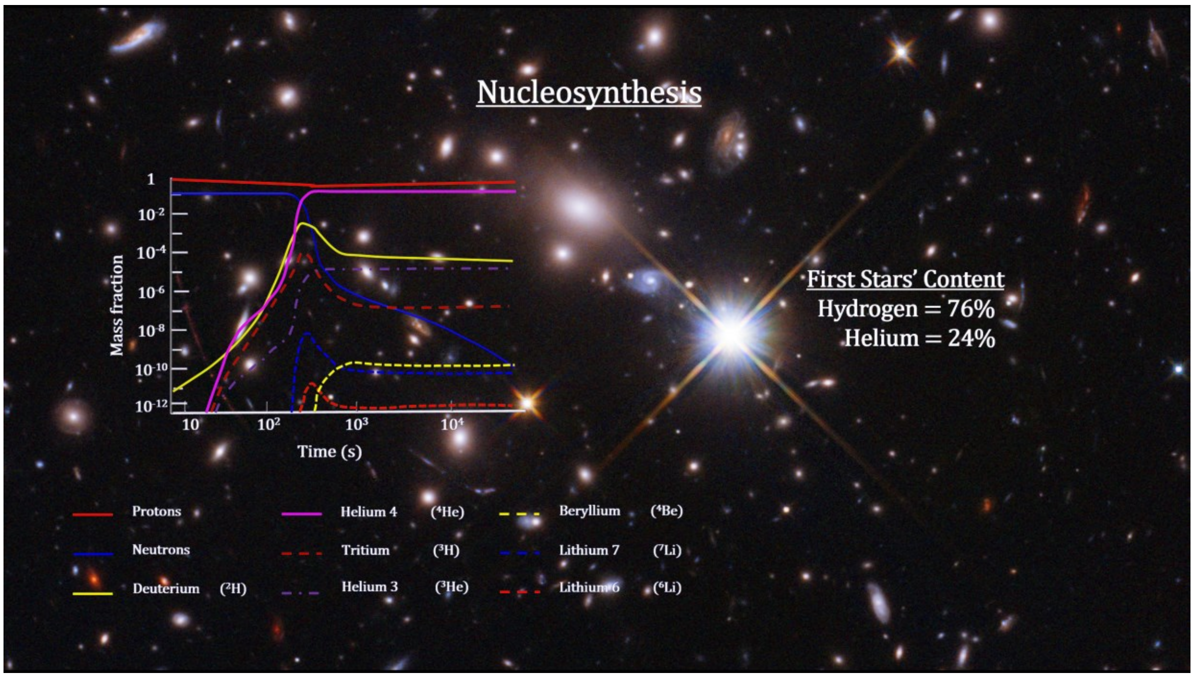
Earendel object – 12.9 bly

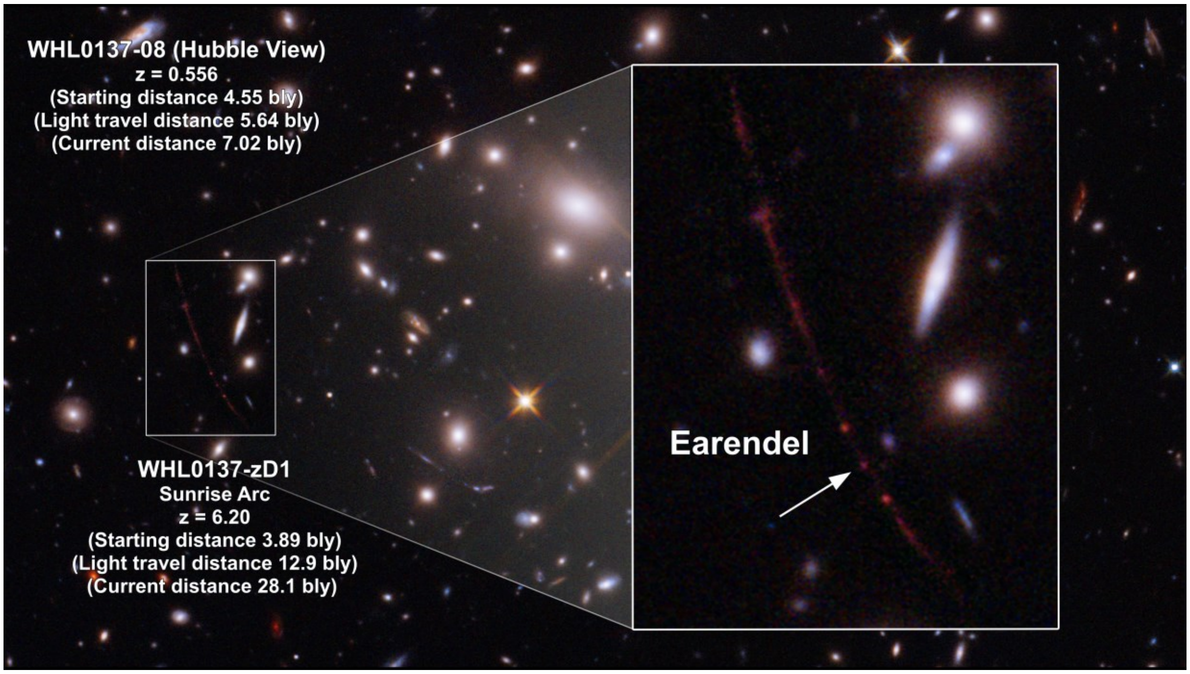
The Lambda Cold Dark Matter big-bang theory predicts that the early universe contained mostly hydrogen, some helium, and only traces of lithium. All the first-generation stars (called Population III stars) had to be made from just these elements. But, up to the summer of 2022, no telescope has ever seen a population III star to determine if this theory is correct.



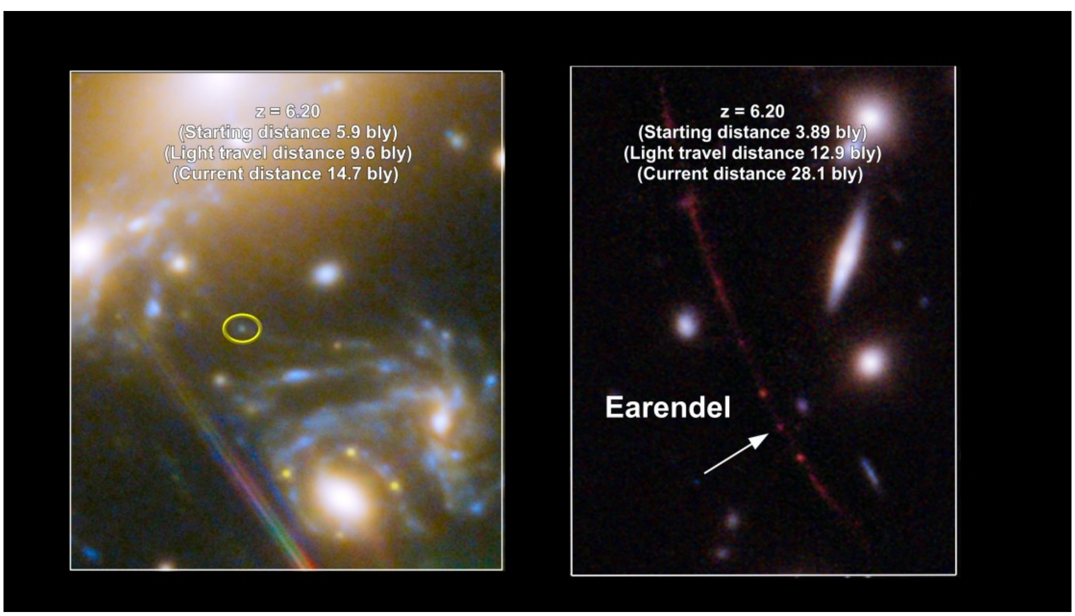
Here we have a massive galaxy cluster [WHL0137-08]. It has been studied for over 5 years since Hubble first captured the image in 2016. The galaxy was 4.5 bly away from us when the light we see started its journey. The light traveled 5.6 bly to get here, and it is currently 7 bly away. In this cluster, Hubble discovered a gravitationally lensed galaxy [WHL0137-zD1] nicknamed the "Sunrise Arc'. Its redshift is 6.2 with an angular size on the sky exceeding 15 arcseconds. That makes it 410,000 lightyears long.

