Educational Guide for 5000 Eyes

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Show Summary

Introduction

5000 Eyes" opens with a view of a CLUES dark matter simulation. This simulation shows dark matter as a glowing, evolving web where galaxies form and interact with each other. These motions happen on timescales much longer than a human lifetime so we can't actually watch it happen in real time. However, there is a way for astronomers to look back in time… The screen fades to a sunset on Kitt Peak and DESI, the Dark Energy Spectroscopic Instrument, is introduced. DESI is mapping out the positions of millions of galaxies to see what the largest structures in the universe look like and how they evolve.

Science Background

We slowly fly away from Earth and outside of the Solar System as the narrator explains that light takes time to travel. This means that when we observe distant stars or galaxies, we are seeing them as they existed in the past. As we leave the plane of the Milky Way, our home galaxy, we start to see other galaxies.

Many cartoon galaxies appear and an animation describing redshift begins. As the universe expands, the galaxies move further away, with the furthest ones moving faster and redder. The narrator explains that their light is being stretched and reddened, so a galaxy's color can tell us how far away it is. We measure this color using a "spectrograph".

The animation fades and we fly through real data of the galaxies around us to see the "large-scale structure" of the universe - a massive web formed by galaxies. Another animation appears showing a slice of the large-scale structure and points out how the light we observe from structure that is further away comes from an older universe. We can observe the universe at different distances to see how it changes over time.

The DESI Survey

DESI is introduced with many pictures of astronomers from all over the world whizzing around the globe. A series of four short videos of DESI members, each from a different continent, appear and explain their role in DESI.

We transition to the night sky and see the images that DESI uses for their survey, before flying through a model of the Mayall Telescope. In the telescope, we see the path of light and fly into DESI's "focal plane", a forest of pencil-shaped robots that separate the light into individual galaxies. This is explained by another interview of a graduate student who worked on the focal plane.

Next we see a time-lapse of the Mayall Telescope in action. A French astronomer explains her job of visiting the mountain to observe for DESI.

Conclusion

The film ends with a beautiful visualization of the first 14 million galaxies observed by DESI. We first see the galaxies as they appear in the sky from Earth, and then fly through the data. Near the end of the flight, the names of the hundreds of people who are part of DESI appear on the screen.

Next Generation Science Standards

Recommended Grades: 3+

> Check back on March 31 for full list of U.S. Next Generation Science Standards which are supported by the film and this educational guide

Main Questions and Answers

What is cosmology?

Cosmology is the study of the universe on its largest scales. Cosmologists study how matter and light are spread across vast, cosmic distances over a time range spanning billions of years. Using this immense catalog of information, cosmologists aim to understand the universe as whole, including how it began, how it arrived at its present era, and how it will ultimately change in the future. Cosmology then teaches us about the universe's history and evolution.

We know from cosmological studies that the universe is expanding and that its expansion is getting faster. The suspected cause of this accelerating expansion is a mysterious concept called dark energy. Very little is known about the nature of dark energy, making it a major focus of modern cosmological research, including DESI.

Why can astronomers “see back in time”?

When astronomers "see back in time," they are really seeing a record of the past, like when you watch an old movie. This record exists because of the way that light behaves. The light that stars emit has to travel across vast distances before it reaches our eyes, and this travel is not instantaneous. Light travels at a fixed speed of three hundred thousand kilometers per second (or one thousand and eight hundred miles per second). This speed might sound very fast, but the light has to travel across such large distances that it takes a full eight minutes for light from our own sun to reach our eyes. This means that the appearance of the sun in our sky is really a record of the sun eight minutes in the past.

The time lag between light being emitted and us seeing it on Earth gets more extreme for more distant stars and galaxies. The closest star to our sun is Proxima Centauri, and this star takes four years to send light to the earth. When we look at Proxima Centauri in the night sky, we are then seeing a record of this star four years in the past. If we look further away at stars near the center of our galaxy, we are seeing twenty-six thousand years into the past. If we look even further away at the Andromeda Galaxy, one of the closest galaxies to our own, we are seeing two and a half billion years back into the past. As we continue to look at more and more distant objects, we are then seeing further and further into the past. The oldest light we can see is the cosmic microwave background, a remnant of the Big Bang.

What is redshift?

