Latest News from the
Early Universe and the Solar System

Lecture 1:
The James Webb Space Telescope

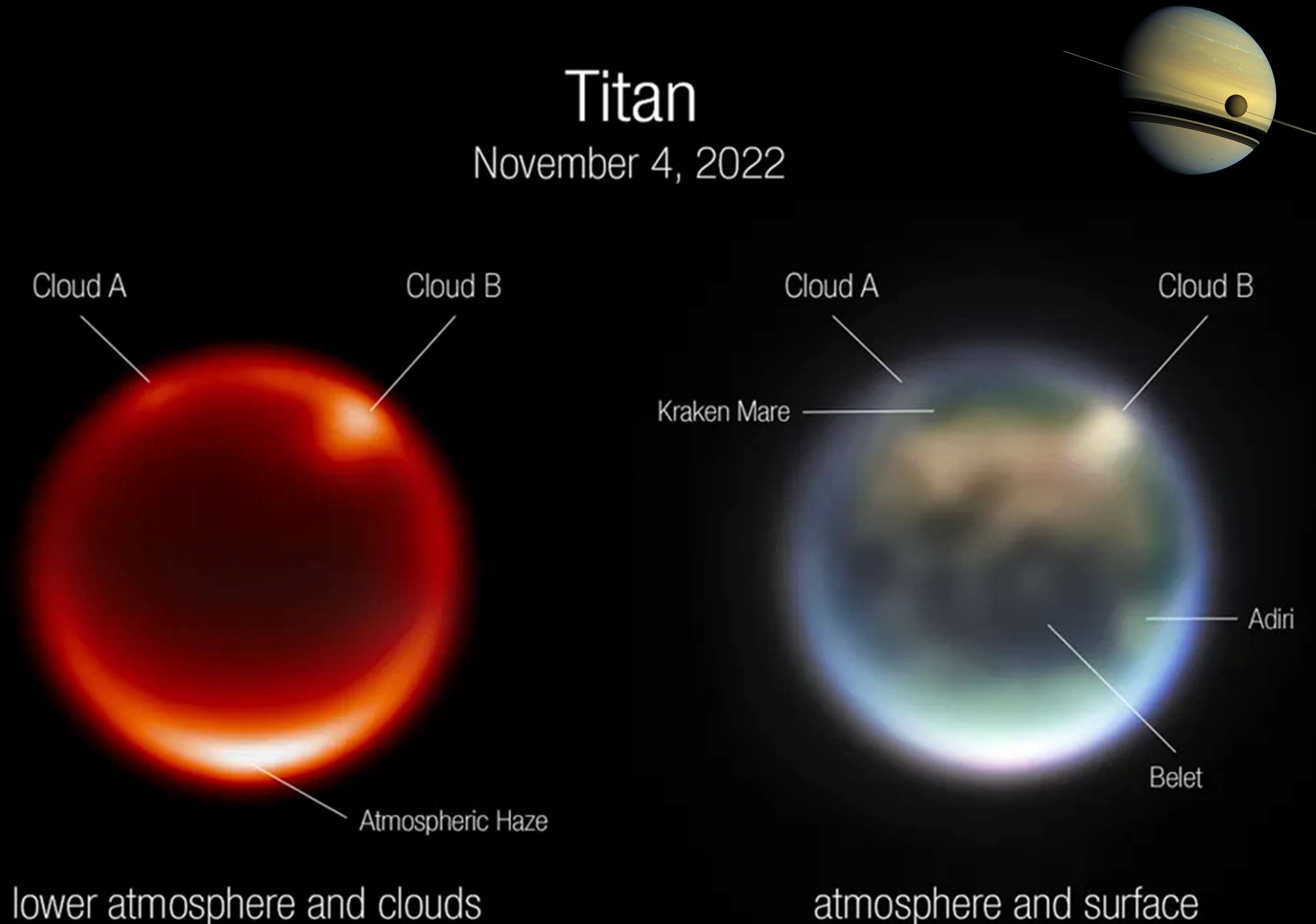
OLLI Spring 2024

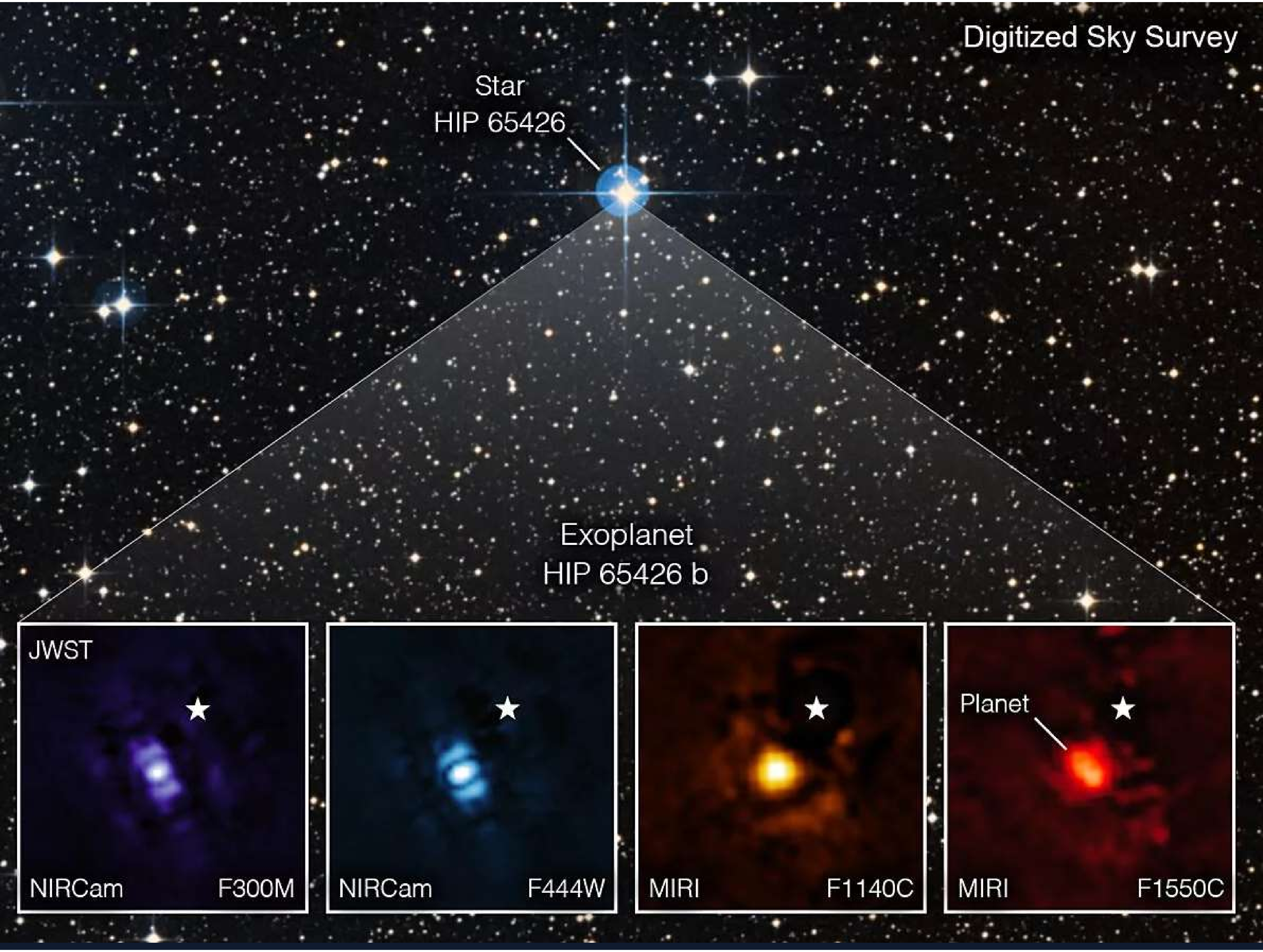
Cathrine Blom

The Pillars of Creation, part of the Eagle Nebula (M16)

Tarantula Nebula with lots of new stars in The Large Megellanic Cloud, 161,000 light-years away.

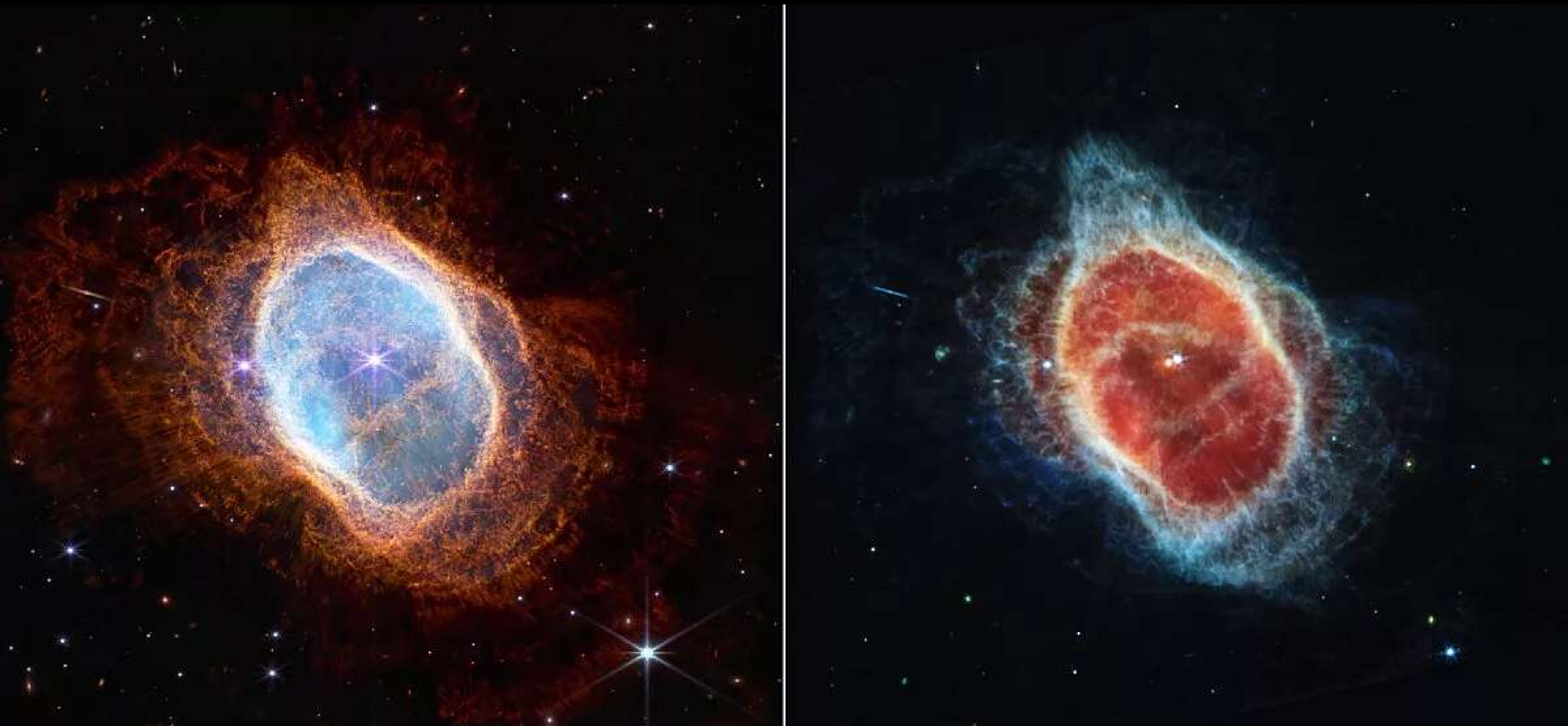
Saturn’s biggest moon Titan with its methane clouds and hydrocarbon seas




Digitized Sky Survey
Star
HIP 65426
Exoplanet
HIP 65426 b
JWST
NIRCam
F300M
NIRCam
F444W
MIRI
F1140C
Planet
MIRI
F1550C

M74 The Phantom Galaxy, a perfect spiral with a star cluster at the center

The Southern Ring Nebula



in near-infrared light and mid-infrared light

Stephan's Quintet – four entangled galaxies, plus one

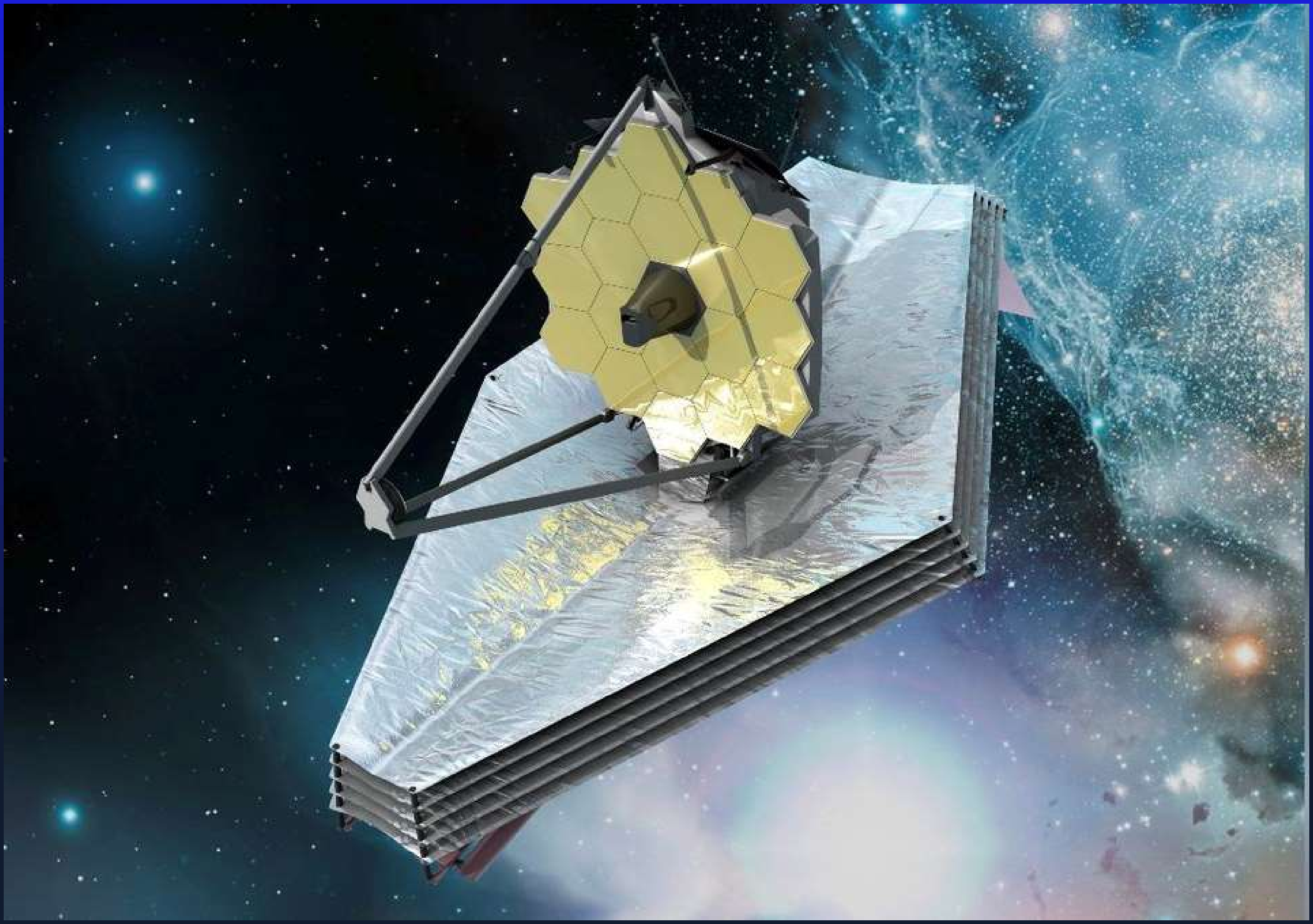
M51 The Whirlpool galaxy

Our old super eyes: Hubble Space Telescope

Orbits the Earth
Period: 95 min.
Low earth orbit: altitude 340 miles
Speed: 17,000 mi/h
Size of a tractor-trailer

