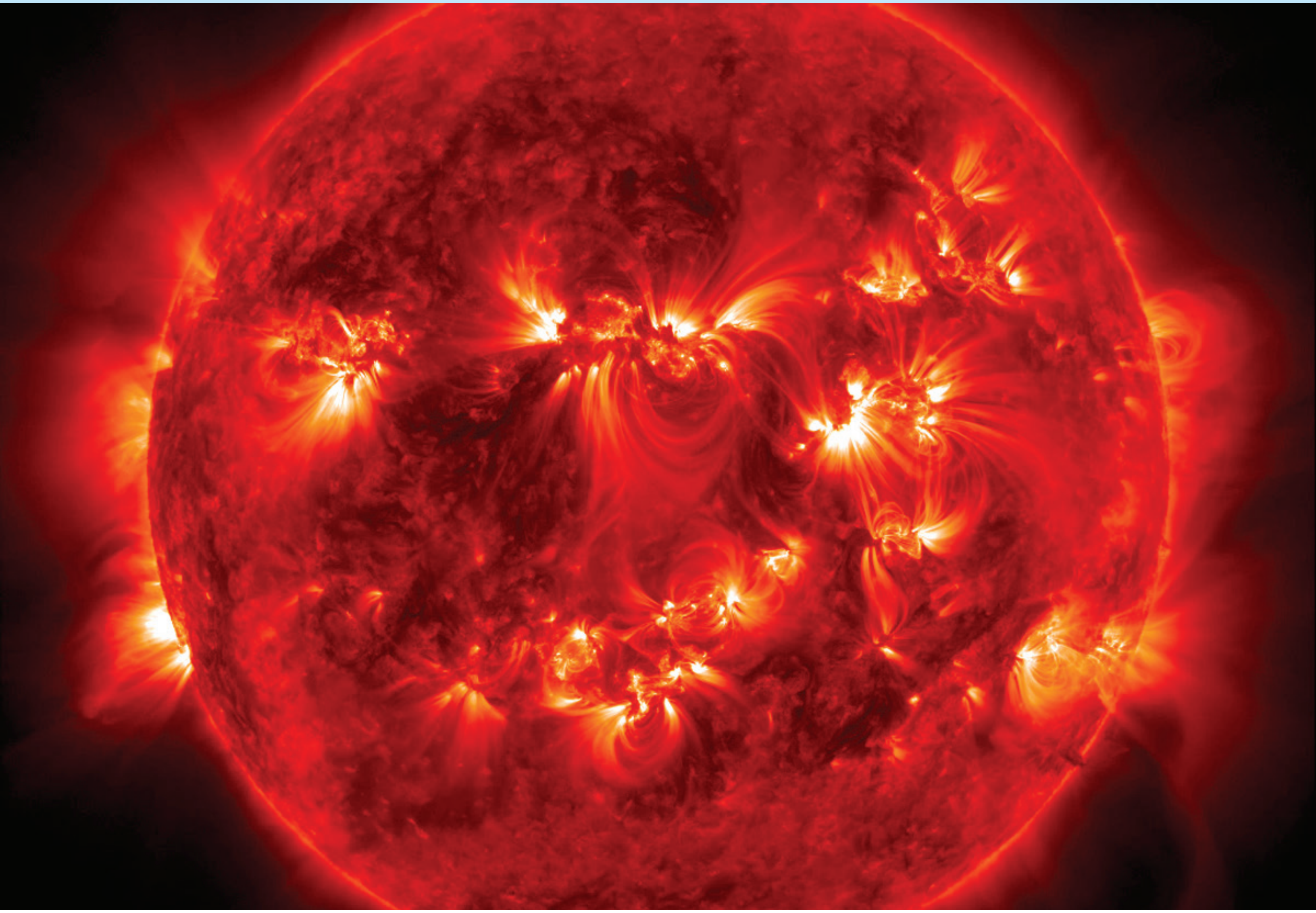
DISCOVER THE UNIVERSE

# THE SOLAR CYCLE

Inquiry-based activity guide for secondary school teachers



DUNLAP INSTITUTE *for* ASTRONOMY & ASTROPHYSICS

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CANADIAN ASTRONOMICAL SOCIETY
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# INTRODUCTION

## When it comes to teaching astronomy in schools, the Sun is our best friend.

One of the challenges of teaching astronomy in schools is that we rarely have access to students when the sky is dark. In the deep of winter, when it might be dark during school hours, we may have to deal with unpredictable weather. We wind up teaching astronomy solely through books. Our students never get to interact with the natural world or to make their own observations, the way they do in other sciences. This guide aims to help with that problem. By focusing on space-based observations of the Sun archived in real time on the internet, we enable our students to explore a familiar astronomical object in new ways.

**Whether you're an astronomy expert or are teaching it for the first time, this guide is for you. We've crafted this guide to satisfy the needs of all secondary school astronomy teachers.** It follows the curricular goals of the Common Framework of Science Learning Outcomes set out by the Council of Ministers of Education, Canada, but will be relevant to secondary school educators around the world. It is intended to support teachers who may not have any background in astronomy. It provides supplementary background material for teachers to help you prepare to teach solar astronomy. This activity has both inquiry-style and more traditional components, so you can choose the ones that suit your resources and teaching style. Each activity is broken into parts, which can be used or skipped, depending on your students' background and the material you've already covered.

For information about other teacher training activities and for more modules, please visit www.discovertheuniverse.ca.

# INTRODUCTION TO INQUIRY

This activity incorporates an inquiry component. In inquiry-based education, students are given the freedom to follow their curiosity and direct their own learning. This helps them to develop their critical thinking skills and encourages them to see themselves as producers of knowledge, not merely consumers. The role of the teacher in inquiry activities is to scaffold the experience and ensure that the students are achieving curricular goals, without giving them "cookbook" instructions.

In this activity, students are guided through a series of exercises to familiarize themselves with the Helioviewer tool for exploring archival observations of the Sun. Once they're familiar with the tool, they are given prompts on how to use it to explore the solar cycle and, where desired, the connection between that cycle and conditions on Earth. **The most important part of the activity can't be scripted in this guide, and that's the students' own self-directed exploration.** It's important for the students to begin the inquiry part of the activity with well-defined questions whose answers they are seeking, but equally important for them to explore those questions on their own, without a pre-written methodology.