Redshift in cosmology refers to when light waves become redder due to the motion of galaxies. Waves in general can become more pressed together or stretched out depending on whether the source of the wave is moving towards or away from you. This is why when you watch a firetruck drive away from you, its siren gets lower and lower in pitch. The sound wave that the siren emits is getting stretched out. A similar concept is also true for the light emitted from galaxies. If the galaxies are moving away from us, then the light emitted from those galaxies gets stretched out and becomes more red. This is what we mean when we say that the light is redshifted.

It turns out that the universe is expanding, and that all galaxies are moving away from each other, and so the light we see from galaxies in the sky is redshifted. The farther away a galaxy is from us, the faster it's moving away. This is because space is expanding everywhere, and the more distant a galaxy is, the more space there is between us to expand. This means we can determine the distance to a galaxy just by measuring how red its light is, or in other words, its redshift.

A useful visualization of how waves are affected by the movement of their source:
https://www.youtube.com/watch?v=h4OnBYrbCjY

How do astronomers make a map of galaxies?

To make a map of galaxies, we need to know where the galaxies are located. We can gather light from galaxies with a telescope to determine where they are positioned in the night sky. However, we still need to understand how far away these galaxies are from Earth. We can use the redshift of galaxies to determine how far away they are and then build a 3D map of the universe.

What can we learn from a map of galaxies?

We can learn many things from a map of galaxies. We know that the universe is expanding, and that this expansion is getting faster due to the mysterious effects of dark energy. The distribution of matter within a map of galaxies reveals how the universe has expanded in the past, which in turn teaches us about how dark energy has evolved over time. We can also learn more about the physical properties of the galaxies in the map themselves. We can even use the map to measure the mass of subatomic particles called neutrinos, meaning that we can use the largest structures in the universe to study the smallest particles within it.

What is DESI?

The Dark Energy Spectroscopic Instrument Survey, abbreviated as the DESI Survey, will study dark energy by making a gigantic map of galaxies. DESI will observe forty million galaxies and allow astronomers to see eleven billion years back into the past. To do this, DESI will collect light from the night sky using the Mayall Telescope at The Kitt Peak National Observatory in Arizona. The DESI instrument will measure the redshifts of galaxies in order to figure out how far away they are, allowing us to create a three-dimensional map of the universe. That map that DESI creates will advance our understanding of dark energy and cosmology as a whole.

Activities

Legacy Survey Viewer

Grades: 3-12
Tools needed: Web browser
Activity time: 30-90 minutes

Learning Objectives: Students will learn about galaxy morphology and explore the imaging of a real astronomical survey.

Description of Legacy Survey Viewer

The DESI Legacy Imaging Survey is a collection of images taken by four telescopes located all over the world. They cover a third of the entire night sky. This is what DESI uses to identify the galaxies that they will observe for their main survey.
For more information, see this blog post: https://www.desi.lbl.gov/imaging-surveys/

All imaging is publicly available view the Legacy Survey Viewer, which is the only tool needed for this activity: https://www.legacysurvey.org/viewer

Every time you click on this link, it will take you to a new galaxy!

1. Using the viewer

Click on this link to open the viewer. In the top right hand corner you'll see the coordinates of the object you're looking at, in Right Ascension (RA) and Declination (DEC). You can click on this bar to enter any coordinates that you want to go to. Move your mouse around the screen and note how these numbers change. Which direction is RA? DEC?

Below these coordinates you'll see a slider which will allow you to zoom in or out. Try zooming all the way out. The shape you see outlines the areas of the sky that the survey has imaged. This is a flat projection of the sky, similar to how world maps are flat projections of the globe. If you could see the Milky Way in this view, it would curve through the gaps between the two sections. DESI doesn't want to observe galaxies in that region of the sky because it's difficult to see galaxies through the dust and gas of our own galaxy, the Milky Way.

Zoom back in to around zoom level 13. You can see what level you're at in the top right bar. The scale bar in the lower right corner will say something like "3 arcmin". Notice how it changes with the zoom level. This is similar to a scale bar you might see on a normal map, which might say something like "one mile". We use miles/meters to measure distances on the ground, and angles to measure distances on the sky. Arcminutes and arcseconds are angles. The moon is about 30 arcminutes across.

