Cosmic Dark to Cosmic Dawn: A Science Outreach Website

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Project Overview

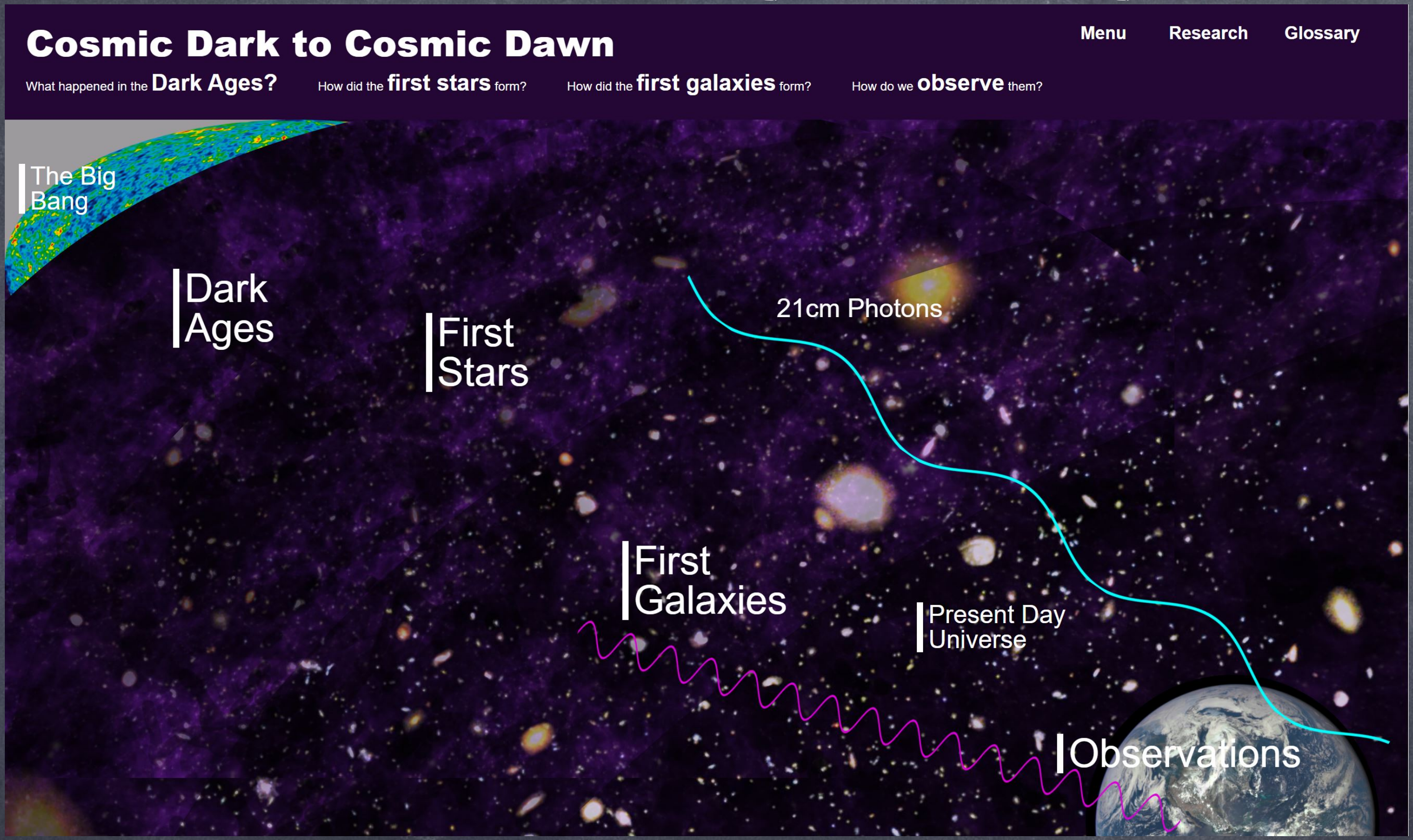
- There are no dedicated websites explaining the Dark Ages, Cosmic Dawn, and the epoch of reionization for laypeople
- We HOPE many people will soon be searching for more information - with DAPPER, EDGES, JWST, HERA, etc.
- We aim to fill that gap with an accessible and informative site covering the science and the instruments
- Project is jointly funded by NESS and NSF

