Astronomy from Space: JWST and Euclid

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Università di Bologna

Outline

- Ground and Space Telescopes
- JWST
- Imaging and Spectroscopy
- Euclid

Refracting telescopes

Galileo Galilei
4 cm (1609)

Yerkes Observatory
1 meter (1892)

Reflecting telescopes

Isaac Newton
5 cm (1668)

William Herschel
1.2 meter (1789)

Palomar Observatory

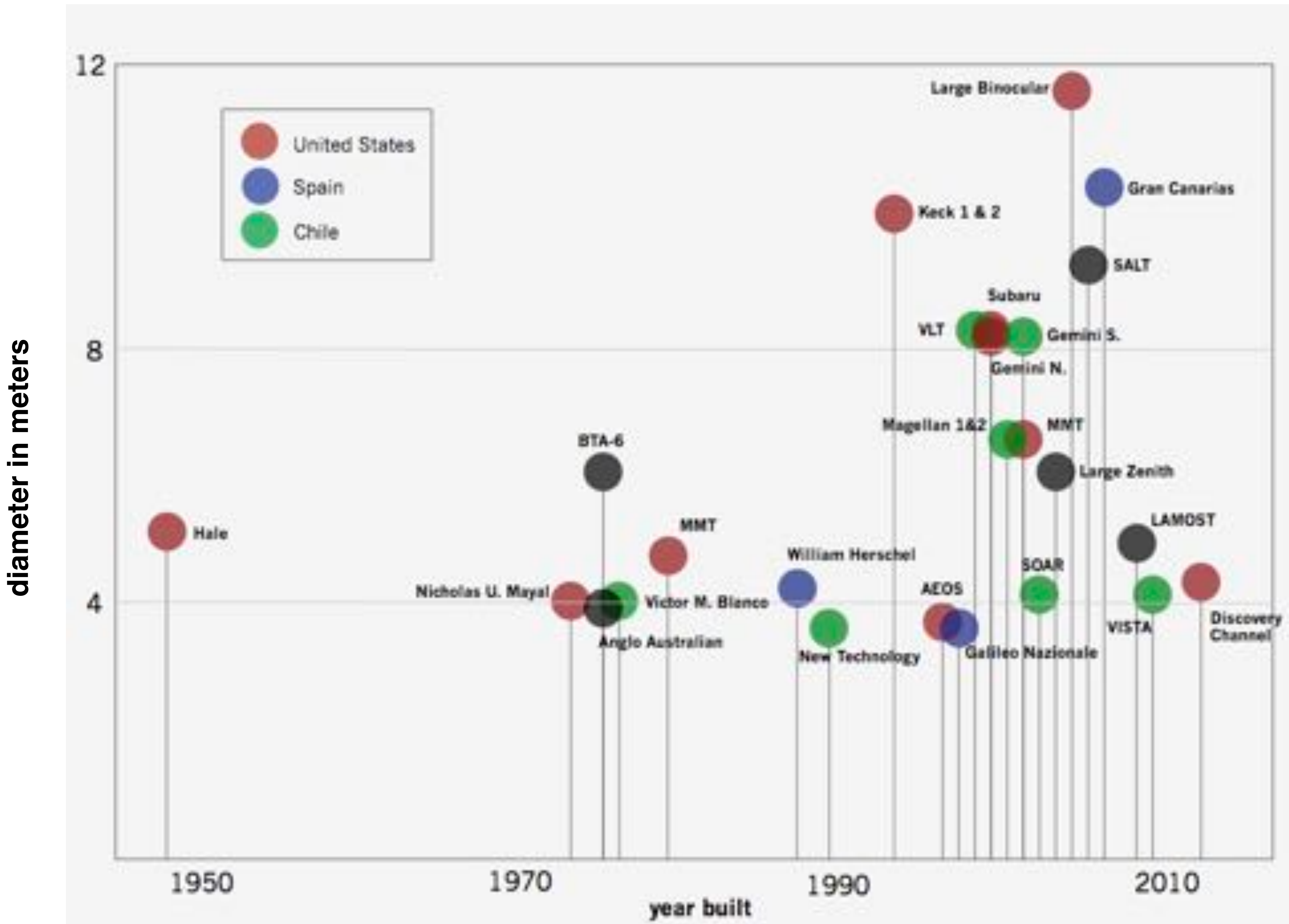
5-meter (1949)

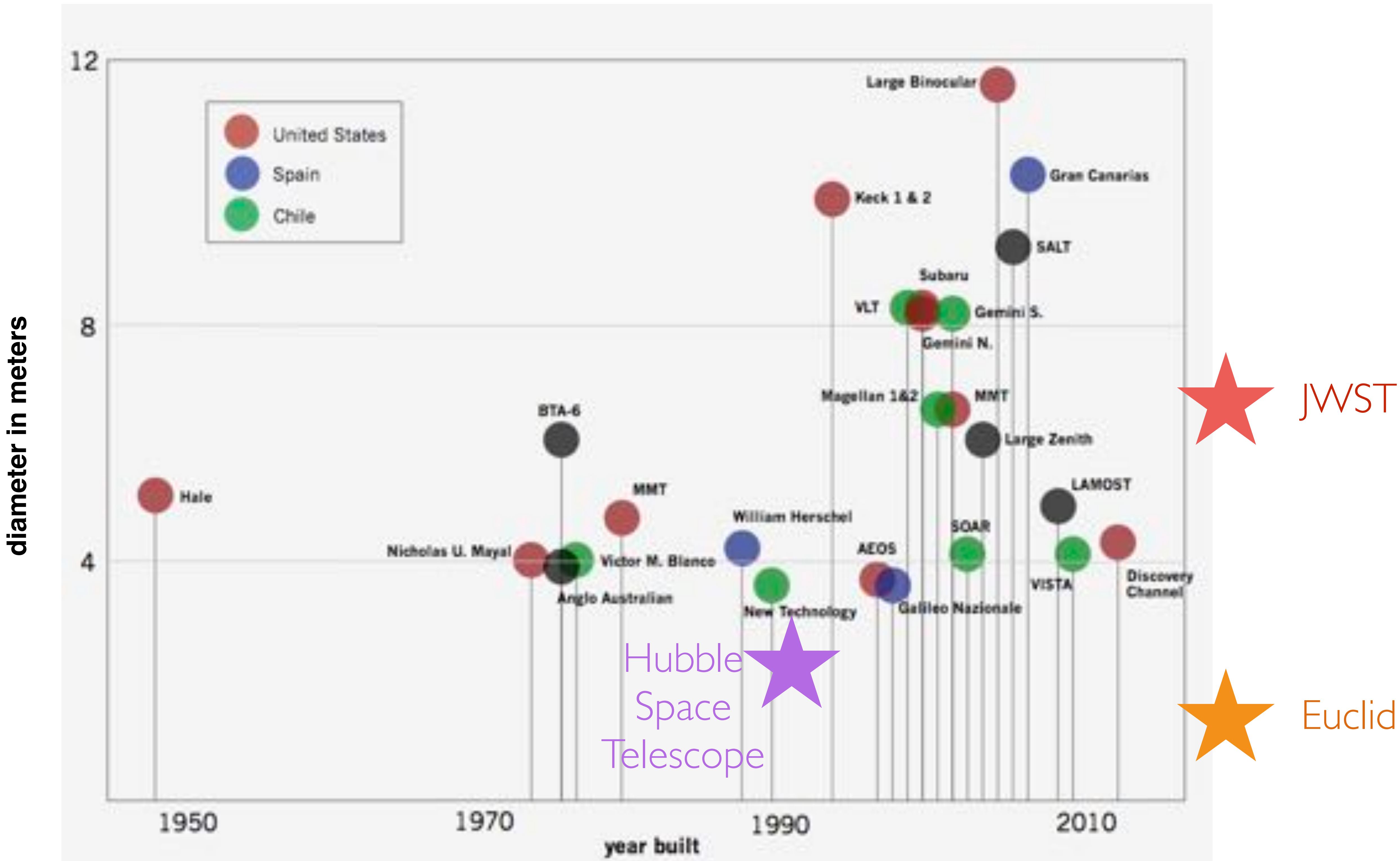
Keck Observatory

2 x 10-meter (1993)

Very Large Telescope

4 x 8.2-meter (1993)