If you've never run an inquiry-based activity with your students before, the most important thing you can do is to help them cope with their uncertainty. When asked to discover things for themselves, they are likely to feel a bit lost and may resist. This is normal. You may be working against years of training that has taught your students to expect book-learning, not self-directed learning. Remind them that it's okay to stumble or even to fail completely, that this is a normal part of the scientific process. Scientific experiments rarely work the first time. Often the questions we wind up answering are not the ones we sought out to answer. The same may be true with this activity: your students should approach it with the intent to learn about the solar activity cycle and the Sun-Earth connection, but both you and they should be open to huge assortment of other things they might learn along the way.

If you feel your students are veering too far from the main goals of the activity, it's totally fine to gently steer them back on track with a few well-chosen prompts, or a redirection ("That's interesting, but it's beyond the scope of this unit. Maybe we can talk about it sometime soon?").

# THE SOLAR ACTIVITY CYCLE

| Grade: | Preparation: | Student Groupings: | Length: | Location: | Activity Type: |
|---|---|---|---|---|---|
| **9 or higher** | **low** | **pairs or small groups** | **1-2 hours** | **classroom or computer lab** | **inquiry, computer-based** |

## BRIEF DESCRIPTION

The purpose of this activity is for students to explore the changing appearance of the Sun over periods ranging from days to decades. Students will use real data from space-based solar observatories, including the Solar Dynamics Observatory (SDO) and the Solar and Heliospheric Observatory (SOHO).

## LEARNING GOALS

After completing this activity, students will be able to:

1. Explain why it's useful to observe astronomical objects at multiple wavelengths, including those not visible to the eye.
2. Distinguish between true and false colour images.
3. Distinguish between pictures of the Sun taken in visible and ultraviolet light.
4. Relate the seemingly chaotic behaviour on the Sun's surface to the long-term pattern of solar activity.
5. Use a web-based tool to access real astronomical observations.
6. Correlate solar activity with terrestrial phenomena, such as auroras. (optional)

## MATERIALS

- Access to a computer or tablet with an internet connection for each pair of students. *If this is not possible, the activity can be modified to run as a demonstration using a single computer operated by the teacher.*
- A projection system so you can display slides (these can also be printed and circulated)
- For each pair of students: 10-15 pieces of paper and a marker
- Tape

A typical sunspot is about the same size as the entire planet Earth? This fact helps students grasp the immense size of the Sun.

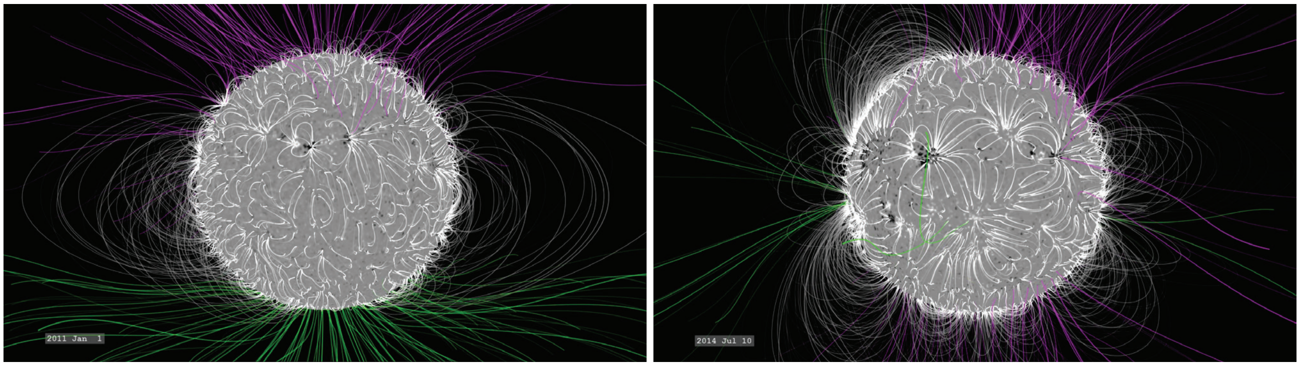
**DID YOU KNOW?**

# BACKGROUND FOR TEACHERS

The Sun is, in many ways, a remarkably simple object: a big sphere of hot plasma. Its relative simplicity and ease of observation have allowed us to understand most aspects of the Sun very well. Yet there remain deep mysteries. Many of these pertain to the Sun's magnetic field and the underlying solar dynamo, which drive the solar activity cycle.

Magnetic fields are created by the motion of electrically charged particles. Because the Sun is made of plasma (ionized gas) its own rotation and the constant churning of its interior create a very strong magnetic field. We call this mechanism the *solar dynamo*.

The magnetic field of the Sun cycles from orderly to complex and back to orderly every 11 years. When it is more orderly, the magnetic field resembles that of a bar magnet. This state cannot persist for long. Unlike the Earth, the Sun is not a solid object. In fact, different parts of the Sun are in constant motion relative to other parts. In particular, the Sun's equator spins faster than its poles. Particles at the Sun's equator take about 25 days to go around once, while those at the pole take nearly 40 days. This *differential rotation* means that the Sun's magnetic field, which is tethered to those charged particles, gets "wound up". As it winds up, it gets tangled. This can be seen in the figure below.

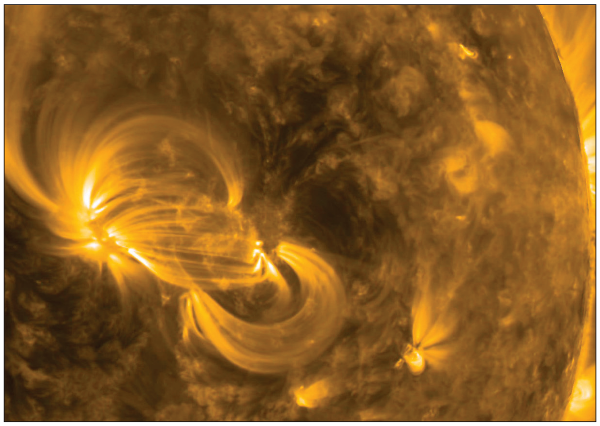



In January 2011 (left) the magnetic field of the Sun was relatively smooth and orderly. By July of 2014 (right) it had become very tangled. (Credit: NASA's Goddard Space Flight Center/Bridgman)

The more tangled the field gets, the more loops it develops, just like a tangled ball of thread. When a magnetic field loop pokes through the surface of the Sun, it creates a visible disturbance. The magnetic field loop channels hot plasma along the field lines, creating a loop that is easy to see in ultraviolet (UV) light, as in the image at the top of the next page.