Launched in 1990
Has revised much of what we know about space

Our new super eyes: James Webb Space Telescope

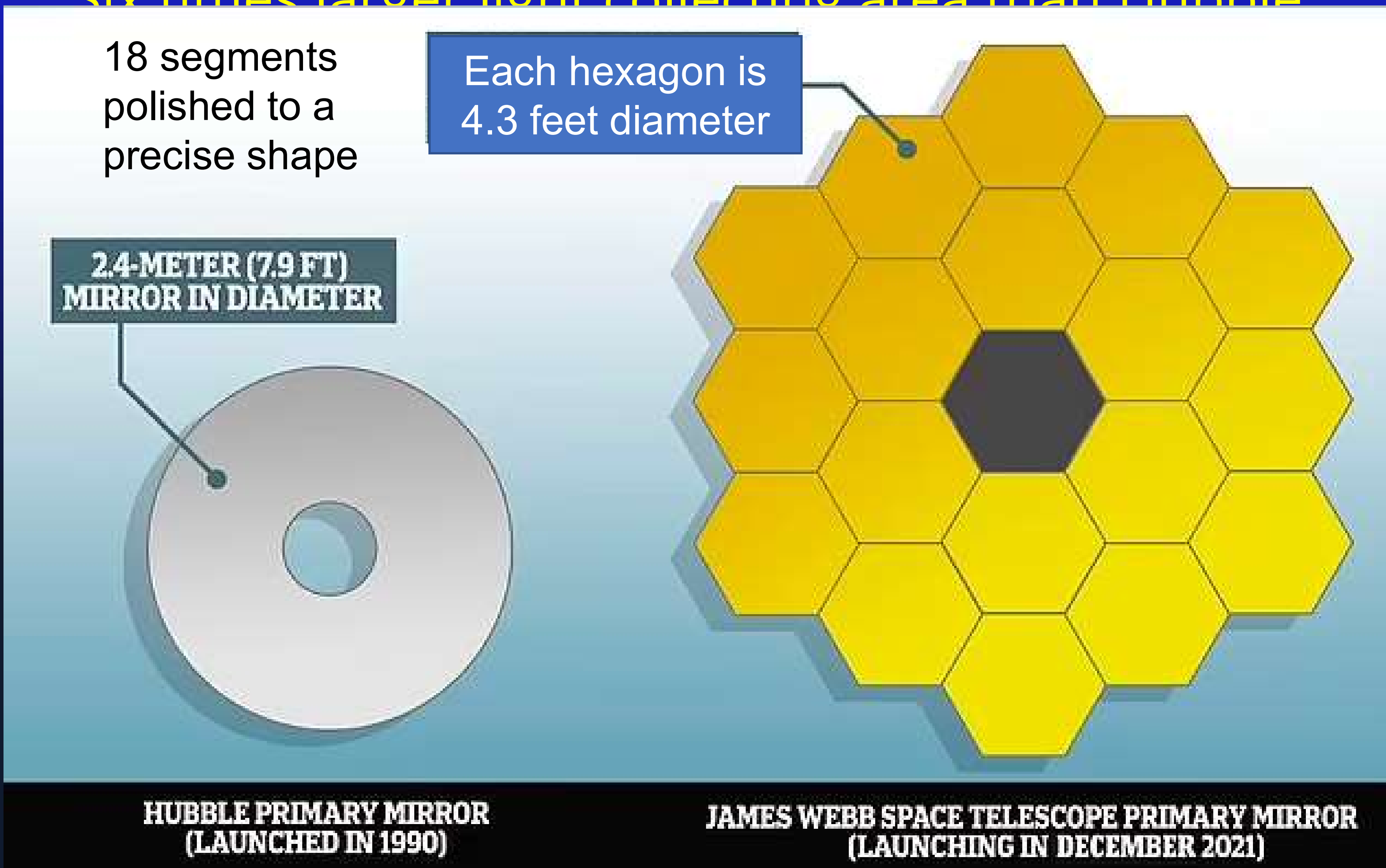


Launched from French Guiana on December 25, 2021

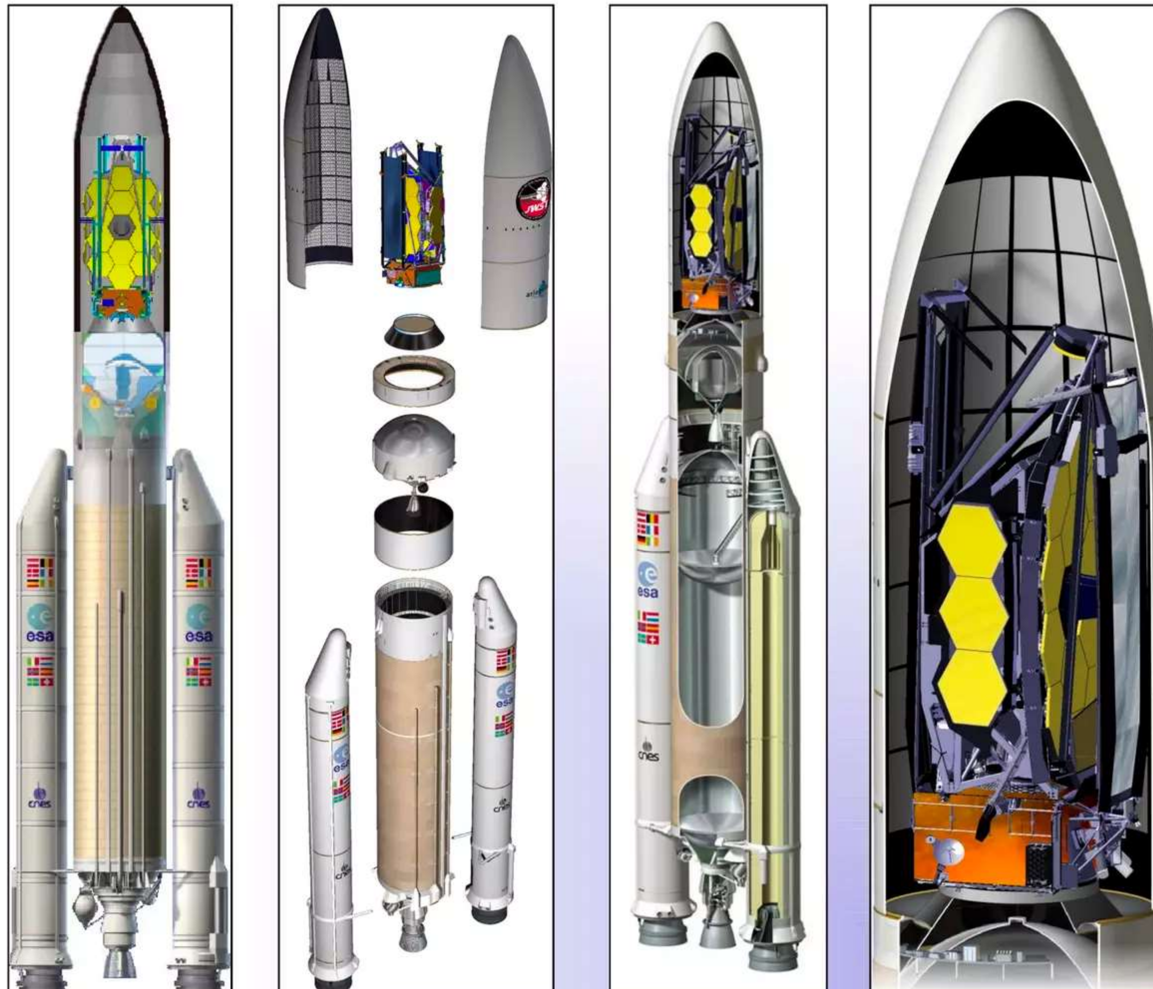
Orbits the Sun with Earth. Distance from Earth: 150,000 mill. km (93,000 mill. mi)

James Webb Space Telescope is the size of a tennis court
-- the largest telescope ever launched into space.

Six times larger light collecting area than Hubble

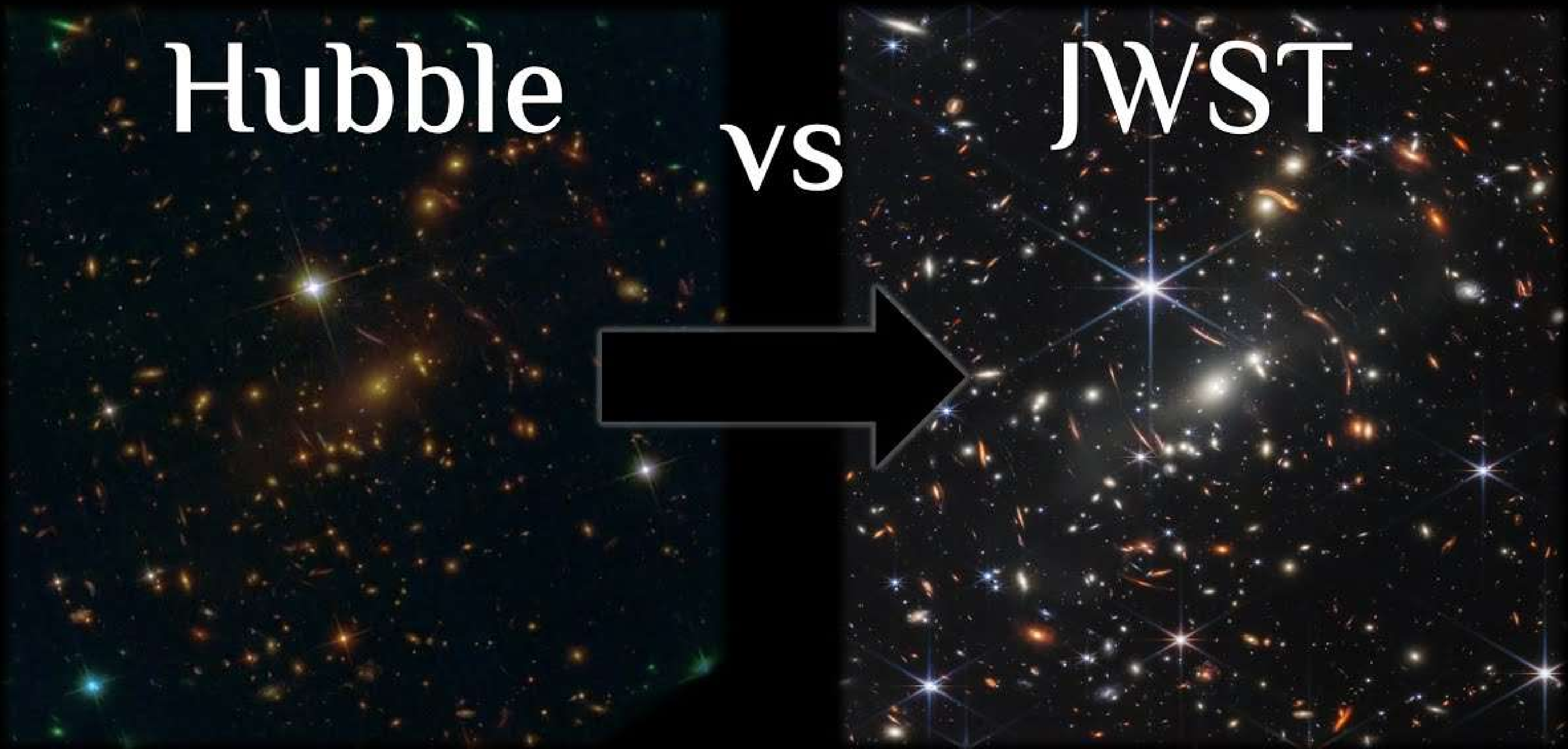


The James Webb Space Telescope is so big that it had to be assembled in space. Commissioned in 1999. Estimated launch in 2007, budget US$ 1 billion. Launched in December 2022, total cost US$ 10 billion.



Arianespace – ESA - NASA

Webb's primary mission is to investigate the origins of the Universe. How do we do that? By looking back in time. Deep Field view by