diameter in meters
12
8
4
1950
1970
1990
2010
year built
United States
Spain
Chile
Large Binocular
Gran Canarias
Keck 1 & 2
SALT
Subaru
VLT
Gemini S.
Gemini N.
Magellan 1&2
MMT
Large Zenith
BTA-6
Hale
MMT
LAMOST
William Herschel
SOAR
AEOS
Nicholas U. Mayal
Victor M. Blanco
Anglo Australian
New Technology
Galileo Nazionale
VISTA
Discovery
Channel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Anglo Australian
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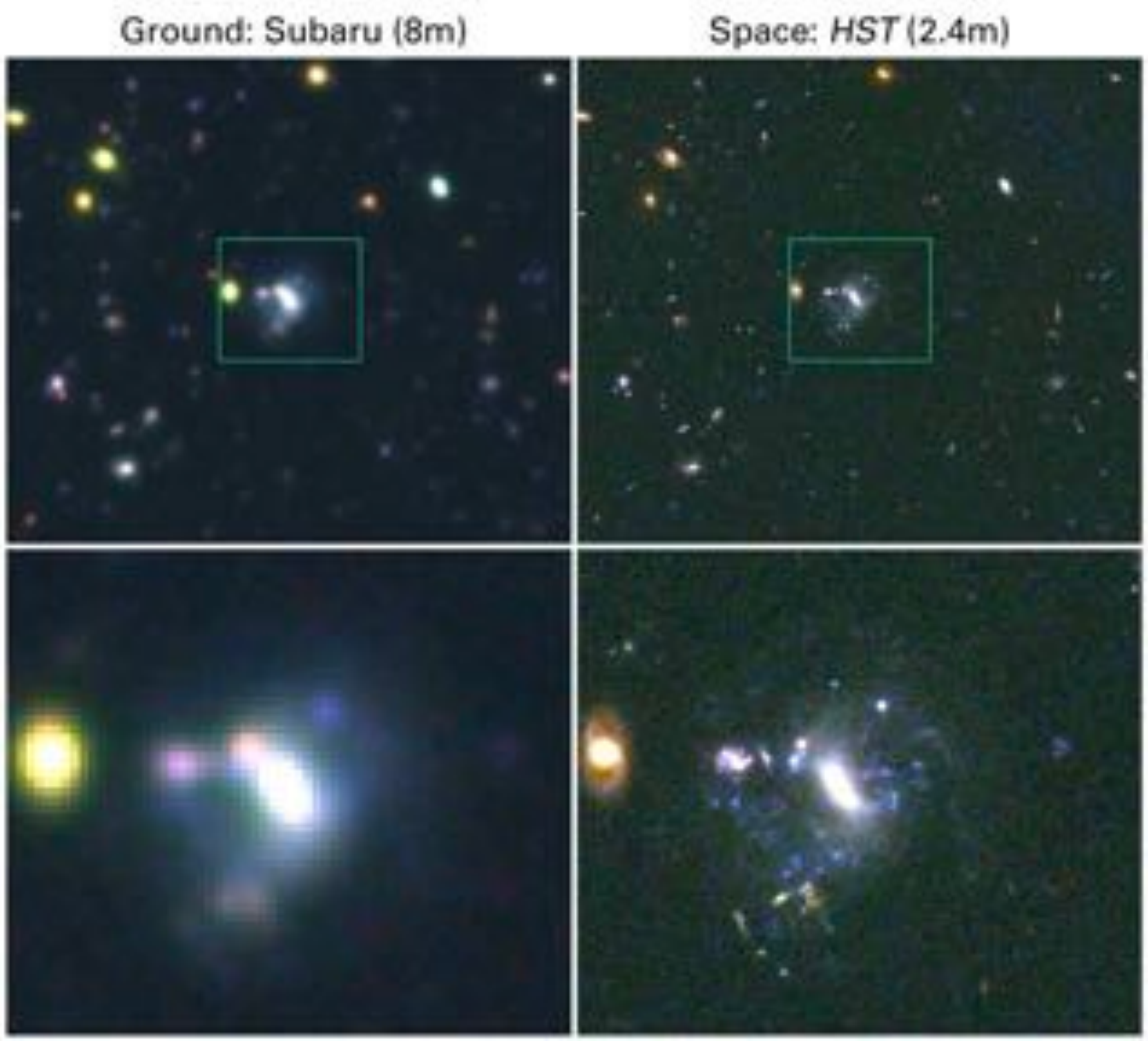
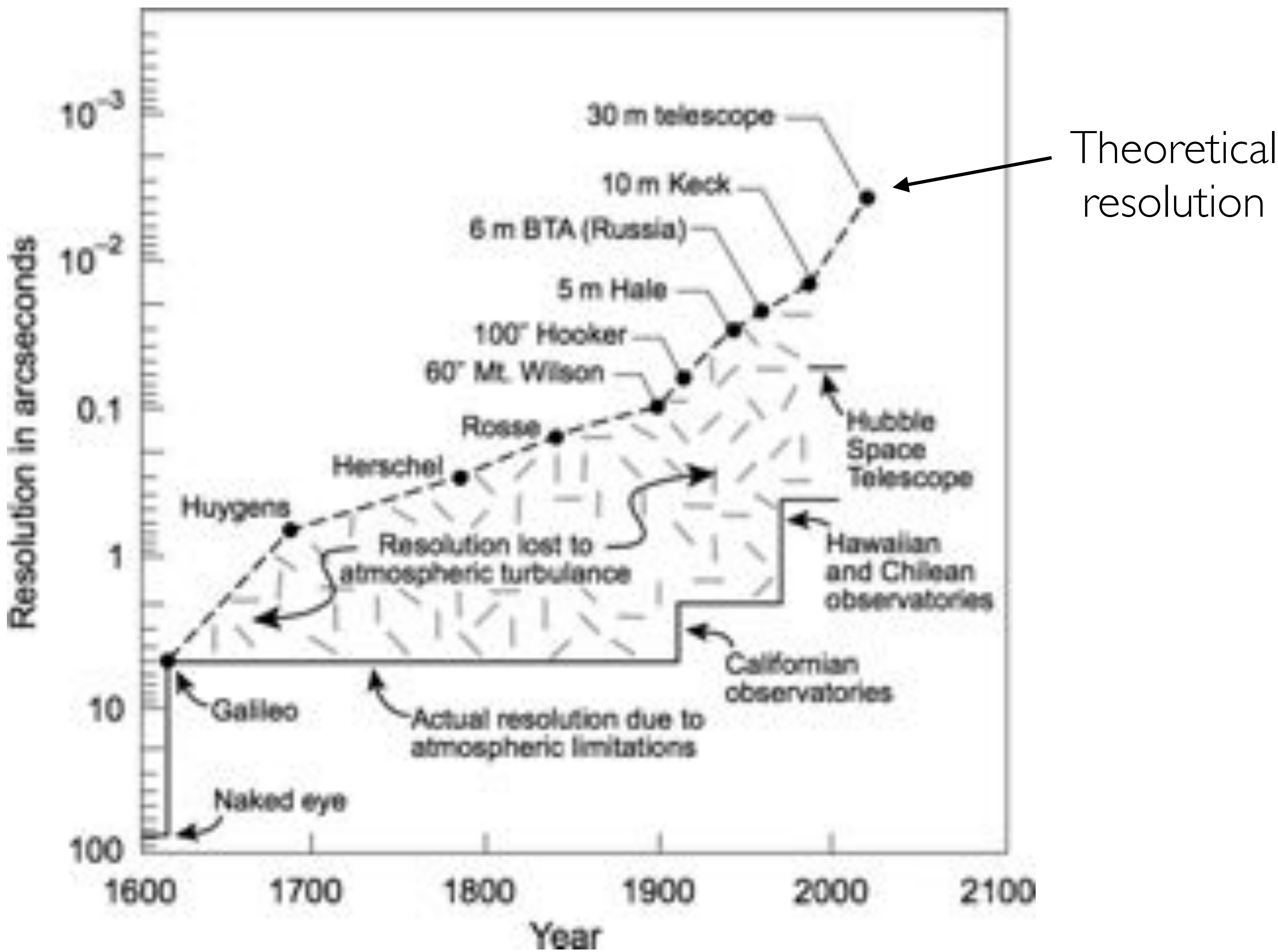
Galileo Nazionale
VISTA
Discovery Channel
Hubble Space Telescope
JWST
Euclid

Hubble Space Telescope

2.4-meter (1990)





30 m telescope
10 m Keck
6 m BTA (Russia)
5 m Hale
100" Hooker
60" Mt. Wilson
Rosse
Herschel
Huygens
Hubble Space Telescope
Resolution lost to atmospheric turbulance
Hawaiian and Chilean observatories
Californian observatories
Galileo
Actual resolution due to atmospheric limitations
Naked eye
Resolution in arcseconds
10^-3
10^-2
0.1
1
10
100
1600
1700
1800
1900
2000
2100
Year
Theoretical resolution

M87 Black Hole (event horizon)