The galaxy was only 3.9 bly away from the Milky Way when the light we see started its journey. The light traveled 12.9 bly to get here, and it is currently 28 bly away receding faster than the speed of light and beyond the visible horizon. No light leaving that galaxy now will ever reach the Milky Way.

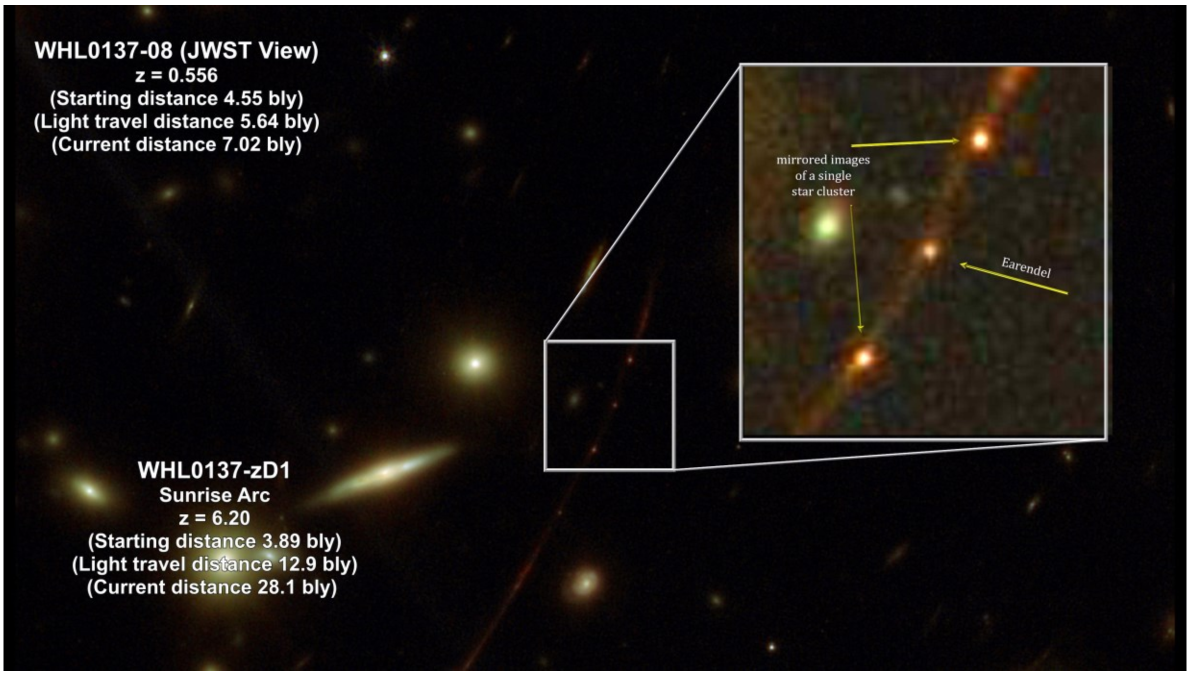
In this galaxy, Hubble discovered a single star. The star, LSz6 is nicknamed Earendel. The light we see from this star began its journey 900 mly into the Universe's expansion. This makes it the oldest most distant individual star ever seen. In addition, it is at least 50 times the mass of our Sun and hundreds of thousands of times brighter. This makes it one of the most massive stars known. Stars that massive only last for a few million years. So Earendel is long gone, having spewed the heaver elements it created into zD1 to become a part of the galaxy's next generation stars.



