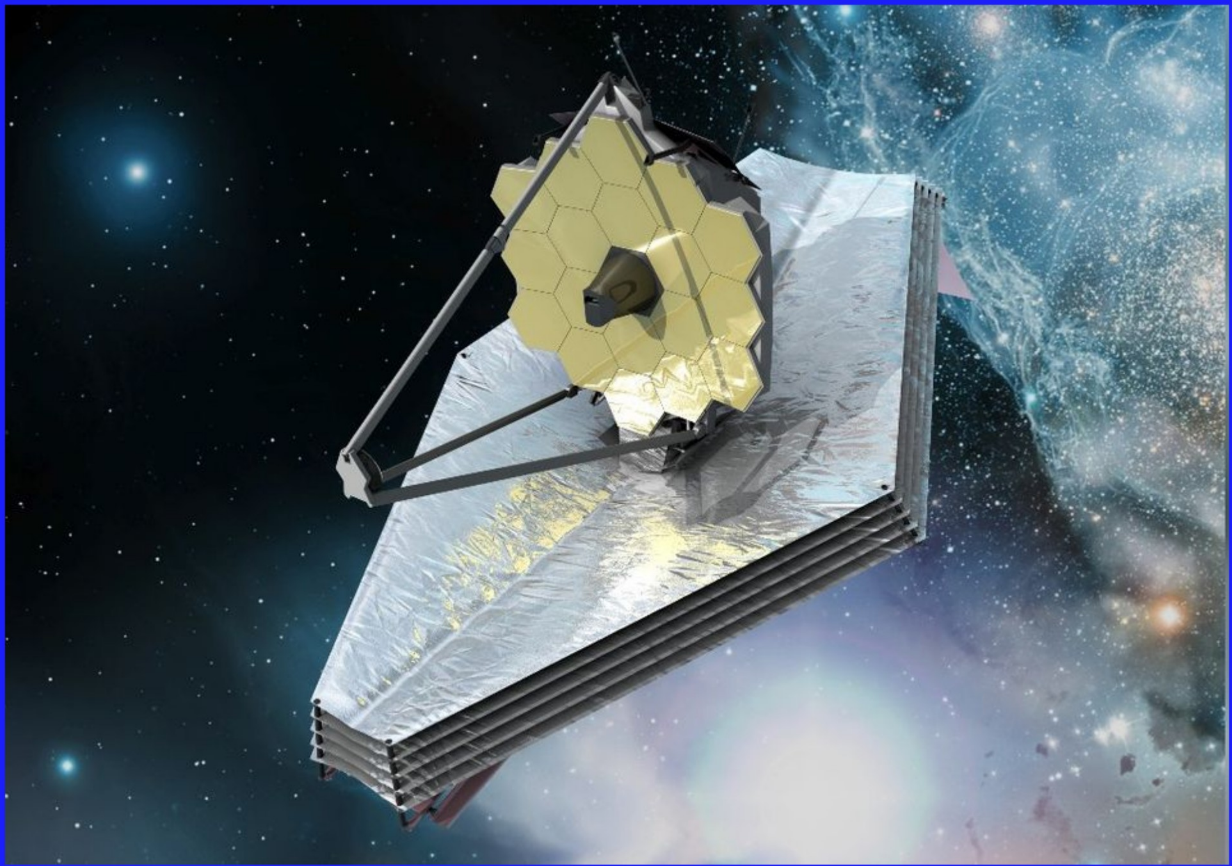
Latest News from the Early Universe and the Solar System

Lecture 2: Light Bending and Stellar Nurseries

OLLI Spring 2024

Cathrine Blom

Our new super eyes on the Universe: the James Webb Space Telescope



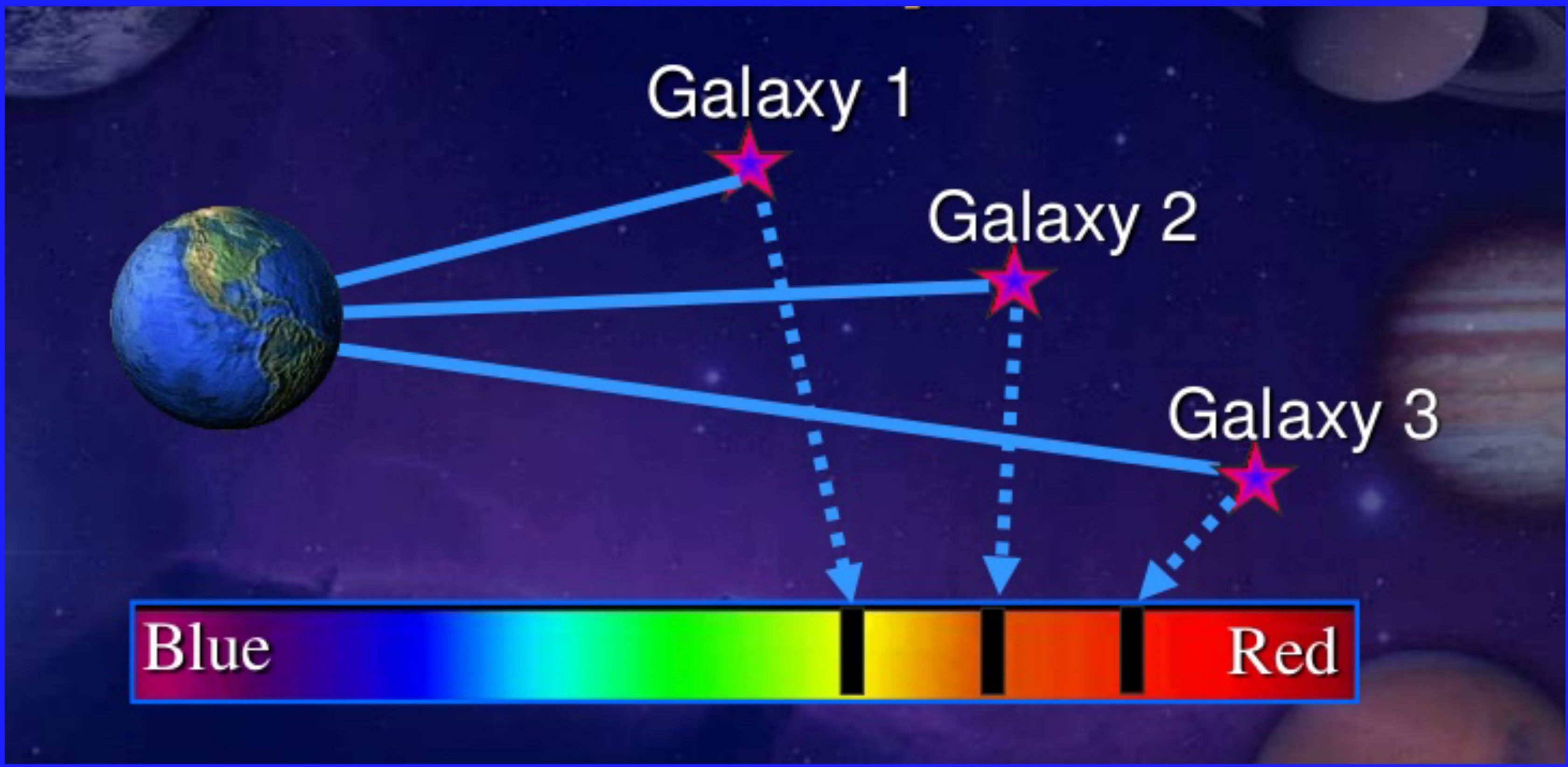
Launched from French Guiana on December 25, 2021

Orbits the Sun with Earth. Distance from Earth: 150,000 mill. km (93,000 mill. mi)

Hubble Ultra-deep Field vs. JWST Ultra-deep Field:

We also talked about:

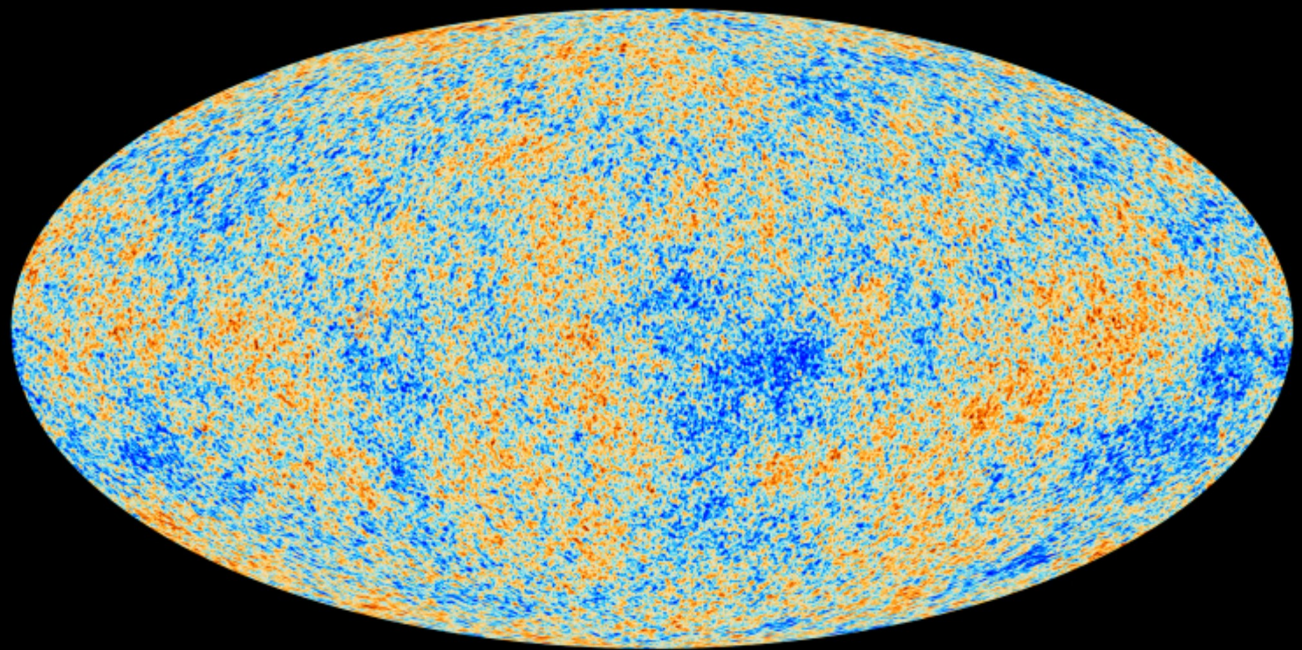
* Redshift, which measures distances. The more the light from a galaxy is redshifted, the further away it is. The redshift tells us when the light left the galaxy we are looking at.



* How far back in time we can see? JWST can see back to about 350 million years after the Big Bang, when the first galaxies had just formed.

Maisie's Galaxy, one of the furthest away galaxies ever detected.

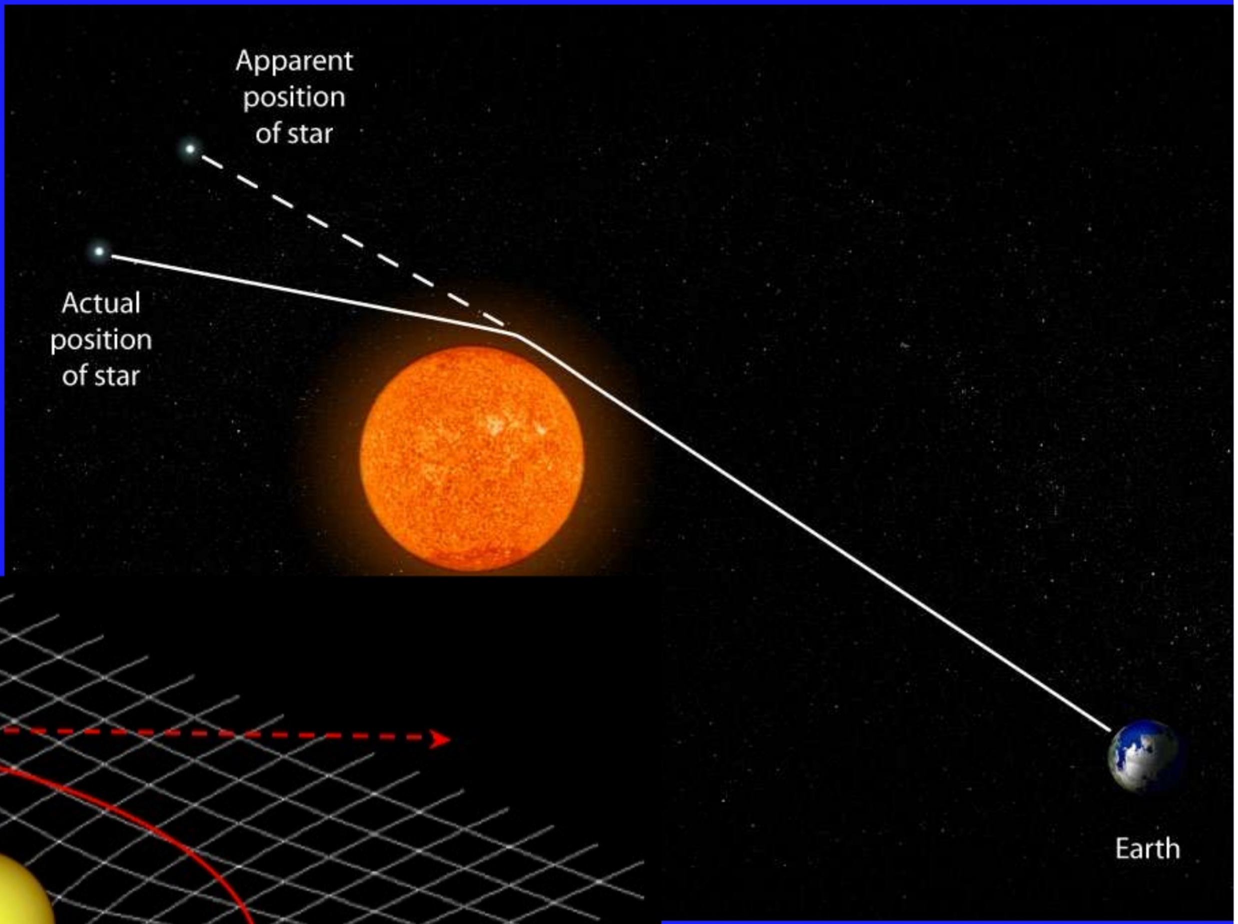
* Cosmic Microwave Background Radiation, the first light from the Big Bang itself, 380,000 years after the Universe became transparent to light.