Project Overview

- Eventually, will include versions for:
  - Interested laypeople (~Scientific American level)
  - Kids (targeting late elementary)
- Eventually, will include animations and tutorials
- First goal: complete science overview for adults
  - We will go "live" once we have this portion complete (target: early spring)

DRAFT Screenshots!

Landing Page



- Goals:
  - Easy drop-in navigation
  - Graphically clean and attractive
- Variety of engagement levels
- Science and technology tracks

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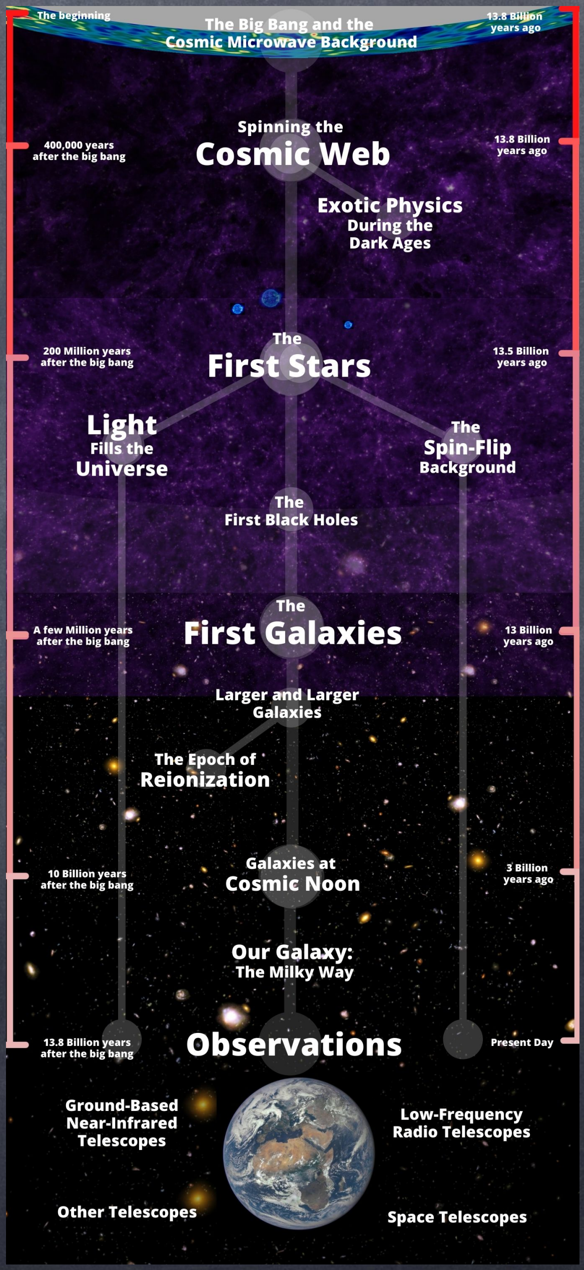
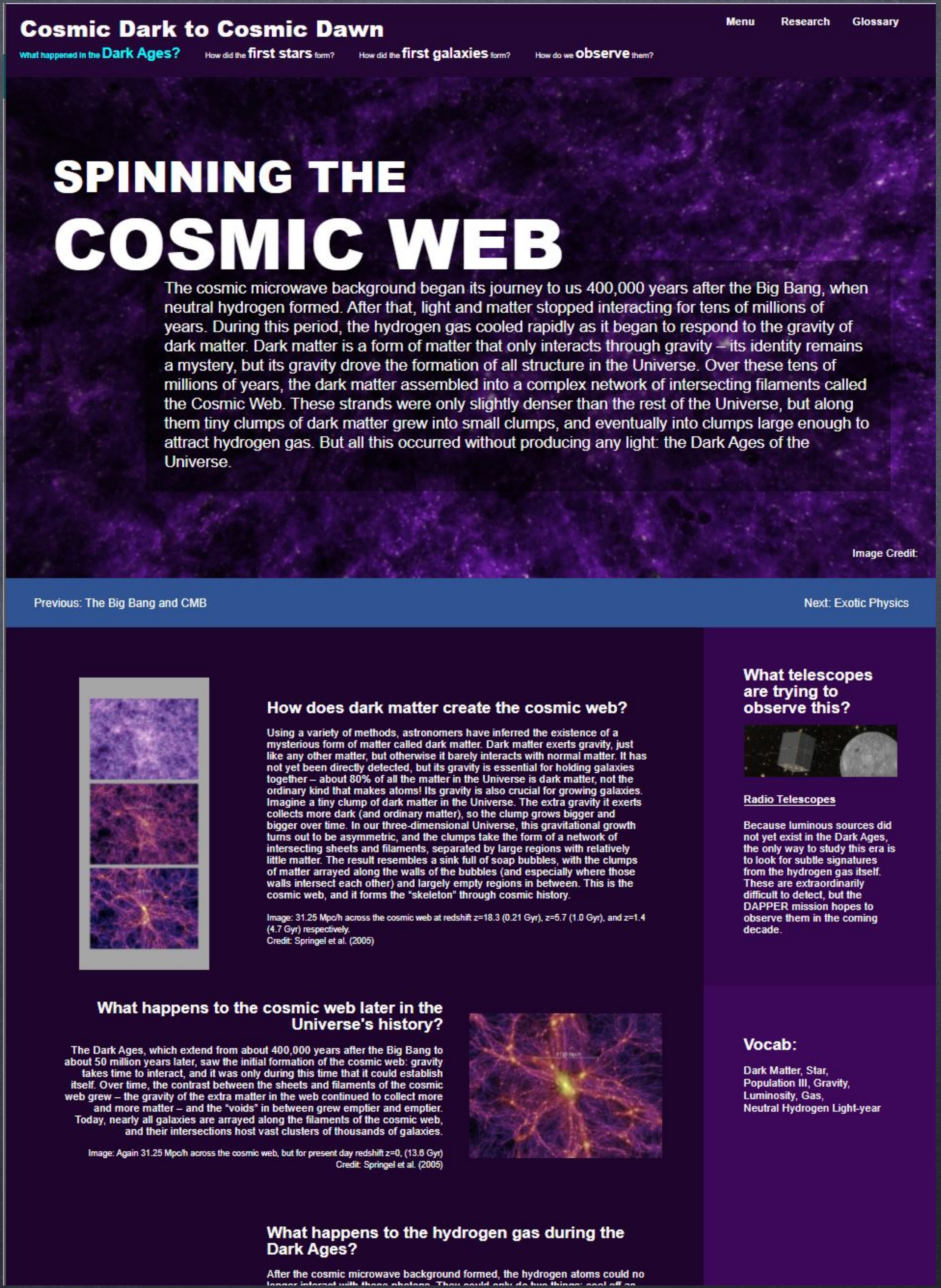


Example Science Pages

- Self-contained opening paragraph
- Main text expands on these points (with images)
- Sidebar points toward observations



Cosmic Dark to Cosmic Dawn

Menu Research Glossary

What happened in the **Dark Ages?** How did the **first stars** form? How did the **first galaxies** form? How do we **observe** them?