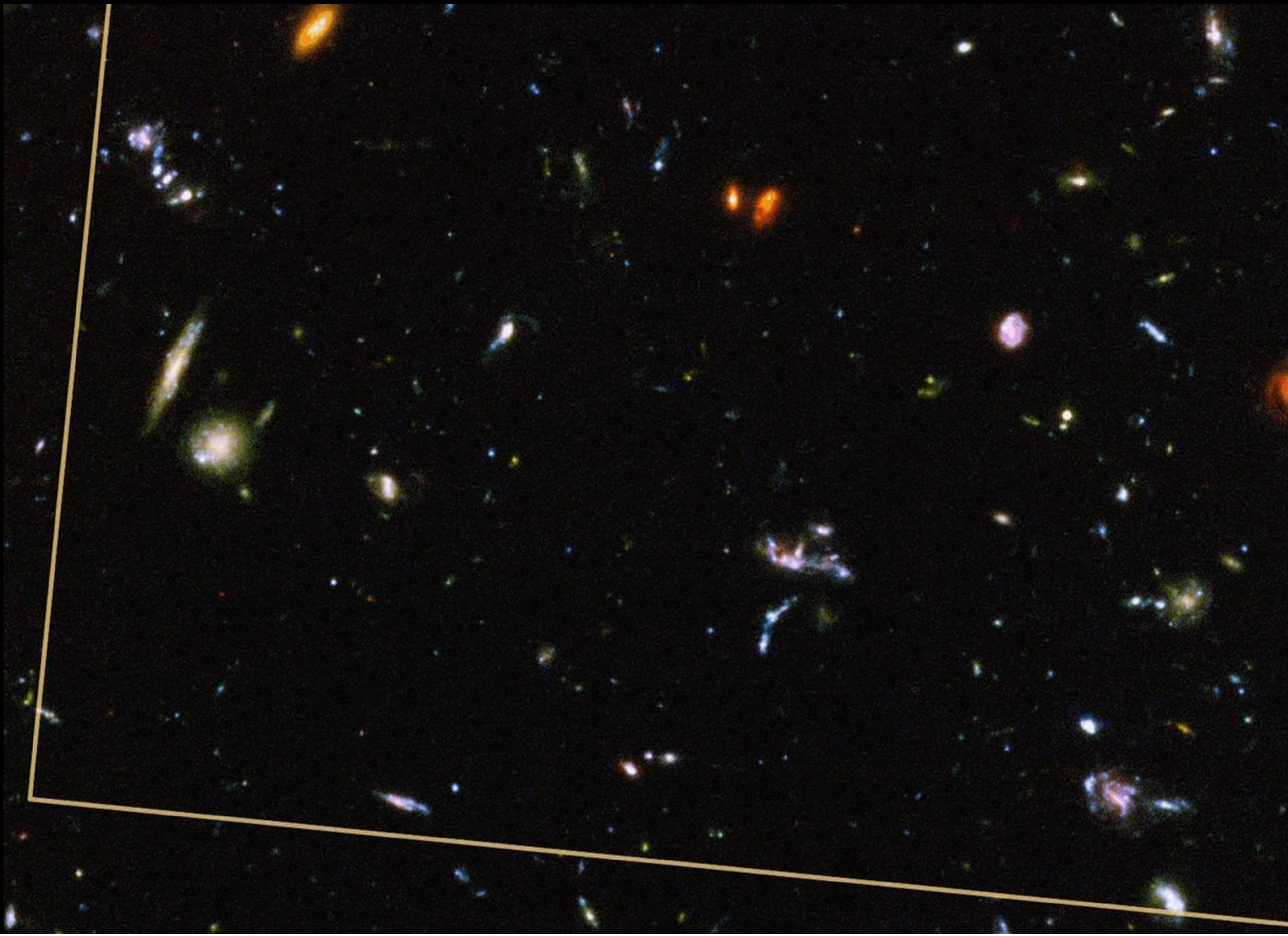


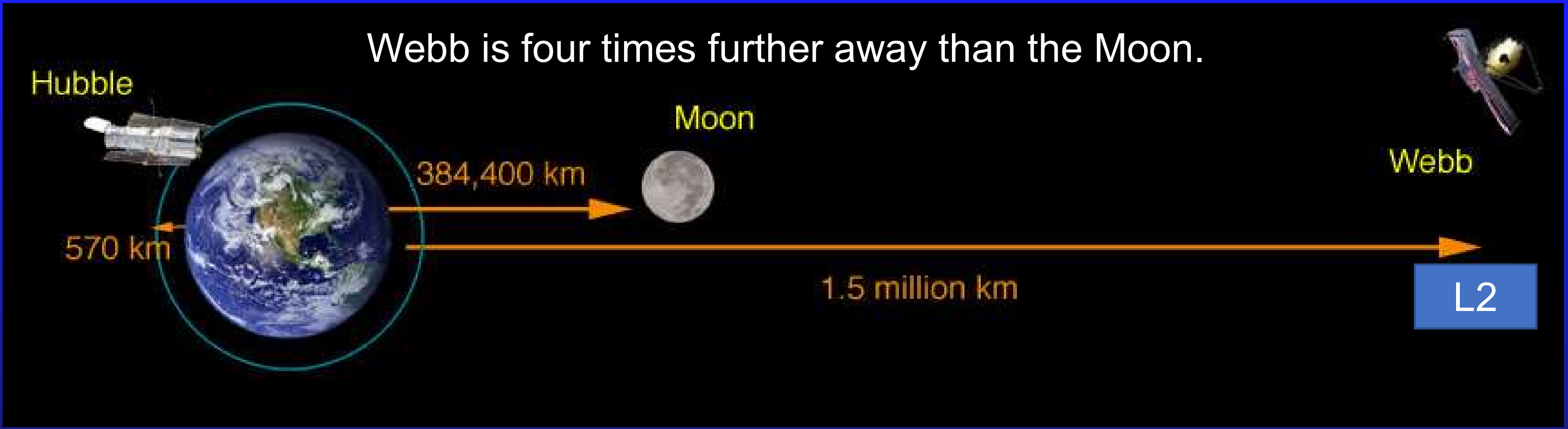
Hubble exposure time: 11.3 days

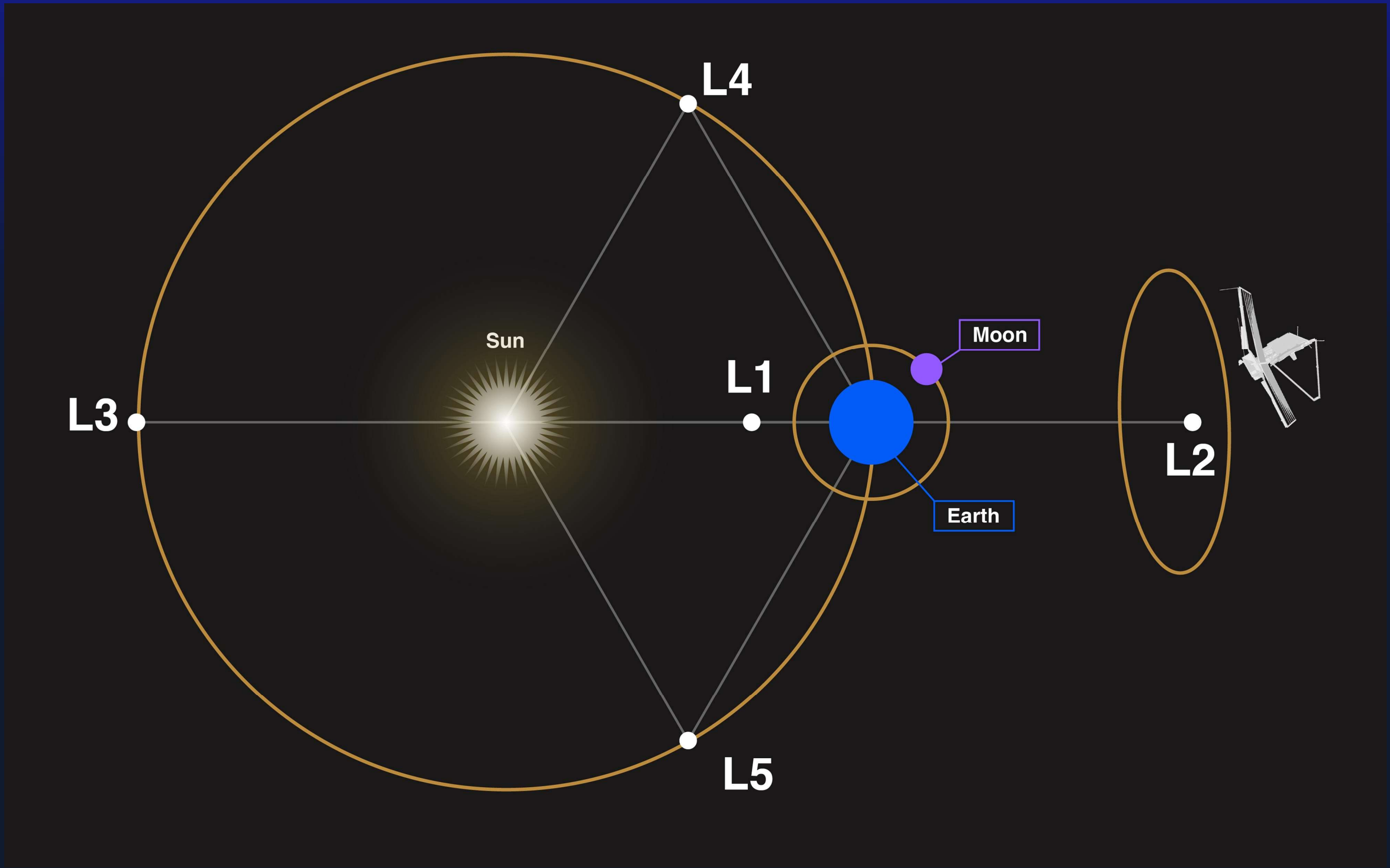
Webb exposure time: 20 hours

All the dots and shapes are galaxies. The field of view is the size of a grain of sand at arm's length.

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



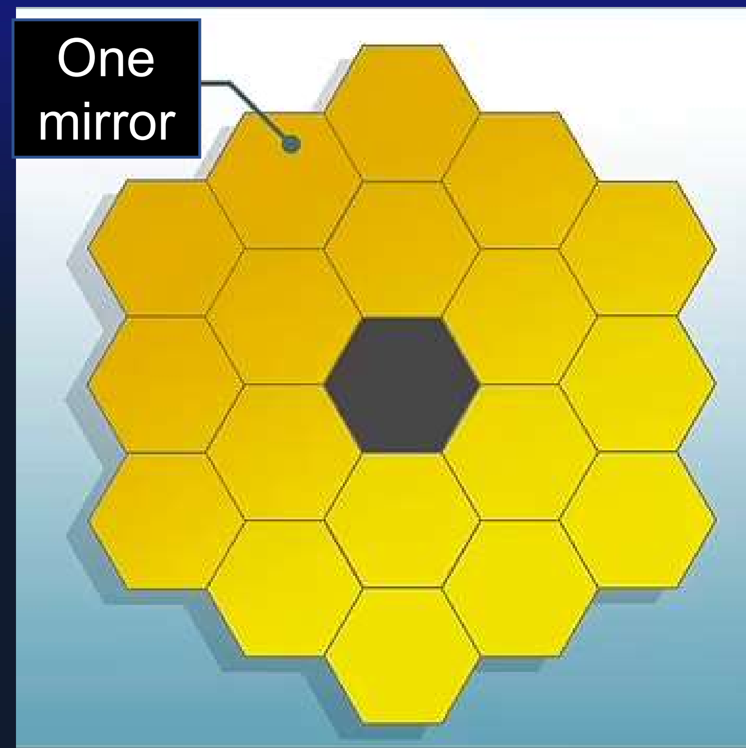




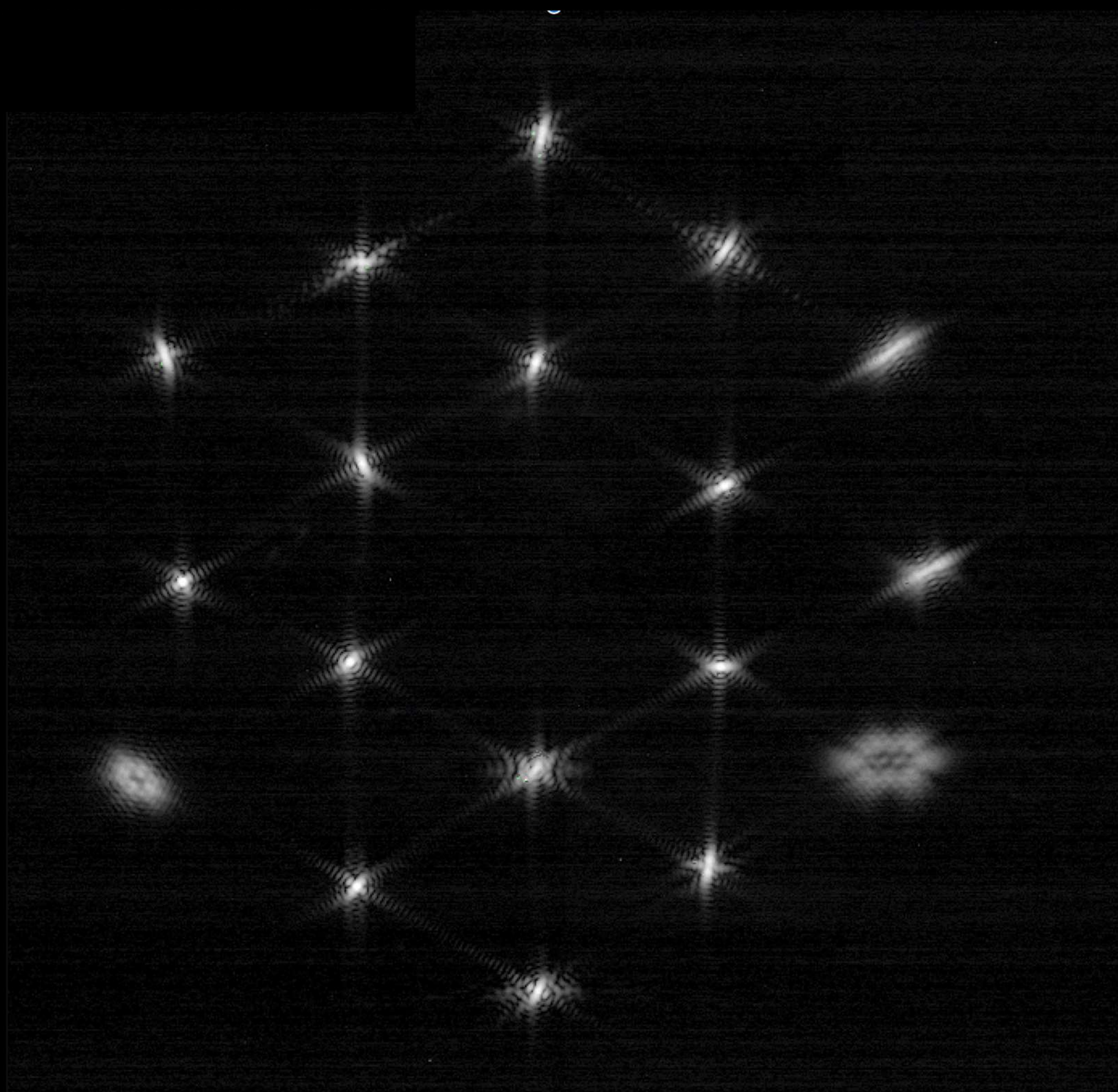
Lagrange point L2 orbits with the Earth. It is a stable point. JWST orbits around L2.