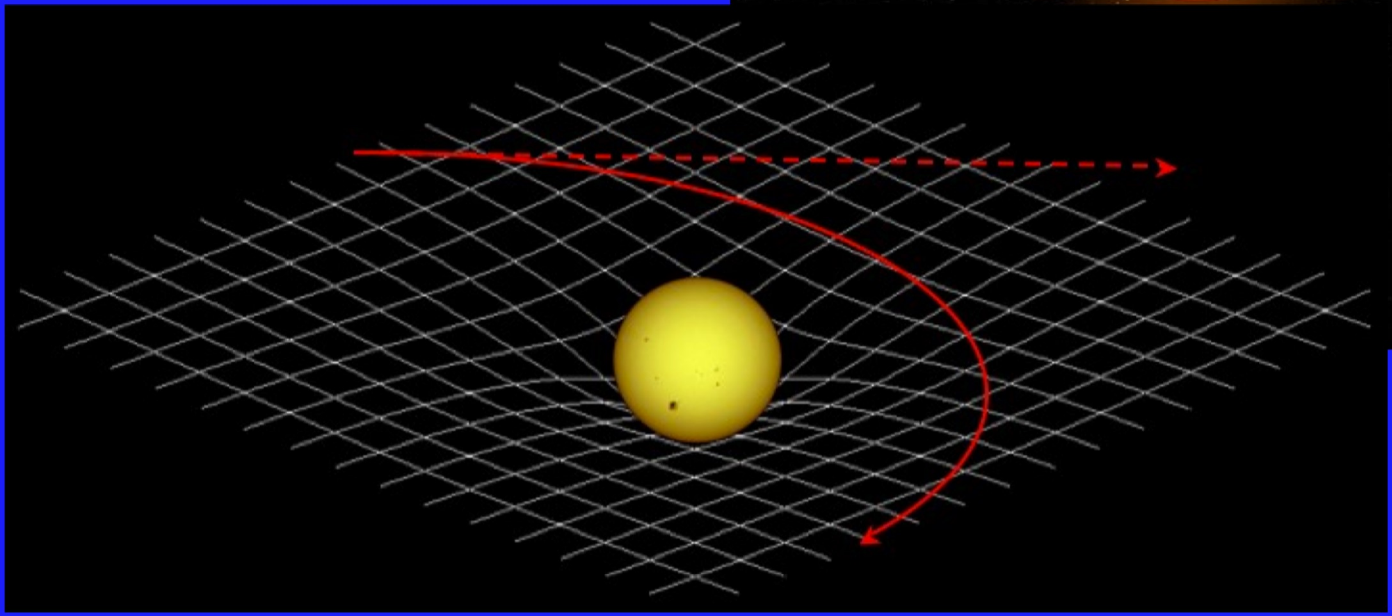


Cosmic background radiation

Avg. CMB temp = 2.7 Kelvin (degrees above absolute zero)
Red areas are hotter, blue are cooler
Temperature variation = 2.7K ± 0.00003, or one part in 100,000

* Bending of light. According to Einstein's General Theory of Relativity (1915) gravity bends light -- *objects curve space.*





What is JWST revealing about the early Universe:

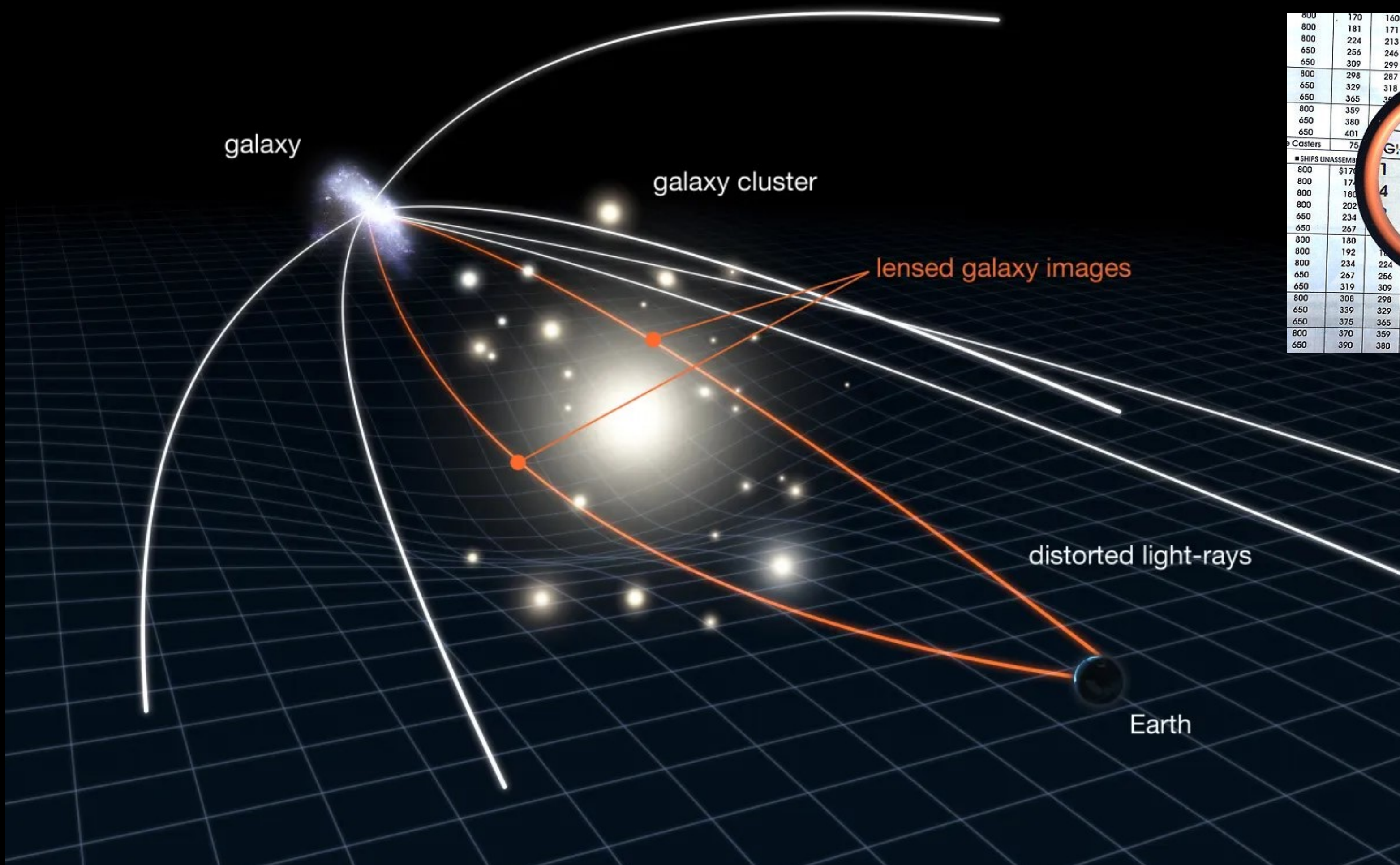
Detection of the earliest stars, made from primordial matter

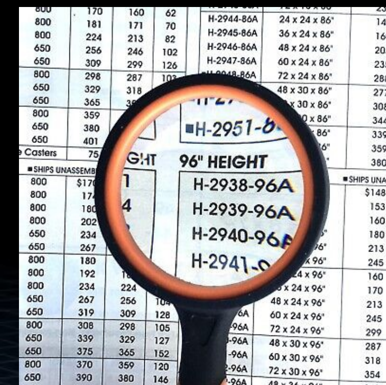
Very big, old stars

Enormous galaxies and supermassive black holes formed much earlier than believed possible

450 000 quasars, the brightest objects in the Universe

Stars bend light, and galaxies and galaxy clusters bend light even more. Light-bending acts like a magnifying glass.

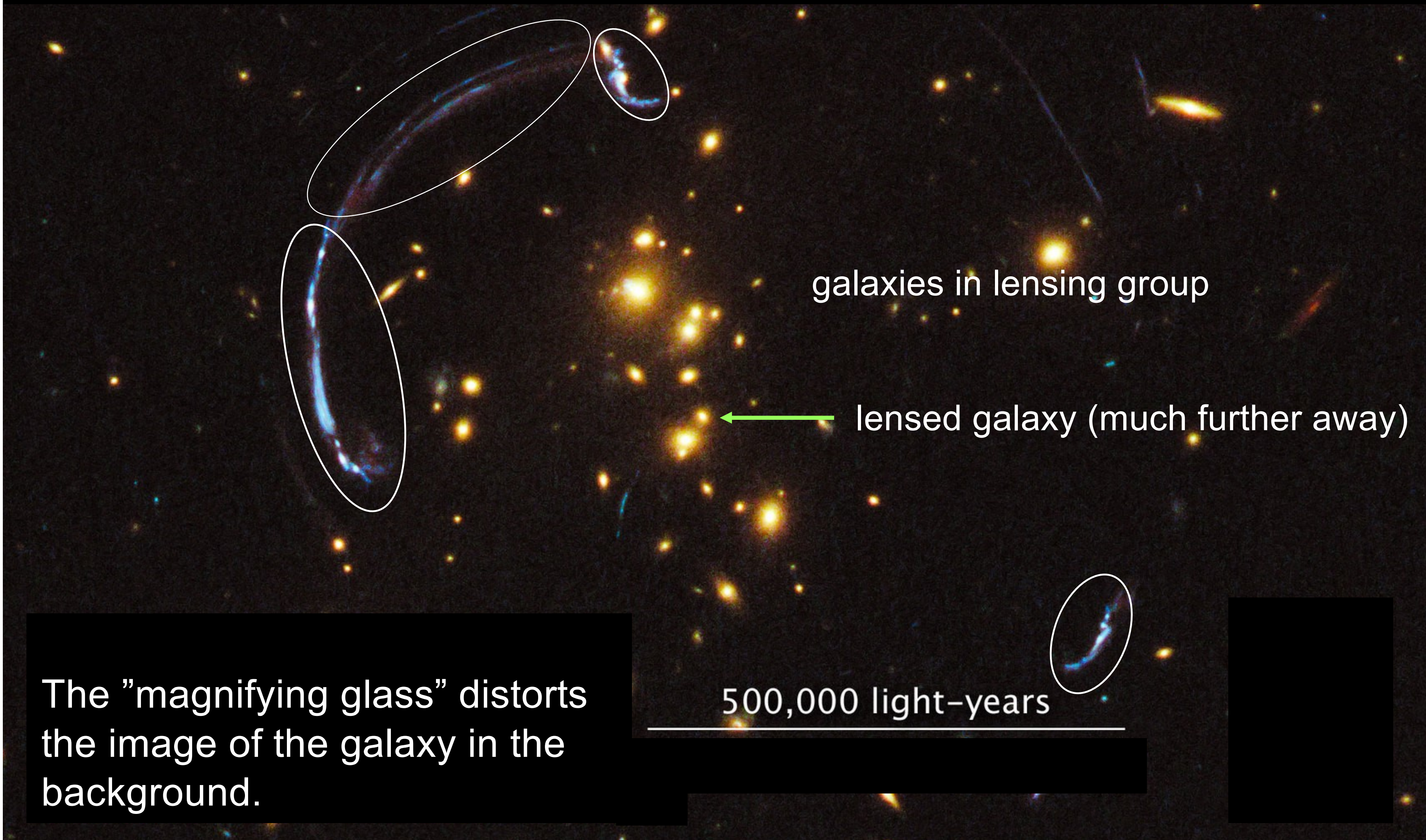


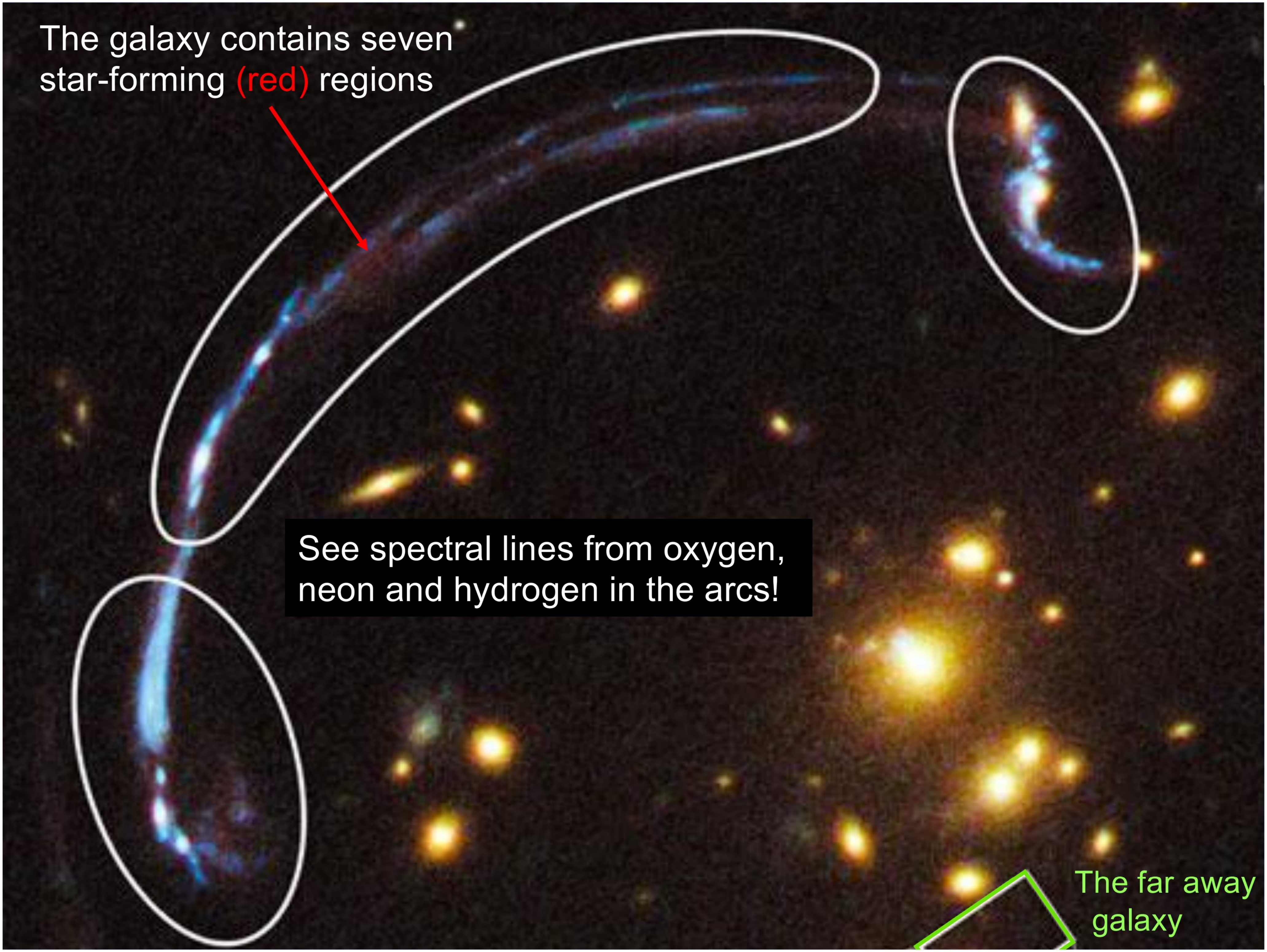


The light from a background galaxy is deflected and brightened by the foreground cluster's strong gravitational field. The bigger the galaxy cluster, the brighter the image of the background galaxy.