SPINNING THE COSMIC WEB

The cosmic microwave background began its journey to us 400,000 years after the Big Bang, when neutral hydrogen formed. After that, light and matter stopped interacting for tens of millions of years. During this period, the hydrogen gas cooled rapidly as it began to respond to the gravity of dark matter. Dark matter is a form of matter that only interacts through gravity – its identity remains a mystery, but its gravity drove the formation of all structure in the Universe. Over these tens of millions of years, the dark matter assembled into a complex network of intersecting filaments called the Cosmic Web. These strands were only slightly denser than the rest of the Universe, but along them tiny clumps of dark matter grew into small clumps, and eventually into clumps large enough to attract hydrogen gas. But all this occurred without producing any light: the Dark Ages of the Universe.

Image Credit:

Previous: The Big Bang and CMB

Next: Exotic Physics

How does dark matter create the cosmic web?

Using a variety of methods, astronomers have inferred the existence of a mysterious form of matter called dark matter. Dark matter exerts gravity, just like any other matter, but otherwise it barely interacts with normal matter. It has not yet been directly detected, but its gravity is essential for holding galaxies together – about 80% of all the matter in the Universe is dark matter, not the ordinary kind that makes atoms! Its gravity is also crucial for growing galaxies. Imagine a tiny clump of dark matter in the Universe. The extra gravity it exerts collects more dark (and ordinary matter), so the clump grows bigger and bigger over time. In our three-dimensional Universe, this gravitational growth turns out to be asymmetric, and the clumps take the form of a network of intersecting sheets and filaments, separated by large regions with relatively little matter. The result resembles a sink full of soap bubbles, with the clumps of matter arrayed along the walls of the bubbles (and especially where those walls intersect each other) and largely empty regions in between. This is the cosmic web, and it forms the "skeleton" through cosmic history.

Image: 31.25 Mpc/h across the cosmic web at redshift z=18.3 (0.21 Gyr), z=5.7 (1.0 Gyr), and z=1.4 (4.7 Gyr) respectively.
Credit: Springel et al. (2005)

What happens to the cosmic web later in the Universe's history?

The Dark Ages, which extend from about 400,000 years after the Big Bang to about 50 million years later, saw the initial formation of the cosmic web: gravity takes time to interact, and it was only during this time that it could establish itself. Over time, the contrast between the sheets and filaments of the cosmic web grew – the gravity of the extra matter in the web continued to collect more and more matter – and the "voids" in between grew emptier and emptier. Today, nearly all galaxies are arrayed along the filaments of the cosmic web, and their intersections host vast clusters of thousands of galaxies.

Image: Again 31.25 Mpc/h across the cosmic web, but for present day redshift z=0, (13.6 Gyr)
Credit: Springel et al. (2005)

What happens to the hydrogen gas during the Dark Ages?

After the cosmic microwave background formed, the hydrogen atoms could no

What telescopes are trying to observe this?

Radio Telescopes

Because luminous sources did not yet exist in the Dark Ages, the only way to study this era is to look for subtle signatures from the hydrogen gas itself. These are extraordinarily difficult to detect, but the DAPPER mission hopes to observe them in the coming decade.

Vocab:

Dark Matter, Star, Population III, Gravity, Luminosity, Gas, Neutral Hydrogen Light-year