This find represents a significant jump back in time compared to the previous single-star record holder – Icarus covered in our 2018 Review. Its redshift is 1.5. Earendel is almost twice as far away from us now as Icarus. It's interesting to note that these views can be transient. Icarus is no longer visible, but Earendel has been stable and studied for over three and a half years.



On July 30, 2022, a few months after Hubble's discovery, a team of astronomers called Cosmic Spring worked with Webb to train its Near-Infrared Imaging camera on the Sunrise Arc for over 4 hours as part of a survey of the lensing cluster [WHL0137-08]. It also managed to capture the red dot corresponding to Earendel. Webb's analysis of the image has already confirmed that this is indeed a single star system, and not a group of several stars. The red dots on either side of Earendel are a single mirrored star cluster.

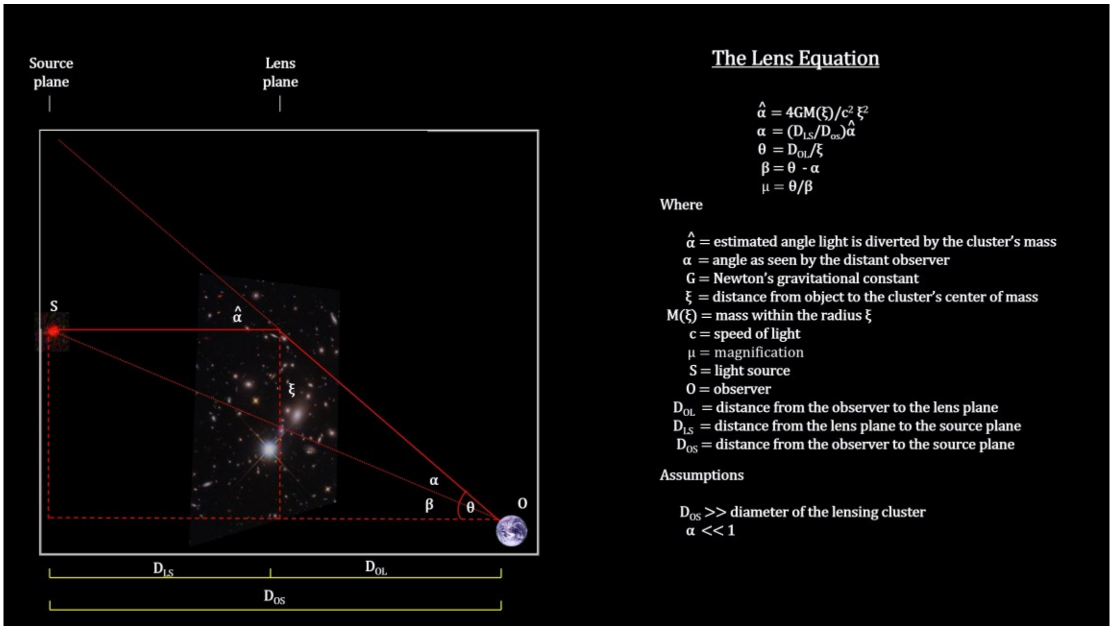


Just how this object in the distorted image of the Sunrise Arc galaxy was determined to be an individual star instead of a star cluster represents a major achievement in astronomy. The "how do we know" on this one will be repeated over and over again as the JWST examines the first billion years of the Universe. Strong gravitational lensing and a natural optical physical process called caustics are used extensively. Without them, we would never see let alone analyze objects like the Sunrise Arc and Earendel. So, we'll take a few minutes to cover how it's done.

From General Relativity, we know that matter curves space and light travels the shortest distance through this curved space (called geodesics). Large masses, such as a galaxy cluster, bend light passing through it – just like a lens.