Light bending by a cluster of galaxies

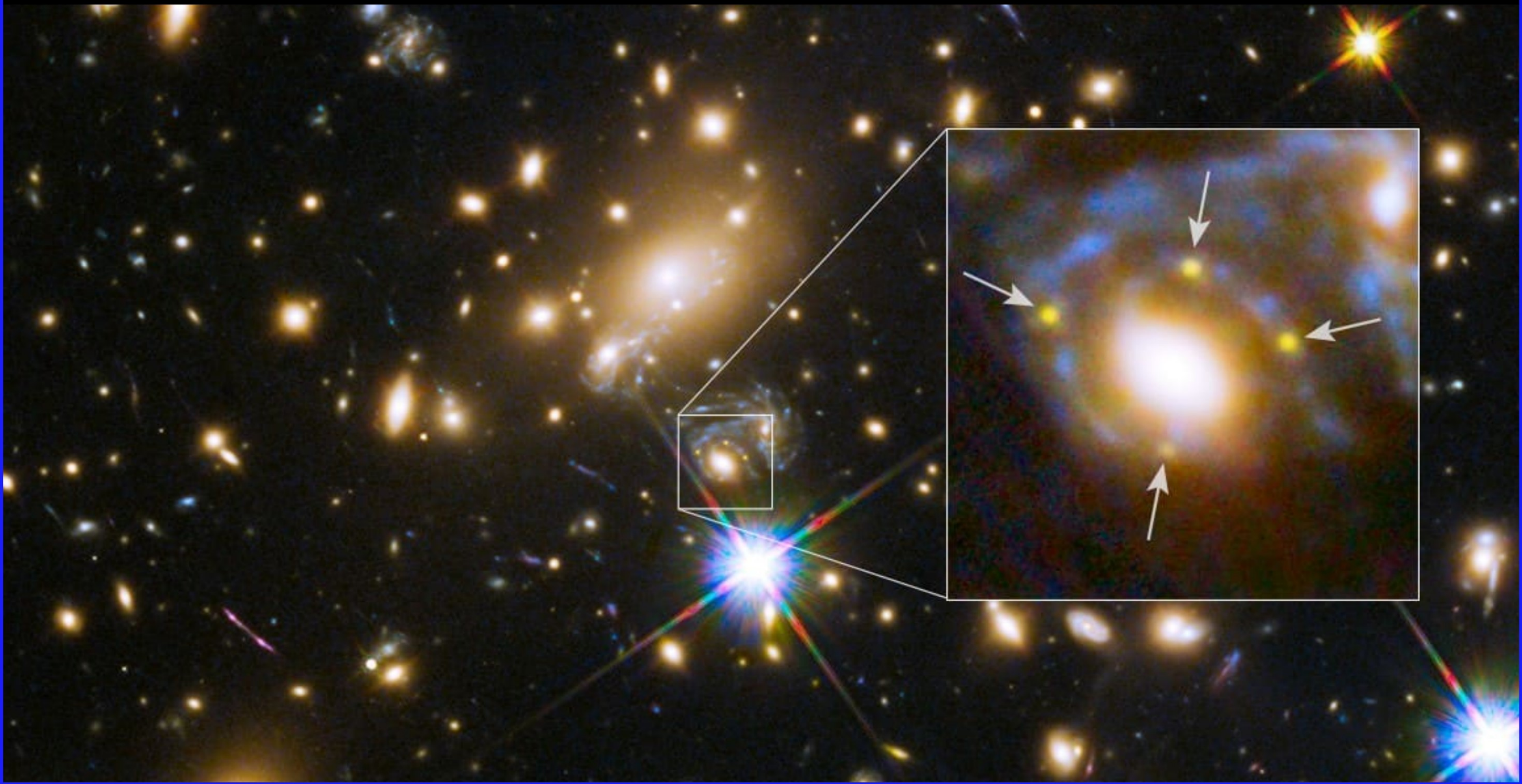
A background galaxy 9.8 billion light-years away (green arrow), lensed by a foreground galaxy cluster 5.5 billion light-years away. The big arcs are images of the background galaxy.



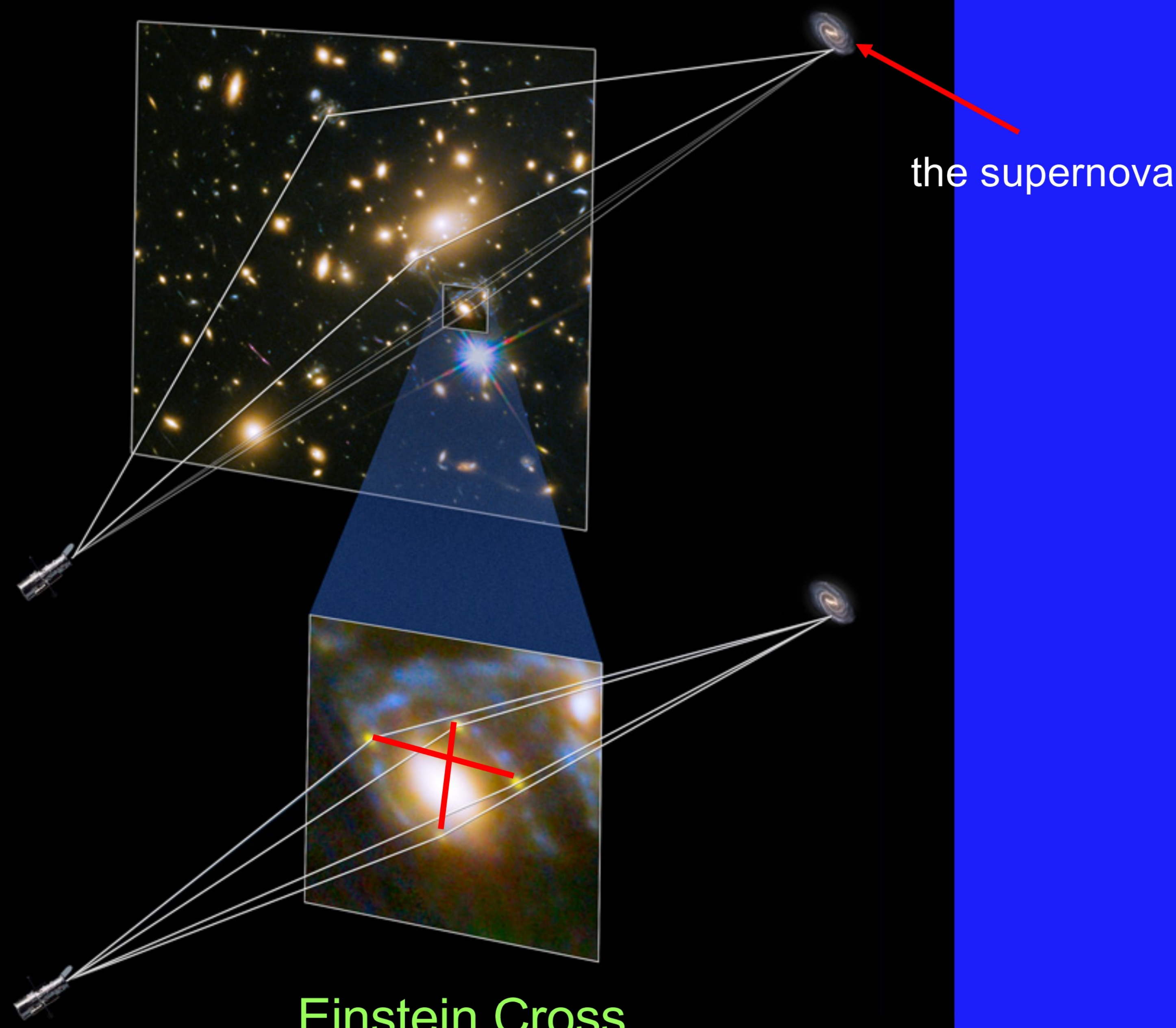

The galaxy contains seven star-forming (red) regions
See spectral lines from oxygen, neon and hydrogen in the arcs!
The far away galaxy

2014: a supernova explosion, lensed by a galaxy cluster, seen as four points of light, each arriving within a few days to weeks of each other -- taking different length routes through the cluster.
2015: A fifth image appeared, taking an even longer route.

Supernova 9.3 billion light-years away, galaxy cluster: 5 billion



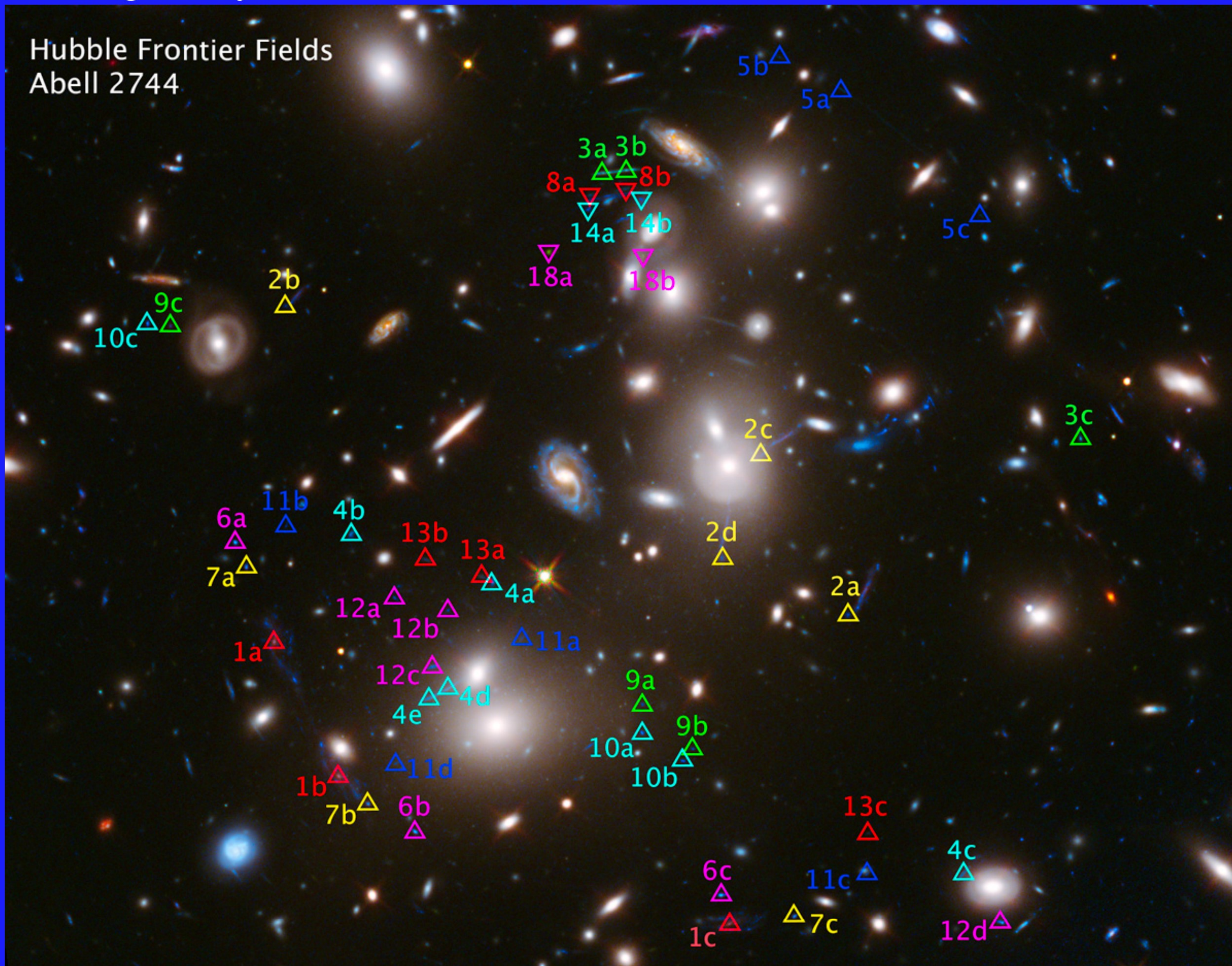
The different paths of the supernova light through the galaxy cluster produces an Einstein Cross