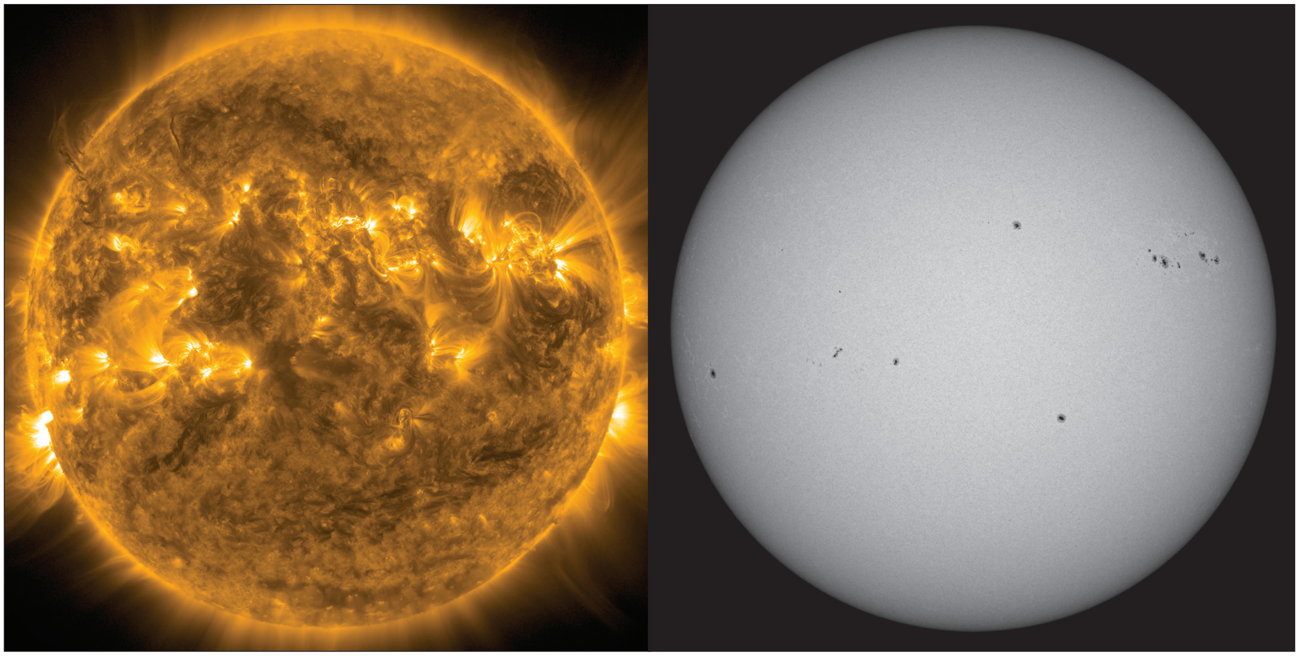
Each loop also creates spots where it penetrates the Sun's surface. In these locations, the magnetic field creates a pressure that allows cool gas inside the spot to be balanced against the pressure of hotter gas outside the spot. Thus, sunspots appear darker than the surrounding solar surface.

Your students can't easily make their own observations of the Sun in UV light. However, **with appropriate precautions**, it is possible for them to observe sunspots in visible light. This can be done either with a telescope with an **approved solar filter**, or sometimes using a pinhole camera. The two images shown below contrast the appearance of the Sun in visible and UV light: UV light is best for seeing the loops of hot plasma, while visible light is best for seeing the cooler, darker sunspots.



A magnetic field loop poking through the surface of the Sun, channeling hot plasma. The loops are most easily seen in UV images, like this one. (Credit: Solar Dynamics Observatory, NASA)

Your students' goal in this inquiry-based activity will be to explore archival observations of the Sun just like these and use them to discover the solar cycle. As we hope they will learn, the Sun goes through a cycle of activity. Every 11 years, the Sun's magnetic field "resets": the tangles mostly disappear, the field goes back to being fairly smooth, and sunspots virtually disappear. The full explanation for this behaviour is one of the outstanding mysteries about the Sun. Nevertheless, the pattern has been observed for centuries —since the invention of the telescope. We hope your students will enjoy discovering it for themselves and exploring it in detail.



Two images of the Sun taken at the same time. Magnetic field loops glow brightly in the UV image on the left. Sun spots appear as dark regions in the visible light image seen on the right. Both images are in false colour. Note the alignment of the active regions visible in UV with the sunspots seen in visible light. (Credit: Solar Dynamics Observatory, NASA)

# PREPARATION

Students can start this activity with little knowledge of the Sun. In fact, it can be more impactful for them to begin the activity with no knowledge of the solar activity cycle.

Parts 1 and 2 of this activity introduce students to the idea of non-visible wavelengths of light and to false colour imaging. If your students are already familiar with these concepts, feel free to skip these portions of the activity.

# METHOD

## Part 1: False Colour Imaging (Optional)

Many astronomical images are taken in wavelengths of light not visible to the human eye, then rendered into visible colours so we can examine them. We call such images *false colour* images. They're an essential tool in astronomy, but are often confusing to students. For example, if an image of UV light is rendered in yellow on a computer screen, students naturally assume it's an image originally taken in yellow light. In this part of the activity, the goal is to help students understand what information is being encoded in a false colour image. It's important to start with terrestrial examples, so that students don't develop the misconception that "false colours" are properties of astronomical objects.

Display SLIDE 1 to your class. Without interpreting the image for them, prompt them with these questions:

1. Is this type of image familiar to you?
2. What kind of light do you think was used to make this image?
3. What does this image tell you about the giraffe?