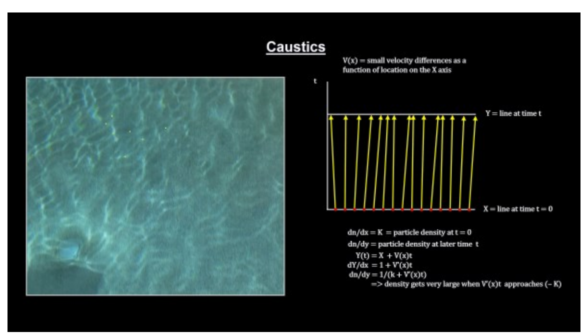
Here's the basic geometry of gravitational lensing. This is Sunrise Arc light on a direct path to us as if the galaxy cluster was not there. We could not detect this light. It is too dim for even our most powerful space telescopes. Here's its light headed in another direction. As it encounters the cluster, it is bent towards us by the cluster's mass. We can estimate the deflection angle once we know the mass and center of mass of the cluster. Analyzing clusters like this one, in order to discover these quantities is a major astronomical project that can take years. On Earth, we observe the image to be on a straight line at an angle from its actual direction. The Lens Equation gives us these angles. This geometry enables us to map points seen on the lens plane back to its position on the source plane.

The typical magnification created by this lensing is around 30 times the source area. This is great for finding galaxies 12 bly away, but it is not nearly enough to find a single star or star cluster inside a galaxy that far away.

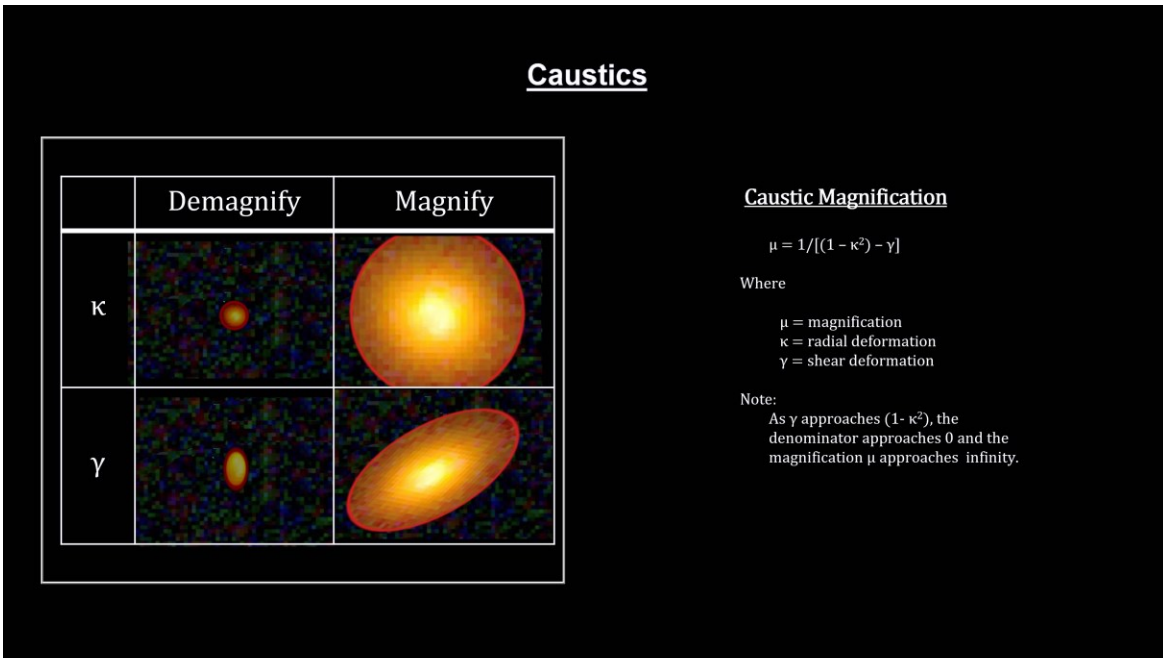


The key to finding Earendel, is the increased magnification created by a process called 'caustics'. It can magnify objects up to 10 thousand times their source sizes. Here's how it works. Picture a set of uniformly distributed photons on a line, each moving in a slightly different direction. They start out with a uniform particle density. But, because of the small velocity differences, the particle density will vary as time goes by. Areas of high and low density will develop. The density at a later time 't' is described by an equation. The equation has hot spots when the denominator approaches zero.