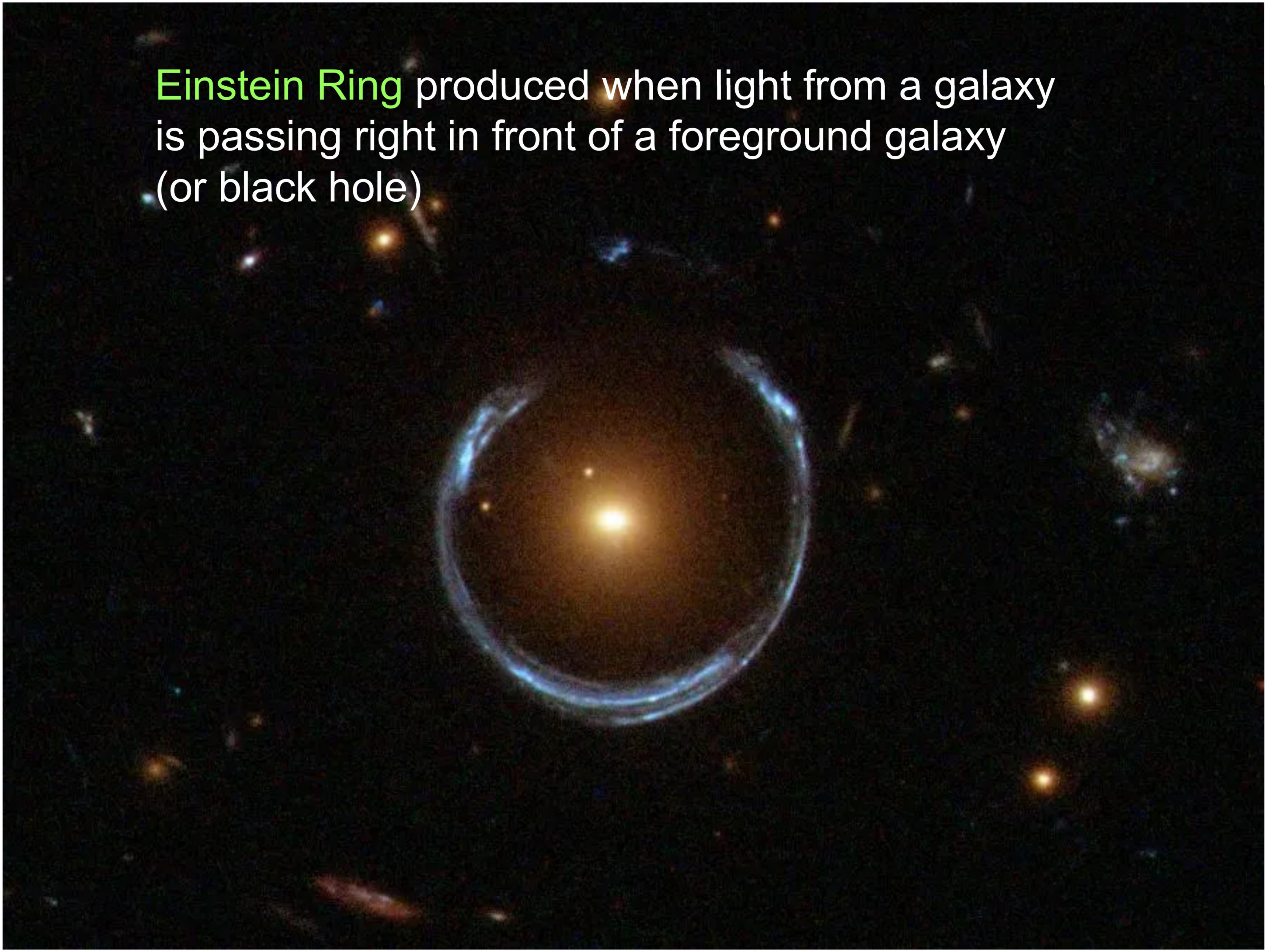
Einstein Cross

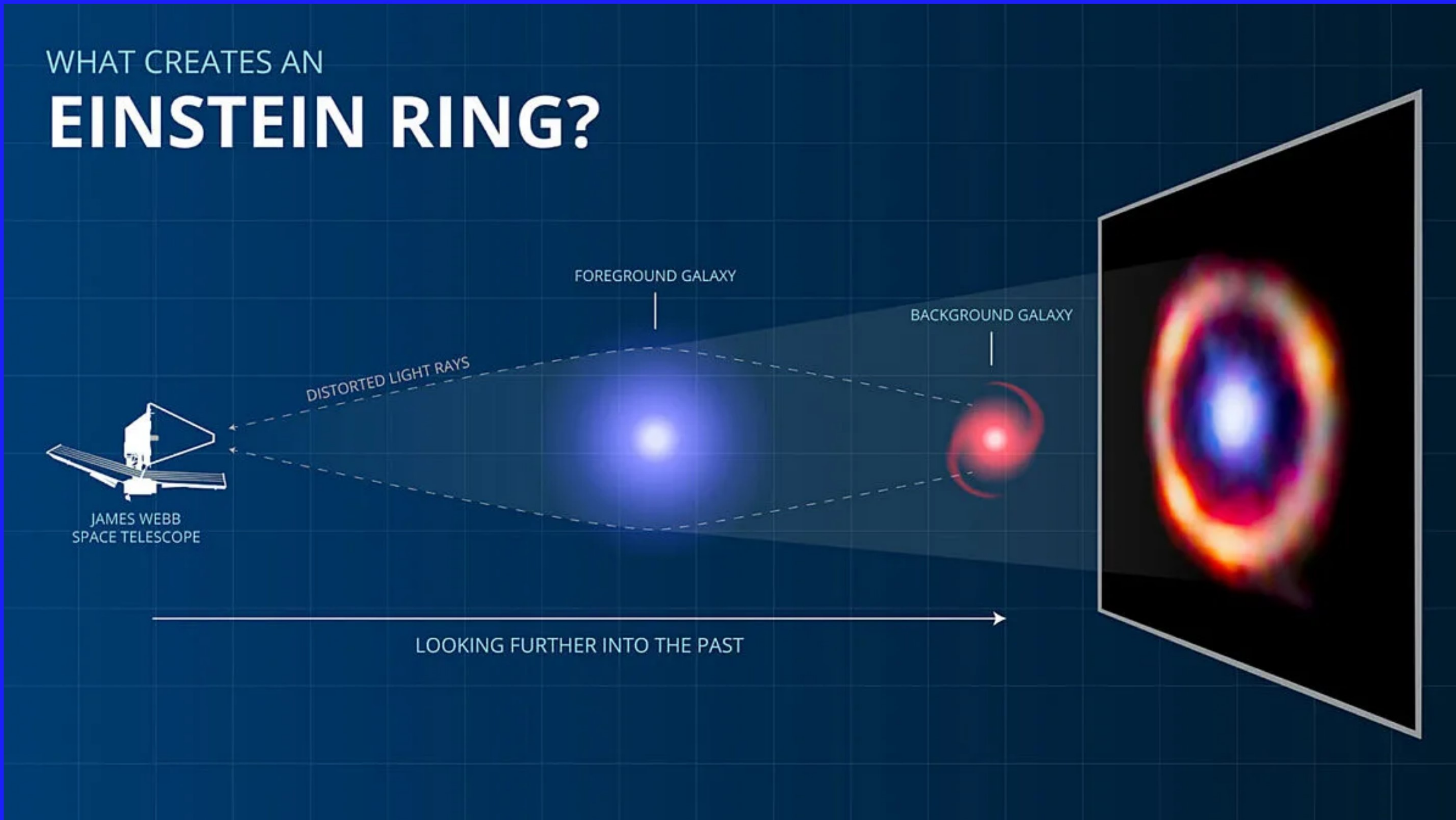
The galaxy cluster Abell 2744 (Pandora’s Cluster) 3.5 billion light-years away is a super-lenser

Multiple images, e.g., 2a, 2b, 2c, and 2d of galaxy 2, etc.
The galaxy itself is not seen.

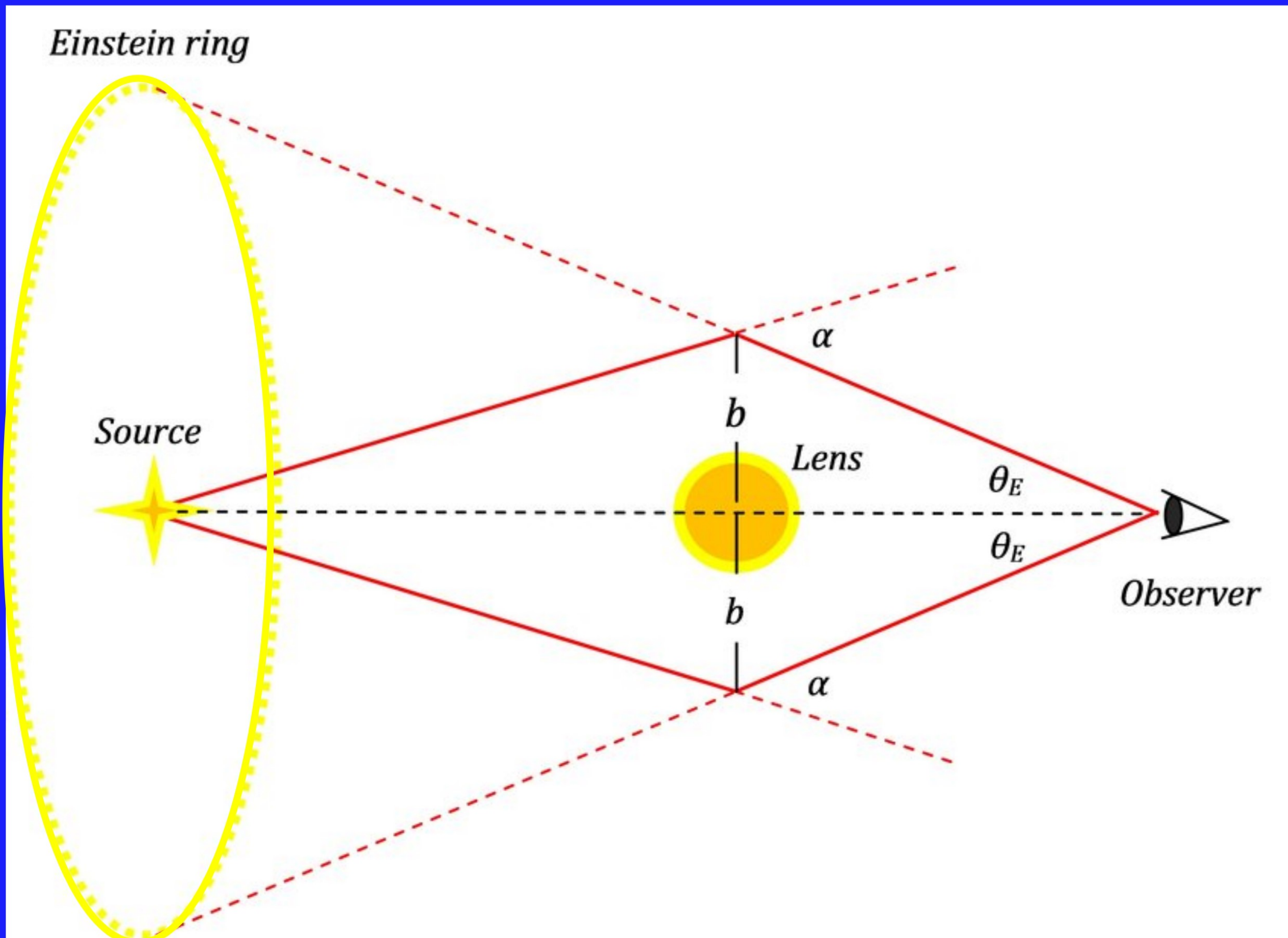


Einstein Ring produced when light from a galaxy is passing right in front of a foreground galaxy (or black hole)

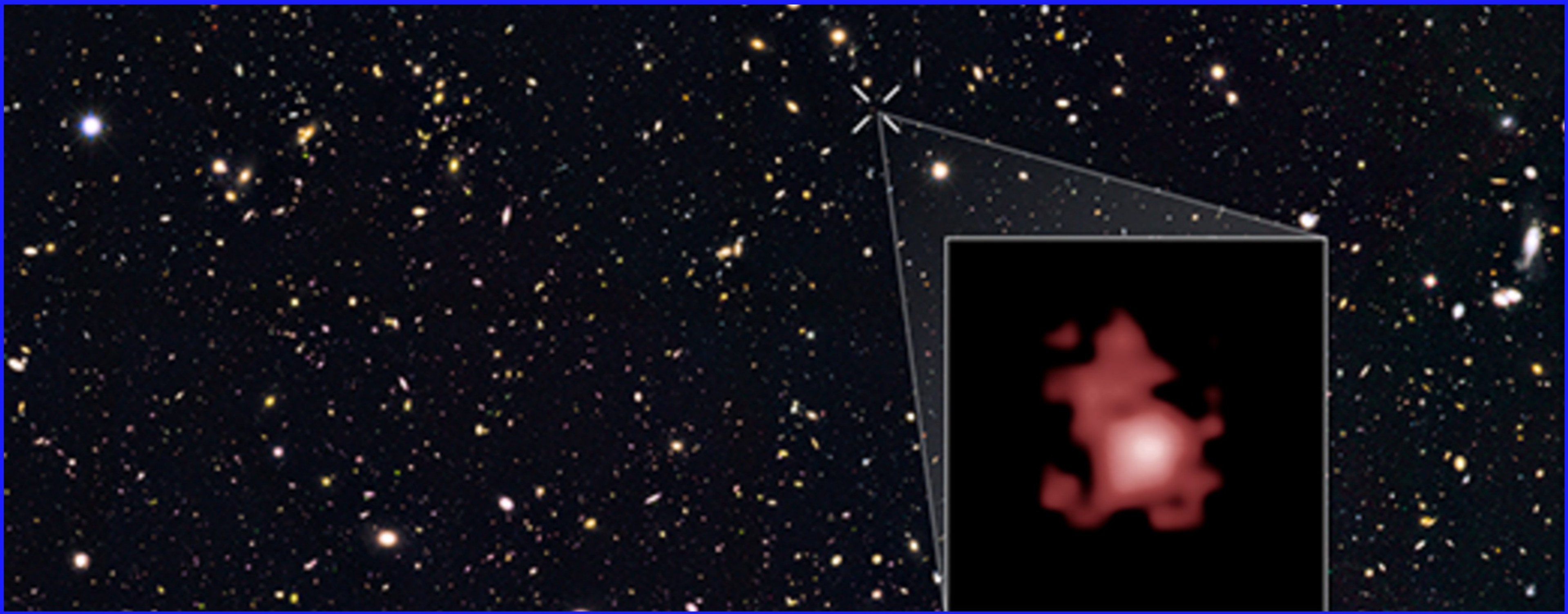




Einstein rings are produced when two galaxies are almost perfectly aligned, one behind the other. The light from the background galaxy is bent *around* the foreground galaxy and forms a ring, which you see.