Sirius

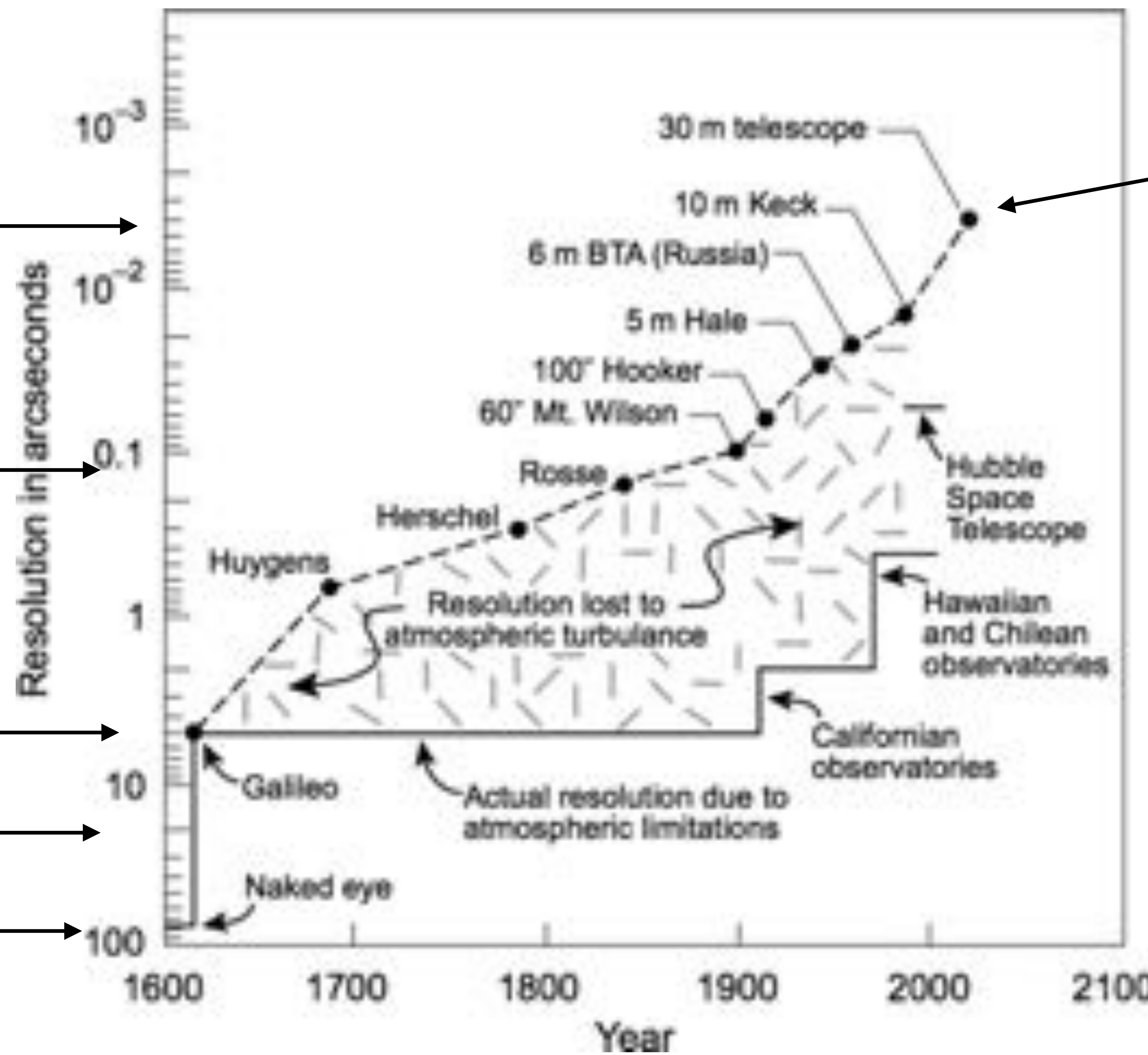
Theoretical resolution

Really distant galaxies

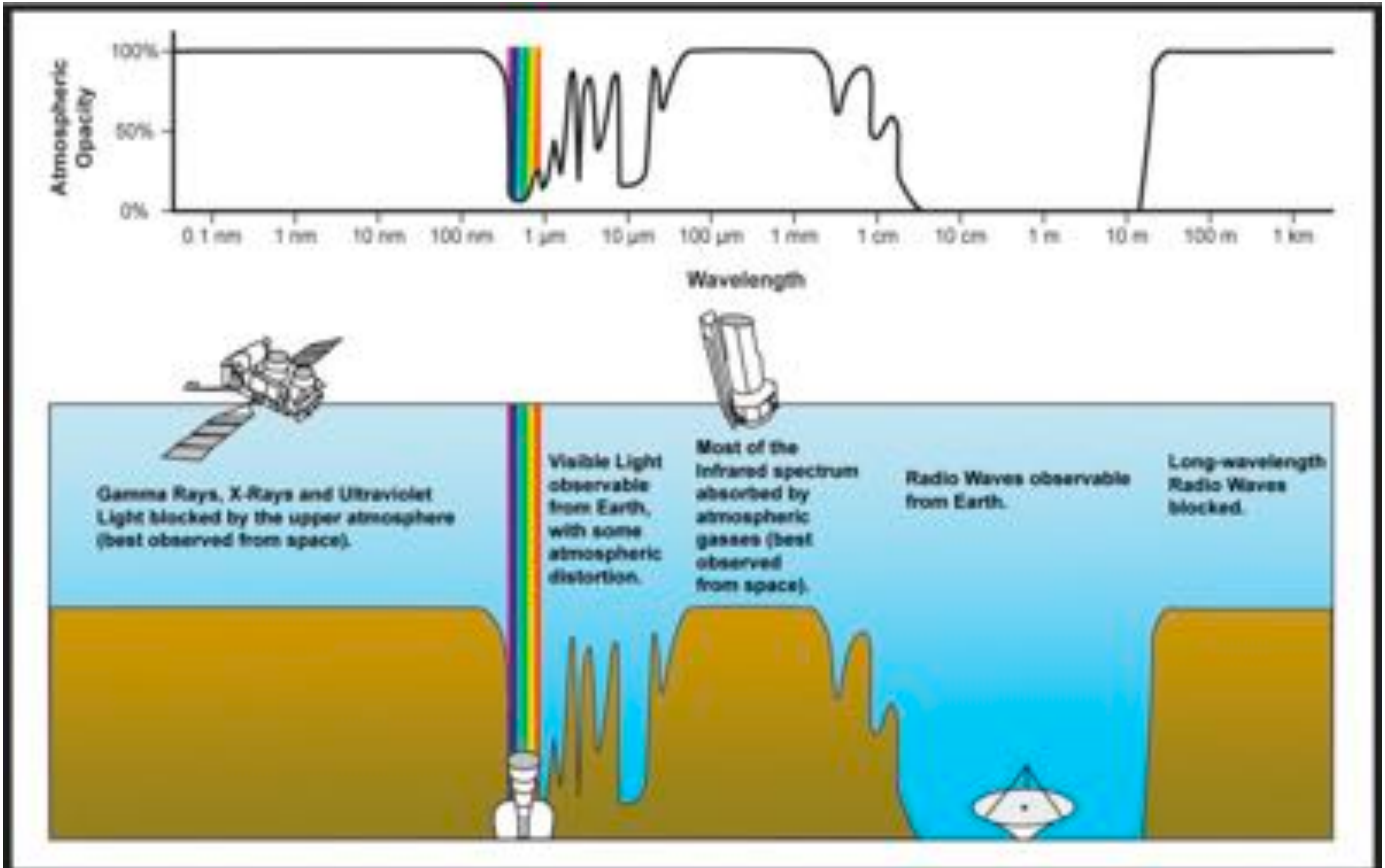
Galaxies

Saturn

A person 6 km away



At some wavelengths, the atmosphere is not transparent!

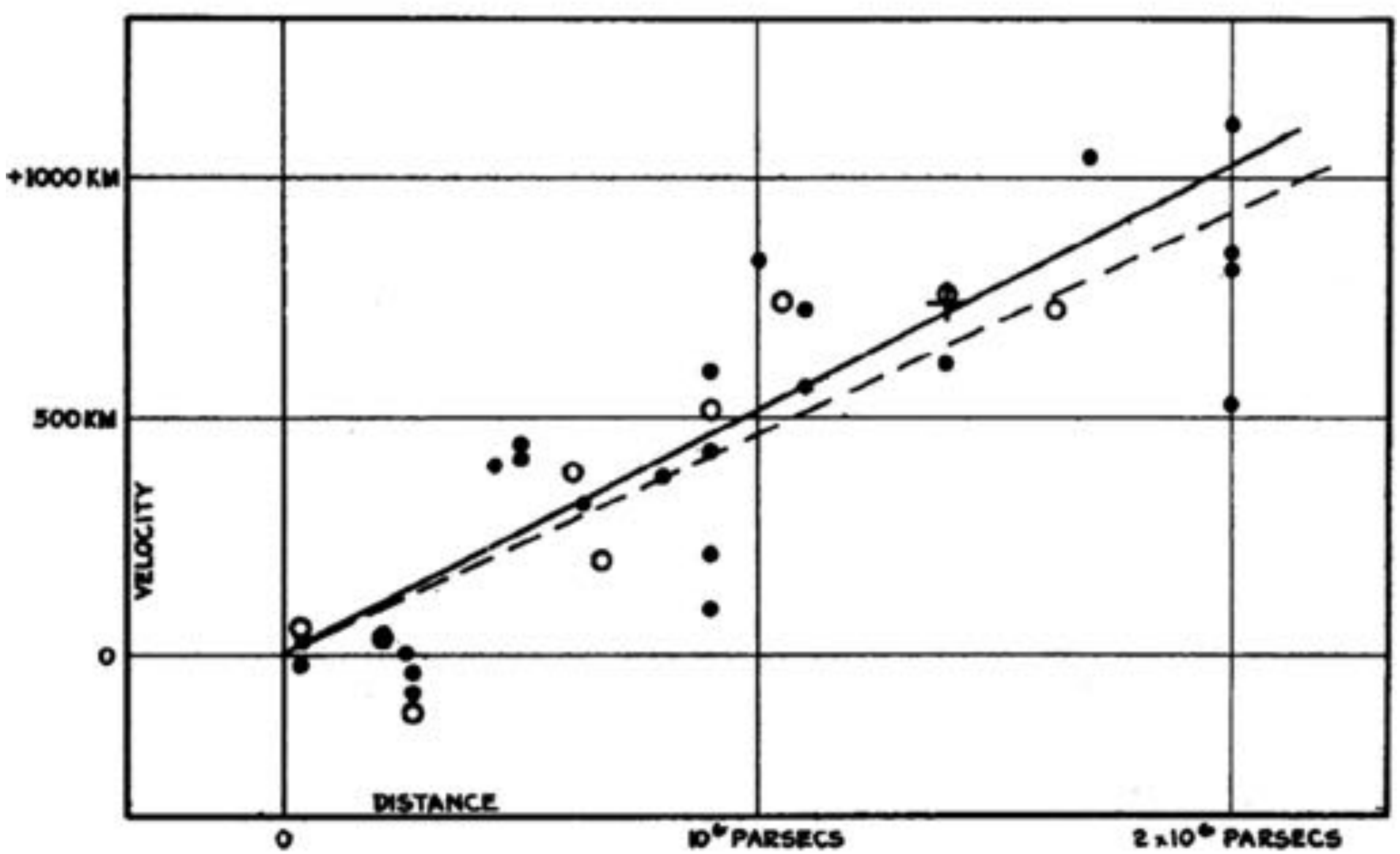


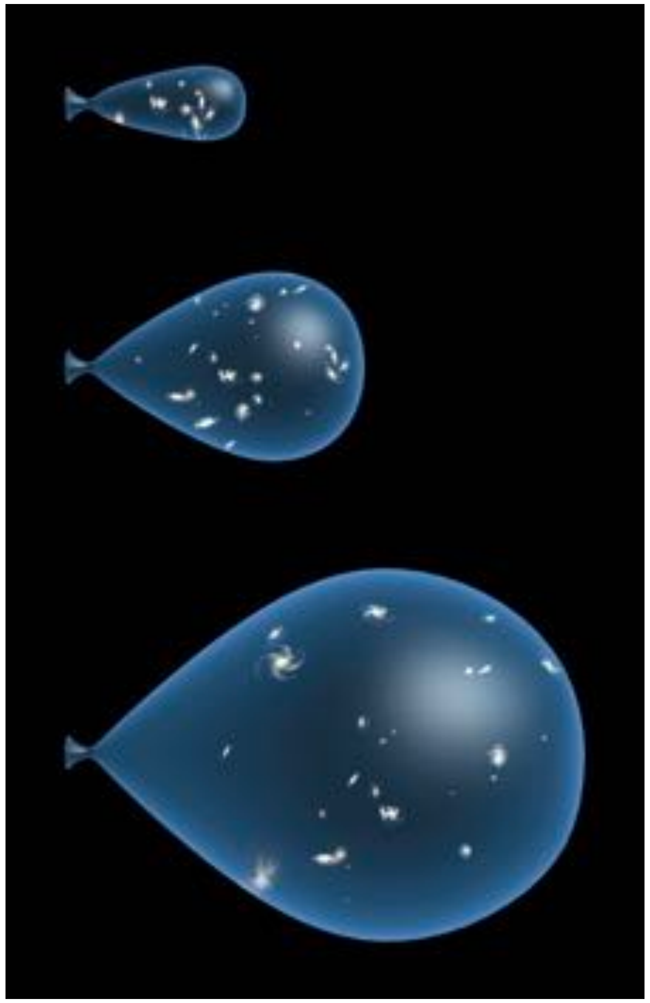
Why do we want infrared observations?

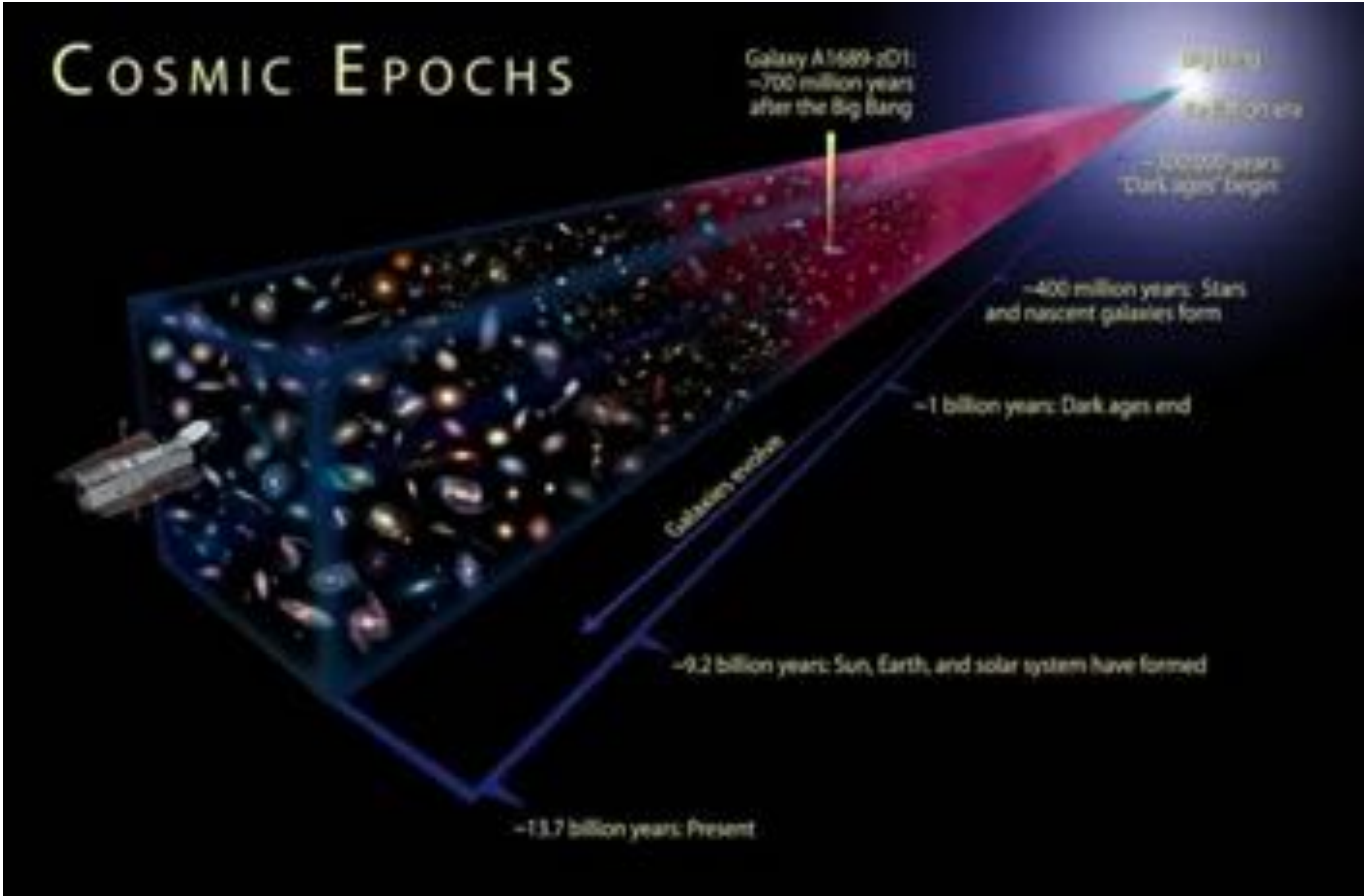
- Some atoms / molecules / black bodies emit in the infrared
- Infrared light can go through dust with minimal attenuation
- Optical light from distant galaxies is redshifted into the infrared