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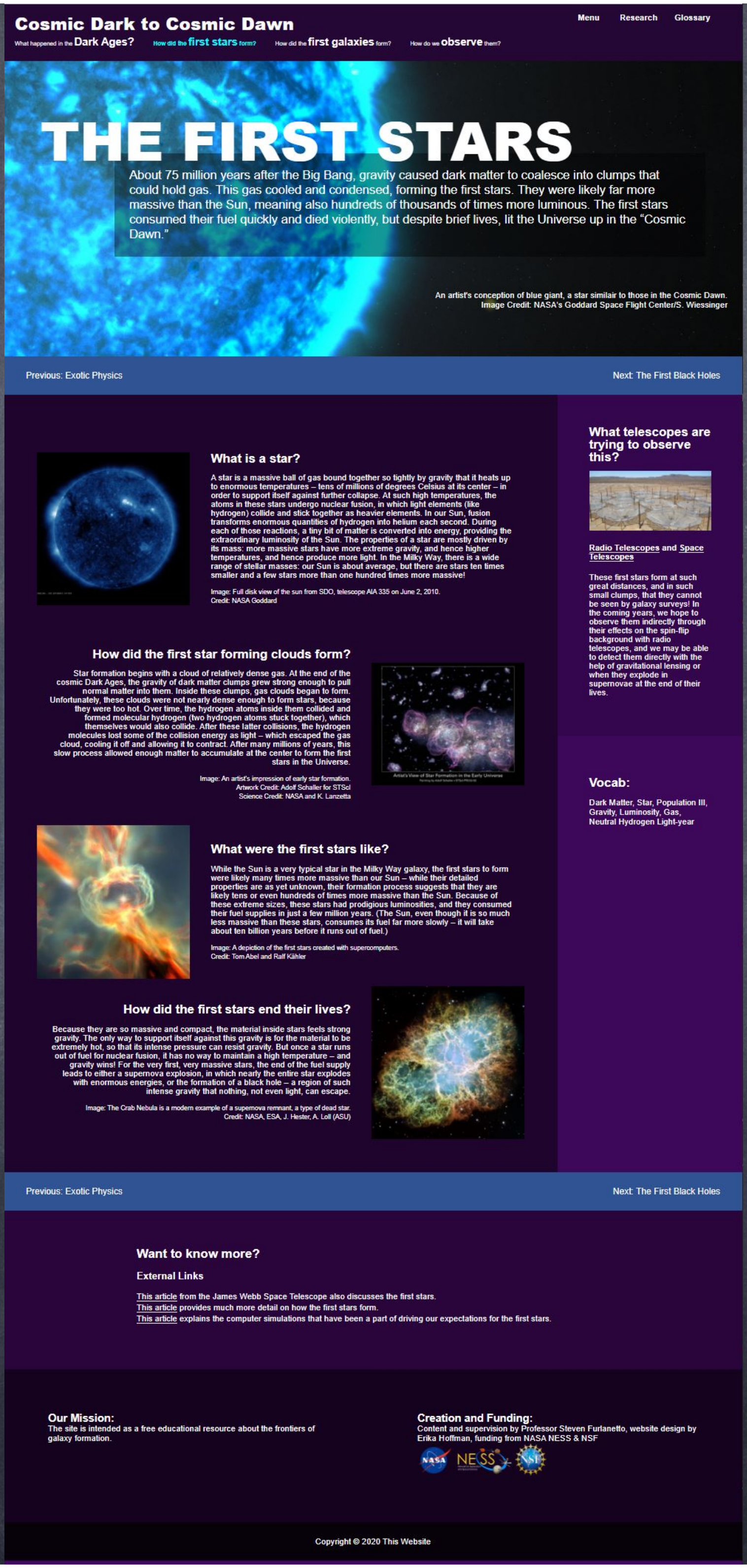
- Main text expands on these points (with images)
- Sidebar points toward observations



Cosmic Dark to Cosmic Dawn

Menu Research Glossary

What happened in the Dark Ages? How did the first stars form? How did the first galaxies form? How do we observe them?

THE FIRST STARS

About 75 million years after the Big Bang, gravity caused dark matter to coalesce into clumps that could hold gas. This gas cooled and condensed, forming the first stars. They were likely far more massive than the Sun, meaning also hundreds of thousands of times more luminous. The first stars consumed their fuel quickly and died violently, but despite brief lives, lit the Universe up in the “Cosmic Dawn.”

An artist's conception of blue giant, a star similair to those in the Cosmic Dawn.
Image Credit: NASA's Goddard Space Flight Center/S. Wiessinger

Previous: Exotic Physics Next: The First Black Holes

What is a star?