Einstein ring
Source
b
Lens
b
α
α
θ_E
θ_E
Observer

One of the oldest galaxies ever discovered is GN-z11, dating back to about 400 million years after the Big Bang



The galaxy is surrounded by primordial hydrogen and helium gas. Could its stars be made from these two elements only?

If true: a sensation!

Population III stars have never been seen before.

Contain *only hydrogen and helium = primordial matter*

Population III = First Stars made from 75% hydrogen + 25% helium
Forming approx. 300 mill. years after the Big Bang.
Extremely massive, bright, and hot. Explode as supernovae and pollute space with new light elements which population II stars fed on.

Population II = older, not bright, stars containing some heavier elements. Found in the bulge and halo around galaxies. Some exploded, shedding carbon, oxygen, calcium, iron.

Population I = Middle aged stars like the Sun. Highest number of heavy elements (metallicity) of all star types. In spiral disks. Slow burning.

GN-z11 also contains the oldest black hole detected

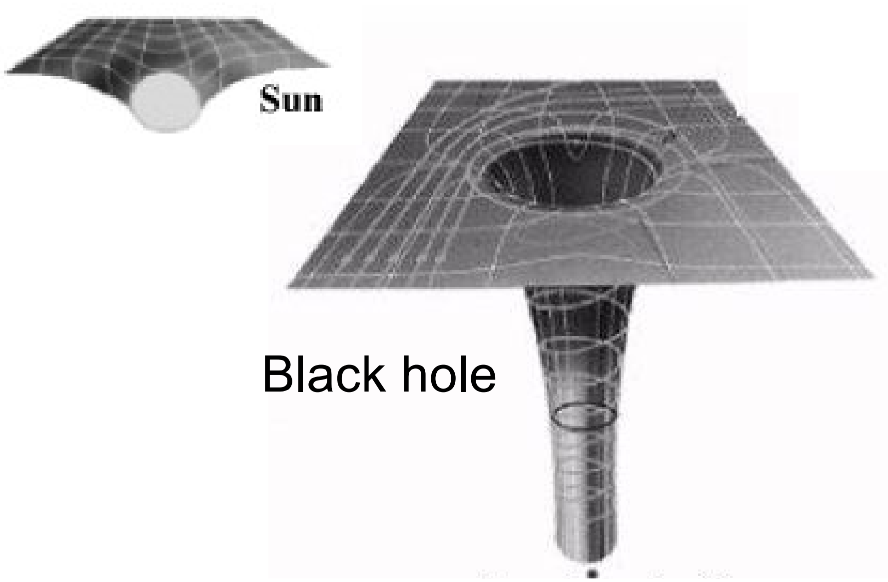
The very bright infant galaxy contains a 1.6 mill. solar mass black hole gobbling matter around it.

Open question: How can an enormous black hole have formed at the end of the Dark Ages, just 400 million years after the Big Bang, when stars and galaxies have just started to form?

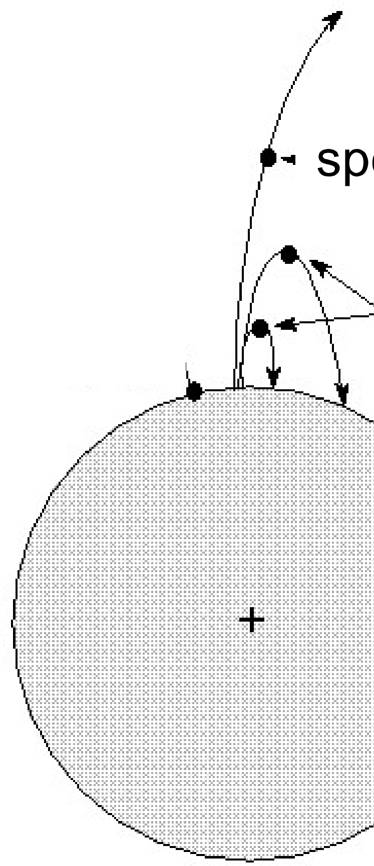
JWST is seeing supermassive black holes right after the Dark Ages

A black hole is a spherical region in space where gravity is so strong – space so bent - that nothing, not even light, can escape.

For a black hole there is no escape, even for light!

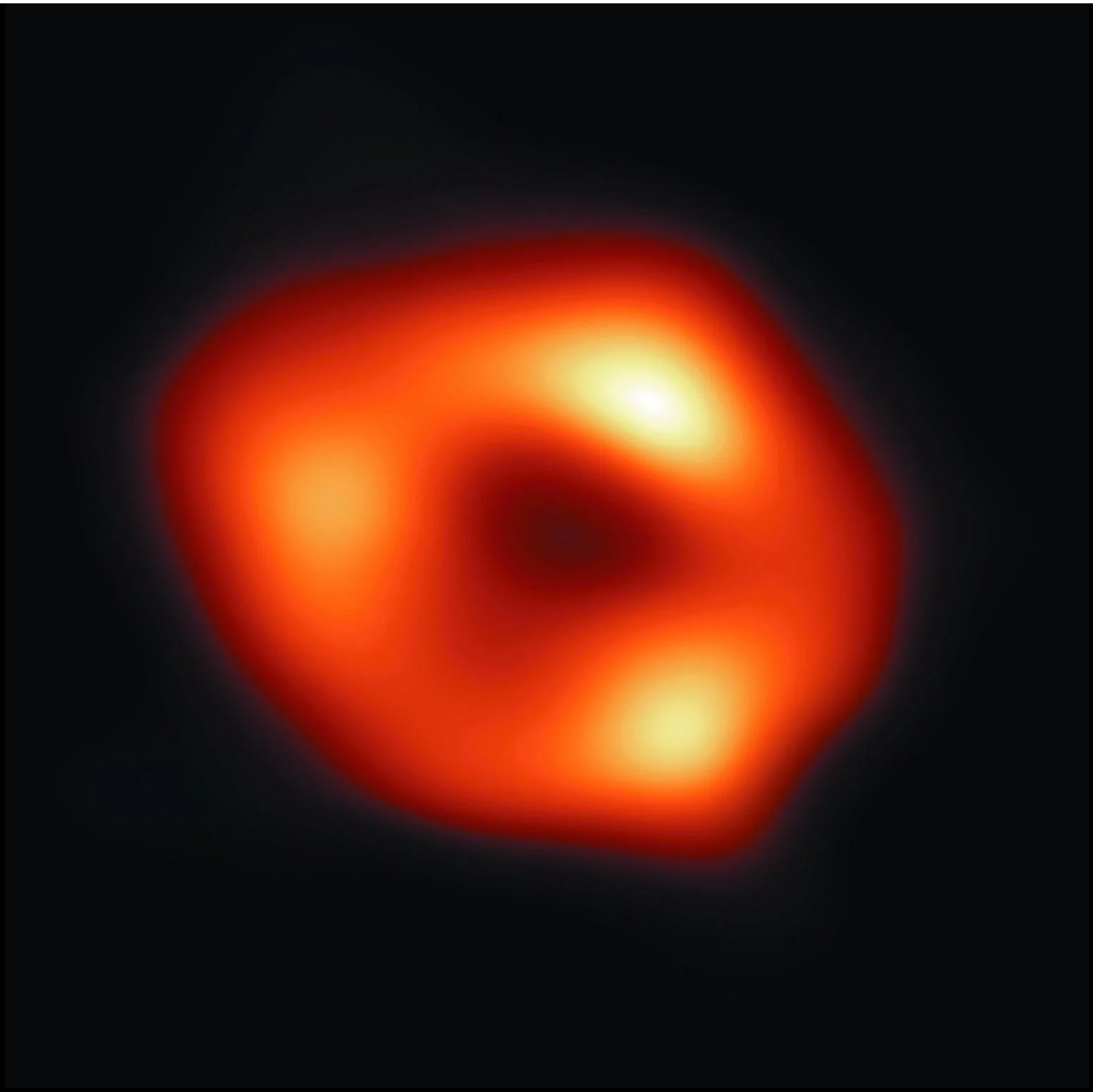


Escape velocity: speed needed to escape an object's gravitational pull



Earth: 10 mi/sec
Sun: 384 mi/sec

The sun is 864,000 miles across.
If squeezed down to 2 miles it would become a black hole.



Sagittarius A* is the black hole at the center of the Milky Way. Size: 4.3 million solar masses. We detect radio and infrared emission from gas and dust heated to millions of degrees while falling into the black hole.

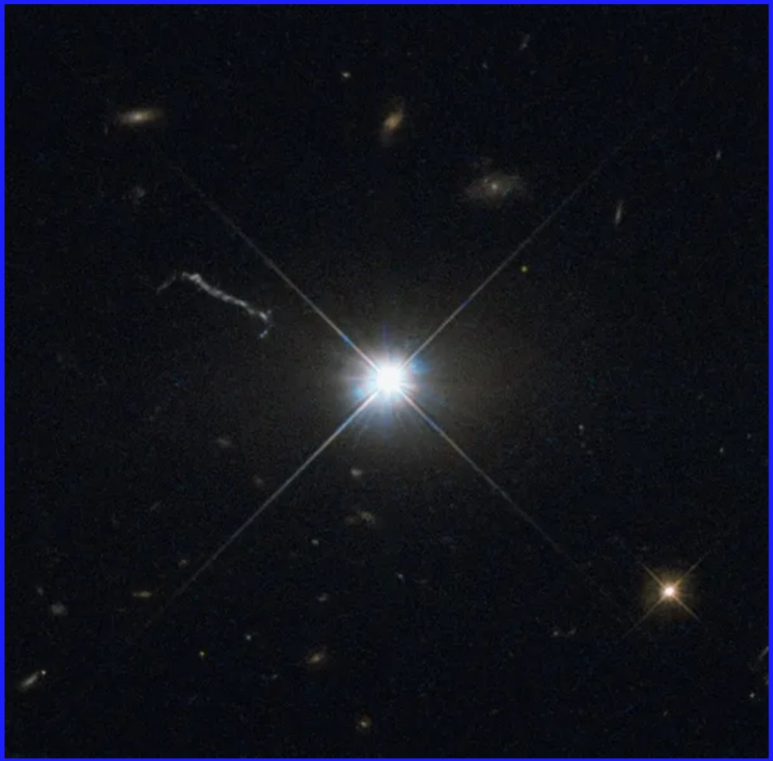
Quasars

* Quasars are the brightest objects in the Universe, supermassive black holes with masses million to billion times that of the Sun.

* More than 450.000 quasars have been detected in the early Universe. They light up their surroundings (ionize gas around them) acting as flashlights revealing the properties of cosmos down to 400 millions years after the Big Bang.

* Located at the center of galaxies

* Emit more light than the entire Milky Way from an area the size of the Solar System



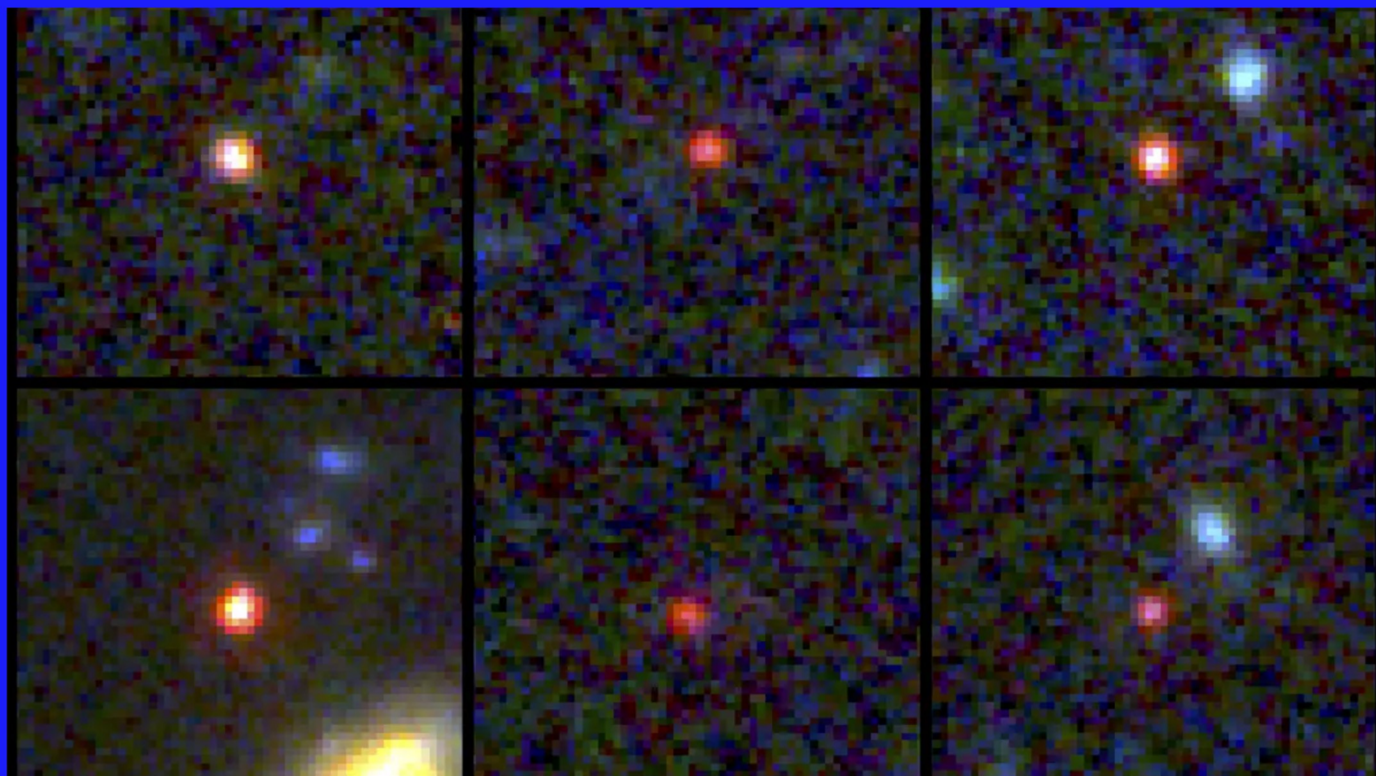
Quasars are so bright that they outshine the galaxies they are embedded in.