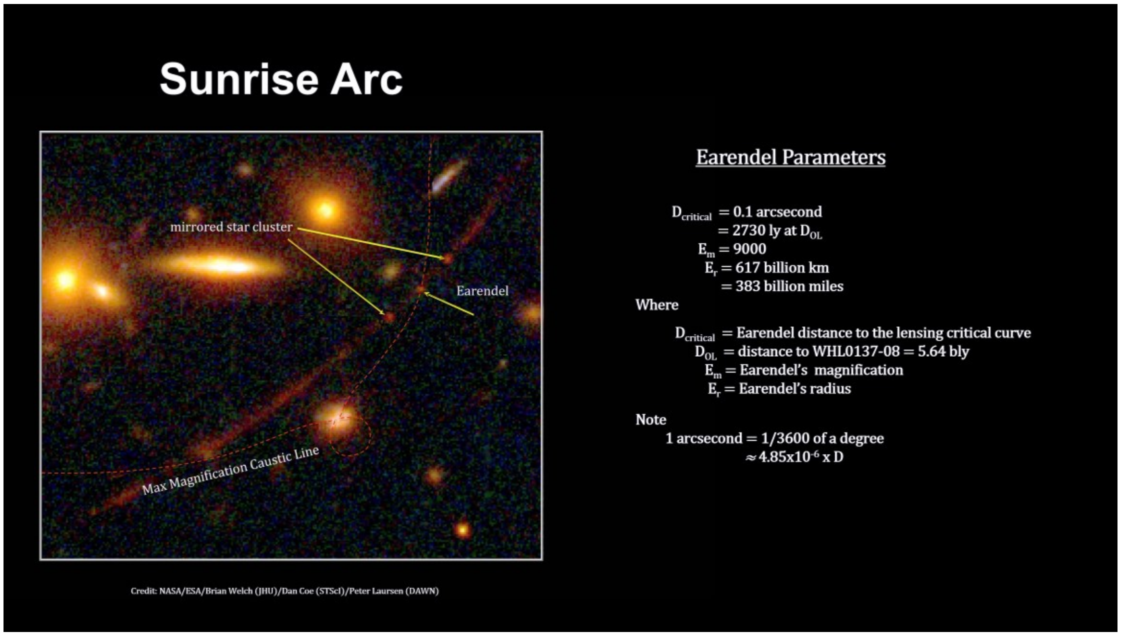
Extending this to three dimensions, we get density peaks along curved lines that themselves intersect at points with maximum intensity. I see this phenomenon in my own back yard swimming pool. Sunlight is evenly distributed as it reaches the water's surface. Small waves on the surface are creating small changes in the sunlight's direction. It's the caustic process that generates the lines at the bottom of the pool. These lines are not 'ripples in space-time'. They are simply lines of intense light magnification.



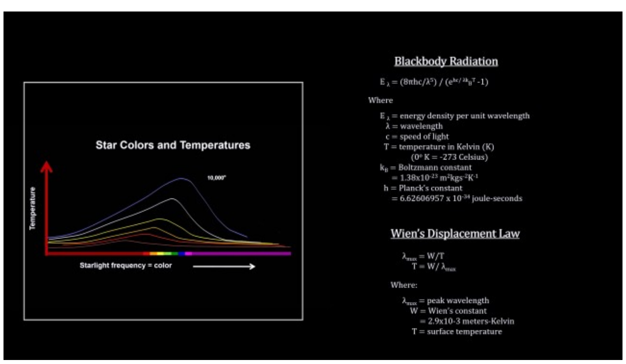
Light passing through a galaxy cluster is impacted in exactly the same way. Lines of extreme magnification, referred to as lensing critical curves, are created by the caustic process. An image on or near a critical curve will be both magnified and distorted with the distortions providing a way to calculate the size of the magnification.