Below the scale bar, you'll see sliders to adjust the contrast and brightness of your image. To reset this, just refresh the page.

Below these sliders, find the text that says "Jump to Object". The text in the field gives you the name of the object you're currently looking at. To see more information about the object, you can Google this name. Most of the default objects you see when refreshing the page will be famous galaxies and have their own Wikipedia page. You can also enter the name of an object that you want to see.

Enter the name "M87". You'll see a massive galaxy. At the center of this galaxy is a supermassive black hole - the very first black hole that humans ever took a picture of! However, the black hole is far too small to show up on this screen. It's less than a pixel across, even at the highest zoom level (and even if you could see it, it's outshone by all the stars in the galaxy).

Note: This survey is designed to image galaxies, but there are many stars in our own galaxy that can get in the way. You can tell which objects are stars because they are so bright they oversaturate the image.They show up as bright, horizontal lines. Any objects which are too bright may create odd patterns. If something has straight lines or edges, it's an artifact caused by oversaturation (NOT aliens!!). To see an extreme example of this, go to the object "alf Boo".

2. Galaxy Morphology

"Galaxy Morphology" is the study of galaxy shapes. Astronomers sort galaxies into three main categories: spiral, elliptical, and irregular. For each of these categories, navigate to the example objects and learn about that type.

<u>Spiral</u>
NGC 1417, NGC 4414, NGC 1300, NGC 4565

Spiral galaxies have spiral arms filled with gas and dust. They are smaller than elliptical galaxies. You may notice some bright blue spots - these are newly forming stars. The center of the galaxy has the most stars and is very bright. Sometimes this center is not round and looks more like a long oval. We call these "barred spiral galaxies" NGC 1300 is a good example of this. Spiral galaxies are shaped like a disk, so when viewed edge-on they appear very elongated and their spiral pattern is not visible. This is the case for NGC 4565, where you can see the edge of gas and dust that lies in the galaxy's plane.

Elliptical
NGC 4365, NGC 1132, Coma Cluster

Elliptical galaxies are larger than spiral galaxies and have no gas or dust. These galaxies are also not as blue as spirals. This is because blue stars are hot and die quickly. Elliptical galaxies have no gas and dust to make new stars, so all that's left are the older, redder stars. Elliptical galaxies are also more likely to be found in clusters of other galaxies, as seen in the Coma Cluster.

Irregular
NGC 1427A, UGC 6945, NGC 6090, NGC 3690

Irregular galaxies are simply any galaxies which are not spiral or elliptical. Usually they are small and can have a lot of gas and dust. Sometimes they are merging galaxies.

3. Sort Galaxies

Now it's your turn. Identify as many of the galaxies below as you can, with either "spiral", "elliptical", or "irregular". If you're working in a group, you may want to split up the galaxies.

NGC 3010C	NGC 2859	NGC 4111
NGC 3009	NGC 2893	NGC 3150
NGC 3008	NGC 2862	NGC 3161
NGC 3006	NGC 2896	NGC 3152
NGC 772	NGC 3697	NGC 2683
NGC 3002	NGC 2885	NGC 3126
NGC 2998	NGC 3005	NGC 3162
NGC 3010	NGC 2403	NGC 3189
NGC 2860	NGC 3202	NGC 3185
NGC 3416	NGC 2834	NGC 3177
NGC 3415	NGC 3106	NGC 4725
NGC 3207	NGC 3068B	NGC 3187
NGC 3205	NGC 3098	NGC 3237
NGC 2655	NGC 4214	NGC 3219
NGC 2852	NGC 3088B	NGC 3254
NGC 2853	NGC 3179	NGC 3204
NGC 2844	NGC 3180	NGC 3545
NGC 2838	NGC 3163	NGC 3088
NGC 2840	NGC 3159	NGC 3151
NGC 2839	NGC 3160	NGC 3193
NGC 936	NGC 3158	NGC 3697C

4. Bonus: discover your own galaxies

Pan around the viewer by clicking and dragging with your mouse. You can also refresh the page to automatically take you to a new galaxy. Find a few galaxies which are interesting to you. Write down their type and RA and DEC. If you click on the object and select “Look up in Simbad”, it will take you to a page with a name for this object. You may be able to Google this to find more information. If you’re working in a class or group, choose one object to share with others. Below is a table to guide you.