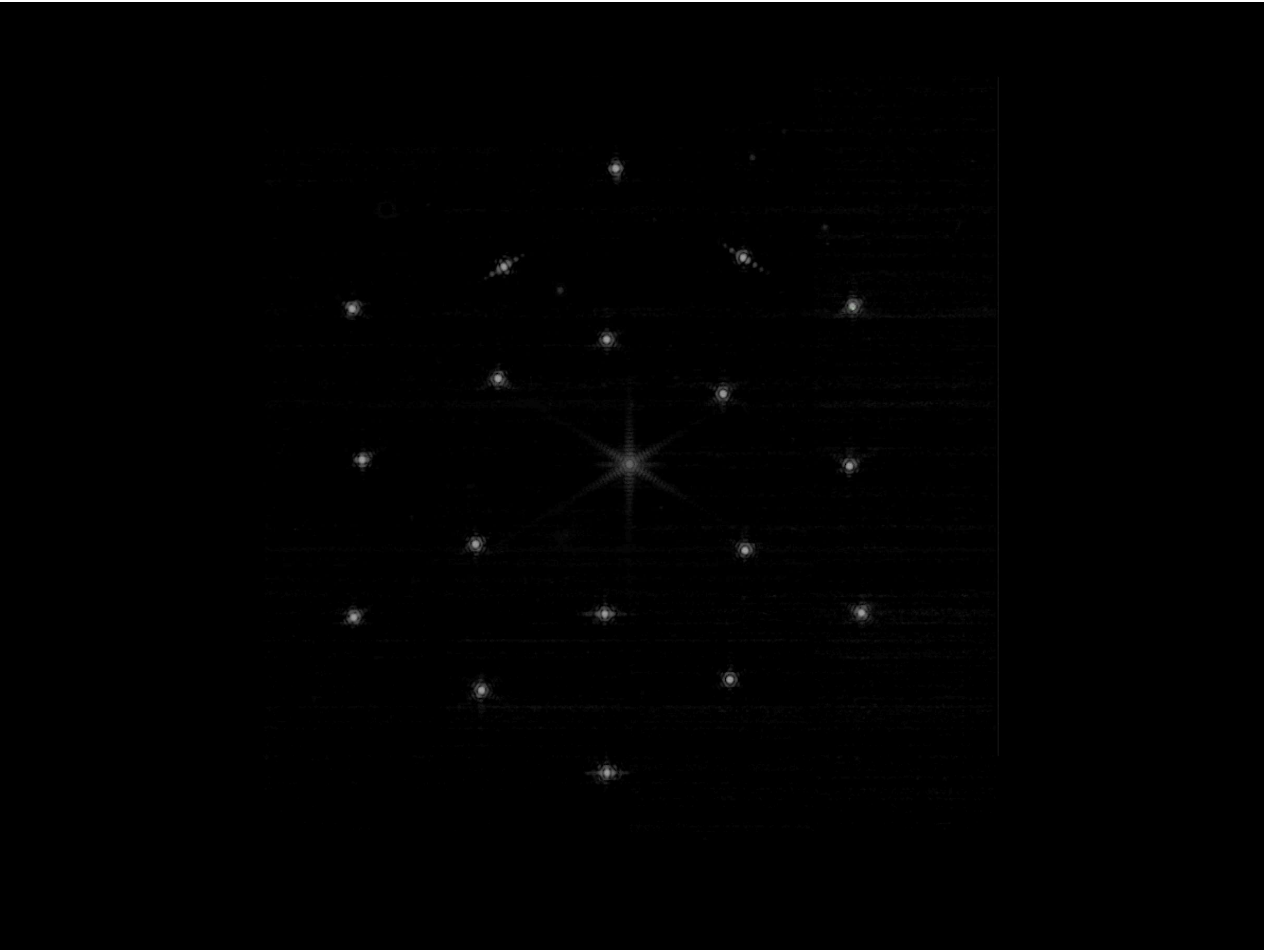
The telescope took about a month to get to its location at Lagrange point 2, and then half a year for the main mirror and instruments to cool down to 7 degrees Kelvin = −447 °F, and be calibrated so all 18 mirrors work like one.

Since the Webb's own electronics and optics emit heat (i.e., infrared radiation), they must be cooled so that the telescope does not detect its own infrared light.



Each mirror's image of the same star



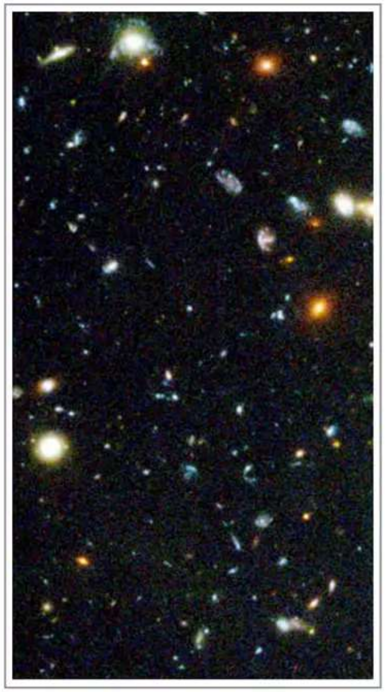


Combined view of a single star

Stacking puts all the light in one place on the detector.

James Webb Telescope's four main science objectives:

1. Look back to end of Dark Ages: Universe becomes transparent



2. The assembly of the first galaxies

3. Birth of stars and proto-planetary systems

4. Formation of planetary systems, origins of life

380,000 years after Big Bang

300 mill. years after Big Bang

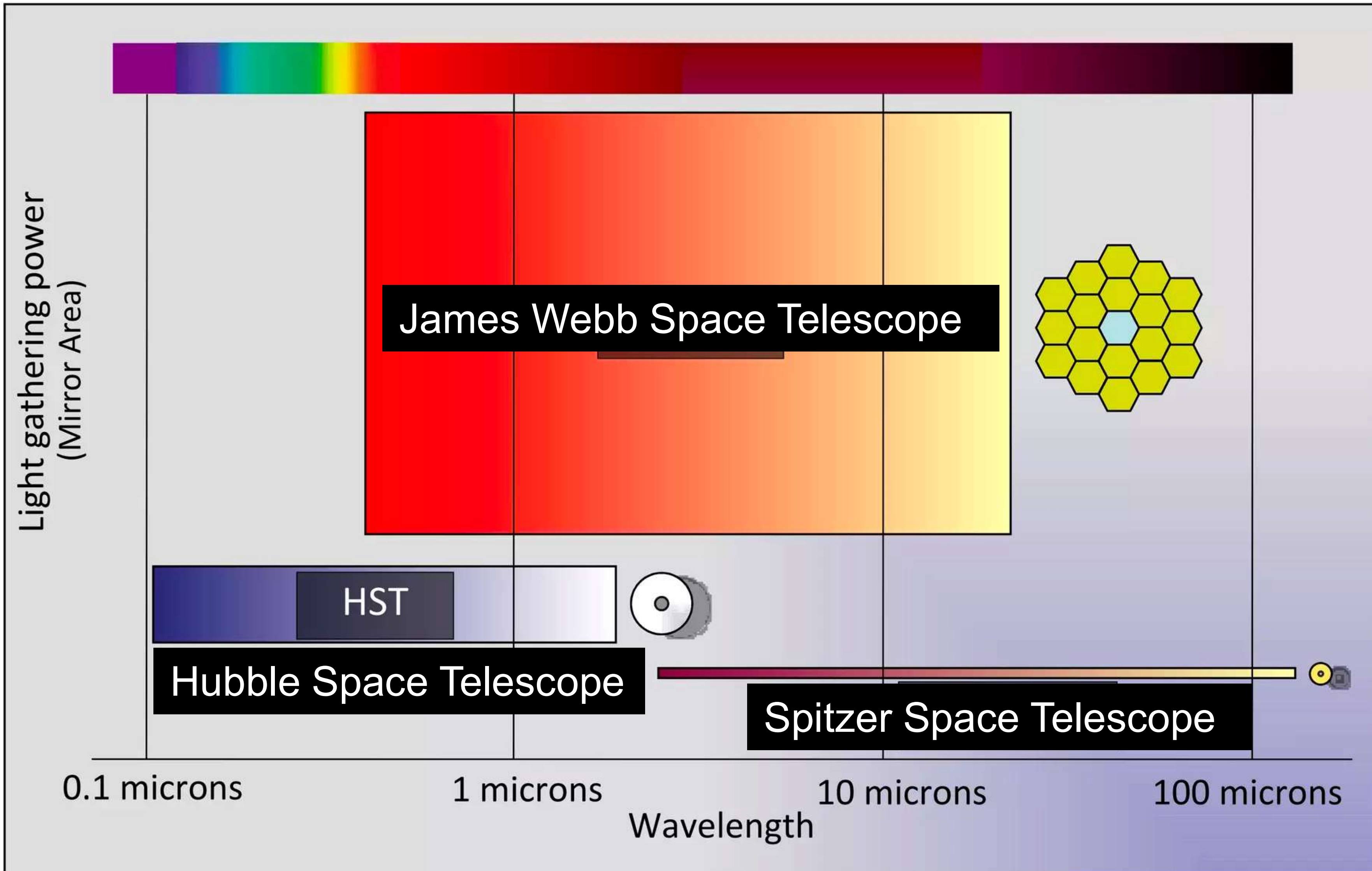
As early as 100 mill., years after BB

As early as 1 billion years after BB

What new has JWST seen?

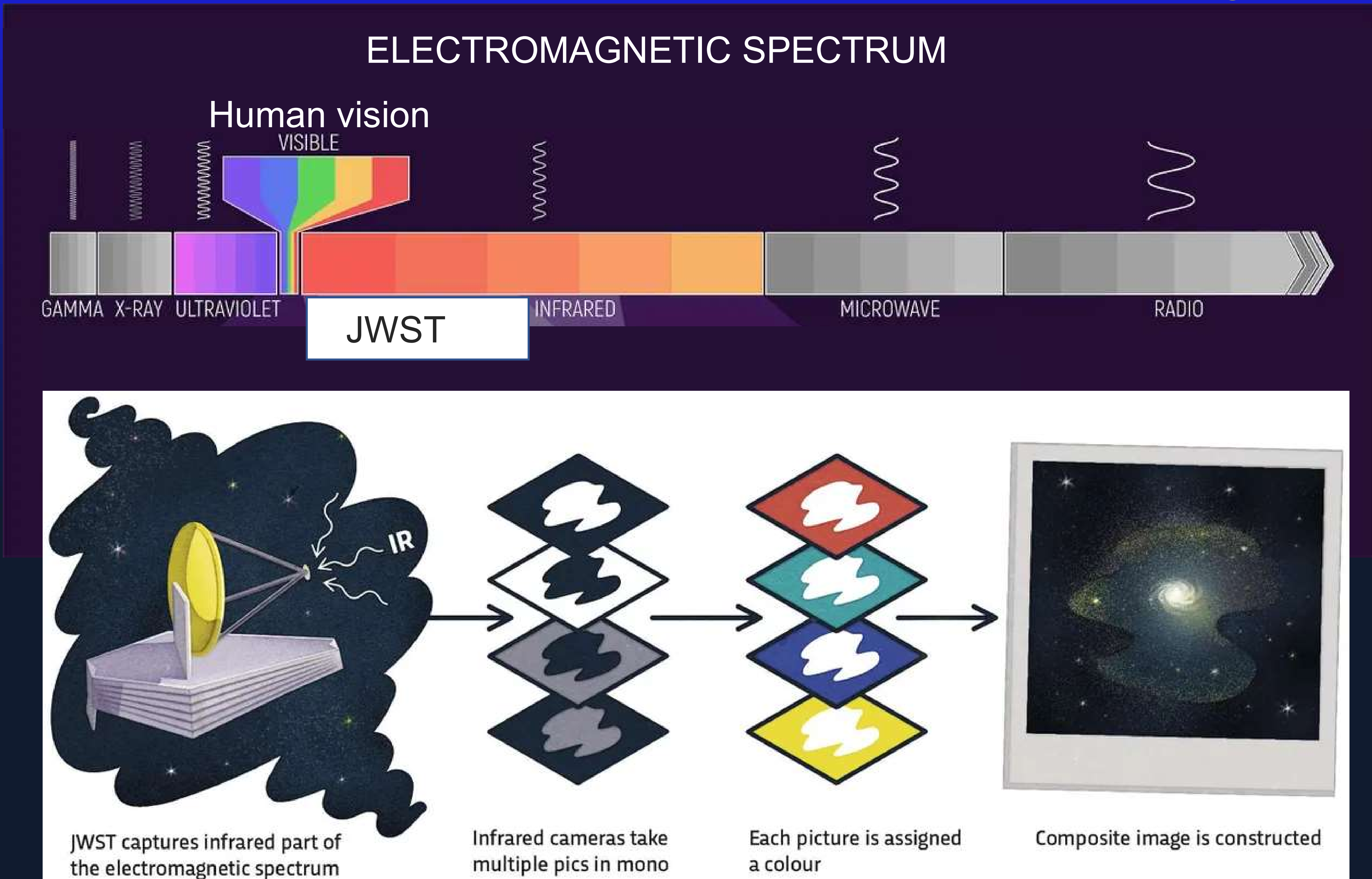
* Big, bright galaxies at cosmic dawn
* Early supermassive black holes
* Dust in the universe's youth
* Star formation
* A JuMBO surprise (Jupiter Mass Binary Objects)
* Molecules in exoplanet atmospheres

What is the difference between JWST and Hubble?



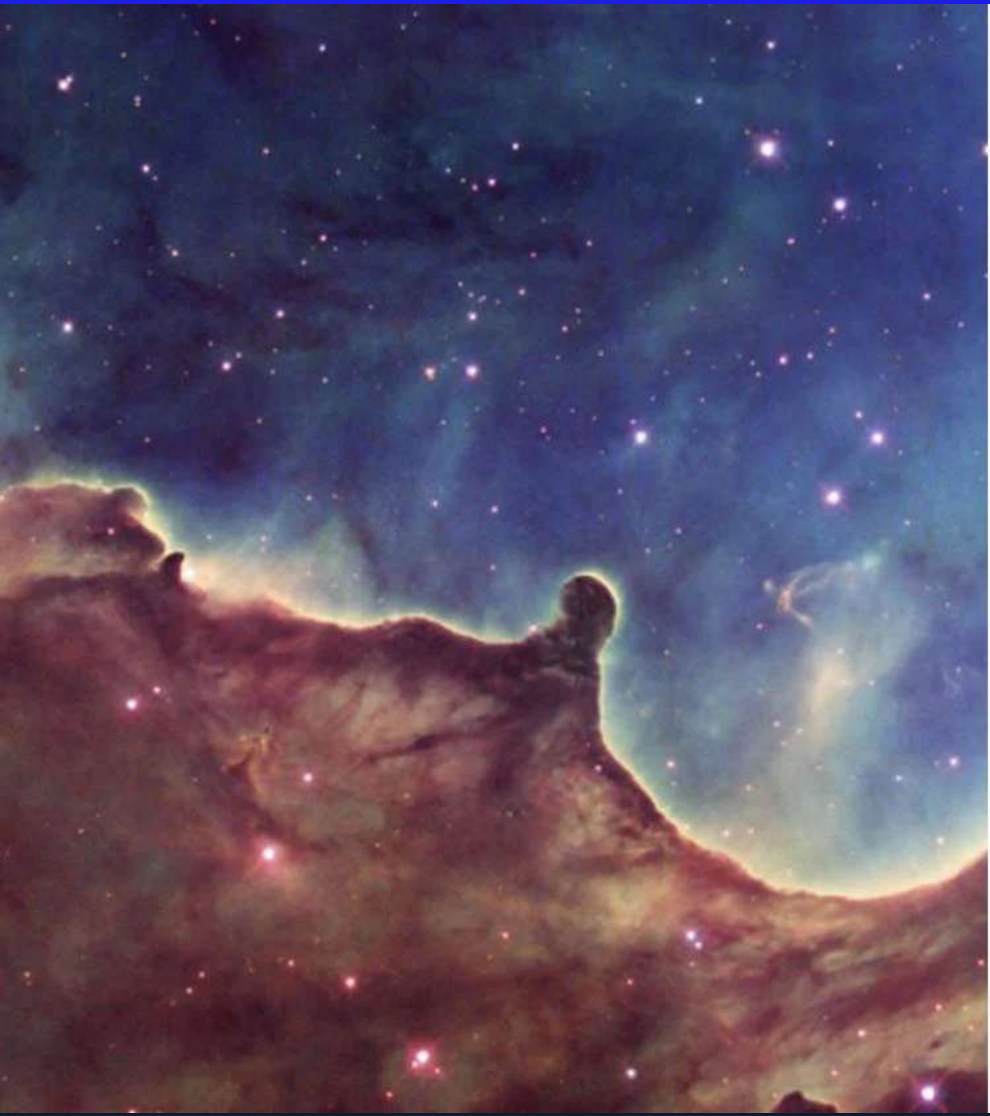
Looking at the universe in infrared light gives much more information than looking simply in visible light.   An analogy:

JWST takes up to 29 greyscale images, each through a different filter, which only passes infrared light of a certain wavelength. Each greyscale corresponds to a certain color. A computer turns them into images.