If your students don't recognize this as an infrared image or a "heat image", guide them toward this understanding. The bright parts correspond to warm areas (more infrared light) and the darker parts to cooler areas (less infrared light). To help them understand that this image represents the scene in colours not visible to the eye, you show them SLIDE 2, which shows the same scene in visible light. Emphasize that the two different wavelengths give *different information* about the giraffe.

## Part 2: Understanding Ultraviolet Images (Optional)

To help the students understand ultraviolet imaging, we begin with an example from daily life. Break students into pairs. Have each pair examine the images on SLIDE 3 and discuss the prompt questions with one another. When they are done, discuss briefly as a class. Note that the correct explanation is that the man in the photo is wearing sunscreen on the left half of his face; the sunscreen is absorbing UV light to prevent it from reaching (and damaging) his skin.

Once the students are mostly comfortable with the idea of UV imaging on Earth, it's time to try an astronomical example. Have them examine the images of Jupiter on SLIDE 4 and again discuss what the UV image reveals that the visible light image does not. In the images on SLIDE 4, the top panel shows a UV image of the aurora on Jupiter. The bottom panel shows a visible light image of the same part of the planet. Students should grasp that this UV image is in false colour and is showing a phenomenon not visible to the naked eye. This will be an important concept when examining images of the Sun.

> Make sure your students are able to tell UV images from visible ones. They should be able to explain that the two types of images encode different information about what's happening.

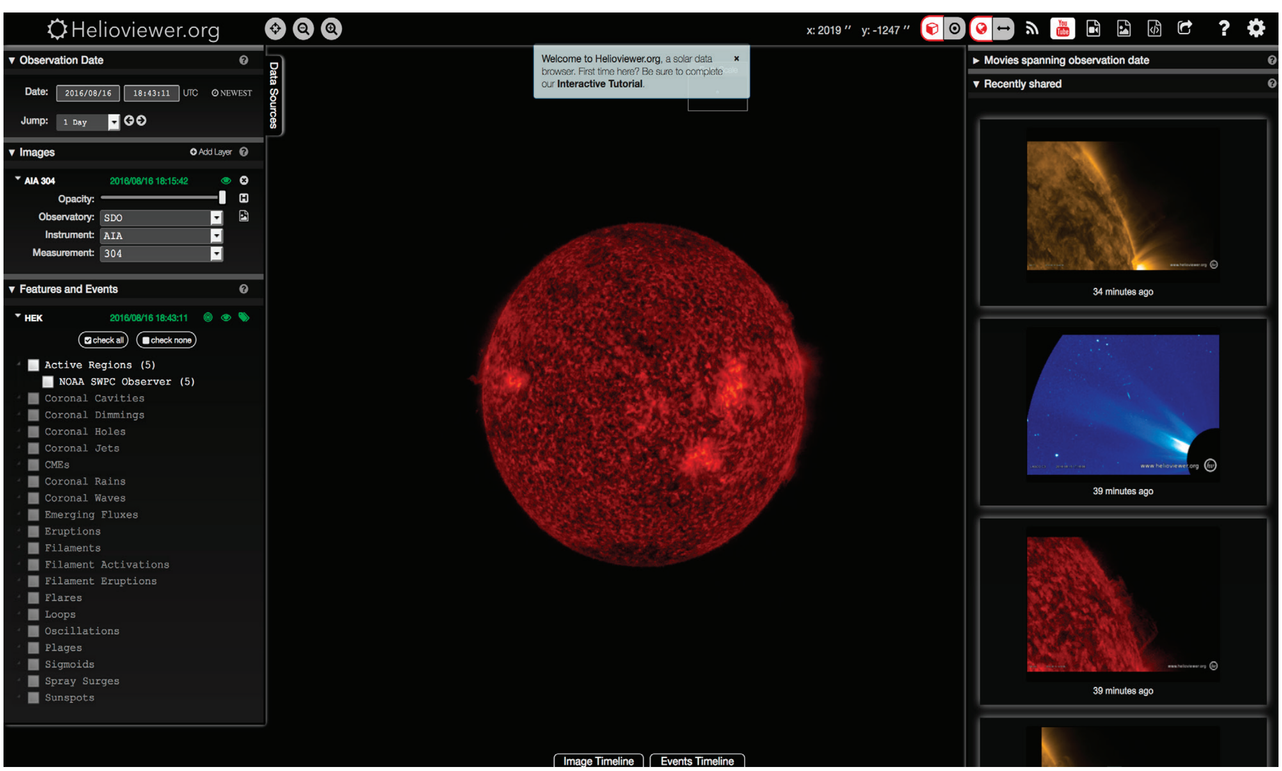
**BEFORE MOVING ON**

## Part 3: Soliciting Existing Ideas

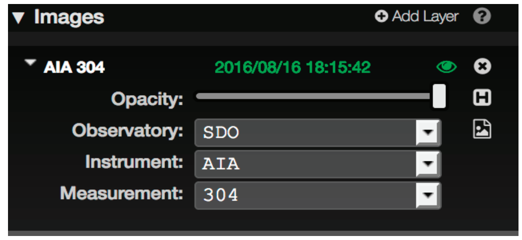
Have your students work in pairs to write a description of the surface of the Sun in one or two sentences *without referring to external resources*. The goal is to elicit their existing thoughts about what the surface of the Sun is like. How hot is it? What state of matter is it? What colour is it? What does the surface look like in detail? This will help stimulate the inquiry process. Time permitting, have the students share their ideas freely with the class, without any reinforcement, *either positive or negative*, from the teacher.

## Part 4: Exploring Helioviewer

Students should load the helioviewer.org web site. When it starts, it will show what the Sun looks like on the day of the activity:



Encourage your students to experiment freely with the interface. Prompt them to focus on the “Images” pane, seen at right, which will allow them to select data from different spacecraft (“Observatory” drop-down), different cameras on those spacecraft (“Instrument” drop-down), and different wavelengths of light observed by each camera (“Measurement” drop-down). Note that, for SDO data, the AIA instrument is an ultraviolet camera and the HMI one is a visible-light camera. For SOHO, the equivalents are the EIT and MDI (“continuum” measurement). The numbers listed under “Measurement” when using either the AIA or EIT cameras refer to wavelengths of UV light. For example, in the above screenshot, we are looking at an image taken in light with a wavelength of 30.4 nanometers with the AIA camera of the SDO spacecraft. Students do not need to understand this in detail.