But, if the quasars are supermassive BLACK holes, how can they shine?

The light comes from an accretion disk, a rotating disk of matter around the black hole, which is sucking up stars and gas from its host galaxy. The matter is “screaming” at all wavelengths when it is being pulled into the black hole.

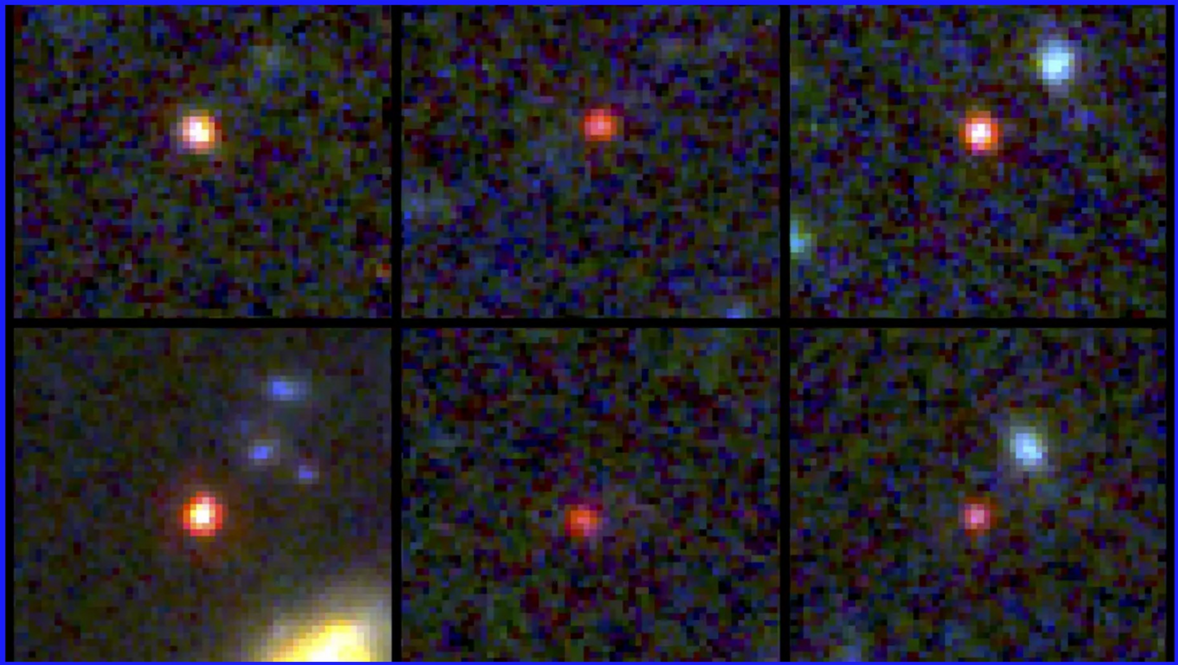
* Before JWST quasars were the most far-away objects known.

JWST is so sensitive that it has detected six galaxies (reddish images) located about 500-700 millions years after the Big Bang even though they don't contain quasars lighting them up



These six Milky Way sized galaxies may force astronomers to rewrite cosmology books

* how could these galaxies be so shockingly big and full of old, red stars when the Universe was so young?
* common wisdom: young galaxies are small, young stars are hot and bright blue



Possible explanations:

Nature favored big stars over small – tons of free gas to build galaxies from

Big stars die much faster than small, explode as supernovae

Galaxies frequently collided and merged, growing in size


How and where do stars form?

James Webb Space Telescope and Star Formation

Dr. Jane Rigby, Nasa Webb Senior Project Scientist

Infrared Light:

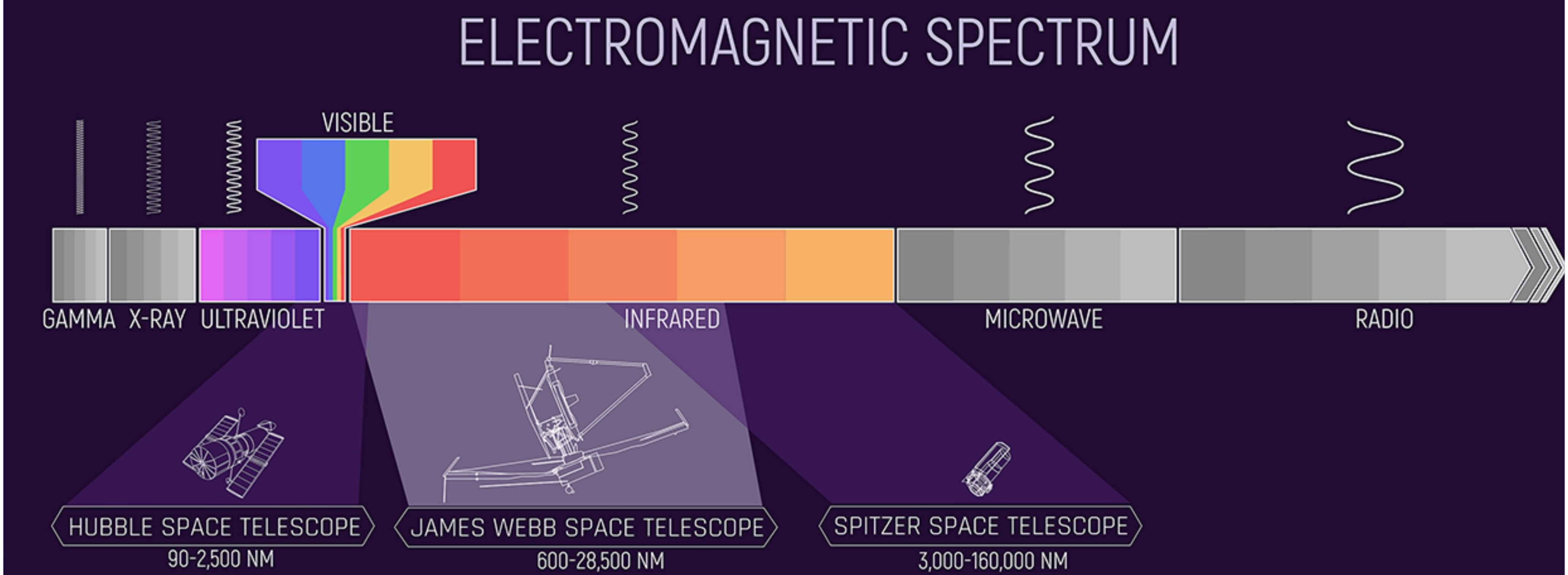
* Humans can feel infrared energy as heat, but not see it

* Infrared radiation is able to pass through areas of dense gas and dust revealing what they hide, e.g., star nurseries hidden behind the gas and dust

* Telescopes like JWST that have "eyes" in the infrared are perfect tools for detecting star forming regions in space

Reminder:

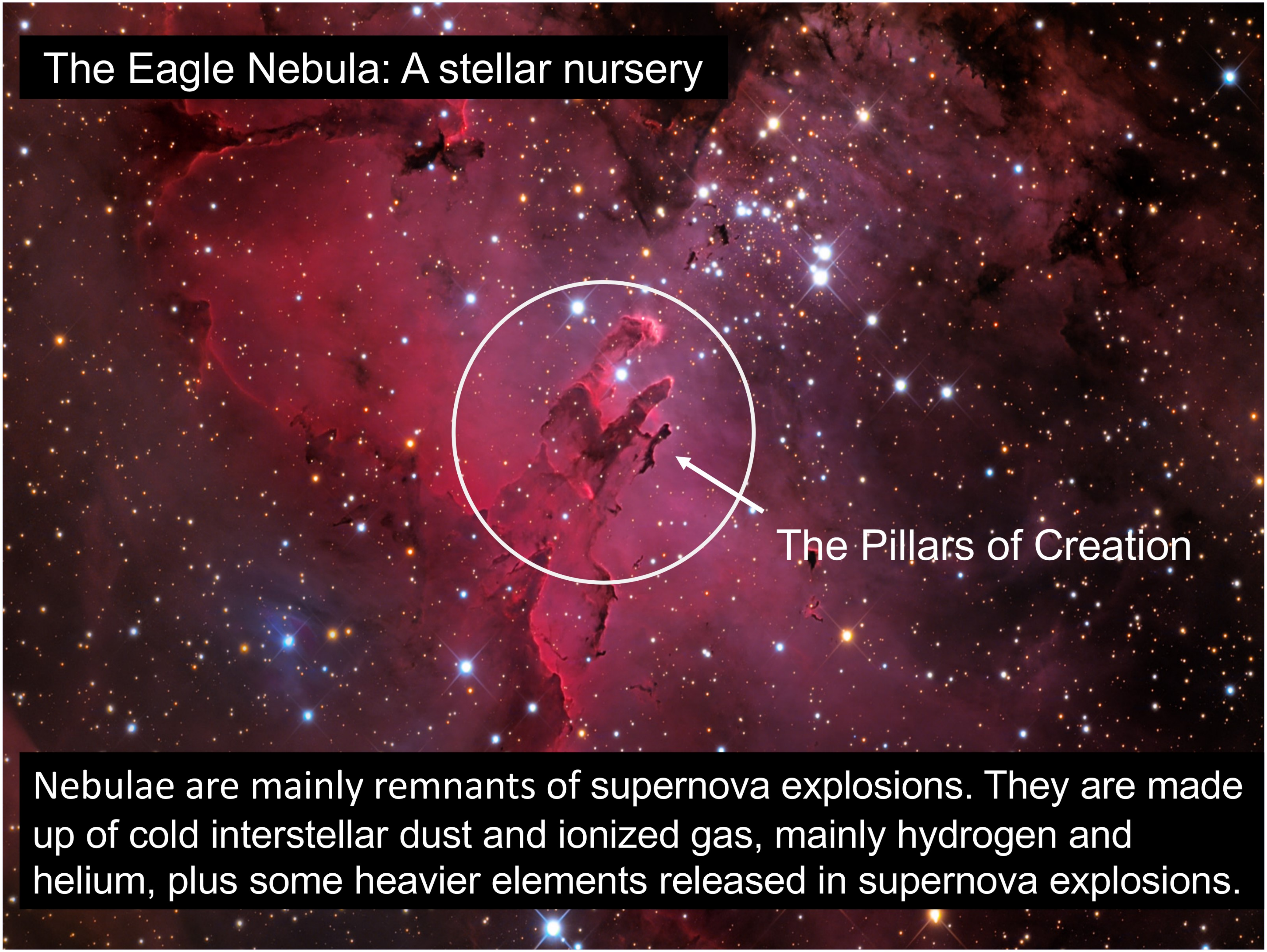
What can JWST see?



0.6 – 28.5 micrometer =
0.6 – 28.5 10^{-6} m

The Eagle Nebula: A stellar nursery

Nebulae are mainly remnants of supernova explosions. They are made up of cold interstellar dust and ionized gas, mainly hydrogen and helium, plus some heavier elements released in supernova explosions.


The Eagle Nebula: A stellar nursery
The Pillars of Creation
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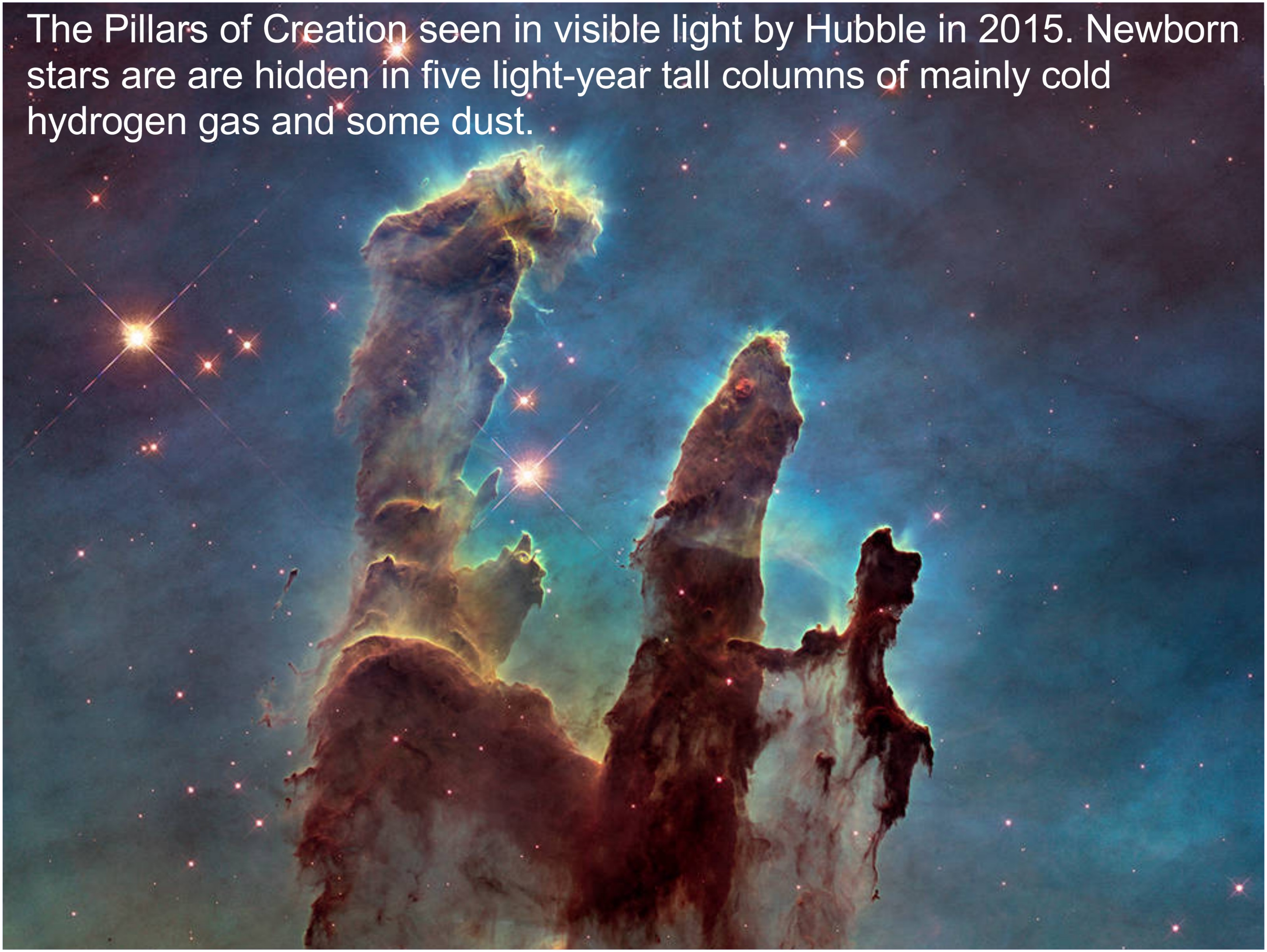


