From the Ground Up!

Exploring the universe with online telescopes

The activities in "From the Ground Up!" were conceived, developed, and tested by members of the project team listed on this page. The format of "From the Ground Up!" is adapted from *Project ARIES*, Charlesbridge Publishing, Watertown, MA.

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From the Ground Up!: Exploring the universe with online telescopes

Introduction

You and your students are about to control a powerful astronomical telescope from the convenience of your classroom. This wonderful new technology has made possible a revolution in astronomy education. No longer does astronomy mean shivering in the cold while standing in line for a ten-second glimpse through a telescope. Now, students are actively involved in posing questions, designing investigations, gathering evidence, and interpreting their own results as they explore the universe.

The MicroObservatory telescopes are controlled by students and teachers over the Internet, from the convenience of their classrooms. Students reserve telescope time, check weather, choose targets, select exposure times, color filters and other parameters. Once a school is enrolled, the system is completely automated; there is no human intervention in the loop. Students thus control the instrument as needed, without dependence on the curriculum developers.

From the Ground Up! is series of explorations using the online telescopes. The activities are designed for middle- and high-school students in physical science, earth science, and astronomy courses. Among the important features of *From the Ground Up!*:

Features of "From the Ground Up!"

Focus on leveraged concepts

From the Ground Up! focuses on core concepts in physical science that will leverage future learning. These include topics such as light and color, size and scale, the laws of motion and gravity, and the nature of scientific inquiry. The activities avoid or minimize jargon, terms of art, and ideas that are not central to the curriculum or standards. For example, students work with brightness (rather than magnitude) of celestial objects.

Investigations are authentic and open-ended

Each investigation is motivated by an open-ended question that makes contact with both the student's curiosity and the cutting edge of science. Students are able to see how the basic concepts of science can be applied to solving real questions of interest.

Qualtitative and quantitative

The activities in *From the Ground Up!* have both a qualitative and a quantitive part. This makes the activities adaptable to classrooms where students may be relatively unprepared in mathematics. The quantitative portions of the activities offer opportunities for applying simple proportions, geometry, and graphing.

Opportunities for reflection and interpretation

Science is not a collection of disconnected facts. It is a dynamic process that begins in curiosity and continues with a search for meaning. The activities in *From the Ground Up!* are designed to allow time for students to reflect on *what* and *why* they are investigating, and to interpret their results in a context meaningful to them.

Focus on inquiry skills

It is often said that you have to *do* science in order to learn science. But a major challenge in the classroom is to focus on those inquiry skills that will be of lasting importance. Learning to use software that may not even exist in a year or two, is not as important as learning how to design an investigation, or how to estimate, or how to interpret results. *From the Ground Up!* activities seek to minimize routine work, allowing more time for the teacher to focus on higher priorities.

Independent student projects

The activities in *From the Ground Up!* come with suggestions for additional student projects. Once students have gained familiarity with how to use the telescopes and how to work with their images, then the sky's the limit for independent student projects.

Publish reports online

From the Ground Up! has a handy project-reporting feature in which students can automatically publish their reports, including up to five images, online. The reports can be sorted by date, topic, and state, and can be read by other students and teachers. (They are not available to the public in order to protect student privacy.) This feature enables teachers to quickly see which concepts are causing difficulty, and which areas need further further work in the classroom.

Online interactive learning tools

The activities are supplemented with several convenient interactive learning tools, including an orbit simulator for visualizing the relationship between mass, distance, and speed for circular orbits.

Access at home

Projects with the telescopes can be done in any home that has Internet access. Students report high parental interest in the telescopes and projects.

Implementing *From the Ground Up!*

Based on workshops with teachers who have used the telescopes and activities, we recommend the following general approach to using *From the Ground Up!*

Model the use of the telescopes with students first. If you have a video-projector and Internet access in your classroom, it is ideal to demonstrate with students how to access the telescopes and download images.

Have students work in teams. The activities recommend that students work in teams of from three to six. This minimizes the number of images that must be taken, and allows students to discuss ideas important to the investigation.

Allow time for students to predict, plan, and reflect. These are integral parts of the activities.

Manage students' projects. Make certain that students understand how to use the telescopes before they begin independent student projects. Otherwise, you will be overwhelmed by individual questions from the students once they begin.

Relate the projects to students. The activities use English units, rather than metric units. Because many of the ideas about the universe may be new and unfamiliar to students, the developers chose to use units more familiar to students, so that ideas of size and scale are easier to grasp. Metric units are used in a few isolated instances where they are essential.

Learning Objectives and Concepts

GETTING STARTED

Exploration 1: How does my eye compare to the telescope?

The purpose of this exploration is to compare the performance of your own eye with the performance of the MicroObservatory online telescope.