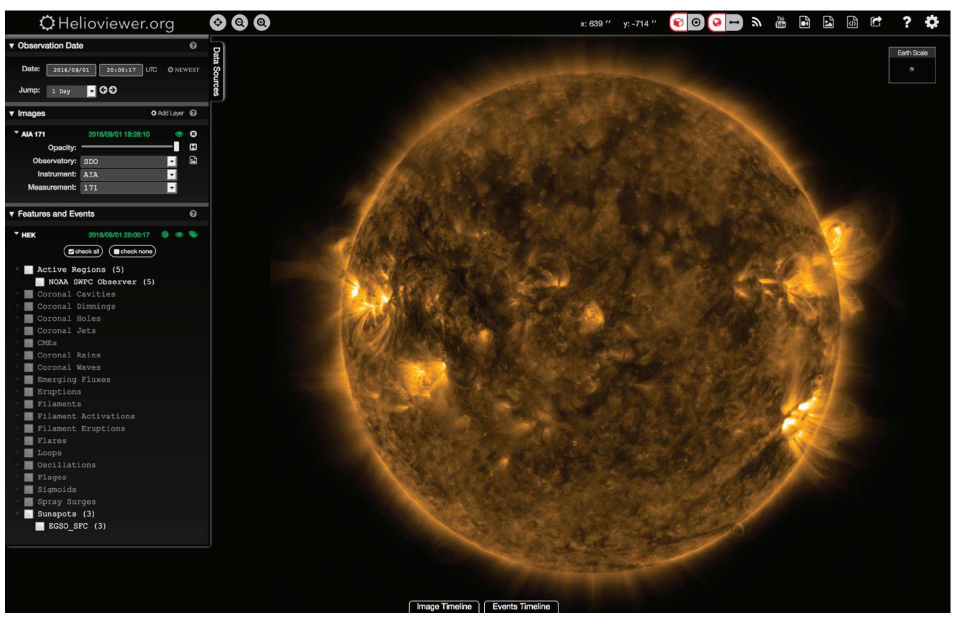

As they explore Helioviewer, prompt your students with the following questions:

1. Are the images you’re seeing true colour or false colour? How can you tell?
2. Are these visible light images, ultraviolet images, or some other kind of image?
3. How does the appearance of the Sun in ultraviolet images relate to its appearance in visible light?

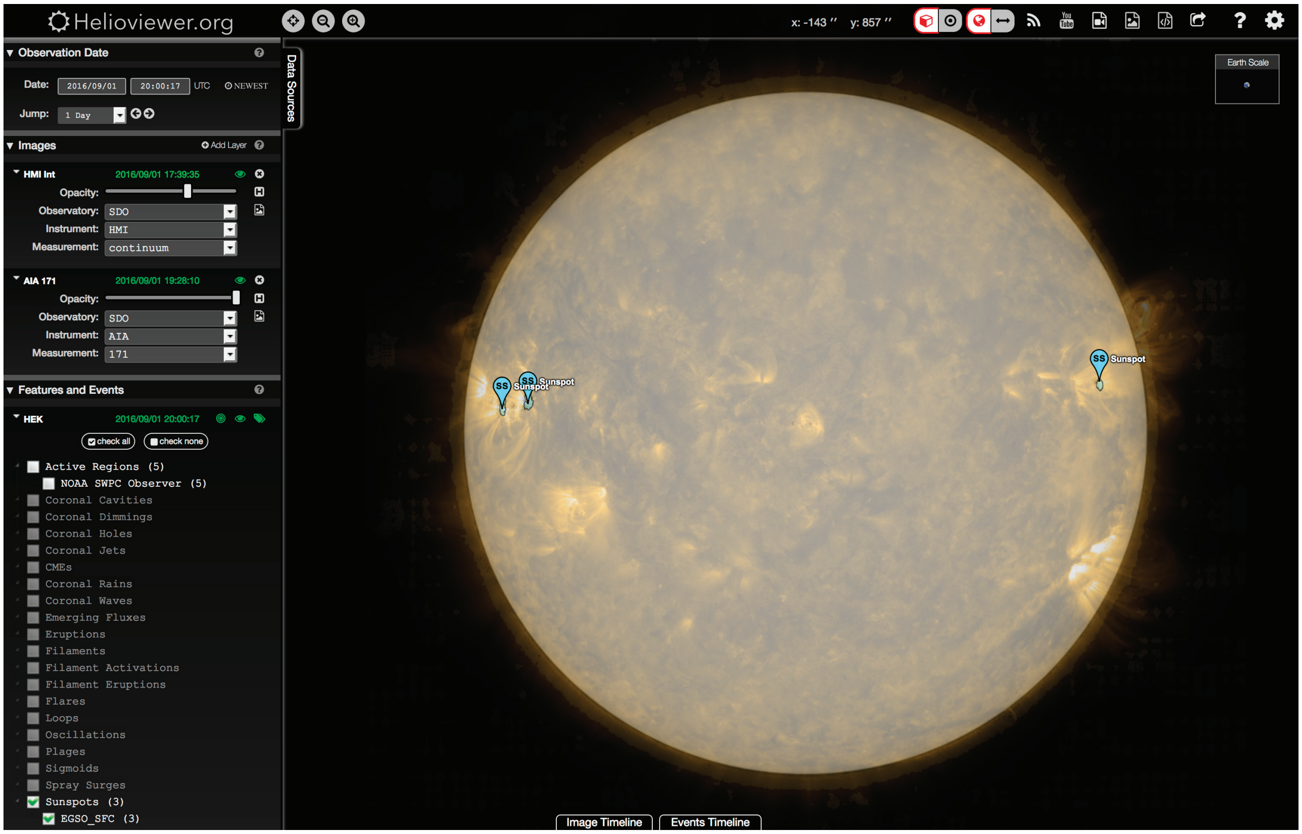
Once you’re comfortable that your students have a basic grasp of the interface, you can move on.