Hubble’s law (1929)

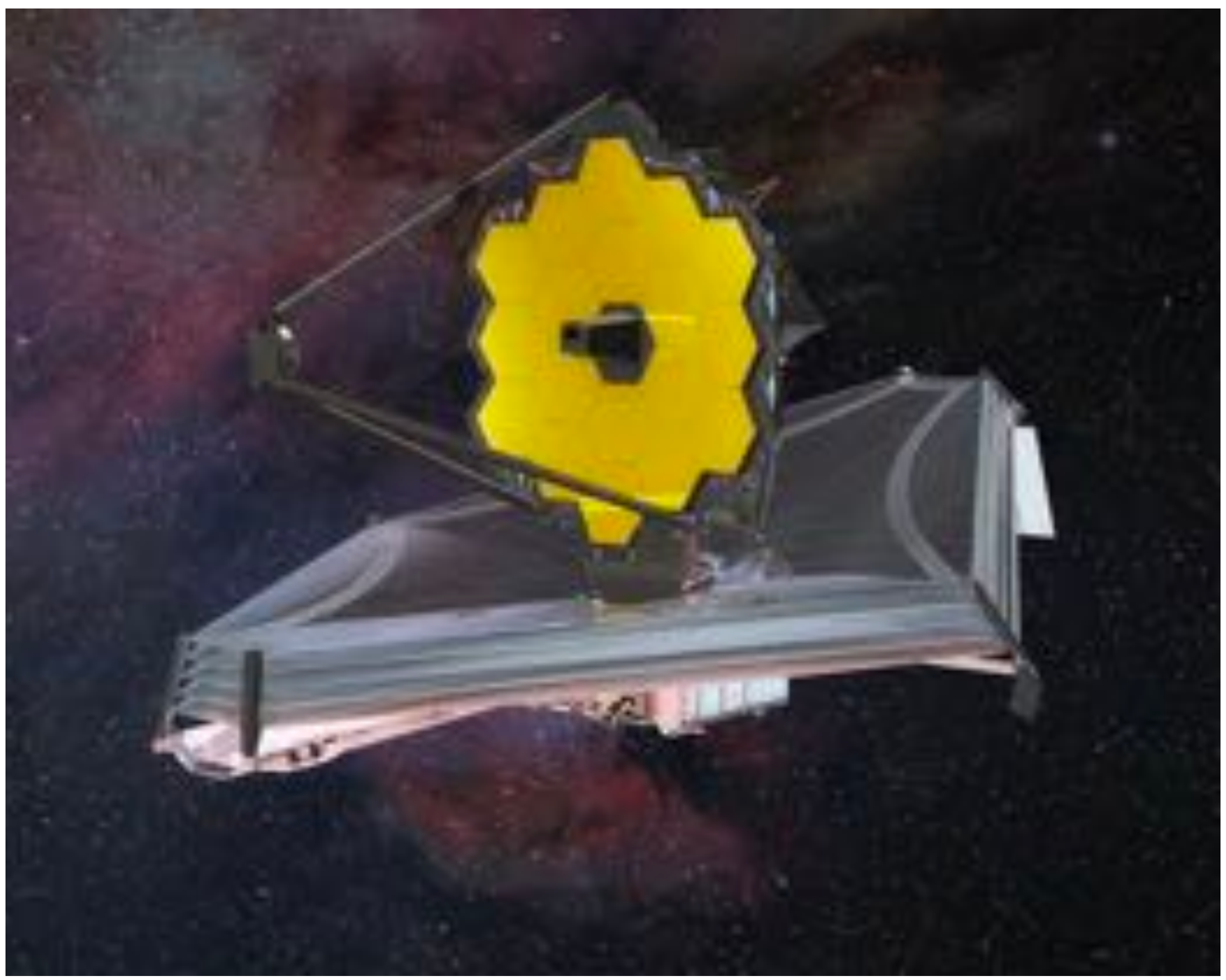
Linear relation between the distance of a galaxy and its receding velocity





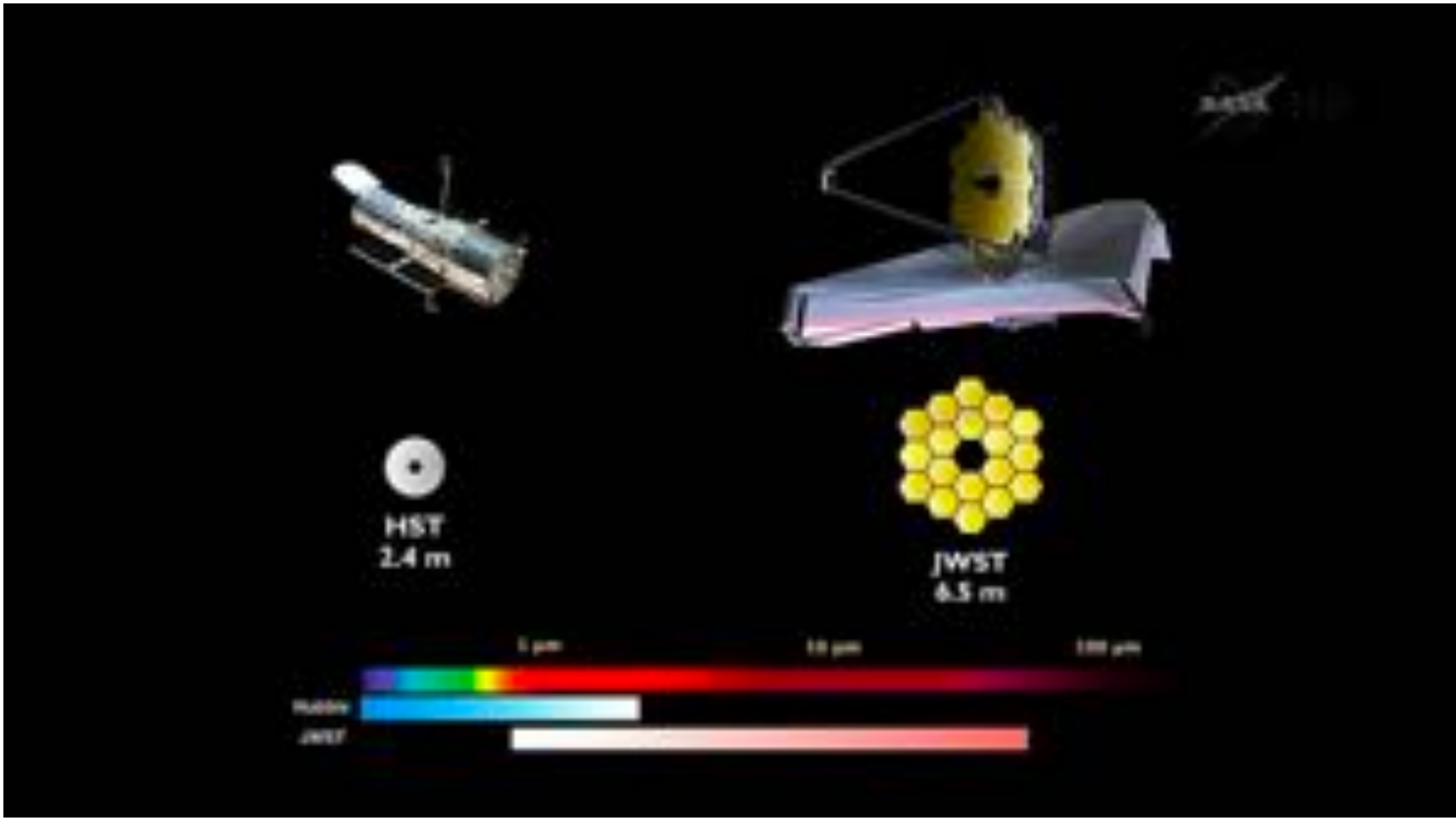

Cosmic Epochs
Galaxy A1689-zD1:
~700 million years
after the Big Bang
~400 million years: Stars
and nascent galaxies form
~1 billion years: Dark ages end
Galaxies evolve
~9.2 billion years: Sun, Earth, and solar system have formed
~13.7 billion years: Present

James Webb Space Telescope (JWST)
6.5-meter (launched December 25th, 2021)

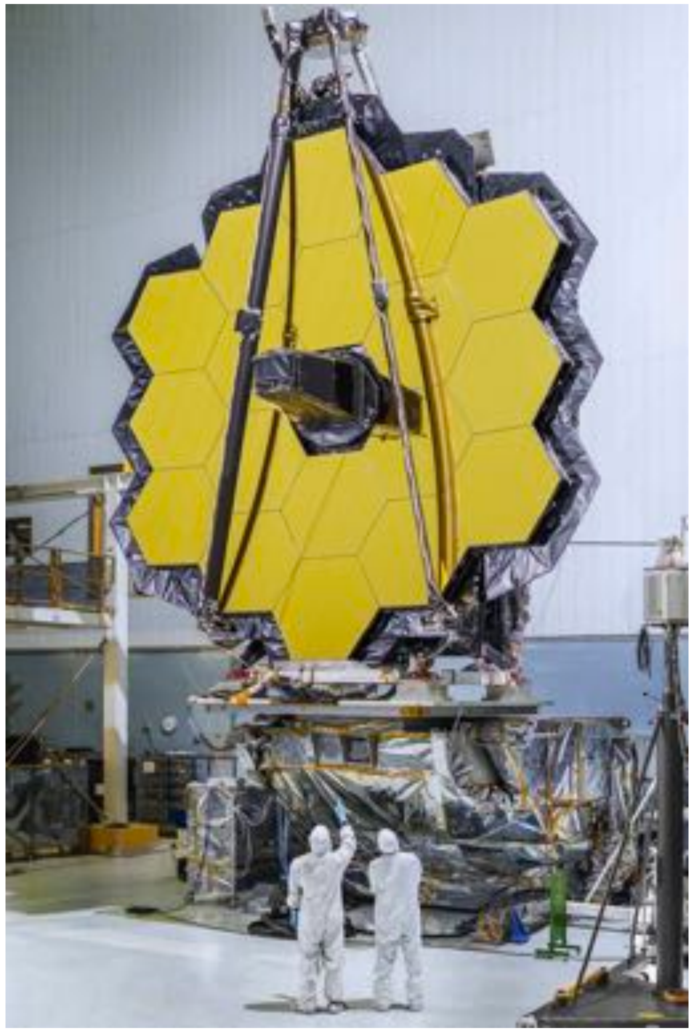


- Relatively big mirror (6.5 m)
- Very good spatial resolution
- Sensitive to near- and mid-infrared light
- Advanced spectroscopic capabilities