29 different black and white images are combined to form the color image, which can contain 65,000 different shades of grey, and compress them into image we can see.

Hubble visual light vs. JWST infrared light



You see additional details in the Webb image

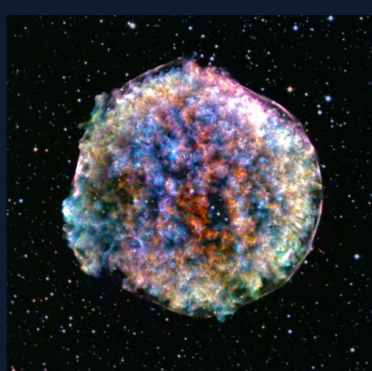
Why is it important to see the Universe in infrared light?

* Cosmic distances – light in travelling across the Universe gets redder and redder, and is no longer visible in ordinary light.

* Dust and gas reflect ordinary light, infrared is not reflected.

* Infrared light can see stars hidden behind gas and dust.

* Dust and gas surround stellar nurseries where stars are born.



* Dust and gas surround supernovae, hiding the dead stars. Infrared radiation passes through dust and gas unhindered.

Crab Nebula, supernova of 4th July, 1054

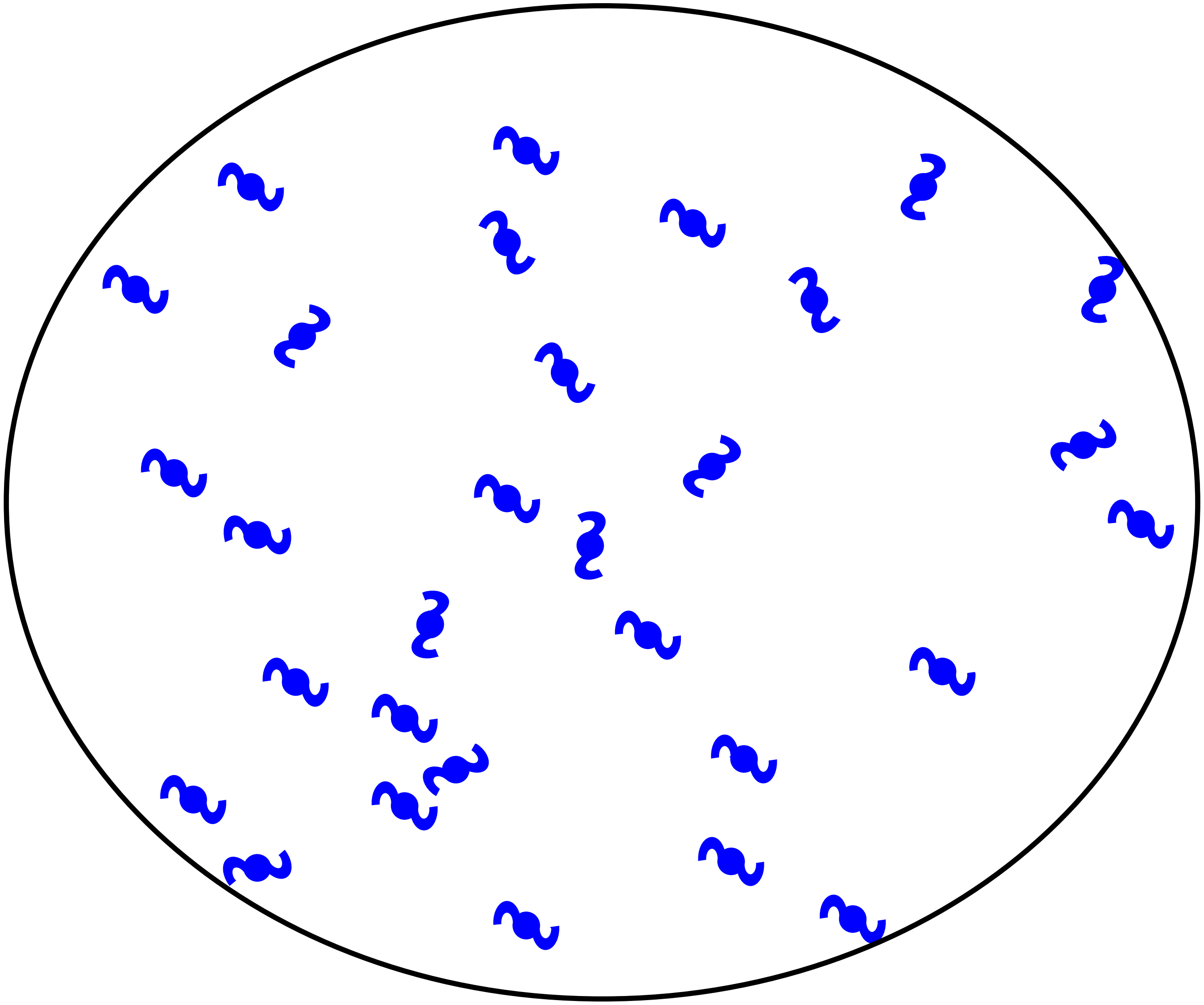
Why is it important to see the Universe in infrared light? (cont.)

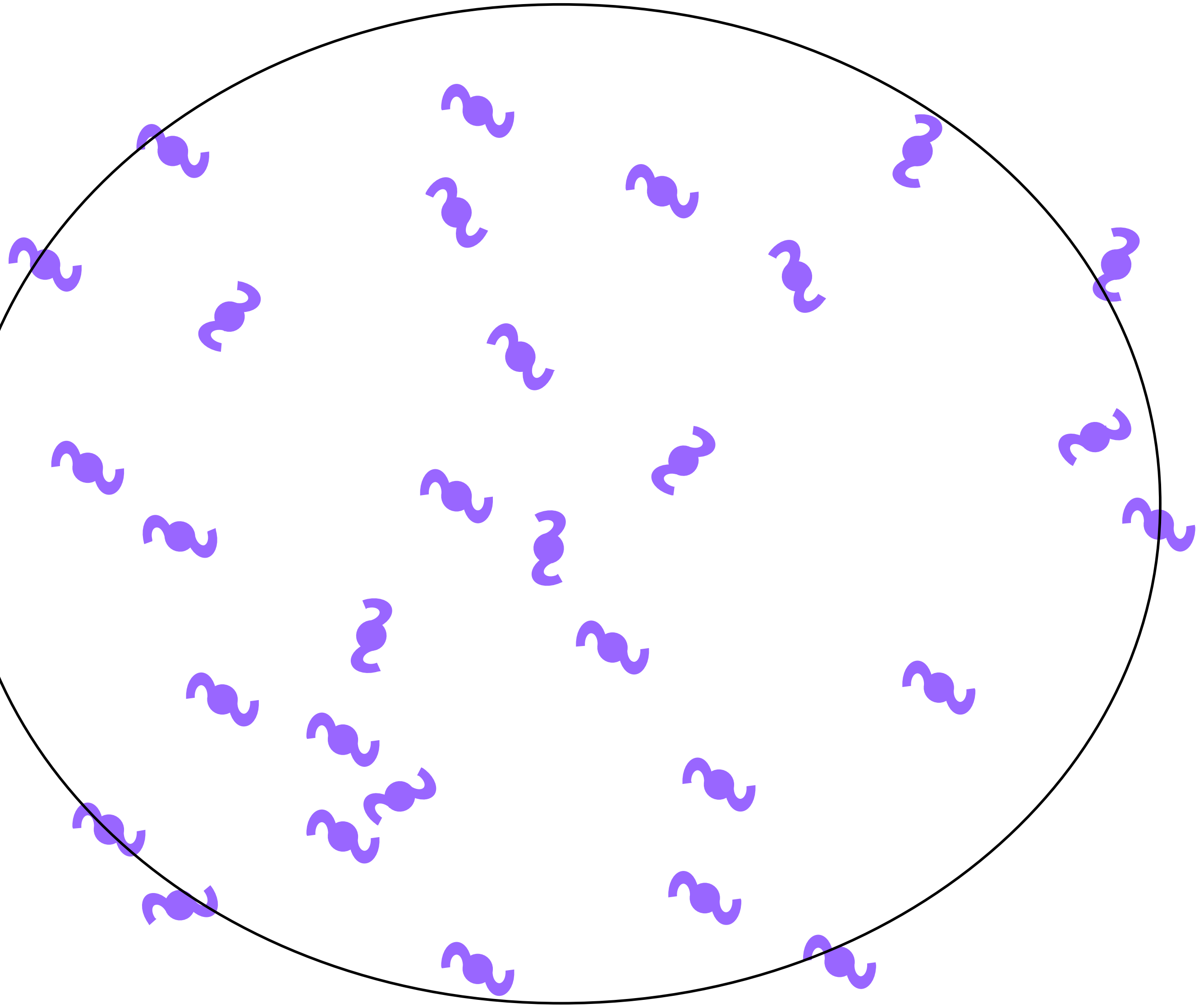
* Detect radiation from hot hydrogen gas in star forming regions (M82)

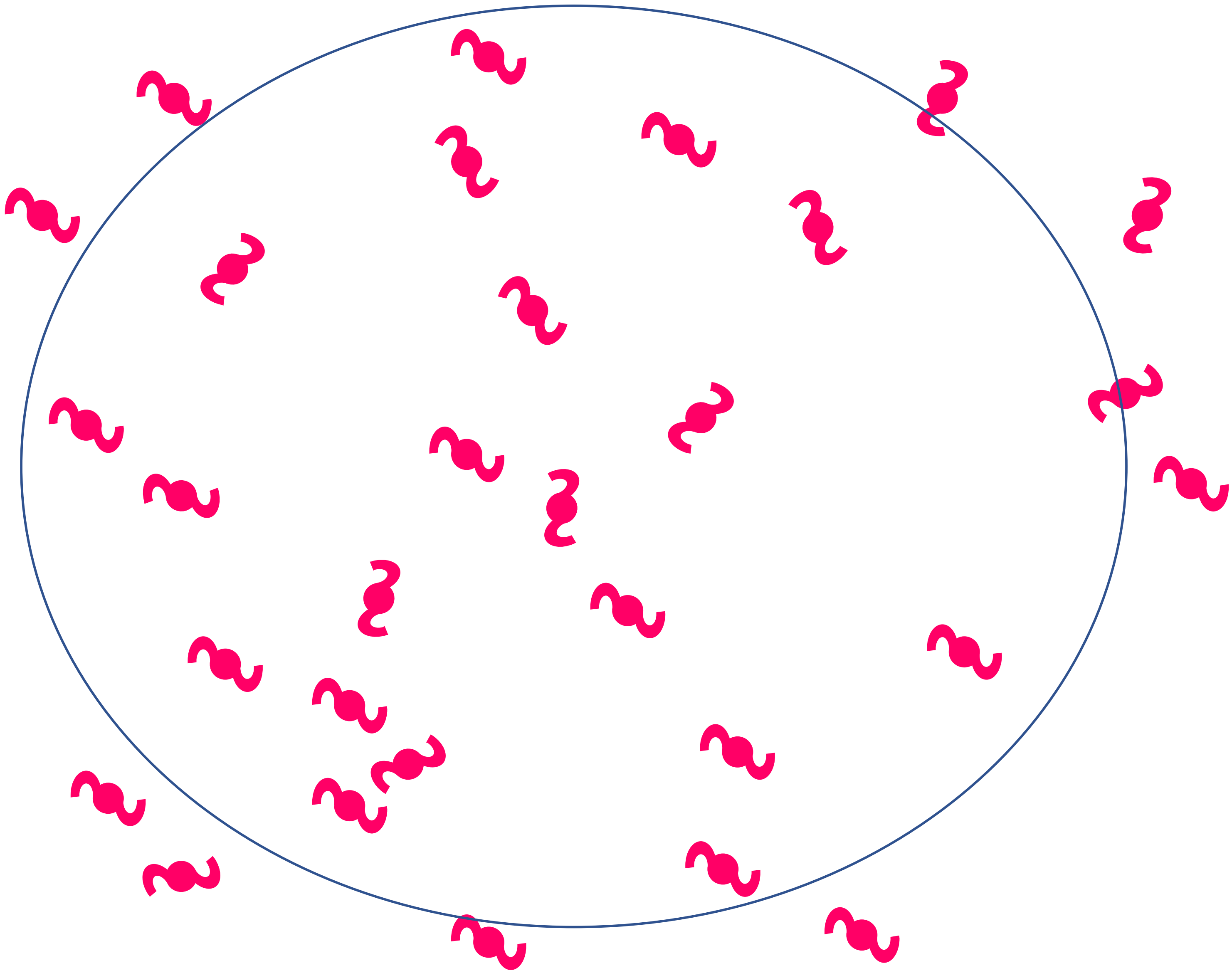
* Merging of two galaxies seeing their star forming regions in infrared

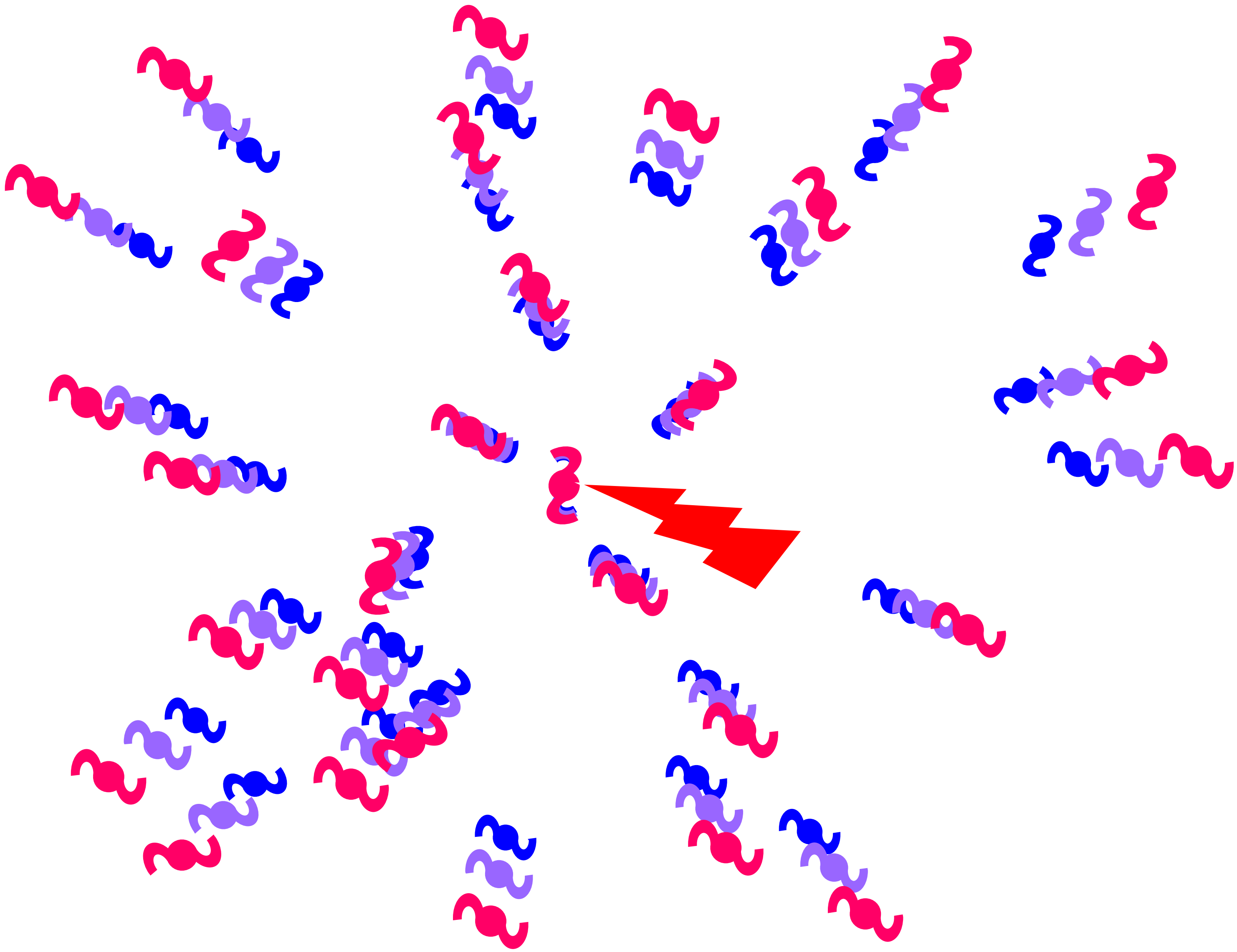
Why does light travelling across the Universe get redder and redder?