## Part 5: Exploring the Solar Activity Cycle

Now that your students are familiar with the helioviewer interface and the basic appearance of the solar surface, they can start exploring the historical appearance of the Sun to look for patterns. This can be done in many ways and you should let your students explore on their own. If they struggle, prompt them to use the image overlay interface to compare visible-light and UV images. We can start by displaying a UV image from SDO, as shown at right. Here we have selected the 17.1 nanometers UV image from the AIA camera, but the specifics don’t matter. Explore all the options!

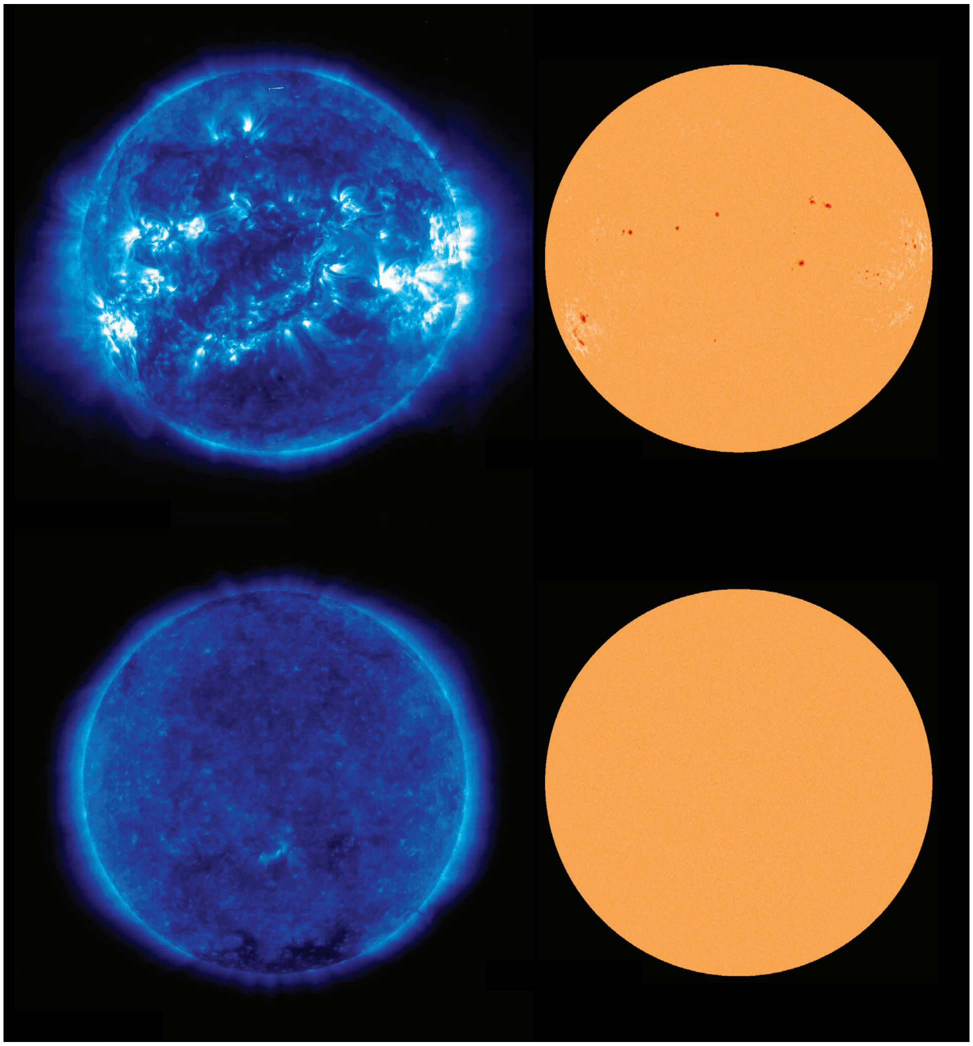


By clicking “Add Layer” at the top of the “Images” pane, we can overlay multiple wavelengths of light at the same time to compare them. In the image below, we have overlaid a visible light image (“HMI continuum”) on top of the existing UV one. We have also toggled on the “Sunspots” overlay in the “Features and Events” pane. This draws markers on sunspots to make smaller ones more visible. Now we can see how sunspots line up with the active regions seen in the UV image:




Note that, in the above image, the Sun is at an intermediate stage of activity. These images come from 2016, during one of the Sun’s least active periods in a century, so there are very few sunspots. In a moment, we’ll examine more active periods in the Sun’s history.

While the SDO spacecraft provides the most eye-catching images, they only go back to 2010 and do not cover a full 11-year solar cycle. For that, you may need to prompt your students to explore data from the SOHO spacecraft, which go back to 1996. By comparing SOHO images from widely-separated dates, students should be able to see that the Sun goes through a cycle of activity, with extremes as depicted on the next page.



Images of the Sun when highly active (top row) and inactive (bottom row). UV images are in the left column.Visible-light images are in the right column. When the Sun is at its peak of activity, there is intense magnetic activity on the surface and many sunspots. When it is less active, there is little magnetic activity on the surface and few or no sunspots. (Credit: SOHO/NASA)

Once your students have the hang of the interface for looking at historical data, it's time to start the inquiry part of the activity. **If you have only a single period, or you don't want to use the full inquiry process, you can conclude the activity here with a discussion of the students' findings about the solar cycle.**

## Part 6: Exploring Your Curiosity and Generating Testable Questions

Have your students set aside Helioviewer for a while. Ask them to reflect on what they've seen of the Sun so far. What kinds of questions have arisen? Students should take a few minutes to independently brainstorm questions they may have. They should write their questions down.

Once the students have generated questions independently, they should discuss in pairs. Ask them to try to formulate research questions about the solar cycle that could be answered by exploring the data available on Helioviewer.org. Encourage them not to self-censor their questions: they should all be written down quickly, without too much thought.

**Distribute several sheets of paper and a marker to each pair. Have them work together to write down research questions, one per sheet of paper, in large letters. Give them 5 minutes. Ensure every group has written down at least one question.**

Once each group has generated their questions, collect the sheets. Take them to the blackboard or a clear wall space and begin sorting them. The goal here is to help the students learn how to formulate a well-posed research question. You can sort their questions visually by taping each one up on the blackboard under the appropriate heading. We suggest the following headings:

1. Questions outside the realm of science (e.g. "Why are solar flares so beautiful?")
2. Scientific questions that **can't** be explored with the available tools (e.g. "What is the power source of the Sun?")
3. Scientific questions that **can** be explored with the available tools (e.g. "How long do sunspots last?")