Hubble Space Telescope vs James Webb Space Telescope



James Webb, NASA
Administrator 1961-1968



Collaboration between US, Europe, and Canada

NASA esa CSA ASC

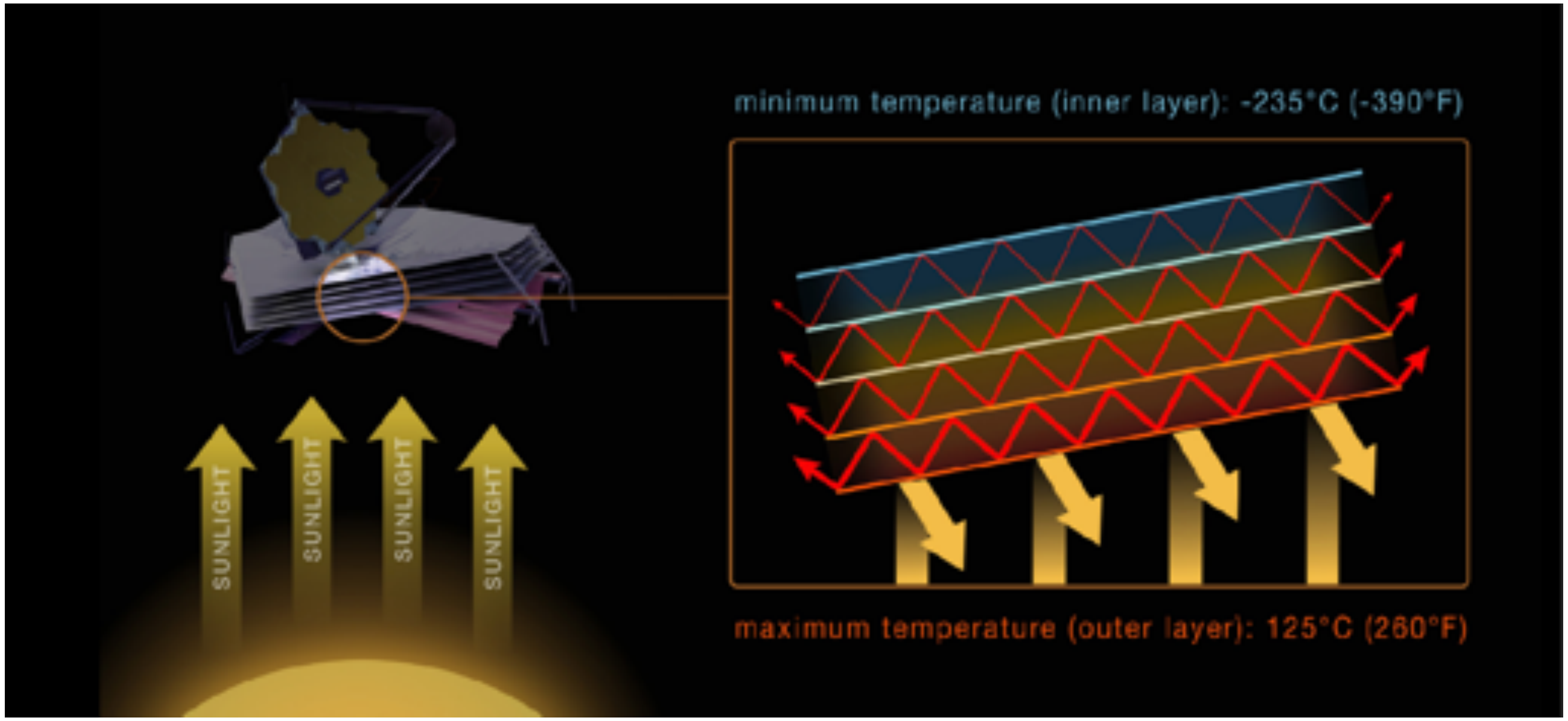
Segmented Mirrors

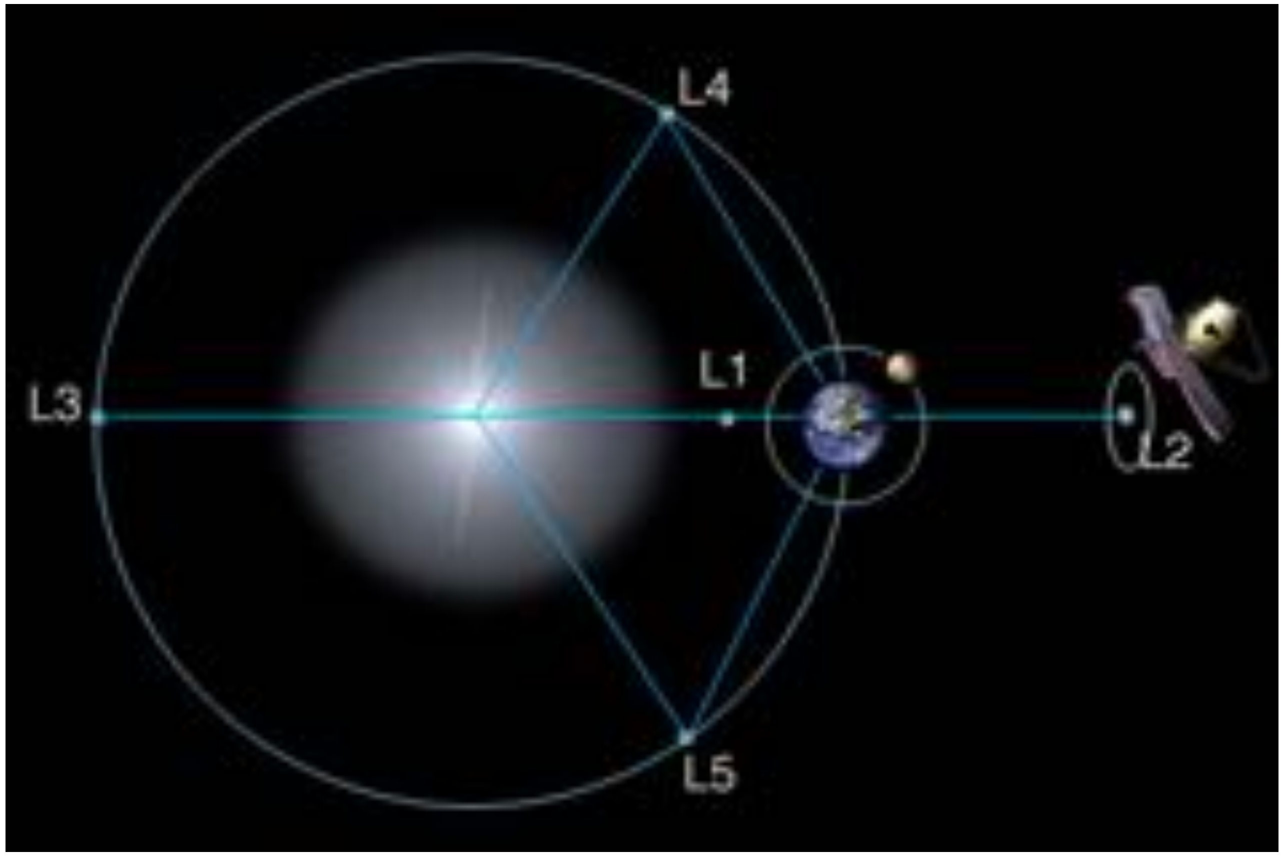
Guido Horn d'Arturo developed the first segmented mirror in Bologna (1932-1952)

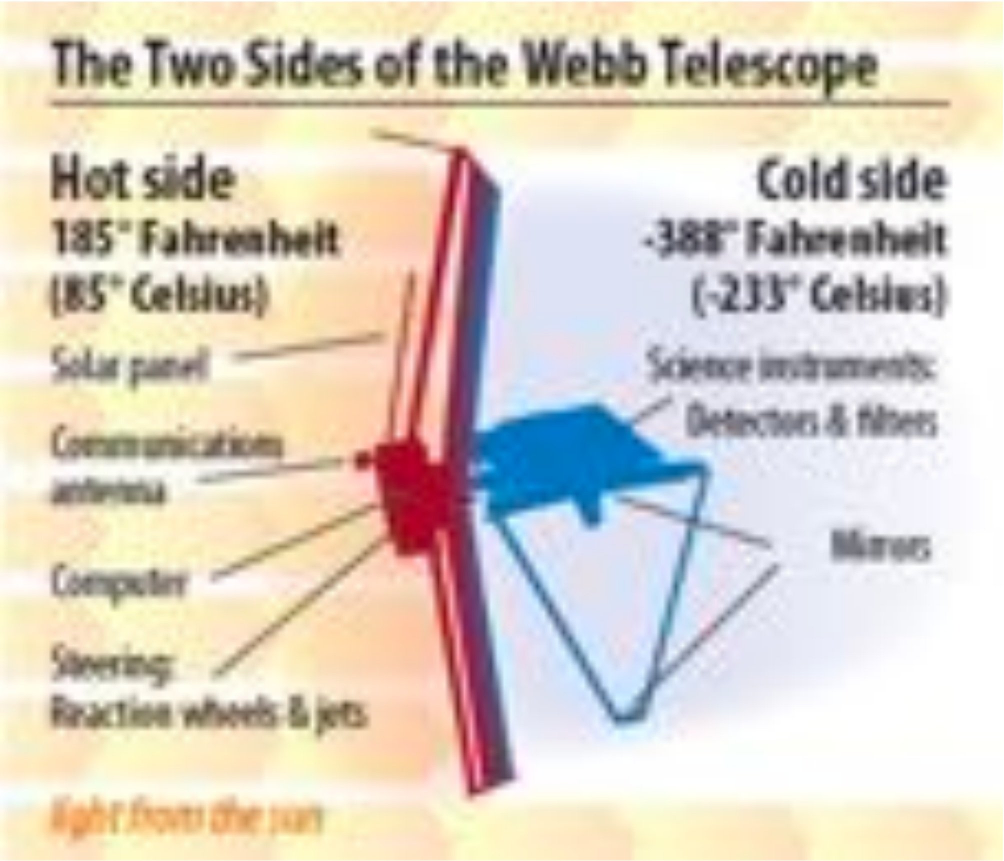
Fig. 12. The complex mechanism of 183 screws to regulate the 61 tiles can be seen on the ceiling of the small room placed under the 1.80 m mirror. (photo: F. Bonoli)

Bonoli (2018)