	RA	DEC	Galaxy Type	Name	Interesting Features / Information about Object
1					
2					
3					

DESI High

Grades: 9+
Tools needed: Computer, web browser
Activity time: 60+ minutes

Learning Objectives: Students will get an introduction to the most common programming language used by astronomers, Python. They'll also get hands-on experience by working with real DESI data and gain an understanding of the data analysis used by cosmologists.

Description:

DESI High is a series of coding tutorials in the form of interactive, online Jupyter notebooks. They require no installations on your computer.

For an overview of DESI High, see this blog post:
https://www.desi.lbl.gov/education-outreach/desi-high/

The notebooks are hosted on Binder:
https://mybinder.org/v2/gh/michaelJwilson/DESI-HighSchool/1.2.6

GitHub repository for the notebooks:
https://github.com/michaelJwilson/desihigh

DESI routinely organizes virtual DESI High events for schools, with real DESI astronomers to guide students through the notebooks. For inquiries, email desihighinitiative@gmail.com

Glossary

Cosmic Web: The large scale distribution of galaxies and galaxy clusters in the universe, which resembles a giant spider web.

Dark Energy: The term given to the cause of the Universe's increasing expansion. We do not understand its true nature, only the effects it has on how the Universe changes.

Dark Matter: The term given to matter that doesn't interact with light - "invisible mass". We do not currently know what dark matter is made of, but can see its gravitational effects on galaxies and how the cosmic web evolves.

DESI: Dark Energy Spectroscopic Instrument. This is used to describe the instrument located on the Mayall Telescope which is gathering millions of galaxy spectra. It's also used to refer to the global collaboration of scientists supporting it.

Fiber Optic Cable: A cable made of thin strands of glass fibers. It's used to transmit light , which bounces around the inside of the cable but does not escape.

Fiber Positioner (aka "Tiny Robot): A pencil-shaped robot with a fiber optic cable threaded through it. The robot moves to point the fiber at a galaxy. The galaxy's light hits the fiber and then travels down to a room containing spectrographs.

Focal Plane: The plane of the telescope where light is focused. DESI's focal plane contains 5000 robotic positioners to separate the light into the light of individual galaxies.

Kitt Peak: A mountain near Tuscon, Arizona on the Tohono O'odham Nation. It's home to the most diverse collection of optical and radio telescopes in the world.

Large-Scale Structure: Aka the cosmic web. It's made up of the largest structures in the world: sheets, strands, and voids of galaxies which are measured on the scale of hundreds of millions of light years.

Mayall Telescope: The 4-meter telescope located on Kitt Peak and home to the DESI Instrument.

Primary Mirror: The first place that light hits when it enters a reflecting telescope. Reflecting telescopes, like the Mayall, have a primary mirror which reflects the light from space back up and focuses it on the instruments which lie above it. The Mayall primary mirror is 4 meters in diameter and weighs 500 tons.

Redshift: The effect of light stretching as its source moves away from the observer. Cosmologists also use it synonymously with "distance".

Spectra: The plural of “spectrum” - the range of light observed from an object. Cosmologists use “spectra” to describe spectroscopic measurements of galaxies that reveal their distances.

Spectrograph: The instrument used to measure the component wavelengths, the spectrum, of incoming light.

Additional Resources

DESI's Website
https://www.desi.lbl.gov/

Meet a DESI member:
https://www.desi.lbl.gov/education-outreach/meet-a-desi-member-all/

Interactive Visualizations of DESI data:
https://www.desi.lbl.gov/education-outreach/interactive-visualizations/

DESI's social media accounts
Instagram: @desisurvey
Twitter: @desisurvey
Facebook: DESI Survey

Comic Series about DESI
https://cmlamman.github.io/desi.html

Legacy Imaging Survey Viewer
https://www.legacysurvey.org/viewer

DESIHigh
https://www.desi.lbl.gov/education-outreach/desi-high/

Additional Educational Activities

Cosmology activities and demos created by David Kirkby
https://dkirkby.github.io/cosmo-demo/

Python notebook to visualize large-scale structure created by David Kirkby
https://observablehq.com/@dkirkby/desi-large-scale-structure