- Both the eye and the telescope produce an image by focusing light onto an array of light-sensors.
- The telescope can image much fainter objects than can the eye, due to its much larger opening and its longer exposure time for gathering light.
- The telescope has greater sharpness of vision than the eye, but the eye has a much wider field of view.

Exploration 2: What does the universe look like?

The purpose of this exploration is to use the telescopes to create images of different celestial objects, and to begin to pose and answer questions about what the images can tell us about the objects.

- Almost everything we know about the universe comes from studying and interpreting the light that comes to us from space.
- MicroObservatory telescope images are all taken at the same scale (or "magnification"). The relative size of an object in the image contains information about how large it is or how far it is.

- Astronomers adjust the brightness and contrast of the images they take, but must be careful when intrepreting features of the image.

- The more we learn about the universe, the more questions we have. Science is the art of asking, as well as answering, questions.

Exploration 3: What does the universe look like in color?

The purpose of this exploration is to create a full-color image of a celestial object, using three black-and-white images taken through the telescope's color filters.

- The human eye can sense red, green, and blue light. Combinations of these three colors are perceived as full-color.

- Any color scene can be separated into its red, green, and blue components and then reconstructed to form full color.

- The color of a celestial object carries information about the object's temperature, composition, speed, and other physical properties.

- When creating an image, scientists may have to make choices about what to display, and these choices may affect the interpretation of the image.

HOW-TO GUIDE

A Wrangle with Angles

This quick-guide shows how to measure the angular width of objects that you have imaged, and to use the results to help find the size or distance of the object.

INVESTIGATIONS

Exploration 4: Is the Moon really larger near the horizon?

The purpose of this exploration is to design an experiment, using the telescope, to investigate the apparent size of the Moon when it is near the horizon, compared to when it is higher in the sky.

- To the eye, the Moon appears much larger when it is near horizon.
- Yet when the Moon is near the horizon, it is actually slightly *further* from Earth than when viewed higher in the sky. If anything, we would expect the horizon Moon to look *smaller.*
- Measurement is important because our senses and our intuition are often a poor guide to reality.

Exploration 5: What are Jupiter and its moons like?

The purpose of this exploration is to observe the motions of Jupiter's moons, and to use these observations to determine various physical properties of the planet Jupiter and its moons.

- The force of gravity extends beyond a planet's surface far out into space, where it holds moons and artificial satellites in orbit.
- The time it takes a moon to orbit once around a planet depends on the moon's distance from the planet and also on the mass of the planet.
- Relationships among physical properties are important, because they can be used to determine one property if the related properties are known.

Exploration 6: Can we communicate with an alien star system?

The purpose of this exploration is to use the telescope to take images of Sun-like stars that have recently been found to be orbited by planets, and to use the images to determine how far away the stars and their planets are.

- Astronomers use "standard candles"—stars of known brightness—to help determine distance.

- The apparent brightness of a star decreases inversely as the square of its distance from the observer.

- Stars are so distant that it would take years to reach even the nearest stars at the speed of light.

Exploration 7: How big and how old is the universe?

The purpose of this exploration is to gather and interpret evidence bearing on the questions, "How large and how old is the universe?"

In Part 1 of the exploration, students use the telescopes to take images of galaxies far beyond our own Milky Way galaxy. In Part 2, students estimate the distances to these galaxies, based on measurements of their images. In Part 3, students look for a pattern to the motions of their galaxies; they construct a graph that combines their results from Part 2 with published data on the speeds of their galaxies.

- The universe is observed to contain galaxies all the way out to the telescope's limit of detection.

- The telescope is a "time machine": It takes so long for light to get to us, that we see the galaxies not as they are now but as they were in the past.

- The galaxies are moving away from us and from each other. Based on the pattern of their motion, we conclude that billions of years ago, the matter in the universe was extremely densely packed together.

Setting up to use the activities

Follow these easy steps and you'll be ready to use the *From the Ground Up!* activities

What you'll need

Here is the minimum that you'll need to get started with the *From the Ground Up!* activities. Additional materials that may be useful are listed in the Teacher's Guide for each exploration.

- Computer(s) with access to Internet
- Web browser, such as Netscape or Explorer, installed
- Printer (black-and-white)
- Image-processing software (see download instructions below).

Set up an account for your class.

To set up an account for your class to use the telescope, you must register online at the following URL. There is no charge for access, but enrollment is limited:

http://mo-www.harvard.edu/MicroObservatory/Enroll

Please note that many of the activities can be done using archived images.

Download the image-processing program, *MOImage*

For most of the activities, students will need to use image-processing software. This software may be downloaded free of charge from:

http://mo-www.harvard.edu/MicroObservatoryImage

Follow the instructions that come with the download. Install the software on the computers that students will be using when they work on their projects.

Set aside room on the computer

Students will be downloading many images from the telescope. Decide ahead of time how you would like students to store these files on the classroom computers. For example, you may want to set up one or more folders to keep students' work separate from other projects that share space on the computer.