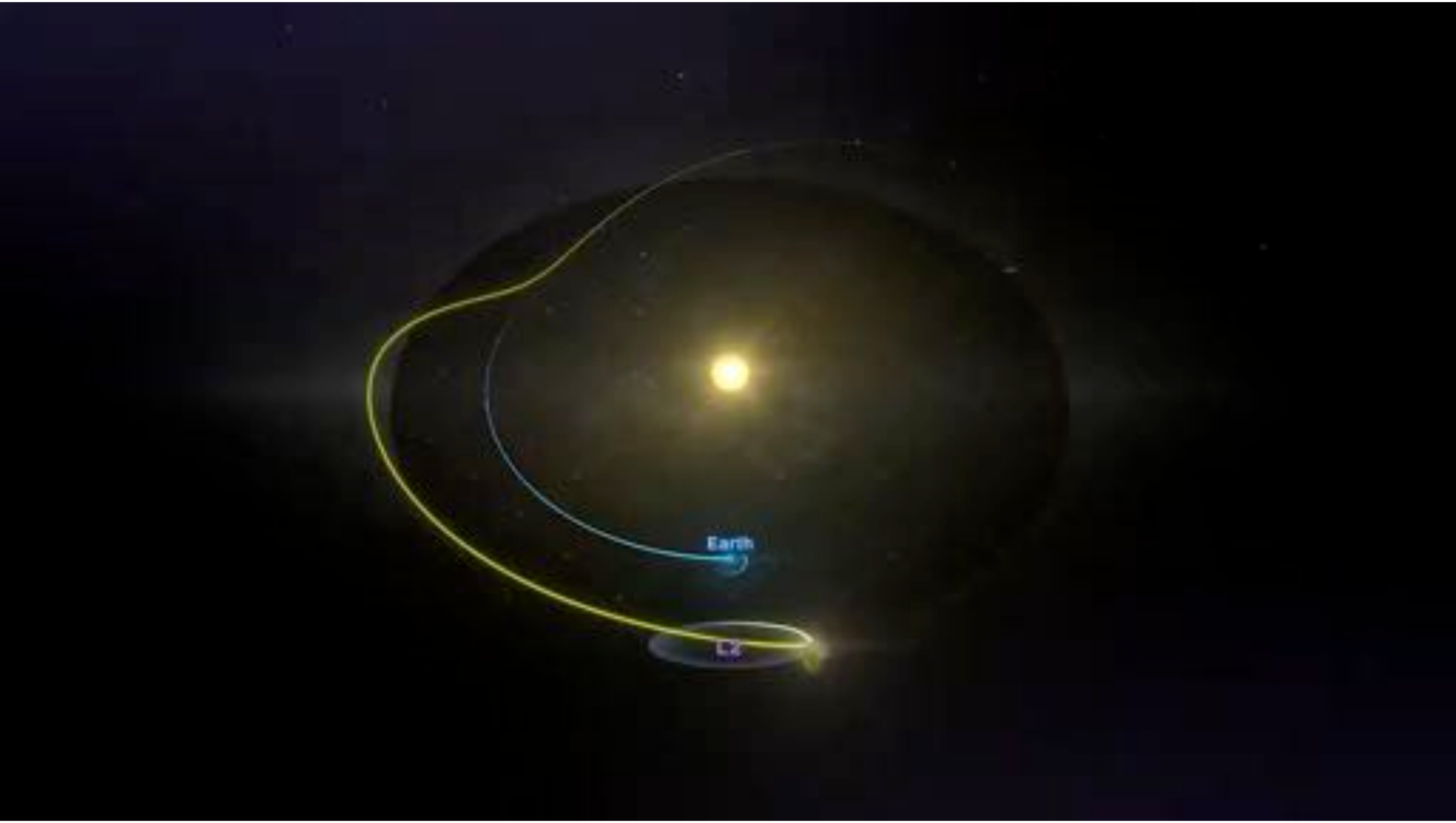
Then re-invented in the 1980s by Jerry Nelson for the design of the Keck telescopes


minimum temperature (inner layer): -235°C (-390°F)
SUNLIGHT
SUNLIGHT
SUNLIGHT
SUNLIGHT
maximum temperature (outer layer): 125°C (260°F)


L4
L1
L3
L2
L5


The Two Sides of the Webb Telescope
Hot side
185° Fahrenheit
(85° Celsius)
Cold side
-388° Fahrenheit
(-233° Celsius)
Solar panel
Communications antenna
Computer
Steering:
Reaction wheels & jets
Science instruments:
Detectors & filters
Mirrors
light from the sun


Hubble
Moon
Webb
384,400 km
570 km
1.5 million km
L2


Earth
L2

Launch: Dec 25th, 2021

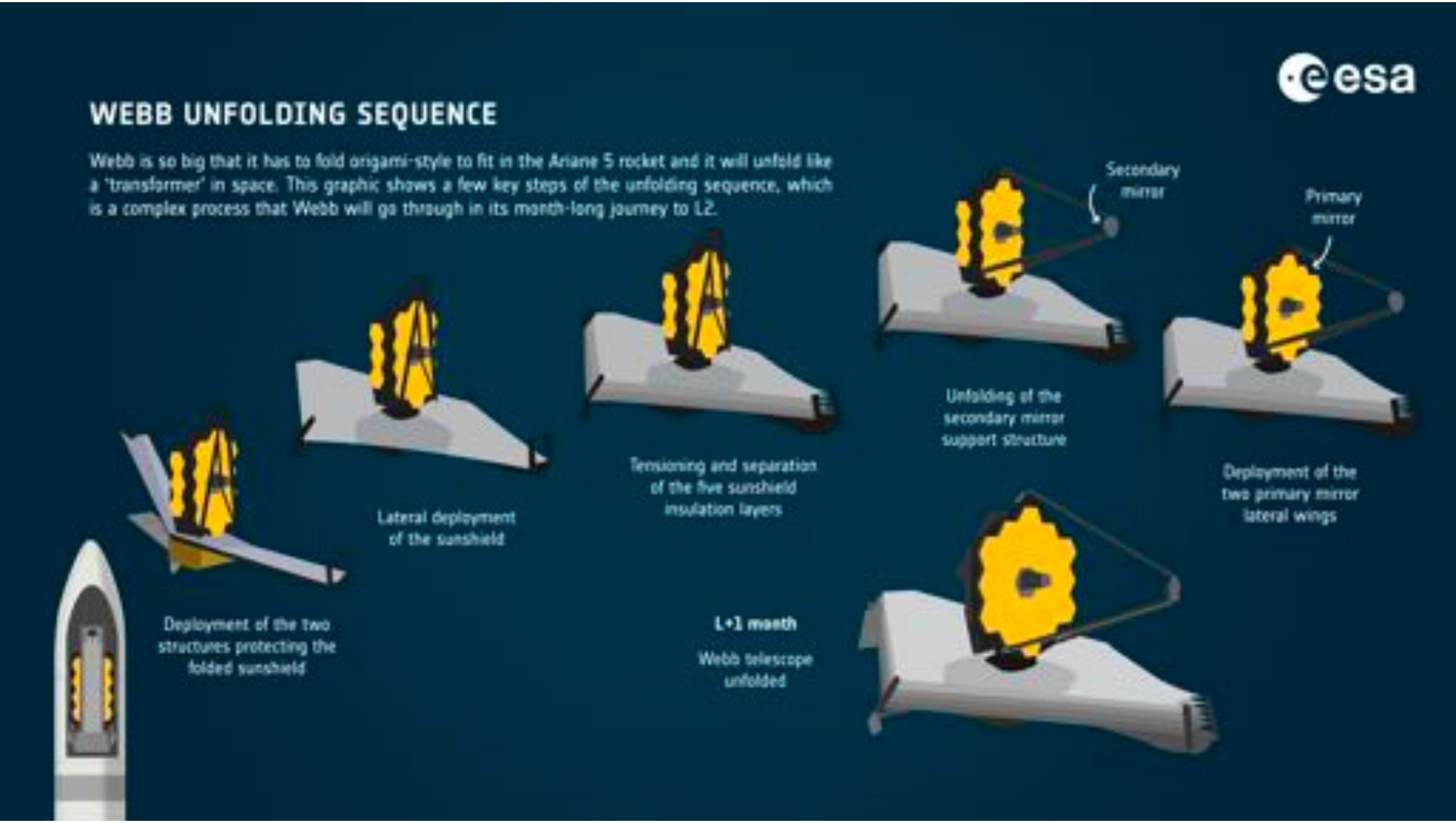
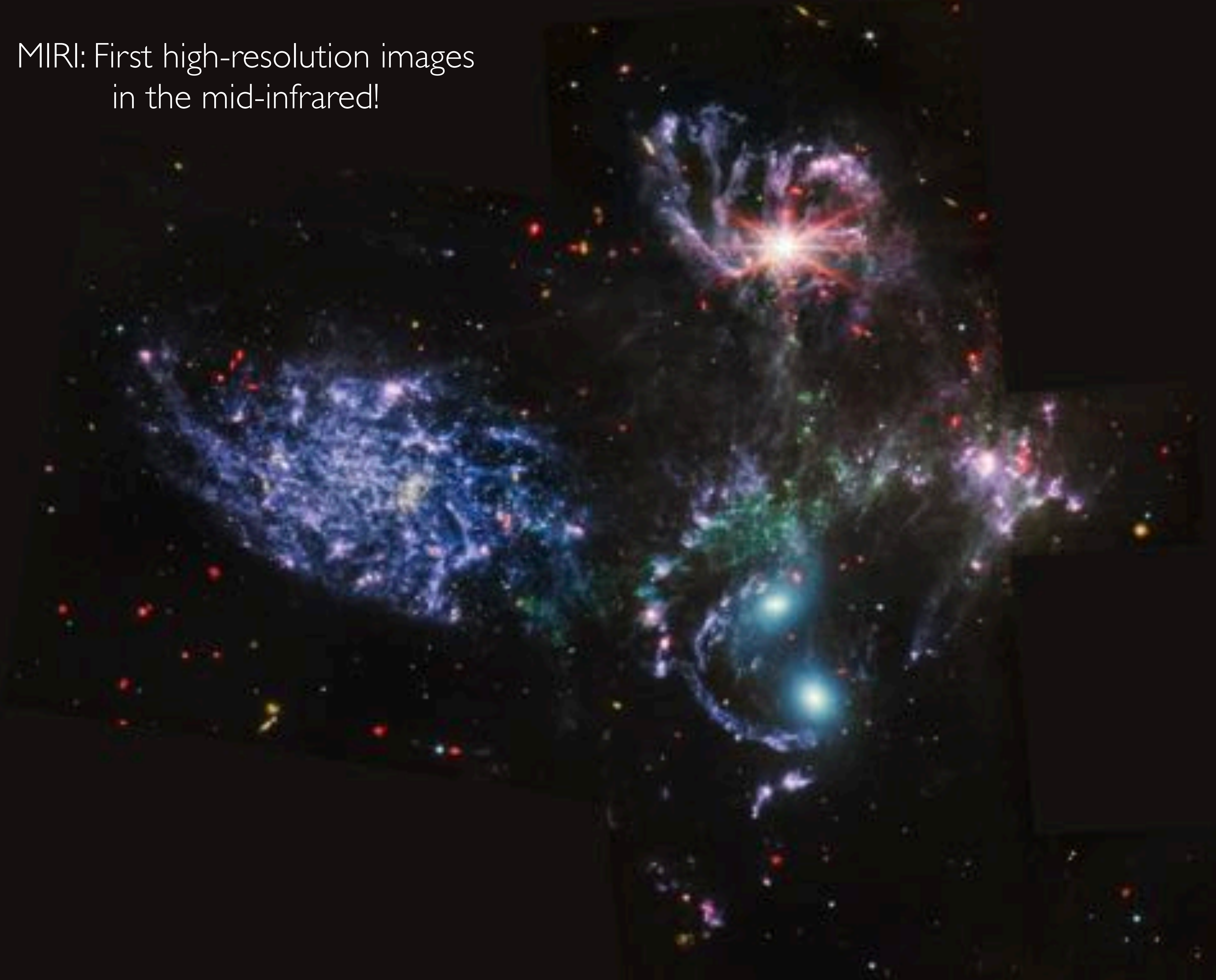

esa
WEBB UNFOLDING SEQUENCE
Webb is so big that it has to fold origami-style to fit in the Ariane 5 rocket and it will unfold like a 'transformer' in space. This graphic shows a few key steps of the unfolding sequence, which is a complex process that Webb will go through in its month-long journey to L2.
Deployment of the two structures protecting the folded sunshield
Lateral deployment of the sunshield
Tensioning and separation of the five sunshield insulation layers
Secondary mirror
Unfolding of the secondary mirror support structure
Primary mirror
Deployment of the two primary mirror lateral wings
L+1 month
Webb telescope unfolded