Don't display these titles until *after* the students have formulated their questions, so you don't dampen their initial curiosity with constraints. When sorting the questions, it's important not to imply that those in the first category are any less valid than those in the latter two: there are many important questions that are not scientific.

Once the questions are sorted, review them with the class, explaining how you sorted them. Pick a few examples to discuss, emphasizing what makes a question **scientific** (e.g. falsifiability), and what makes it **suitable for exploration with the tools available.**

Now the students should spend a few minutes choosing a favourite question and reworking it into a form that can be productively investigated using Helioviewer.

## Part 7: Culminating Inquiry Investigation

Now that you've shown them how to identify workable questions, you have a decision to make. You can give them some time (5-10 minutes) to refine the questions they've already come up with, or you can have a class discussion and establish a set of refined questions everyone will work on. More senior or self-motivated students will do fine with their own questions, while younger or less confident students will benefit from you helping to shape the questions they will use.

Whichever method you choose, make sure that their questions can be productively investigated using Helioviewer in the time allowed.

Once each group has a workable question, give them time to do some research. They will need at least 20 minutes for this, and likely more. This is the part that is impossible to script. You will need to supervise them, helping them stay focused and troubleshooting their problems.

Once they're done, you can conclude the activity in several ways:

1. **Class discussion:** Ask each pair of students to come up with a 1-2 minute oral summary of their findings, to be shared with the class. Each group should present both their question and their summary of their findings. This can be graded or not, as you prefer. Grading gives them extra incentive to remain focused and keep their findings concise.
2. **Jigsaw discussion:** Have each pair of students split apart and make new pairs with students from other groups. Instruct them to present their results orally as in the class discussion option. Each student should focus on articulating their question and their findings in a clear, concise manner.
3. **Homework assignment:** Ask students to work individually or in pairs to summarize their findings in writing, focusing on providing specific evidence to support a conclusion related to their question. Again, assigning a small number of grades will help with focus.

## Part 8: Independent Research (optional)

Now that your students have learned about the solar cycle, you may optionally like to have them research connections between the solar cycle and terrestrial phenomena. For this step, we recommend a written homework assignment ranging in length from a single page to a short essay. You can allow students to choose their own topics, or select from our list of suggestions:

1. What effects does solar activity have on human infrastructure on the surface of Earth and in orbit?
2. What effects does solar activity have on astronauts in orbit around Earth?
3. How are solar activity and short-term variations (over years or a few decades) in Earth's climate related?
4. How are solar activity and long-term trends (over hundreds or thousands of years) in Earth's climate related?
5. What is the relationship between increased solar activity and auroras on Earth?
6. Does increased solar activity have any effect on human health?
7. How and when was the solar cycle discovered?
8. What kinds of sudden, violent activity can the Sun produce?
9. Why is it important for astronomers to monitor the activity of the Sun?
10. How will the Sun change over the next 5 billion years and what effect will the changes have on life on Earth?

## Short Written-Answer Questions

1. What is ultraviolet light?

   *Ultraviolet light is a type of light with a shorter wavelength and higher energy than visible light.*

2. What is meant by the term “false colour image”? Give an example.

   *False colour images are those in which colours other than the true ones which would be visible to the human eye are used to represent different wavelengths of light.*

   *One example is rendering types of light not visible to the human eye (e.g. UV light) into visible-light colours. Another is rendering visible-light images in colours other than those which would naturally be perceived by the human eye (e.g. reversing red and green, or changing a colour image to black and white).*

3. What do pictures taken in ultraviolet light reveal about the Sun that pictures taken in visible light do not?

   *UV images show hot, active regions and magnetic field loops on the surface of the Sun that cannot be seen in visible-light images.*

4. What is the solar activity cycle and how long does it last?

   *The solar activity cycle is an 11-year cycle during which the solar surface goes from having a messy, active appearance and many sunspots, to having a tidy, inactive appearance and few sunspots.*

5. What drives the solar cycle?

   *The solar cycle is driven by changes in the shape of the Sun’s magnetic field. The exact mechanism connecting the changes in the magnetic field to changes inside the Sun is not fully understood.*

6. What direct observations of the Sun can we make to confirm the existence of the solar cycle?

   *We can record the number of sunspots and we will find that it takes them approximately 11 years to go from being plentiful, to sparse, and back to plentiful again.*

## Multiple-choice Questions

1. Which of the following observations would most clearly reveal the existence of the solar cycle?

    a. Measuring the rise and set times of the Sun daily for six months.
    b. Observing the height of the Sun above the horizon at the same location on Earth daily for fifty years.
    c. **Counting the number of sunspots on the surface of the Sun daily for seventy years.**
    d. Measuring the temperature of the Sun daily for three years.
    e. Measuring the distance between the Sun and the Earth daily for a year.

2. Compared to visible light, ultraviolet light is:

    a. longer in wavelength and lower in energy
    b. shorter in wavelength and lower in energy
    c. longer in wavelength and higher in energy
    d. **shorter in wavelength and higher in energy**
    e. it is impossible to say without more information

3. Why is it useful to observe the Sun in multiple wavelengths of light?

    a. **Different wavelengths reveal different physical processes.**
    b. Magnetic fields can only be seen in visible light.
    c. Sunspots are invisible in visible light.
    d. Ultraviolet light doesn't make it through Earth's atmosphere.
    e. The Sun emits some kinds of light at some times, and other kinds at other times.

4. Which of the following is true about the appearance of the Sun when it is most active?

    a. Fewer sunspots are visible on its surface.
    b. **Hot gas trapped in magnetic field loops can be seen on its surface.**
    c. The Sun appears visibly brighter to the human eye.
    d. Sunspots switch from being dark to being very bright.
    e. The Sun appears larger than normal because the extra heat it is generating causes its outer layers to expand.