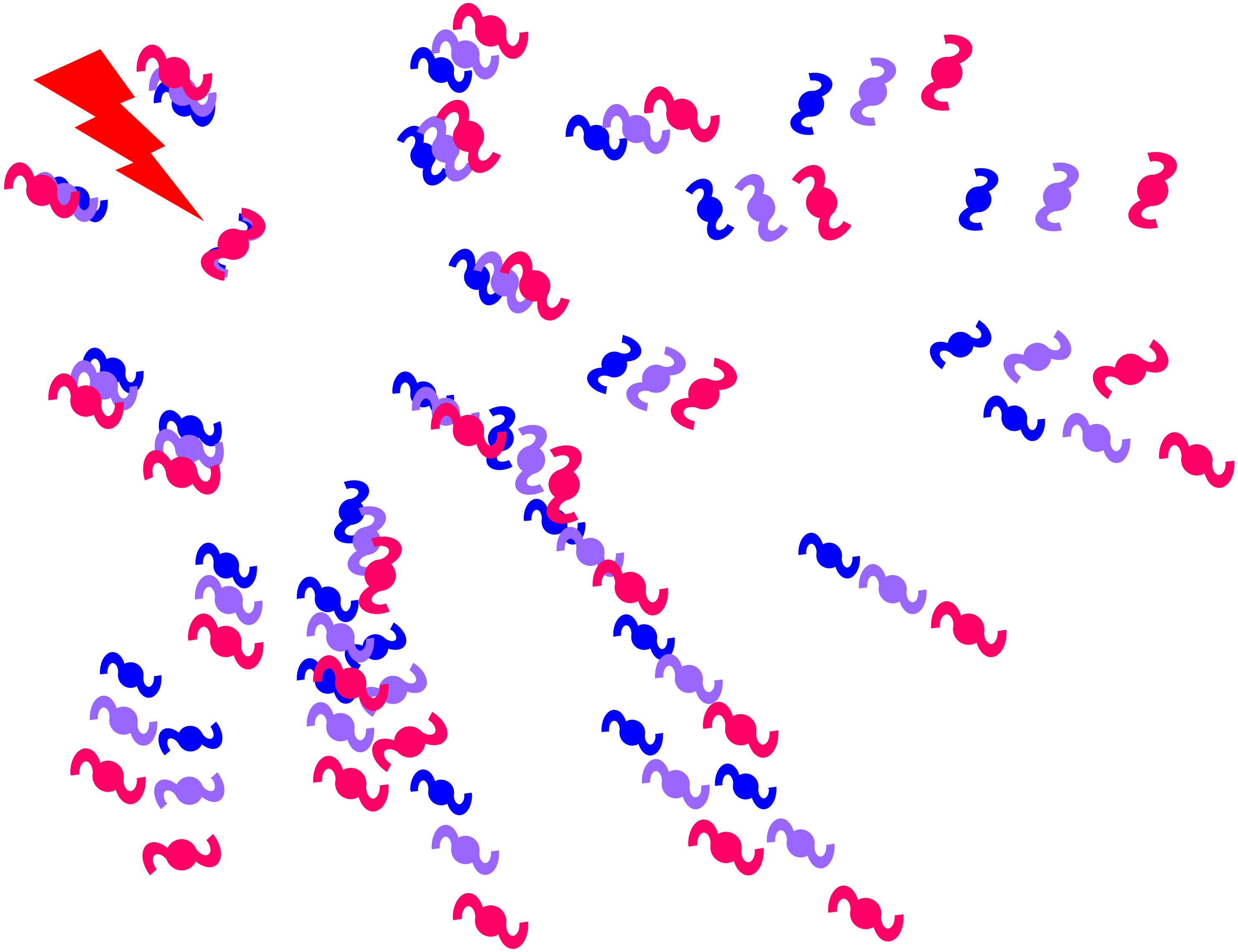
The Universe has no center and space itself is expanding. There is no space “outside” or “inside” the balloon. Expansion indicates that the Universe had a beginning – the Big Bang – when the density and temperature were “infinite.” (Open problem)

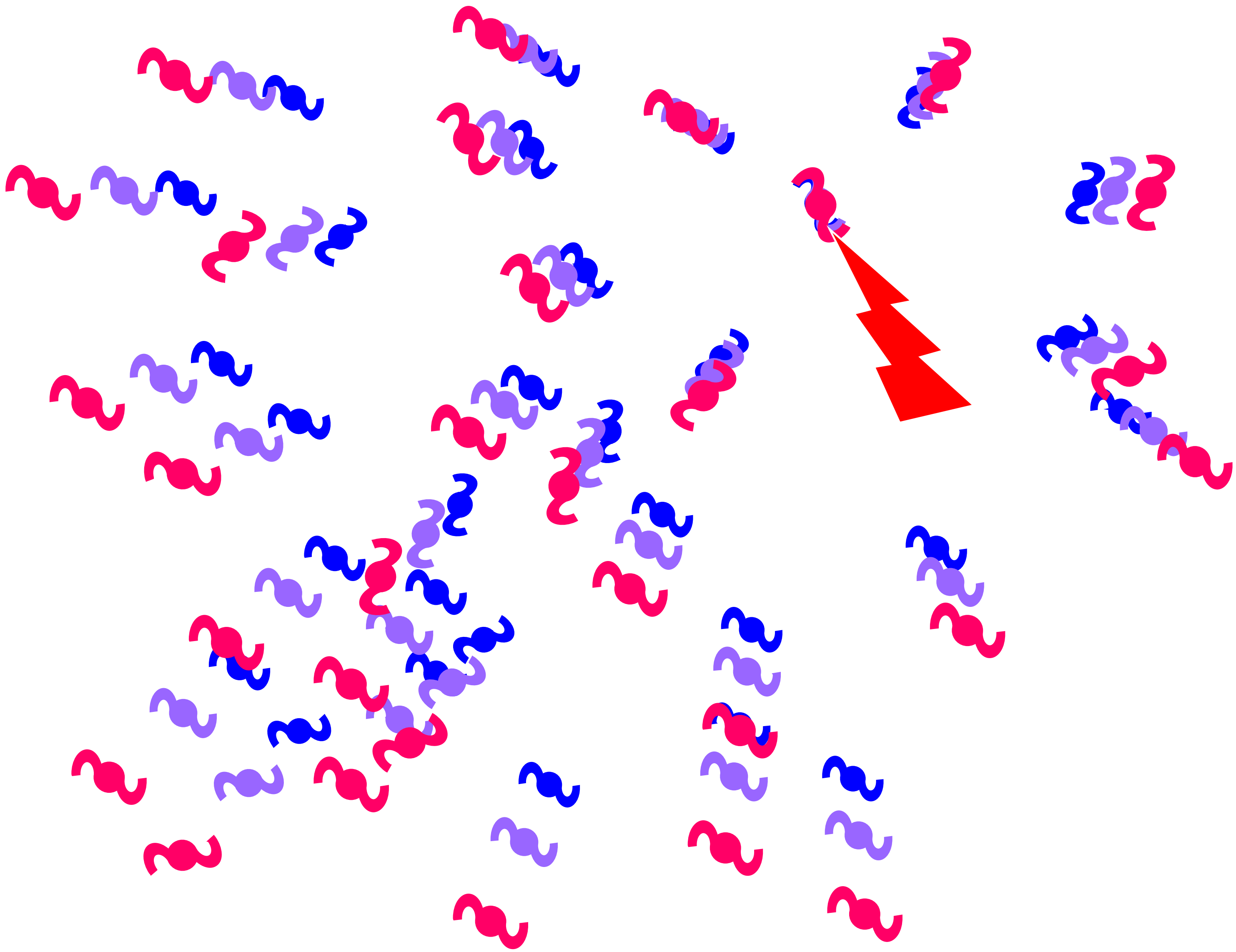






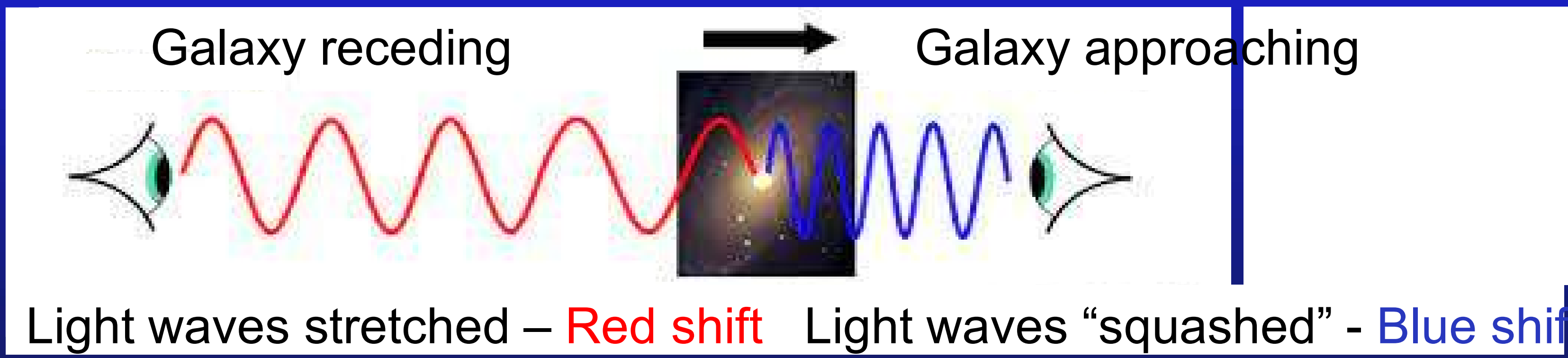




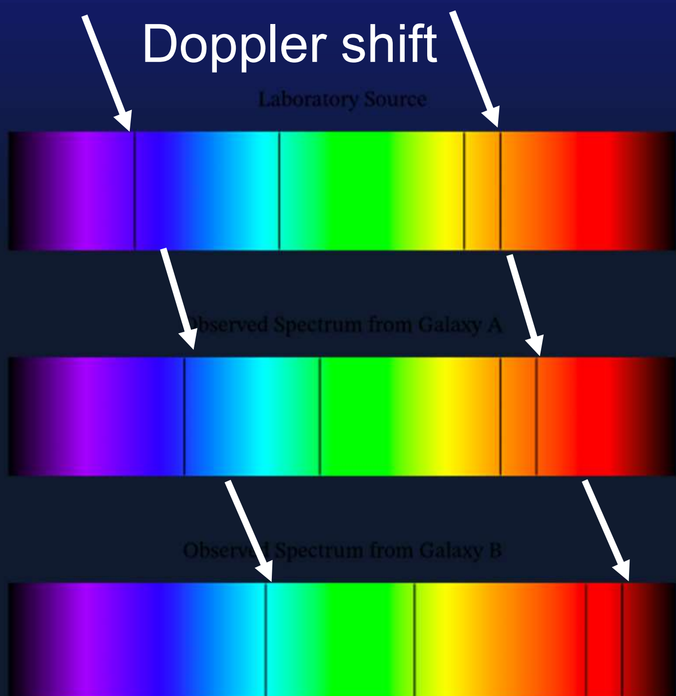


Seeing back to the Big Bang

Light is made redder by the expansion of the Universe: Doppler shift



Absorption lines from hydrogen

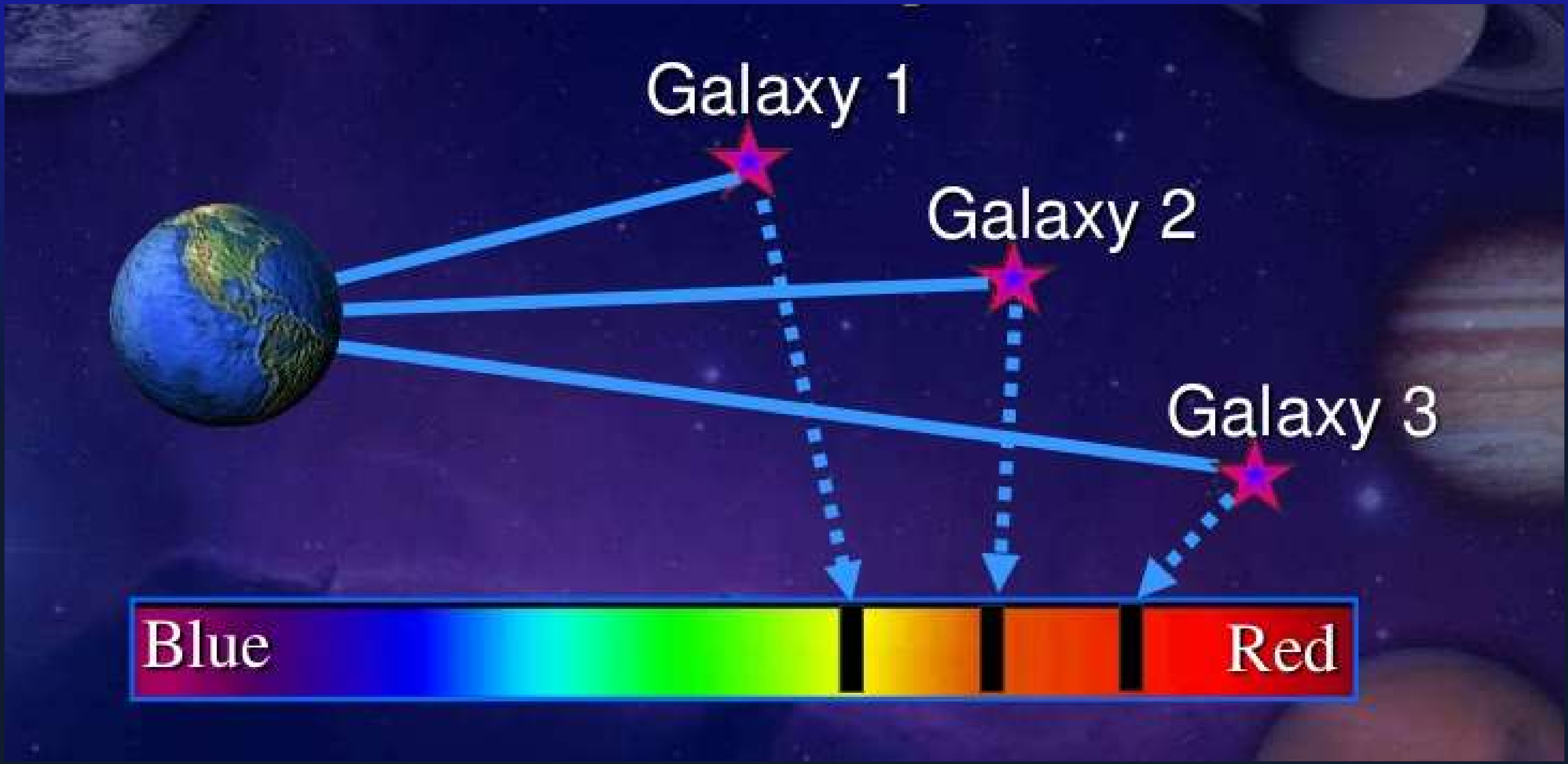


Galaxy not moving away from us. The spectral lines are what we see in lab experiments.