A star is a massive ball of gas bound together so tightly by gravity that it heats up to enormous temperatures – tens of millions of degrees Celsius at its center – in order to support itself against further collapse. At such high temperatures, the atoms in these stars undergo nuclear fusion, in which light elements (like hydrogen) collide and stick together as heavier elements. In our Sun, fusion transforms enormous quantities of hydrogen into helium each second. During each of those reactions, a tiny bit of matter is converted into energy, providing the extraordinary luminosity of the Sun. The properties of a star are mostly driven by its mass: more massive stars have more extreme gravity, and hence higher temperatures, and hence produce more light. In the Milky Way, there is a wide range of stellar masses: our Sun is about average, but there are stars ten times smaller and a few stars more than one hundred times more massive!

Image: Full disk view of the sun from SDO, telescope AIA 335 on June 2, 2010.
Credit: NASA Goddard

How did the first star forming clouds form?

Star formation begins with a cloud of relatively dense gas. At the end of the cosmic Dark Ages, the gravity of dark matter clumps grew strong enough to pull normal matter into them. Inside these clumps, gas clouds began to form. Unfortunately, these clouds were not nearly dense enough to form stars, because they were too hot. Over time, the hydrogen atoms inside them collided and formed molecular hydrogen (two hydrogen atoms stuck together), which themselves would also collide. After these latter collisions, the hydrogen molecules lost some of the collision energy as light – which escaped the gas cloud, cooling it off and allowing it to contract. After many millions of years, this slow process allowed enough matter to accumulate at the center to form the first stars in the Universe.

Image: An artist's impression of early star formation.
Artwork Credit: Adolf Schaller for STScI
Science Credit: NASA and K. Lanzetta

What were the first stars like?

While the Sun is a very typical star in the Milky Way galaxy, the first stars to form were likely many times more massive than our Sun – while their detailed properties are as yet unknown, their formation process suggests that they are likely tens or even hundreds of times more massive than the Sun. Because of these extreme sizes, these stars had prodigious luminosities, and they consumed their fuel supplies in just a few million years. (The Sun, even though it is so much less massive than these stars, consumes its fuel far more slowly – it will take about ten billion years before it runs out of fuel.)

Image: A depiction of the first stars created with supercomputers.
Credit: Tom Abel and Ralf Kähler

How did the first stars end their lives?

Because they are so massive and compact, the material inside stars feels strong gravity. The only way to support itself against this gravity is for the material to be extremely hot, so that its intense pressure can resist gravity. But once a star runs out of fuel for nuclear fusion, it has no way to maintain a high temperature – and gravity wins! For the very first, very massive stars, the end of the fuel supply leads to either a supernova explosion, in which nearly the entire star explodes with enormous energies, or the formation of a black hole – a region of such intense gravity that nothing, not even light, can escape.

Image: The Crab Nebula is a modern example of a supernova remnant, a type of dead star.
Credit: NASA, ESA, J. Hester, A. Loll (ASU)

What telescopes are trying to observe this?

Radio Telescopes and Space Telescopes

These first stars form at such great distances, and in such small clumps, that they cannot be seen by galaxy surveys! In the coming years, we hope to observe them indirectly through their effects on the spin-flip background with radio telescopes, and we may be able to detect them directly with the help of gravitational lensing or when they explode in supernovae at the end of their lives.

Vocab:

Dark Matter, Star, Population III, Gravity, Luminosity, Gas, Neutral Hydrogen Light-year

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Want to know more?

External Links

This article from the James Webb Space Telescope also discusses the first stars.
This article provides much more detail on how the first stars form.
This article explains the computer simulations that have been a part of driving our expectations for the first stars.

Our Mission:
The site is intended as a free educational resource about the frontiers of galaxy formation.