Try out the telescope and activities yourself

Before using From the Ground Up with your students, make sure that you have successfully taken images with the telescope, and have tried or examined each activity.

How to use the telescopes

It's easy to use the MicroObservatory telescopes over the World Wide Web. Just follow these steps.

Important general information

You control the telescope yourself, with no human intervention in the loop. Therefore you must tell the telescope when and how you want it to take an image. Normally, you access the telescope site anytime during the day and request that it take an image at night; to do this you must sign up for one of the three-minute slots allotted per image.

You may also control the telescope "live," but only during the day i.e., from 6 AM to 6 PM as measured at the telescope site. Among the objects you can see during the day are the Moon, provided it is above the horizon then.

As soon as the telescope takes an image, it e-mails you an alert that your image is ready. The e-mail is posted on the Web, with your username and other information about the image. The image remains on the Web for one week, and is then deleted. If you wish to keep your image, you should download it from the Web as soon as possible.

Information you'll be asked for

Before you control the telescope, have the answers to the following handy:

Which telescope do I want to control?

What is my username and password?

Which celestial object will I image?

Will I need the coordinates of the object, or will I use the pull-down menu?

When do I want the telescope to take an image?

You will be asked for several other parameters, described below.

Access and bookmark the MicroObservatory website

To access the MicroObservatory website, go to this Web address, being sure to observe upper and lower case:

http://mo-www.harvard.edu/MicroObservatory

From the menu, select TELESCOPES. Alternatively you can go directly to the telescope control page at

http://mo-www.harvard.edu/MicroObservatory/

Bookmark this page to make it easy to return to the telescopes whenever you want.

Check the weather and forecast

You MUST check the weather and forecast at a particular telescope site, before using that telescope. Simply click on the city where you would like to use the telescope.

Check the telescope queue

Telescope time is allotted in 3-minute increments. To check whether the time slots you have in mind are already taken, you can view the telescope queue: Just click on the telescope you want to use to see the queue.

To help you determine when you'd like to take an image, refer to specific activities.

Select a telescope on the world map

To select a telescope, just find the site you'd like to access (red dots on the world map), and click on the red dot. You'll be controlling the telescope at that site.

Enter your username and password.

The username and passwords for you and your students are determined when you register online to use the telescopes. If you haven't already enrolled, see "Set up an account for your class," above.

Enter the time you'd like to take an image.

To have the telescope take an image at night, select AM or PM, then use the pull-down menu to select a time for taking the image. If the time slot is already taken, the telescope will let you know when you try to take an image.

To take an image during the day (between 6 AM and 6 PM at the telescope's site), you do not have to enter a time. The telescope will take an image as soon as you send the request. Use this mode if you need to image the Moon when it is above the horizon during the day.

Tell the telescope where to point.

To observe the Moon, planets, or other popular target on the handy list: Select the button **"Using list"** and then select your target on the list.

To image a target not on the list: Select **"Using coordinates**" and then enter the coordinates of your target. All activities in *From the*

Ground Up list the coordinates of the targets you will need. These coordinates are the "zip code" of your celestial object on the sky.

> The coordinates of a celestial object are written as "Right Ascension" and "Declination." Right Ascension (R.A.) is measured in hours and minutes. (Example: 13 hr 27.5 min). The Declination (Dec) is measured in degrees and minutes. (Example: -12 deg 14 min). These sky coordinates are similar to the latitude and longitude coordinates that specify a location on Earth. To learn more about them, consult any astronomy text or the World Wide Web.

Enter the name of your target

Be sure to enter the name of your target. This will help you find your image when it is listed in the Image Directory.

Select "main camera" or "finder camera."

You will normally use the telescope's main camera, which has a field of view of almost one degree. On occasion you may need to use the finder scope, which has a field of view of about ten degrees.

Enter exposure time

You may use any exposure time between 0.1 and 60 seconds. The recommended exposure time for various targets is listed in the *From the Ground Up* activities.

Select a filter

The default selection is "clear filter" which is no filter at all.

For very bright objects such as the Moon, you must use a grey filter (called a "neutral density" filter). This filter reduces the light that reaches the camera by a factor of 10^4.

The color filters are generally used to reconstruct color images (see the Exploration, *Astro-Photographer*).

Select "zoom in" or "zoom out"

Normally you should use "zoom out," which is the default setting. Use "zoom in" only when trying to image a very small object such as the rings of Saturn or the ring nebula. A zoomed-in image will generally appear sharper than a zoomed-in image.

The zoom settings do not actually change the magnification that the telescope uses. Regardless of the setting, the telescope takes an image that is 1300 pixels wide by 1000 pixels high—too much information to return to the user. If you select "zoom in," the telescope returns just the center of the image, 650 pixels by 500 pixels; each pixel represents 2.5 arc-seconds in the field of view. If you select "zoom out," the telescope sends the whole image, but compressed to 650 pixels by 500 pixels; each pixel represents 5 arc-seconds in the field of view.