Galaxy moving away from us. The spectral lines are redshifted.

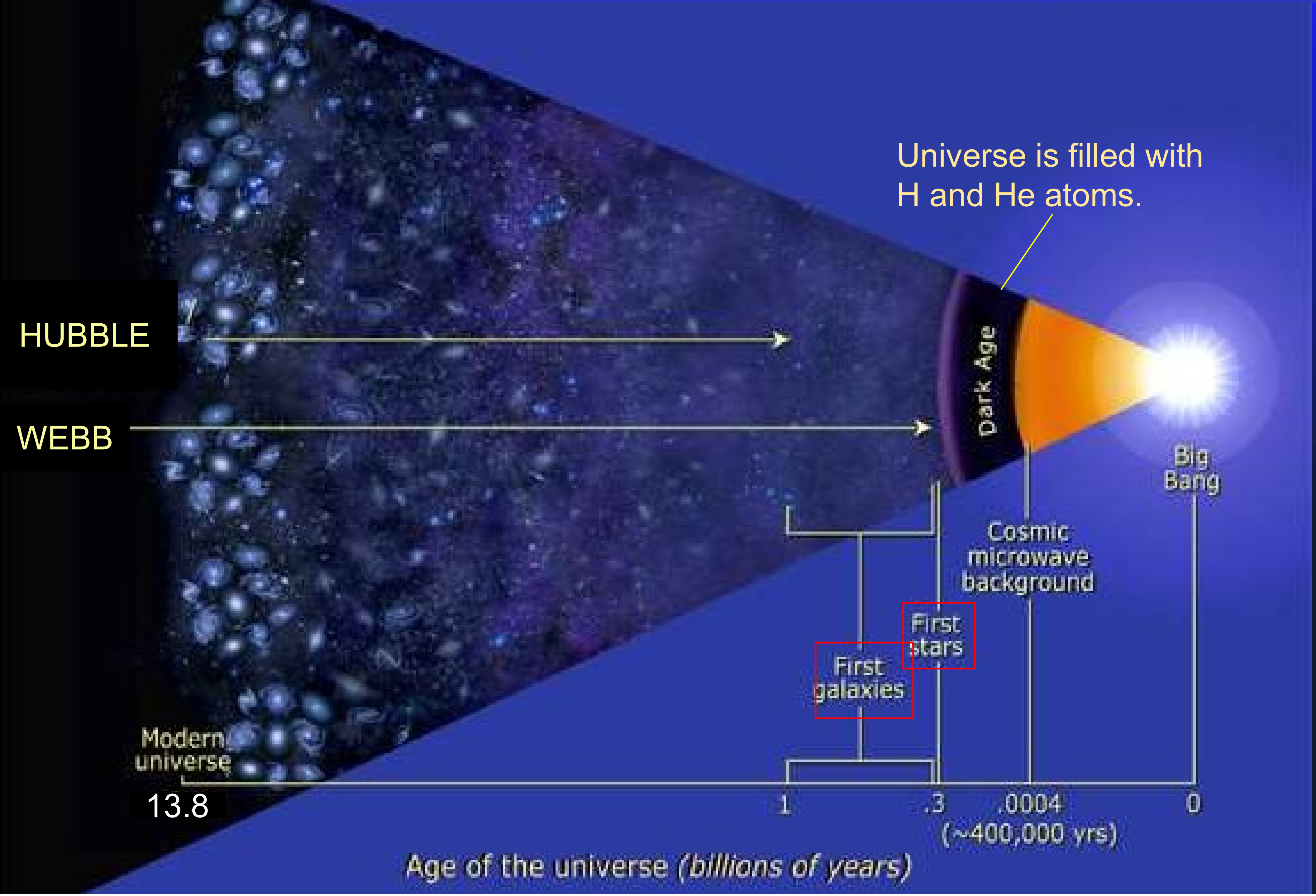
Galaxy moving much faster away from us. he spectral lines are highly redshifted.

The further a galaxy is from us the redder it looks. Because the light from the galaxy takes longer to get to us, we see the galaxy as it was much earlier in time. Seeing redshifted galaxies is looking back in time. The redshift tells us when the light left the galaxy we are looking at.



Can we see all the way back to the beginning of time?

Not quite, due to the “Dark Ages.”



The Big Bang:

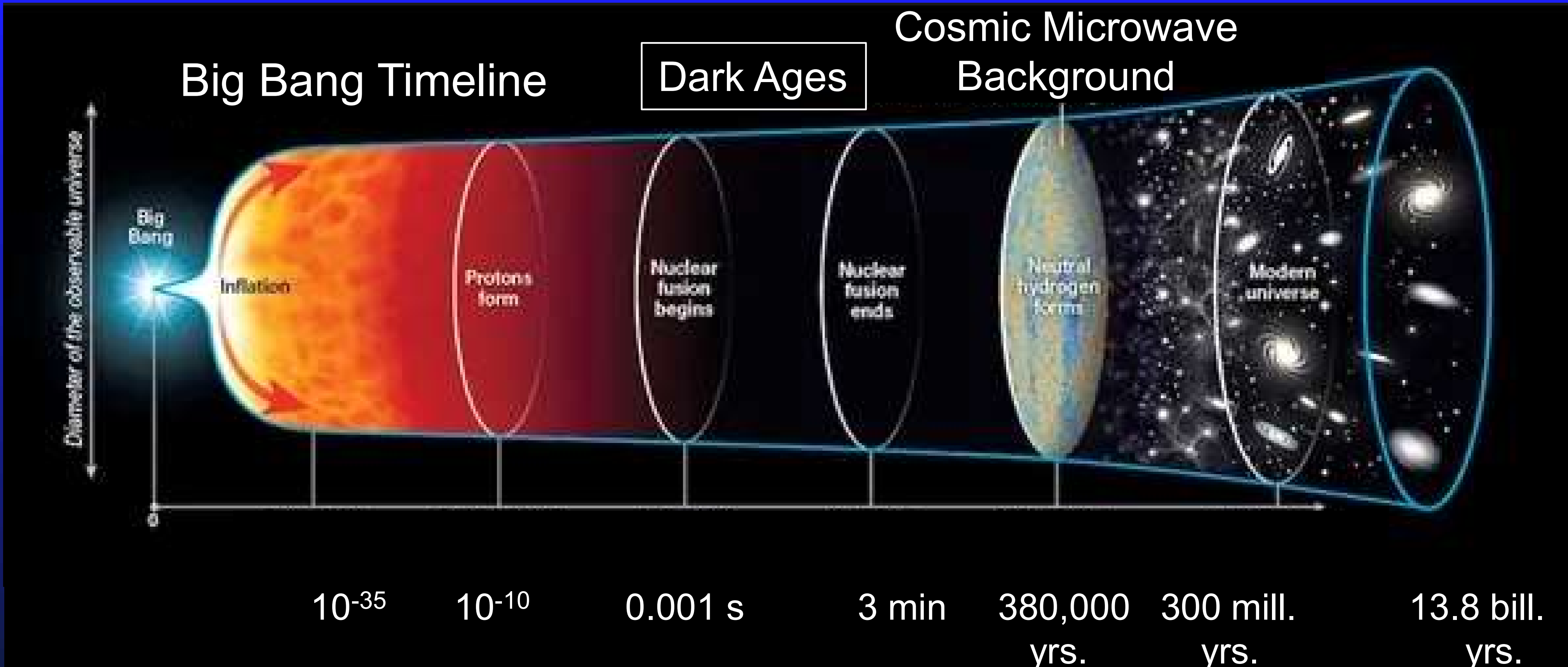
The earliest time of the universe, when the entire universe was condensed in an infinitesimally small point approaching infinite density and temperature.

Cosmic Inflation:

The Universe expanded very fast for a tiny fraction of a second, explaining why the Universe looks almost the same in all directions and has approximately the same temperature everywhere.

Particles start to form:

As far as we know, quarks, electrons, and photons were there from the beginning. Protons and neutrons formed from the quarks at about one microsecond. Light nuclei formed about 3 minutes later. Photons (light) bounced around in the hot particle “soup”. The light was unable to escape so the universe was opaque.



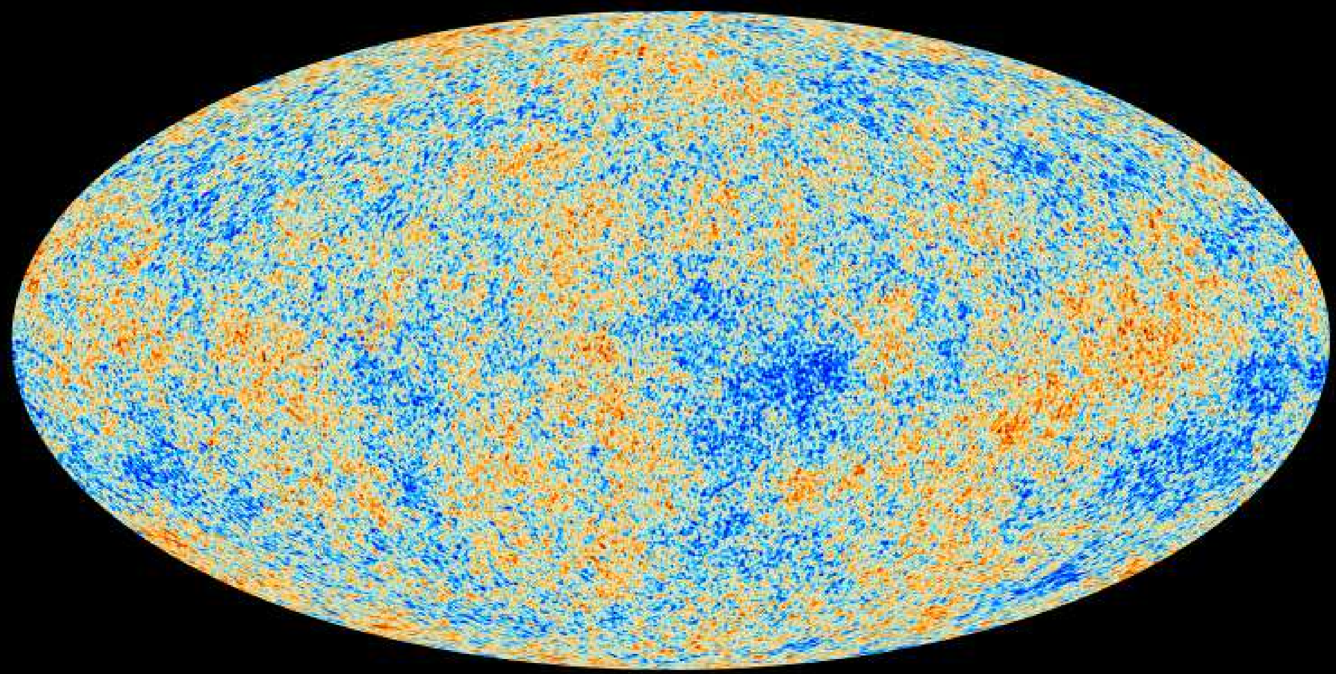
1 microsecond: Quarks form protons and neutrons. Electrons and photons present.

3 minutes: Protons (hydrogen nuclei) and neutrons combine to helium, and a trace of deuterium and lithium nuclei. Hydrogen roughly 75%, helium nuclei 25%. Still too hot for atoms to form.

3 min to 380,000 yrs. : Universe is dark. No stars yet (Dark Ages).

380,000 yrs.: Atoms form and the Universe becomes transparent to light. First light from the Big Bang was detected in 1965 = Cosmic Microwave Background Radiation, T = 2.7^0 K or -454.8^0 F.