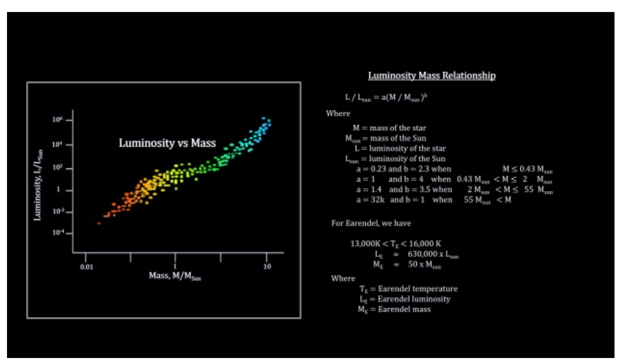


Astrophysicists and astronomers model these lines, and use the lens equations to map them back to the source. They can then reconstruct the shape and dimensions of an object, determine its deformations, calculate its observed magnification and deduce its intrinsic luminosity. Here's a higher resolution image of the area around Earendel produced by the JWST team. Objects close to a critical curve get mirrored into multiple images like these two images of a star cluster inside the Sunrise Arc galaxy. The critical curve responsible for this will pass through the midpoint between the two images. An object found at this midpoint like Earendel, would be so close to it that its multiple images cannot be resolved – it will appear as a single object. Four different models were used to locate the lensing critical curves. Here's one of them. The others are quite different, but they all pass through Earendel. It is important to note again that this is not a 'ripple in spacetime'. It is simply a line of maximum light magnification. The magnification drops off rapidly as the distance from the line increases. Earendel's distance from the line is within 0.1 arcseconds. That's a very small angle, but at these distances it represents 2730 ly. This distance along with its shape puts its magnification between 1,000 and 40,000 with 9,000 being the most likely. With this and the size of the image, we get a source object that has a radius less than 617 billion km. (That's 383 billion miles) This is a hundred times smaller than known small star clusters, leading to the conclusion that it is a single gigantic star or binary star system.