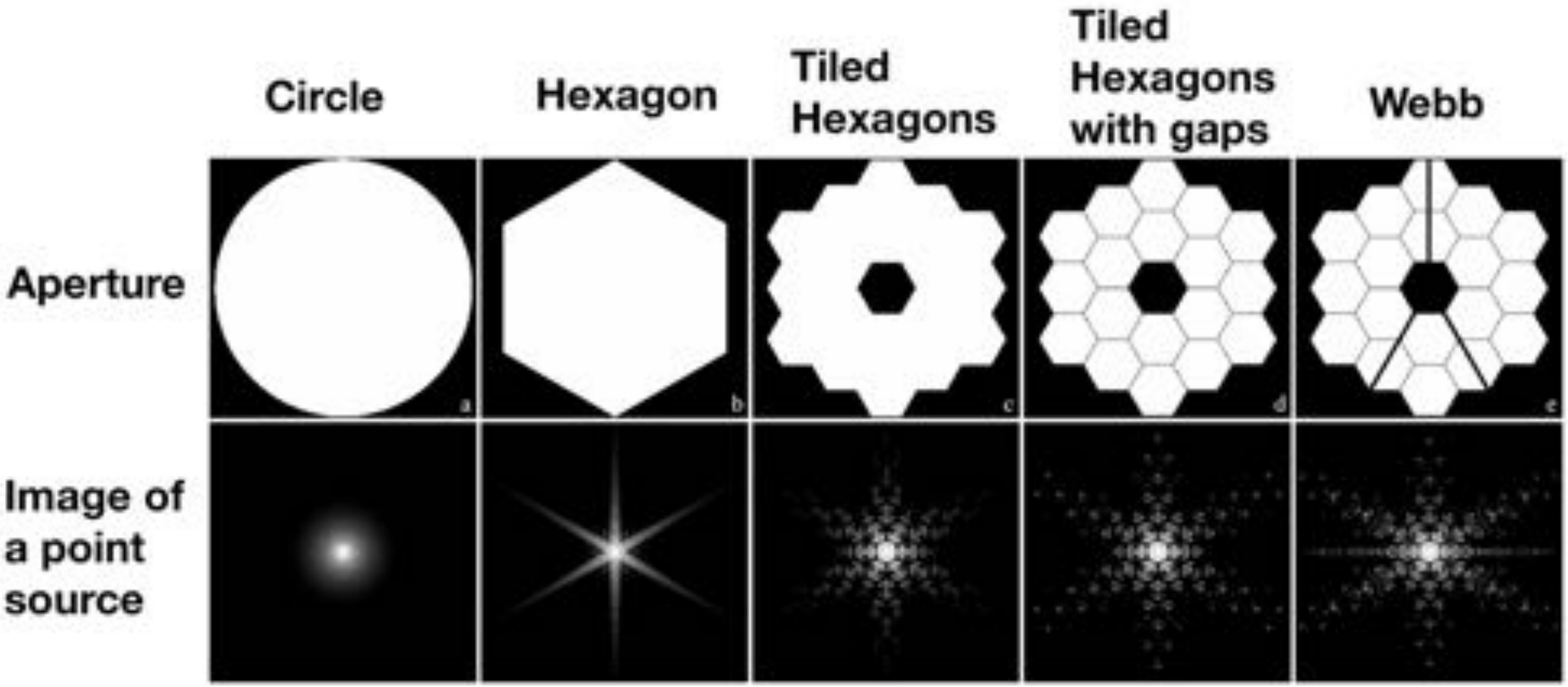
Image stacking: from 18 small telescopes to one large telescope

First images revealed on July 12th, 2022

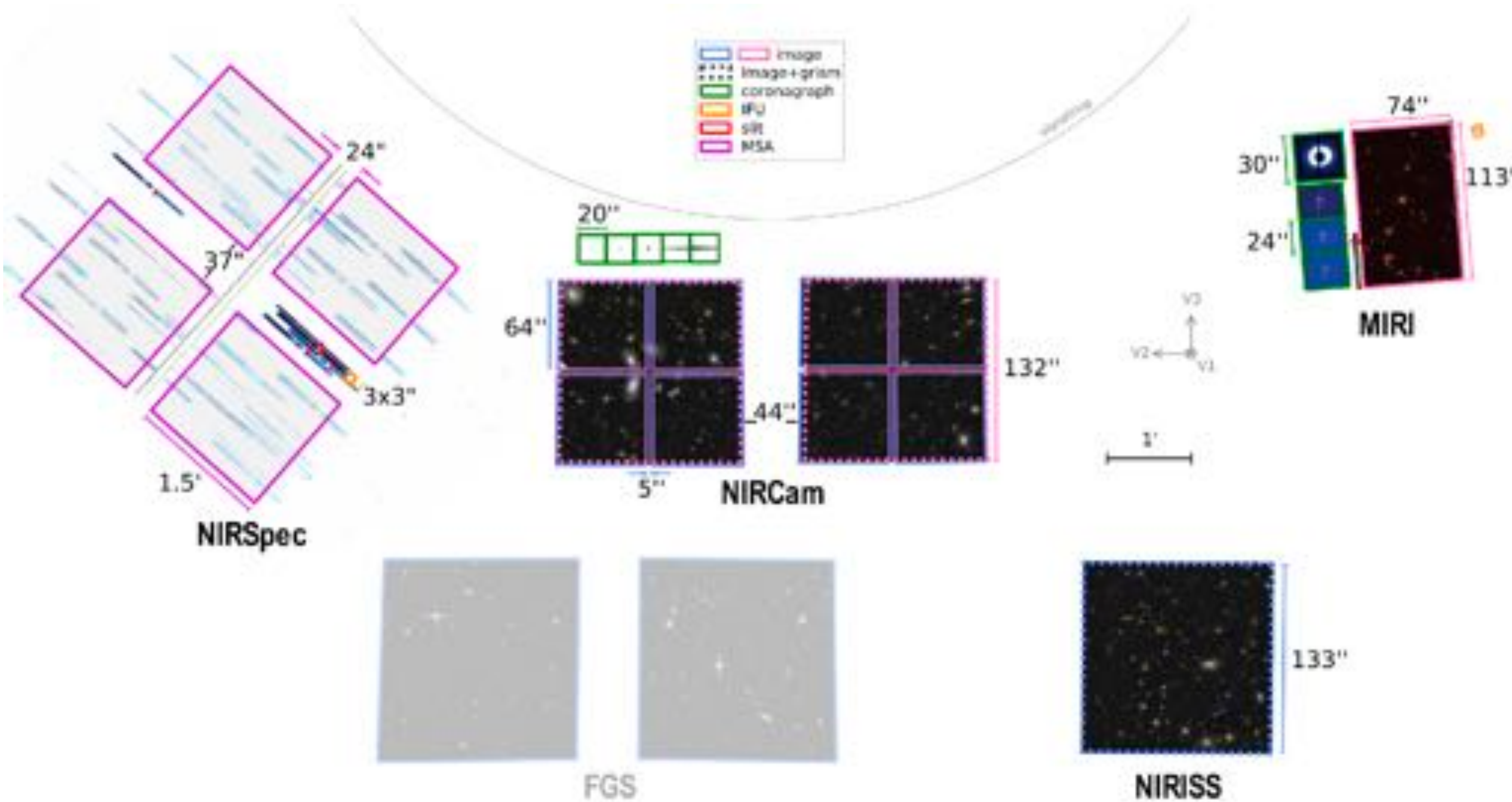
MIRI: First high-resolution images in the mid-infrared!




First JWST “deep field”

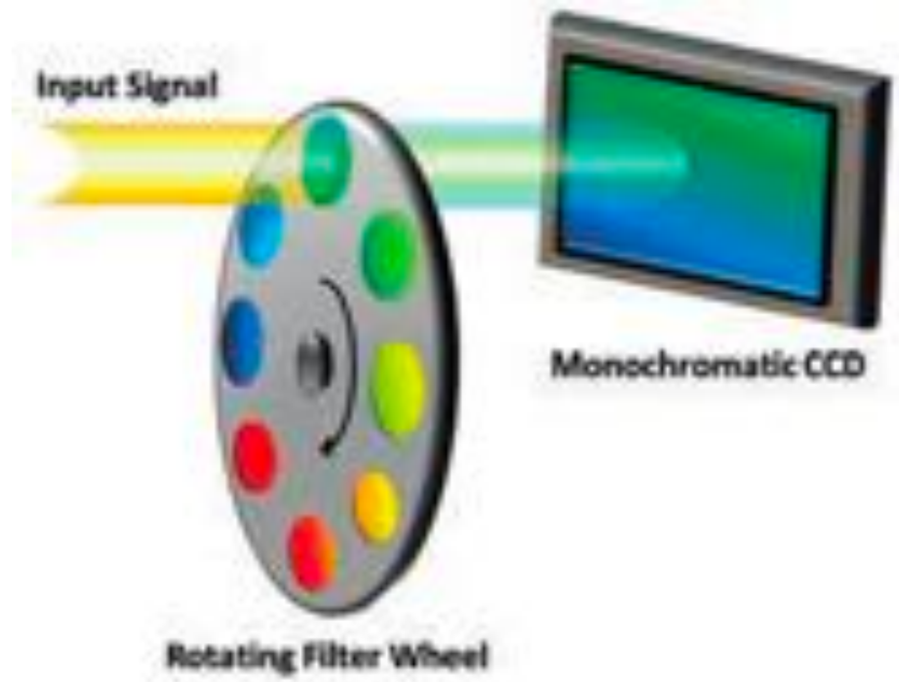

Circle
Hexagon
Tiled Hexagons
Tiled Hexagons with gaps
Webb
Aperture
Image of a point source
a
b
c
d
e

JWST has four instruments on the focal plane:
they receive light from the sky **simultaneously**