Creation and Funding:
Content and supervision by Professor Steven Furlanetto, website design by Erika Hoffman, funding from NASA NESS & NSF

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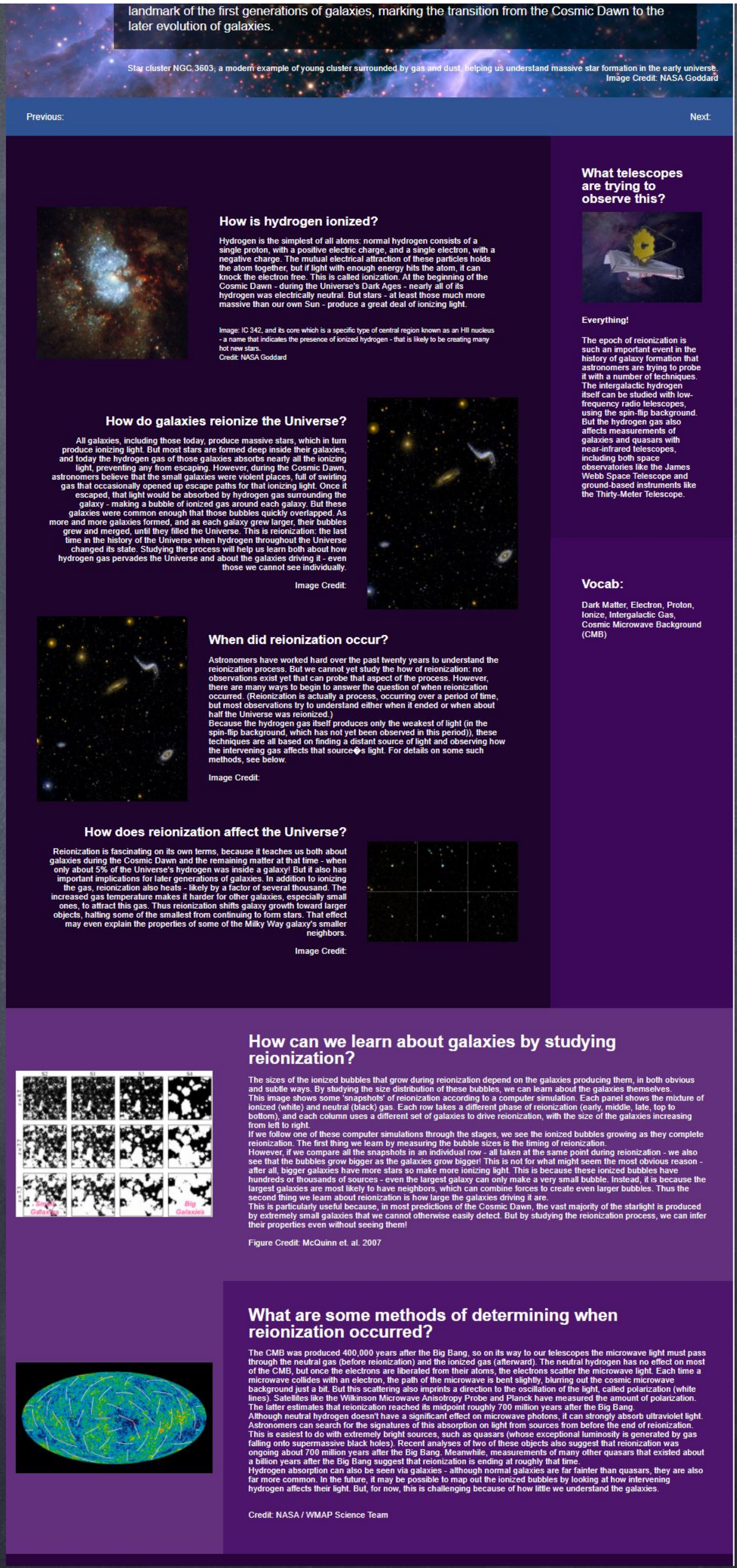
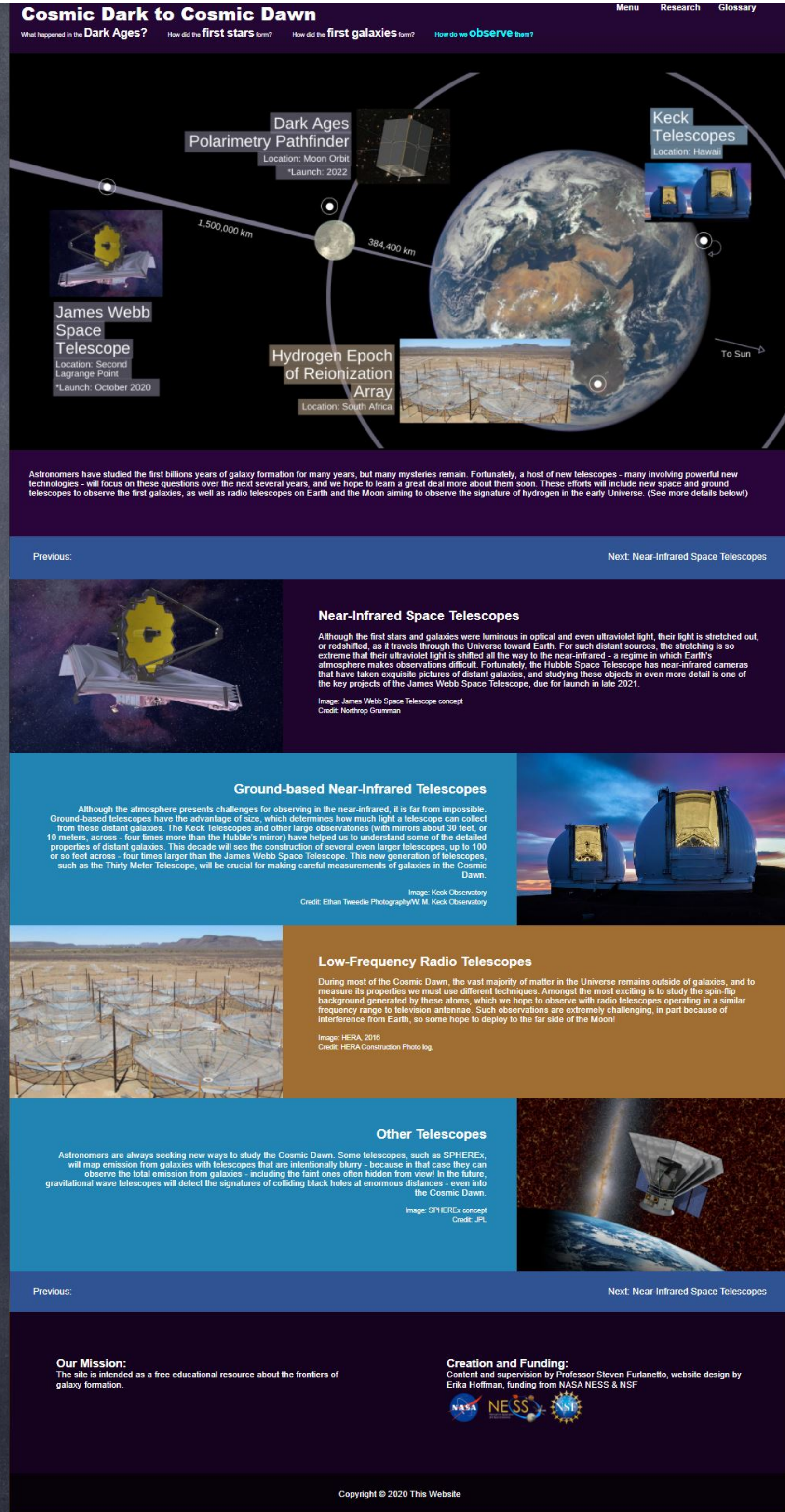
Example Science Pages

- Self-contained opening paragraph
- Main text expands on these points (with images)
- Sidebar points toward observations
- Some pages have a third "layer" with focused research questions (these will become tutorials)



Example Telescope Pages

- Opening "splash" page highlights several techniques
- Includes a visual map that highlights lunar work



Example Telescope Pages

- Main pages organized similarly to science part:
- Self-contained opening paragraph
- Main text expands on these points (with images)
- Sidebar points toward science topics