Cosmic Microwave Background Radiation from the time when the Universe became transparent, 380,000 yrs. after the Big Bang



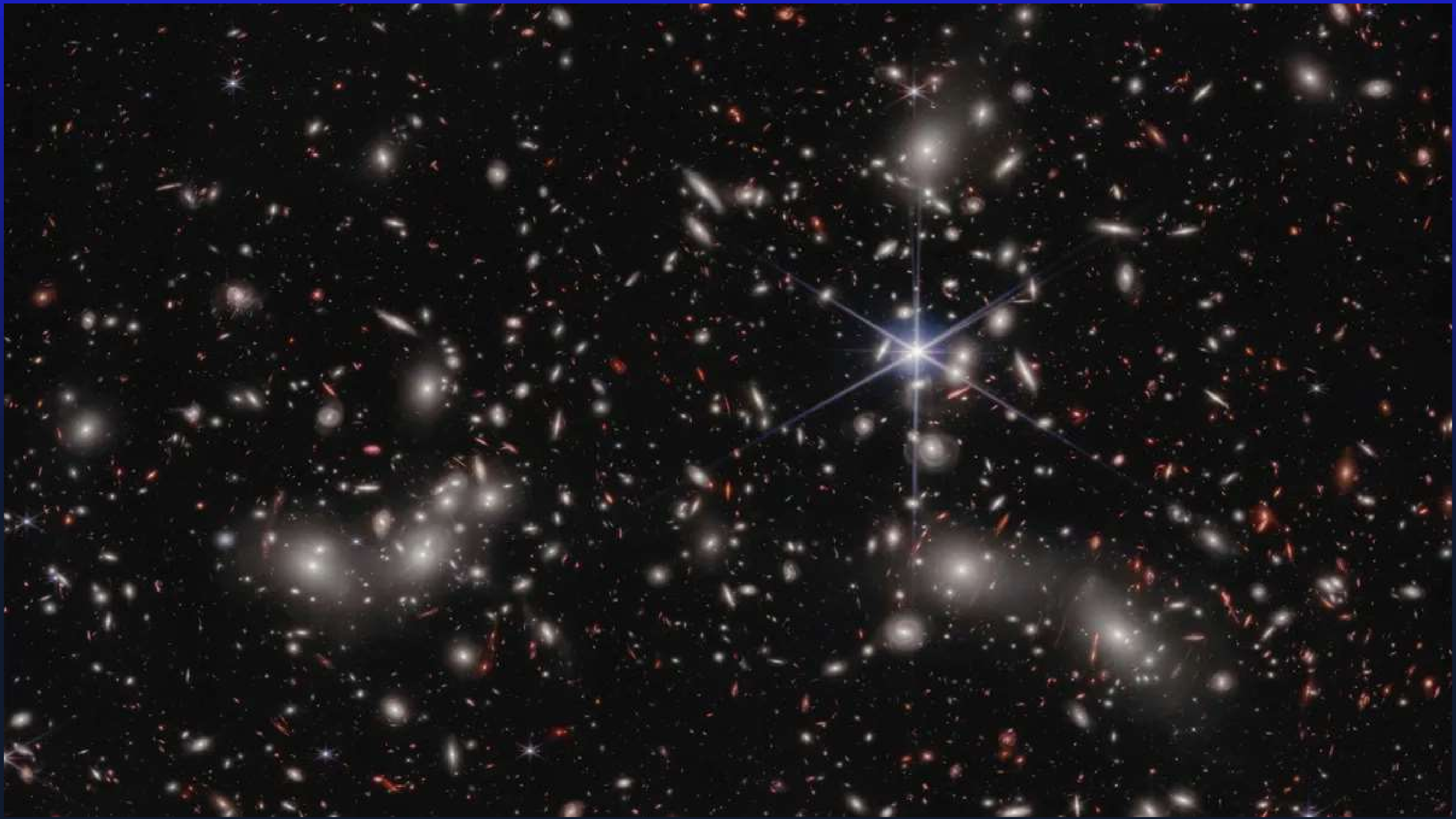
Cosmic background radiation

Avg. CMB temp = 2.7 K. Red areas are hotter, blue are cooler.
Temp. diff. = 2.7K ± 0.00003, or 3/100,000.

Why is the Universe lumpy?

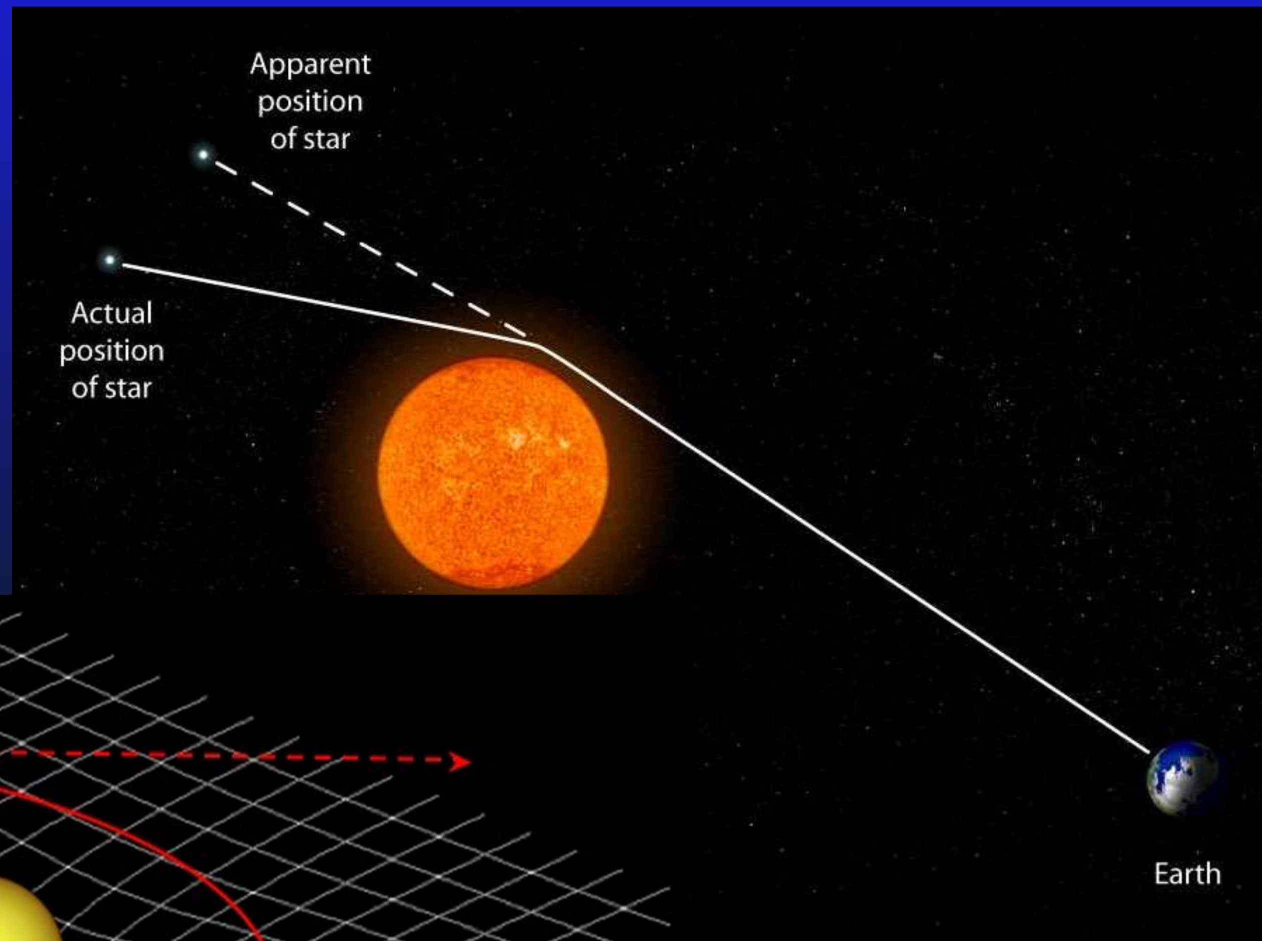
Probably due to *Dark Matter*, an unknown substance that accounts for about 25% of the matter in the Universe.

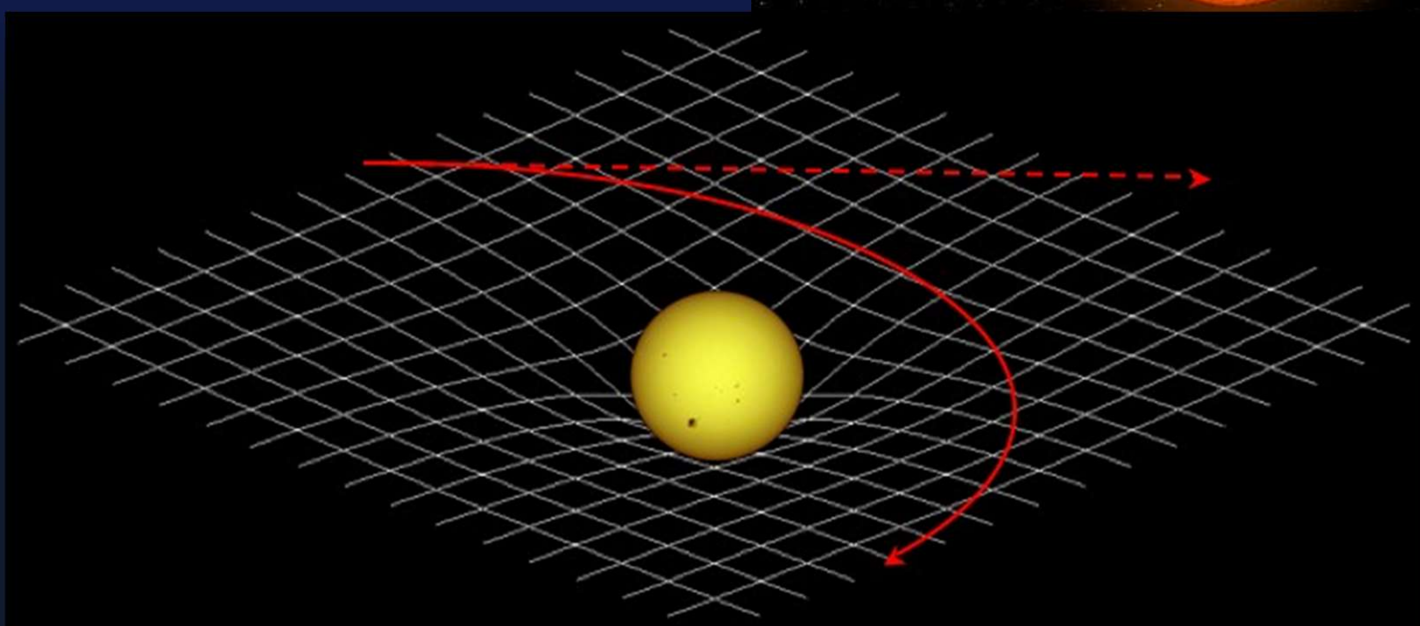
In this JWST picture we can see individual galaxies almost back to the beginning of time,13.8 billion years ago. How is that possible?

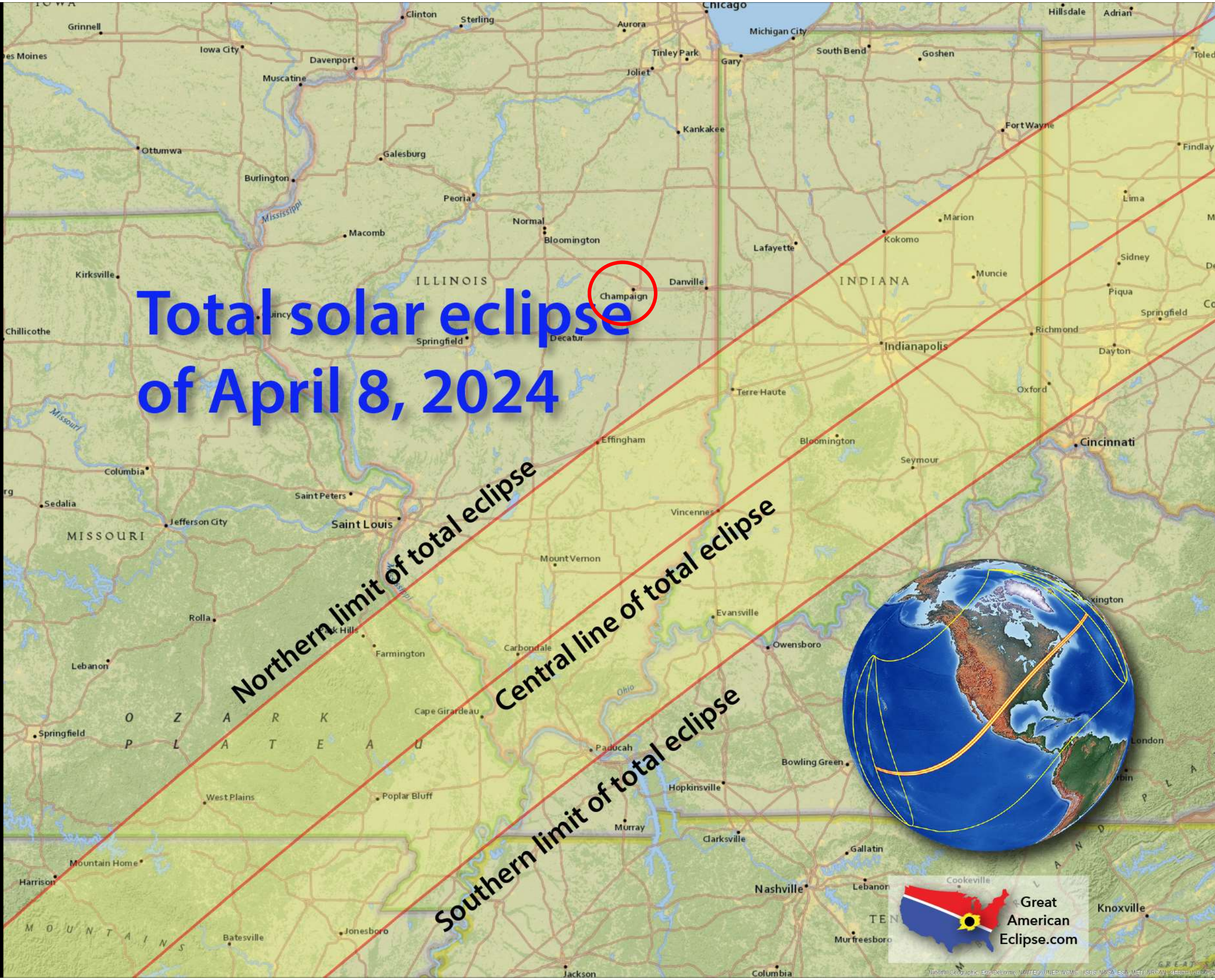


Due to Einstein's Theory of General Relativity claiming that heavy objects bend light, *actually curve space.*

Test: Solar eclipse of 1919







Total solar eclipse
of April 8, 2024
Northern limit of total eclipse
Central line of total eclipse
Southern limit of total eclipse
Great
American
Eclipse.com
ILLINOIS
INDIANA
MISSOURI
OZARK PLATEAU
Chicago
Michigan City
South Bend
Goshen
Hillsdale
Adrian
Toledo
Clinton
Sterling
Aurora
Grinnell
Iowa City
Davenport
Muscatine
Tinley Park
Gary
Joliet
Kankakee
Fort Wayne
Findlay
Ottumwa
Galesburg
Burlington
Peoria
Mississippi
Macomb
Normal
Bloomington
Lafayette
Kokomo
Marion
Lima
Kirksville
Danville
Champaign
Muncie
Sidney
Piqua
Springfield
Chillicothe
Decatur
Indianapolis
Richmond
Dayton
Terre Haute
Oxford
Missouri
Effingham
Bloomington
Cincinnati
Seymour
Columbia
Sedalia
Saint Peters
Saint Louis
Jefferson City
Vincennes
Mount Vernon
Evansville
Rolla
Owensboro
Farmington
Carbondale
Lebanon
Ohio
Cape Girardeau
Springfield
Paducah
Bowling Green
Hopkinsville
West Plains
Poplar Bluff
Murray
Clarksville
Gallatin
Mountain Home
Harrison
Nashville
Lebanon
Cookeville
Knoxville
Murfreesboro
Batesville
Jonesboro
Jackson
Columbia
London

Total Solar Eclipse

Mon, Apr 8, 2024. 1:00 pm – 2:30 pm

This phenomenon occurs when the moon perfectly aligns with the sun, casting a shadow over our planet and turning day into twilight.

The solar eclipse will begin in Champaign at approximately 12:47 pm and reach its maximum at 2:05 pm.

It will reach about 98% totality here.

LOOK AT THE ECLIPSE ONLY WITH SAFETY GLASSES

The Sun does bend light. Einstein’s Theory of Relativity is proved.