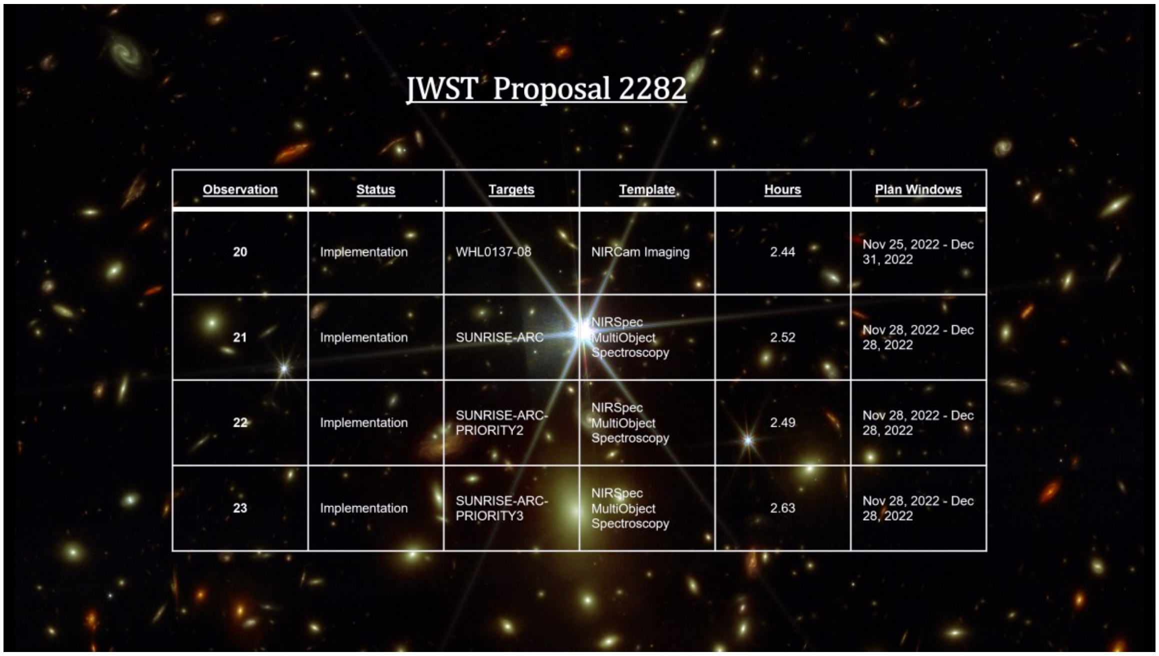


As outlined in the 'How Far Away Is It' chapter on 'Distant Stars', the blackbody radiation formula gives us the relationship between a star's color and its temperature. (An object's color gives us its temperature.) In addition, the Mass vs Luminosity Relationship provides a way to relate a star's temperature to its mass. Hubble's visible and ultra-violet light measurements indicate that Earendel is a hot blue star with a temperature between 13,000 and 16,000 degrees Kelvin. In addition, it's delensed luminosity is around 630,00 times the luminosity of our Sun. It's mass is then 50 times the mass of our Sun. This fits the profile for a Luminous Blue Variable star. Webb's analysis added the possibility that Earendel is a binary star system with one star at 20,000 degrees and the other at around 13,000 degrees.





A spectrographic study by the JWST is scheduled for November 2022. It will provide detailed data on its mass, radius and the elements it's made of. This will be enough to place Earendel on the Hertzsprung-Russel Diagram and we'll know if it is our first Population III Star.



JWST Proposal 2282

Observation	Status	Targets	Template	Hours	Plan Windows
20	Implementation	WHL0137-08	NIRCam Imaging	2.44	Nov 25, 2022 - Dec 31, 2022
21	Implementation	SUNRISE-ARC	NIRSpec MultiObject Spectroscopy	2.52	Nov 28, 2022 - Dec 28, 2022
22	Implementation	SUNRISE-ARC-PRIORITY2	NIRSpec MultiObject Spectroscopy	2.49	Nov 28, 2022 - Dec 28, 2022
23	Implementation	SUNRISE-ARC-PRIORITY3	NIRSpec MultiObject Spectroscopy	2.63	Nov 28, 2022 - Dec 28, 2022

Credits

Here are the links to the sources for the material in this video.

Websites

https://kipac.stanford.edu/highlights/population-iii-stars-universes-ultimate-reclusive-pop-stars

https://esahubble.org/news/heic2203/?lang

https://www.sci.news/astronomy/webb-earendel-image-11078.html#:~:text=On%20July%2030%2C%202022%2C%20the,CSA%20James%20Webb%20Space%20Telescope

Whitepapers

https://iopscience.iop.org/article/10.3847/1538-4357/ab5a8b
RELICS: The Reionization Lensing Cluster Survey and the Brightest High-*z* Galaxies

https://web.pa.msu.edu/people/abdo/GravitationalLensing.pdf
A good paper on lensing.

https://www.stsci.edu/jwst/phase2-public/2282.pdf
JWST Proposal 2282 to study Sunrise Arc

YouTube

https://youtu.be/CeSqIokr9CI
How Old Is It - 03 - Big Bang ΛCDM Cosmology (4K)

https://youtu.be/9HNjFs-vG_c
How Far Away Is It - 06 - Distant Stars (4K)

https://youtu.be/UmHQ2Y1hD0U
Classroom Aid - Cosmic Caustics