia.org/wiki/Hertzsprung-Russell_diagram

- When seeing photographic images of the Sun that show it as white, they believe the whiteness has been caused by an over-saturation of the camera.

- Sometimes the display color of the Sun is culturally determined. If a young child in the USA colors a picture of the Sun, they will often make it yellow. However, a similar child in Japan might color it red!

- They believe what other people tell them rather than exploring for themselves.

- They have seen the Sun through telescopes with filters or through eclipse glasses, which give it a false color.

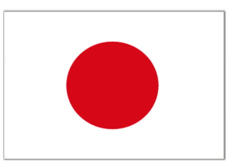
- They see a lot of scientific and press imagery with the Sun colored yellow, orange, or red.

- It is traditional in their culture to refer to the Sun as being a certain color.

- Science museums and planetariums often further the misconception of a colored Sun.

- Sun images seen on the web, in books, on advertisements, etc. are often yellow, red, or orange.

- They are accustomed to seeing the Sun as a certain color on their country's flag.



Japan

Rwanda

Niger

Argentina

- *..... Can they think of more explanations?*

Appendix A

Why is water blue?

Ask participants why they think water is blue. Accept all answers. We often hear that people believe water is blue because it reflects the blue sky. In Hawai'i some students report that the sky is blue because it reflects the color of the water!

While relatively small quantities of water appear to be colorless, water's tint becomes a deeper blue as the thickness of the observed sample increases. The blue hue of water is an intrinsic property and is caused by selective absorption and scattering of white light and the absorption of reddish wavelengths. Impurities dissolved or suspended in water may give water different colored appearances.

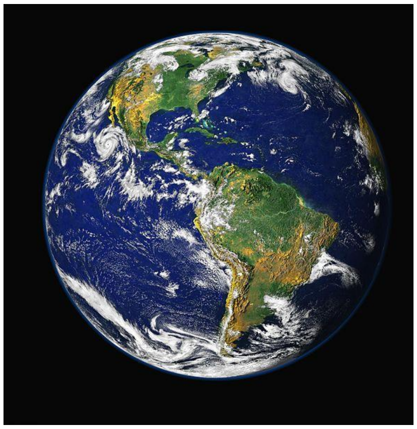
The blue color of water may be seen with the naked eye by looking through a long tube filled with purified water. In the image to the right, a 3 m long by 4 cm diameter aluminum tube was used, with a Plexiglass™ window expoxied to the ends of the tube.

The color of water can also be seen in snow and ice as an intense blue color scattered back from deep holes in fresh snow. Blue to blue-green hues are also scattered back when light deeply penetrates frozen waterfalls and glaciers.

This, and more information, written by Charles L. Braun and Sergei N. Smirnov, is available at: http://www.dartmouth.edu/~etrnsfer/water.htm

Water images from Braun & Smirnow

So the oceans and lakes are inherently BLUE! That color can be affected by the depth of the water, algae, pollution, runnoff from agriculture or from a storm, or reflections from the sky.

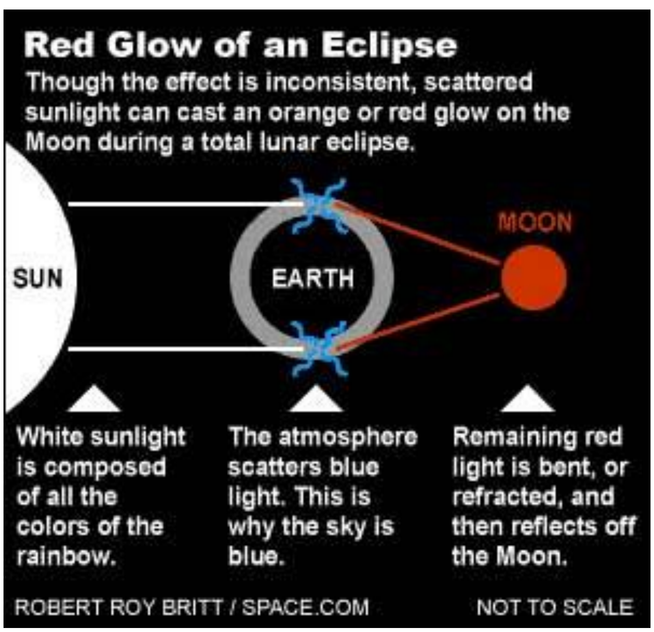






Appendix B

Why does a lunar eclipse look red?



The Moon turns reddish during a lunar eclipse for similar reasons to why sunrises and sunsets are reddish – light refracting through Earth's atmosphere!

The Earth is larger than the Sun in the sky as seen from the Moon, so it blocks all direct sunlight from hitting the Moon during a lunar eclipse. But, since we have an atmosphere, some sunlight just grazes the Earth, is bent through our atmosphere, and ends up hitting the Moon. Our atmosphere scatters blue light more effectively than red light, so some of the same long-wavelength red light that you see at sunrise or sunset continues on into space and colors the Moon.

Appendix C

What color would a Mars sunset be?

Here is a photo of sunset on Mars taken by NASA's Spirit rover at Gusev crater.

Dust particles make the Martian sky appear reddish and create a bluish glow around the Sun.

See http://blogs.agu.org/martianchronicles/2010/12/20/solstice-eclipse

What color might the sunsets be on the other planets?