Ignore the focus commands

The telescope focuses automatically. The default focus always produces the sharpest image. Manual focus is used only for specialized experiments that require the telescope to be unfocused.

Select the "take picture" button when ready

After you select this button, the server tells the telescope to take an image at the time you selected. A screen will automatically appear to confirm your request. If you have forgotten any required information, the screen will prompt you to re-enter it. Note: On some browsers, you will have to re-enter all the information again, or at least your username and password. Take your time when entering your request; it will save time in the long run.

Retrieving your images

As soon as the telescope takes your image, it will e-mail your account to alert you. Depending on your e-mail utility, you may be able to click on the Web address for your image directly in this e-mail. Alternatively, go directly to the Image Directory page as follows.

Access the Image Directory page

From the menu bar, select "GET IMAGES." This link takes you to the website's Image Directory page, where the image you took is automatically posted.

Find your image file

The image files for all users are listed in the order of when they were taken (latest images at the top). To help find your file, you can sort the list by username, name of target, or date taken. To sort the list, click on the appropriate column heading above the list.

Examine your image: Important information

When you find your image, download it immediately to your computer. (Follow the instructions below.) ALL IMAGES ARE DELETED FROM THE IMAGE DIRECTORY WITHIN 7 DAYS AFTER THEY ARE TAKEN. Once deleted, they cannot be retrieved.

The telescope stores *two* different versions of your image. Click on your filename to view the *GIF-format* version of your image in your browser. This version will be satisfactory for images of the Moon, planets, or other very bright objects.

For fainter objects such as galaxies and nebulae, you should download the FITS-format version of your image. The FITS-format contains all the original information in your image—more than you can see in the GIF-format version. You should always use the FITS-format image if you plan to measure the brightness of your image.

The FITS-format images cannot be viewed in your web browser. They must be downloaded and opened in the free image-processing program provided with *From the Ground Up*. (See instructions below.)

View the thumbnail and Image Info window

To the right of the image's filename is the Image Info link for your image. Click on this to see all the information about how and when your image was taken. For some activities in *From the Ground Up!* you will need to know when the image was taken, or how high above the horizon it was, or what the exposure time was. It is good practice to print or download this information window when you retrieve your images.

Retrieve your image

For bright images, such as the Moon or Jupiter and its moons, it may be fine to simply download the GIF-format image that you see in your browser. Do this download as you would any image in your browser. (Click on the image and hold until the menu appears...)

For fainter objects, or to process the image, you will need to download the original image in its original FITS-format. To do this, follow the instructions at the top of the Web page.

You can view FITS images using the MOImage processing program, described below.

Save and name your image file

The name of your image file contains the first few characters of the name of the target, followed by a string of 12 digits that tell you exactly when the image was taken (mo da yr hr min sec). The time the image was taken is given as Greenwich Mean Time, which is typically 6 hrs. ahead of Eastern Standard Time.

You can keep this long filename or, if you prefer, you can rename your image. Make sure you have saved all the information you will need later.

Processing your images

For images of very bright objects (such as the Moon and the planet Jupiter) you can usually work directly with the image that appears in your browser window.

However, many faint celestial objects (such as galaxies and nebulae) have very low contrast. You may have difficulty even seeing these objects when you look at the image that appears in your browser. To enhance these images and bring out the fine details, you must first download the FITS-format version of the image to your computer, and then use an *image-processing* program.

> The image that appears in your browser is called a GIF-format image. This is an "8-bit" image, meaning that it is made up of dots each of which can have one of $2^8 = 256$ different grey-levels, ranging from white to black.
>
> The FITS-format image, which you can download to your computer, is the original image that comes back from the telescope. It is a "12-bit" image, meaning that each dot in the image can have any one of $2^{12} = 4096$ grey levels. The original FITS-format image therefore contains much more information than the GIF-format image you see in your browser.

The MOImage software enables you to:

- enhance the brightness and contrast of your image
- create a digital movie from individual images
- measure the brightness of an object in your image
- measure the angular width of an object
- create a full-color image from three images taken through color filters

The program is available for download at:

http://mo-www.harvard.edu/MicroObservatory/MOImage

To use the program, follow the instructions in the *From the Ground Up!* activities.

Printing your images.

When you print your images, use the landscape format rather than portrait format (i.e., horizontal rather than vertical).

Astronomical images usually have black backgrounds which can use up your printer's toner ink. If this is a problem, a handy solution is to *invert* your image before printing it; by printing black against a white background, you will save your toner and also bring out finer details in your object. You can invert your image in most image-processing programs, including MOImage. Simply find the appropriate menu and choose INVERT.