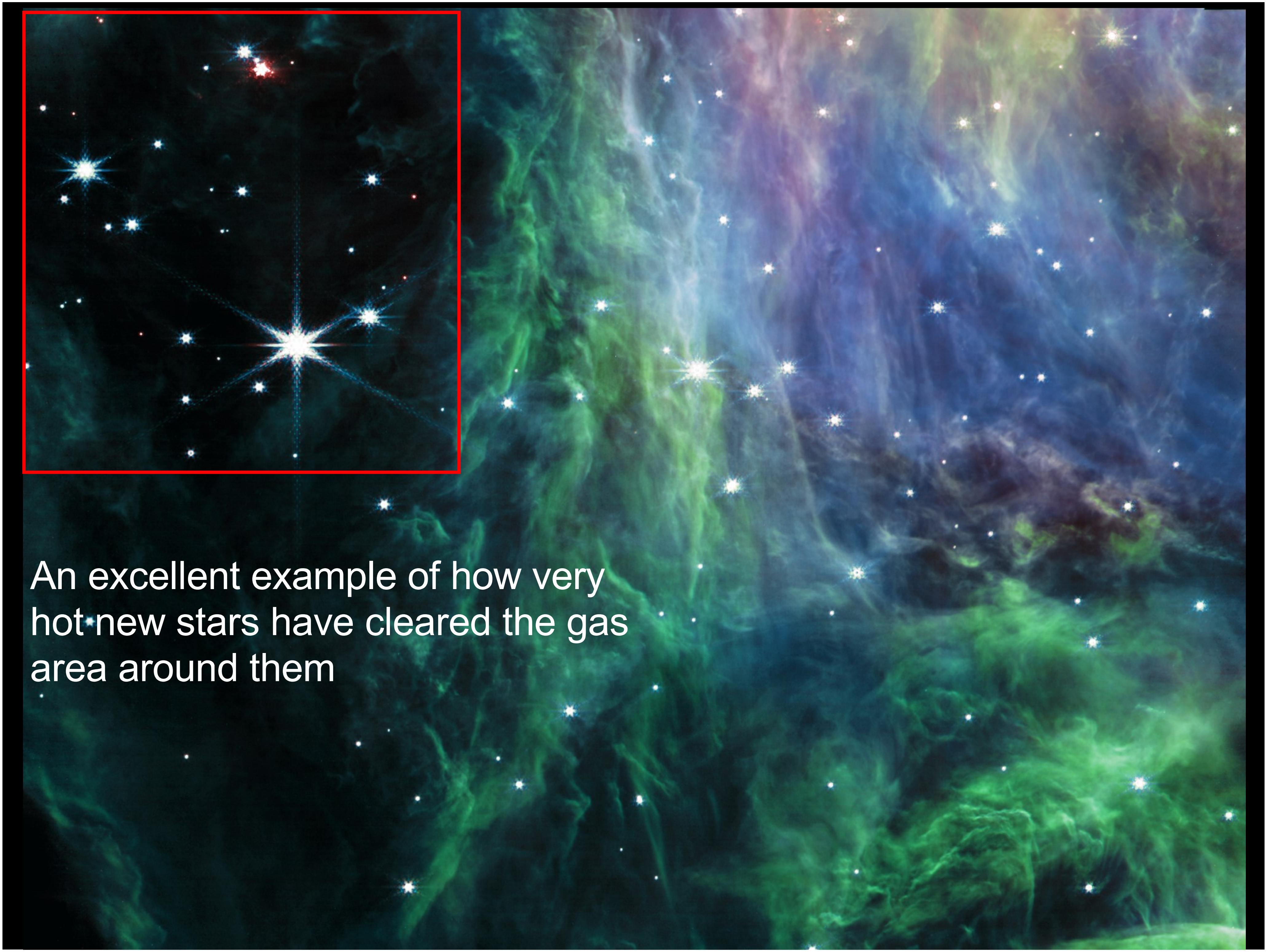
The Pillars of Creation seen in visible light by Hubble in 2015. Newborn stars are are hidden in five light-year tall columns of mainly cold hydrogen gas and some dust.

James Webb Space Telescope, 2022

The Pillars of Creation seen in infrared light. Areas circled in red are star forming regions, where very hot, newborn stars release ultraviolet light.

The light ionizes the surrounding clouds causing them to break up and disappear -- like a hair dryer on a wet bathroom mirror making water vapor disappear.


An excellent example of how very
hot new stars have cleared the gas
area around them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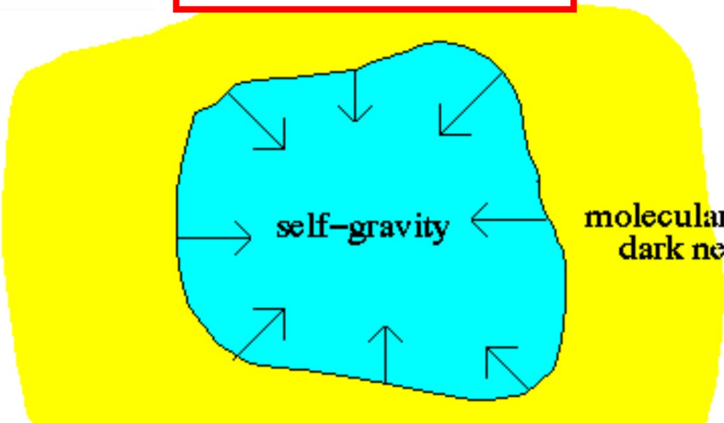
Comparison of Hubble and James Webb

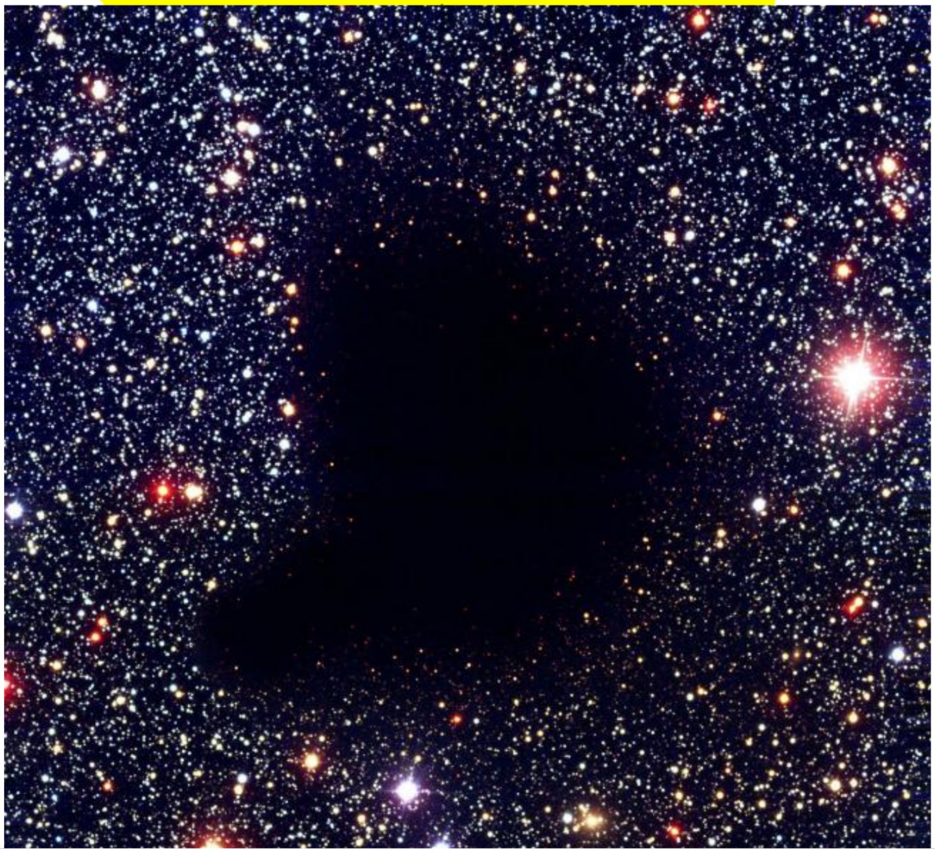
Hubble Space Telescope, 2015

James Webb Space Telescope, 2022

Star forming region and background much clearer in the JWST image

Star formation

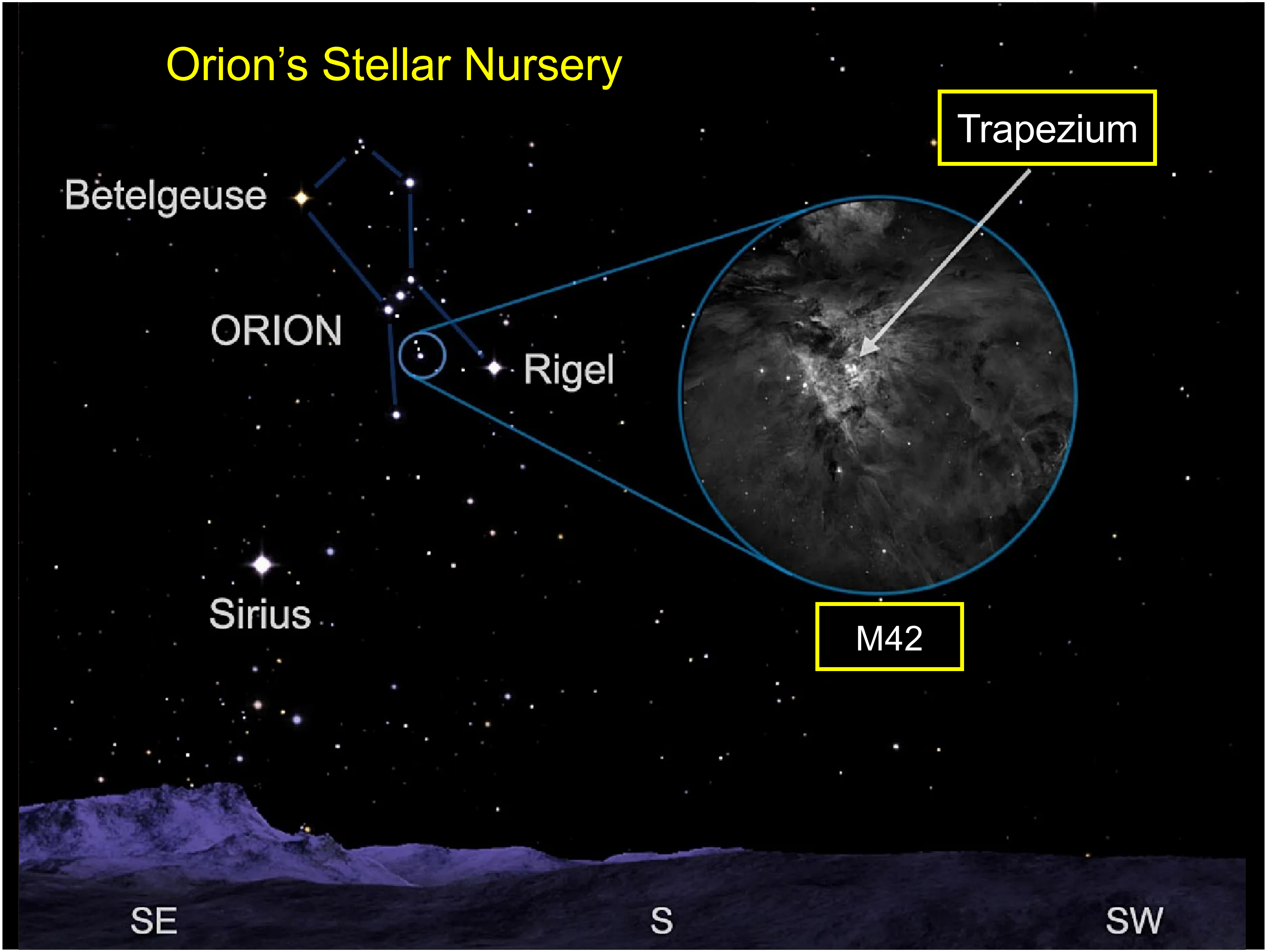




Star forming regions generally contain molecules. H_2 (molecular hydrogen 90%) and CO (carbon monoxide 10%) are the most common molecules in interstellar gas clouds. The gas clumps together due to low temperatures, 10^0 to 20^0 above absolute zero (K) Star formation begins when the cores of the clumps collapse under their own weight/gravity, typically 10,000 solar masses.

As the cores collapse and frag-ment into clumps of 10 to 50 solar masses.