## Get Help From Astronomers and Astronomy Educators

**Discover the Universe/À la découverte de l'univers, http://www.discovertheuniverse.ca/**

DU provides free, online training webinars for teachers who want to learn more about astronomy. Webinars are provided in both English and French.

**University of Toronto Astronomy Speaker's Bureau, http://universe.utoronto.ca/speakers/**

The Dunlap Institute for Astronomy and Astrophysics at the University of Toronto coordinates access to UofT astronomers who are available to speak to your class in person (within the Greater Toronto Area), or via video-conference nationwide.

## Canadian Solar-Terrestrial Astronomy

**AuroraMAX, http://www.asc-csa.gc.ca/eng/astronomy/auroramax**

AuroraMAX has a camera in Yellowknife which makes daily recordings of the northern lights. Recordings can be viewed at any time. This service is operated by the Canadian Space Agency.

**Space Weather Canada, http://www.spaceweather.gc.ca/index-en.php**

Space Weather Canada gives forecasts of upcoming auroral activity. It can be used to investigate connections between increased solar activity and auroral activity, even if the northern lights cannot be seen at your location.

## Major Solar Observatories

**Solar and Heliospheric Observatory, http://sohowww.nascom.nasa.gov/**
**Solar Dynamics Observatory, http://sdo.gsfc.nasa.gov/**

SOHO and SDO both provide daily images of the Sun in many wavelengths. SOHO has been operating longer, but SDO provides higher-resolution imagery. Both of their data products eventually appear on Helioviewer, but can also be viewed on the website of each spacecraft in near real-time.

Credit: NASA/JPL-Caltech

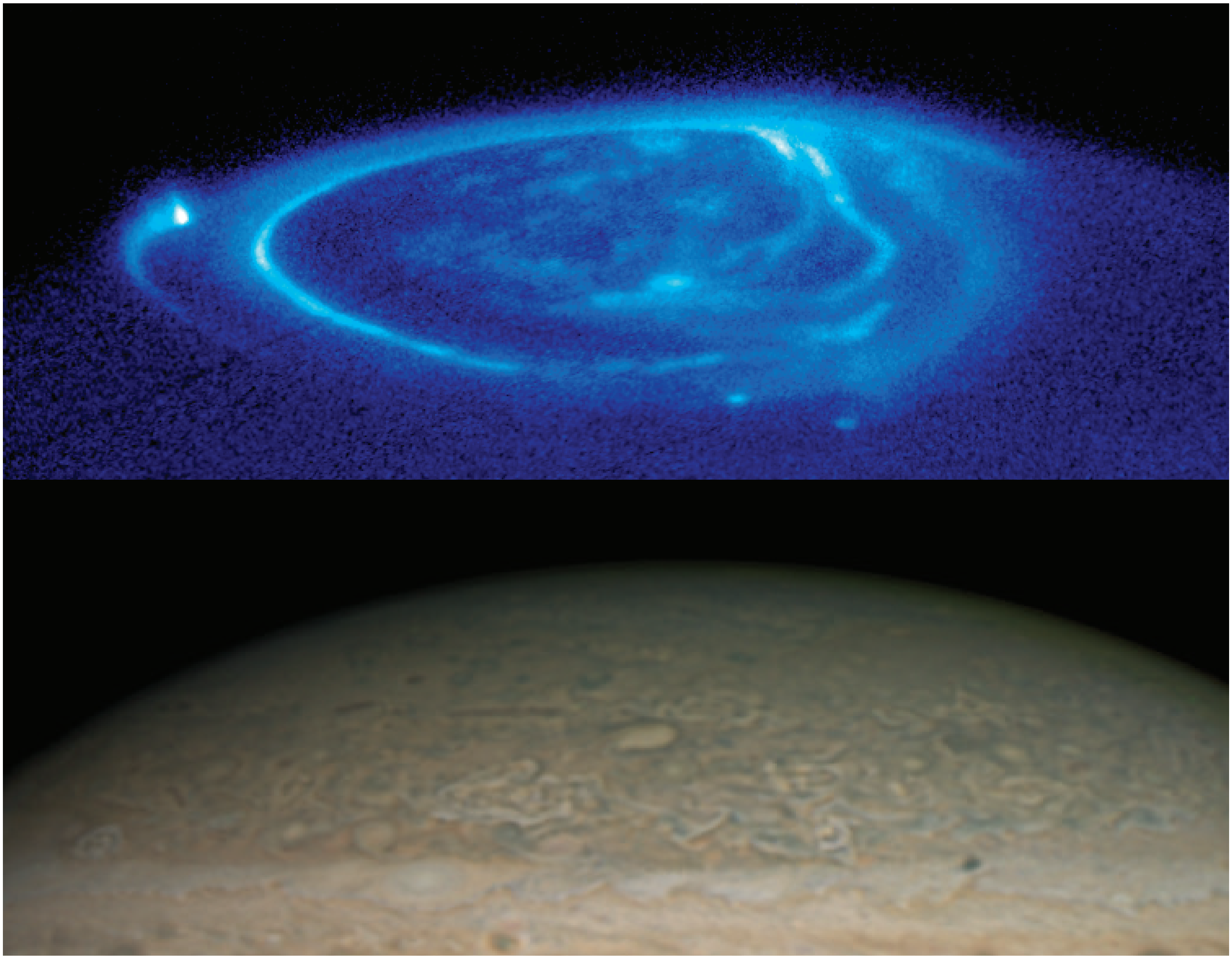
Credit: NASA/JPL-Caltech

## VISIBLE LIGHT | ULTRAVIOLET LIGHT

Credit: Wikimedia Commons user Spigget

These images were taken at the same time, but using different wavelengths of light. Examine them and discuss the following questions with your partner. Be prepared to share your answers with the class:

1. **What could be on part of the man's face that causes it to turn dark in the UV image?**
2. **What does the UV image tell us about the man that we could not know if we only had the visible image?**



Credits: top -- NASA and the Hubble Heritage Team (STScI/AURA); bottom -- NASA, ESA, and A. Simon (Goddard Space Flight Center)

Both of these images show the north pole of the planet Jupiter, one in UV light and the other in visible light.

1. **Which one do you think is the UV image and how can you tell?**
2. **What does the UV image tell us that we could not know if we only had the visible image?**