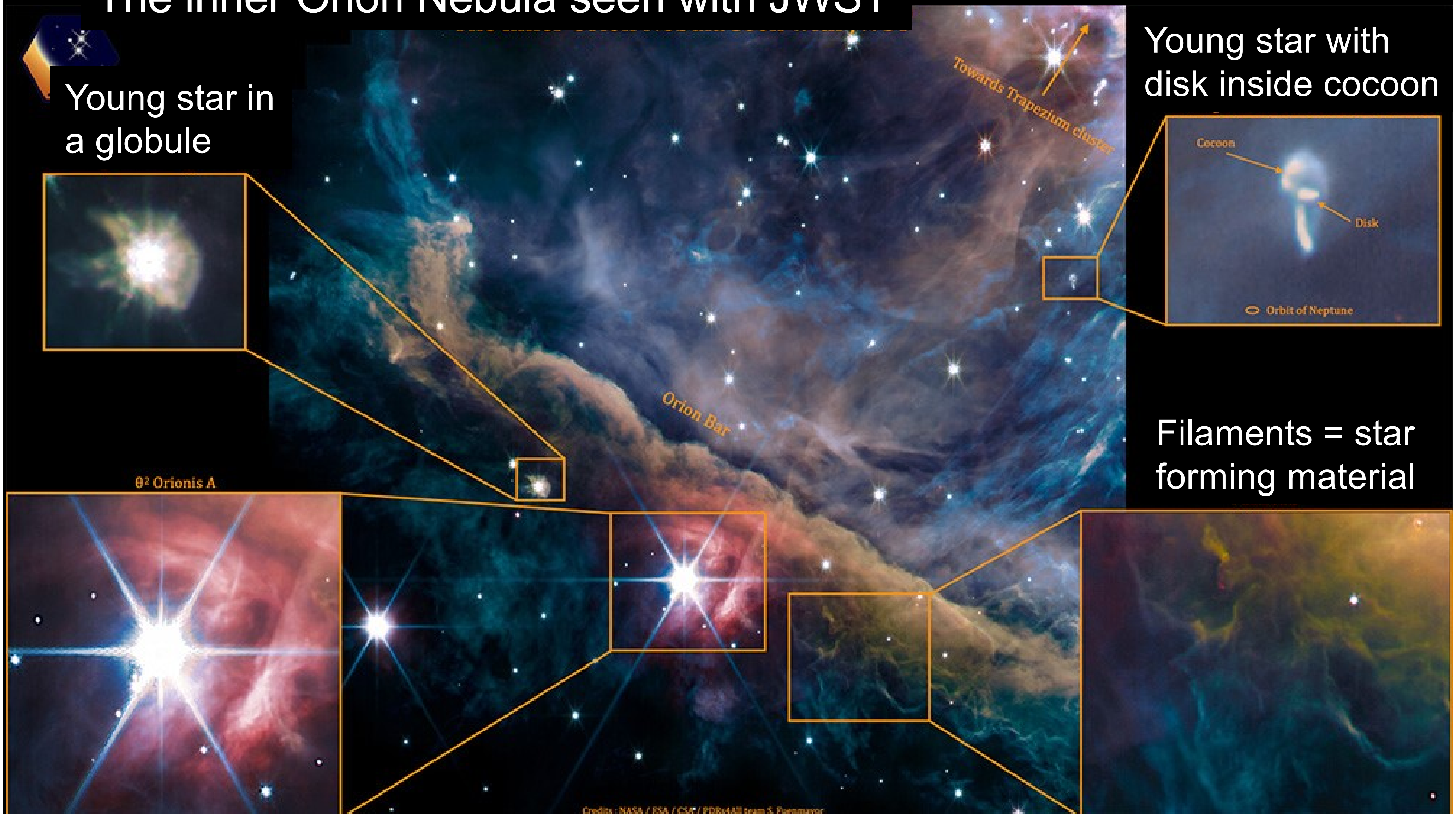
These clumps become proto-stars The whole process takes about 10 million years.


Orion's Stellar Nursery
Trapezium
Betelgeuse
ORION
Rigel
Sirius
M42
SE
S
SW


M42 distance = 1400 light years
Trapezium, the sword in the Orion Constellation, discovered by Galilei Galileo in 1617, is an area filled with thousands of newly born stars less than 300,000 years old.

180 protoplanetary nebulae = “baby-stars” found in the Orion Nebula emitting infrared radiation

The inner Orion Nebula seen with JWST



The one star you see, *Theta2 Orionis A,* is part of a triple star system that has dug a hole in the gas and dust around it. The image is of the star spans roughly the size of the Solar System.

The New York Times

https://www.nytimes.com/2024/01/05/science/space/astronomy-galaxies-bananas.html

OUT THERE

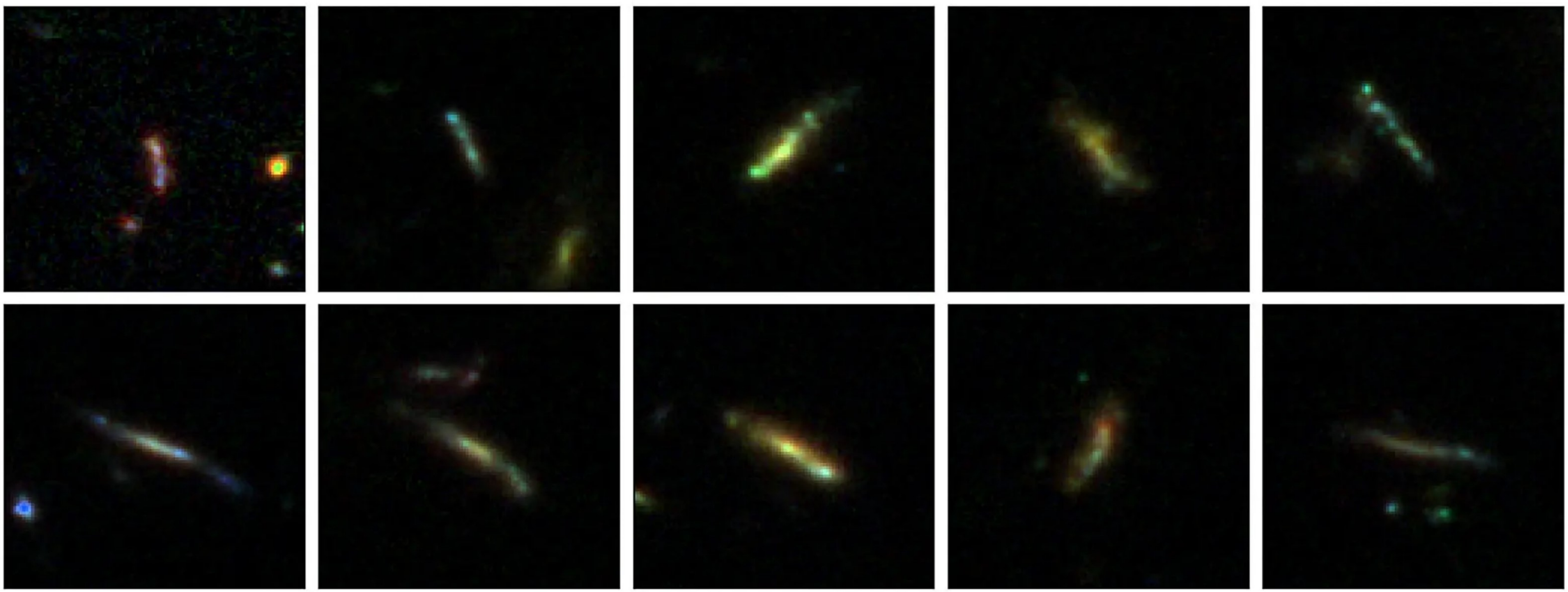
The Early Universe Was Bananas

Images from the Webb telescope suggest that newborn galaxies look weirder than expected. Exactly how screwy was physics at the dawn of time?

By Dennis Overbye

Published Jan. 5, 2024 Updated J

Baby galaxies were neither eggs nor discs. They were bananas. Or pickles, or cigars, or surfboards, according to a study of 4000 galaxies from the early Universe. Just like baby stars.

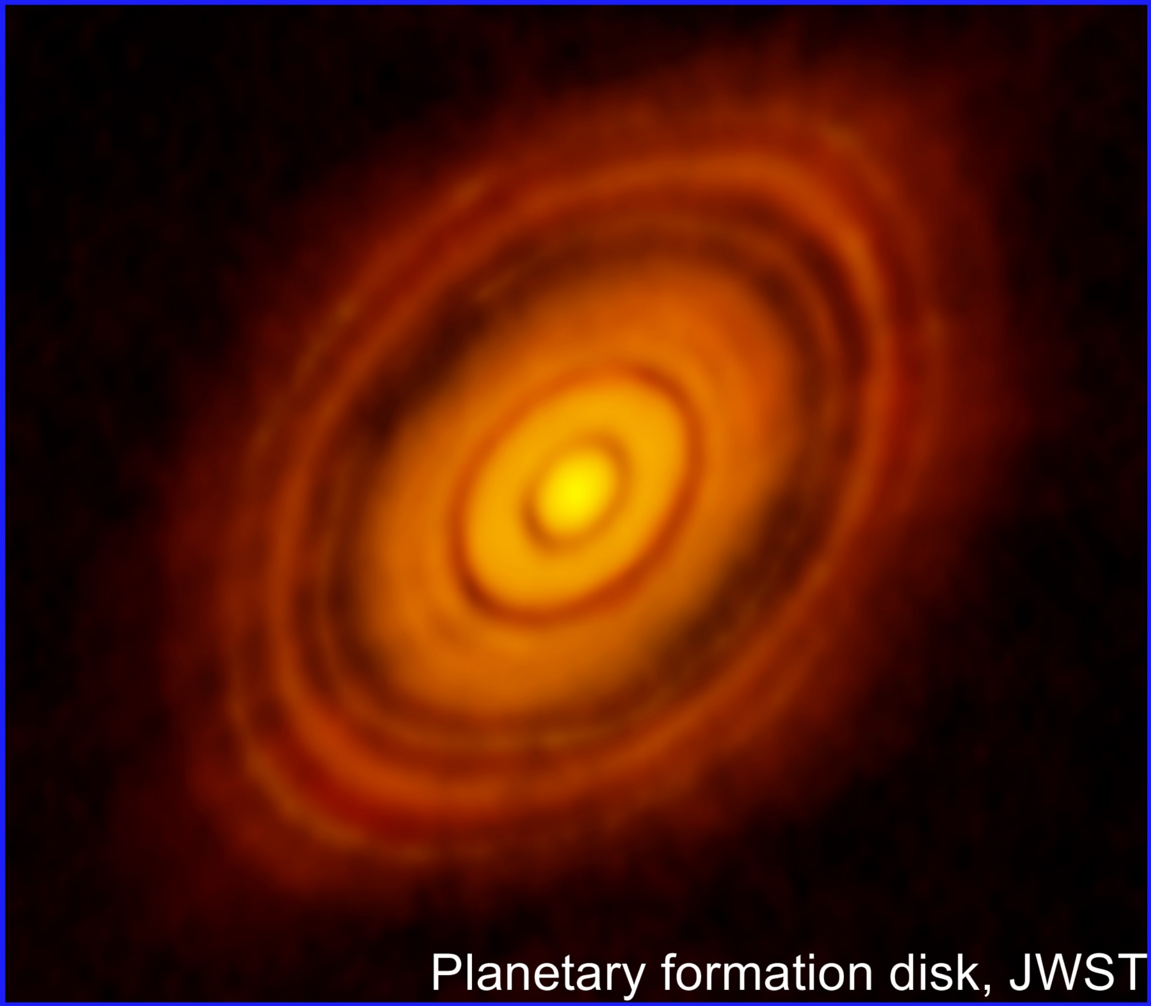


Also in the Trapezium: the mysterious JuMBOs

JuMBOs = Jupiter Mass Binary Objects = new gaseous planets,
0.6 – 13 x size of Jupiter, very wide orbits (20,000-80,000 years),
temperature 1000 – 2300 F, about 1 million years old.

How were they formed? Where did they originate?
There is no explanation.

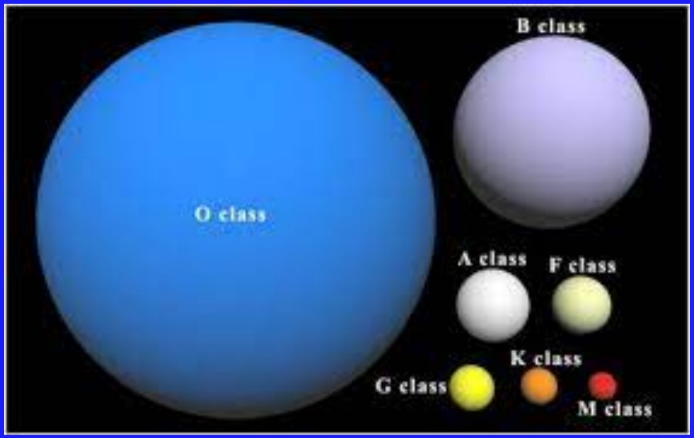
Formation of star with disk that might becomes planets



Some planets might be ejected, but how can they be ejected in pairs and stay gravitationally bound to each other afterwards? Furthermore, orbits in JuMBOs are very large, 20,000 – 80,000 years.

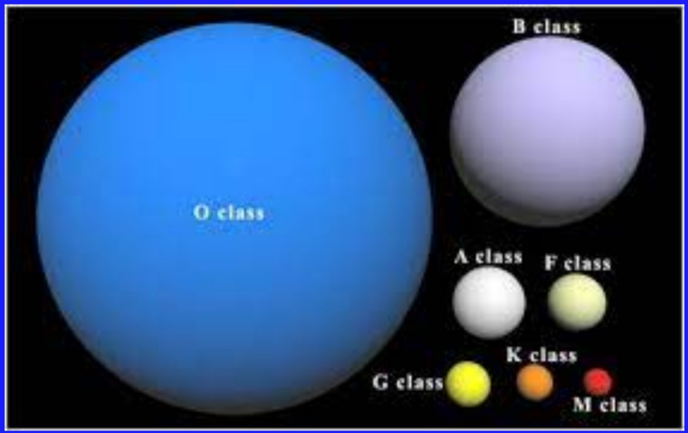
Could they form as a mini star pair? Probably not, masses too low.

Very big stars like O and B class stars: nearly all have companions



Example: *Theta2 Orionis A* is an O class star with a B class companion

Medium sized stars like our Sun: more than half have companions



Example: Alpha Centauri A and B and Proxima Centauri. The Sun has has no companion star, just planets.

But small stars seem rarely to have companions

Low mass stars like brown dwarfs (less than tenth of the Sun): max 15% have companions

Also called failed stars, too small to ignite fusion (converting hydrogen to helium). Have to be above 0.10 solar masses to ignite nuclear burning. They can be single, have planets, or have a companion star.

Jupiter sized planets haven't been seen before with companions

The JuMBOs are the first such pairs.
JWST has found 40 bound pairs and two triplet systems in the Trapezium.
They don't belong to a star system.
Masses = .6 – 13 times Jupiter.
Orbits = 20,000 – 80,000 years!

The End