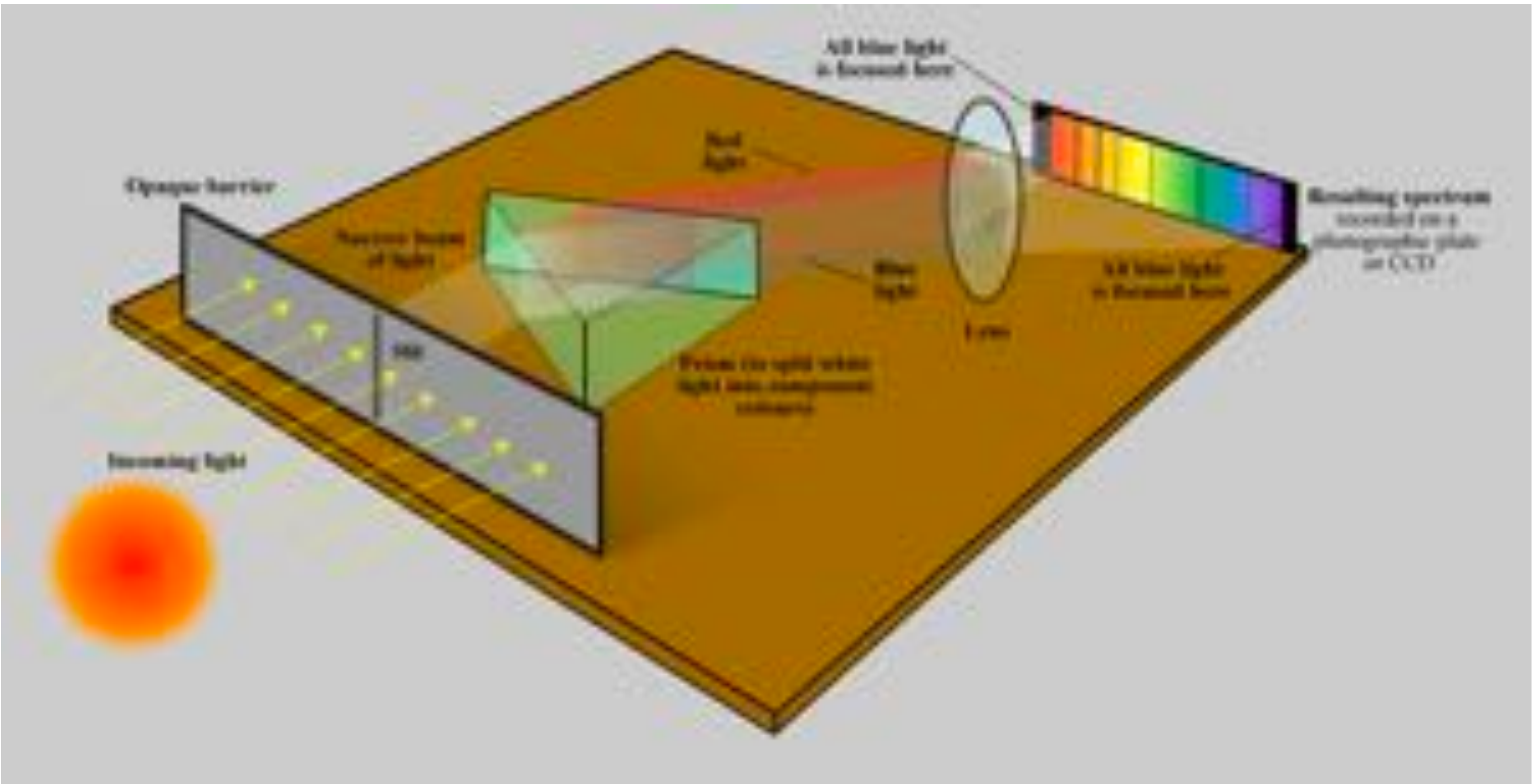
Imaging

A "photograph" taken in a specific wavelength interval



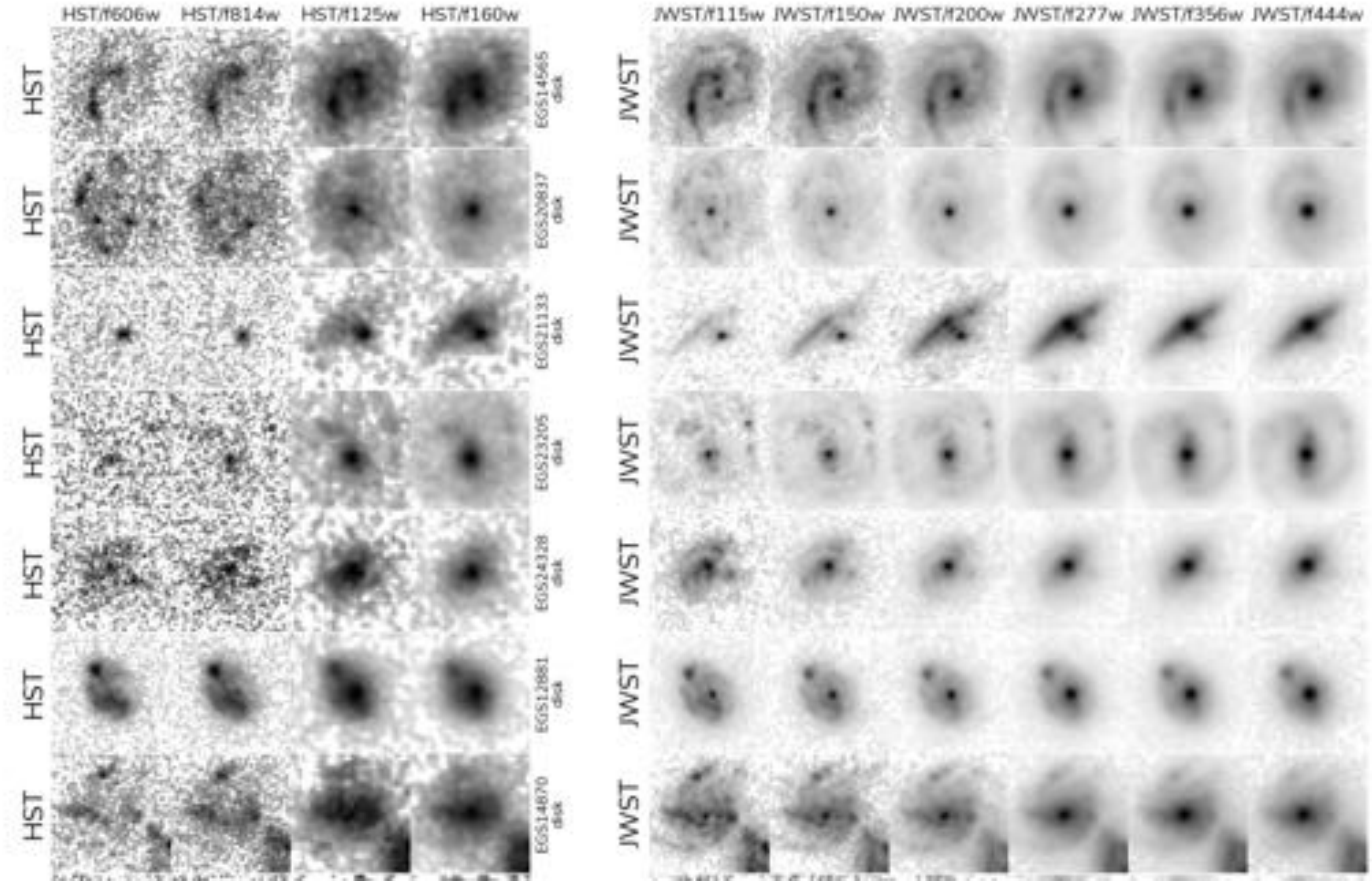
Spectroscopy

Light is decomposed into different wavelengths using a disperser (prism, grating, etc)



Distant galaxy observed at 1.15 micron

Distant galaxy observed at different wavelengths

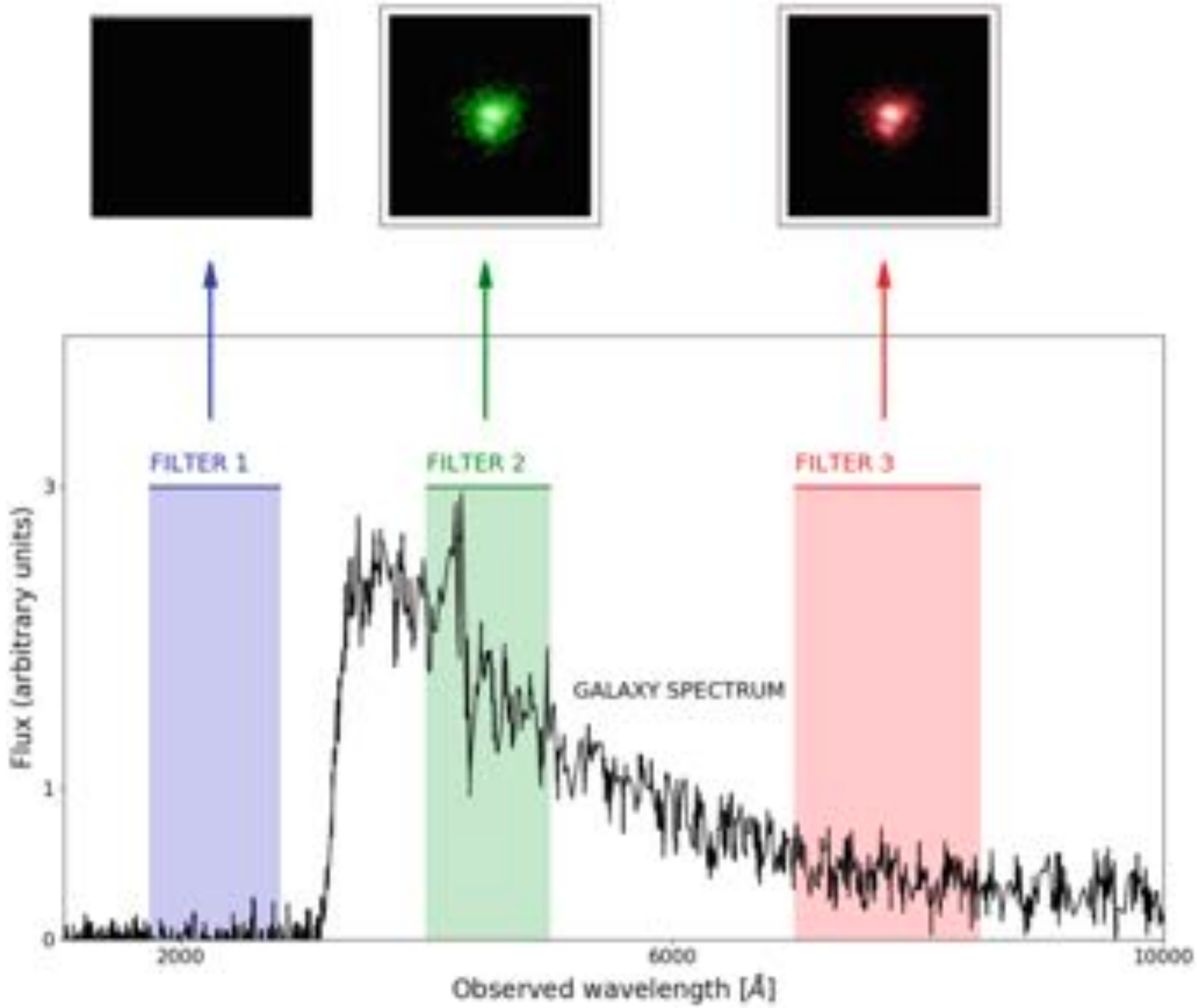


Ferreira et al. (2022b)

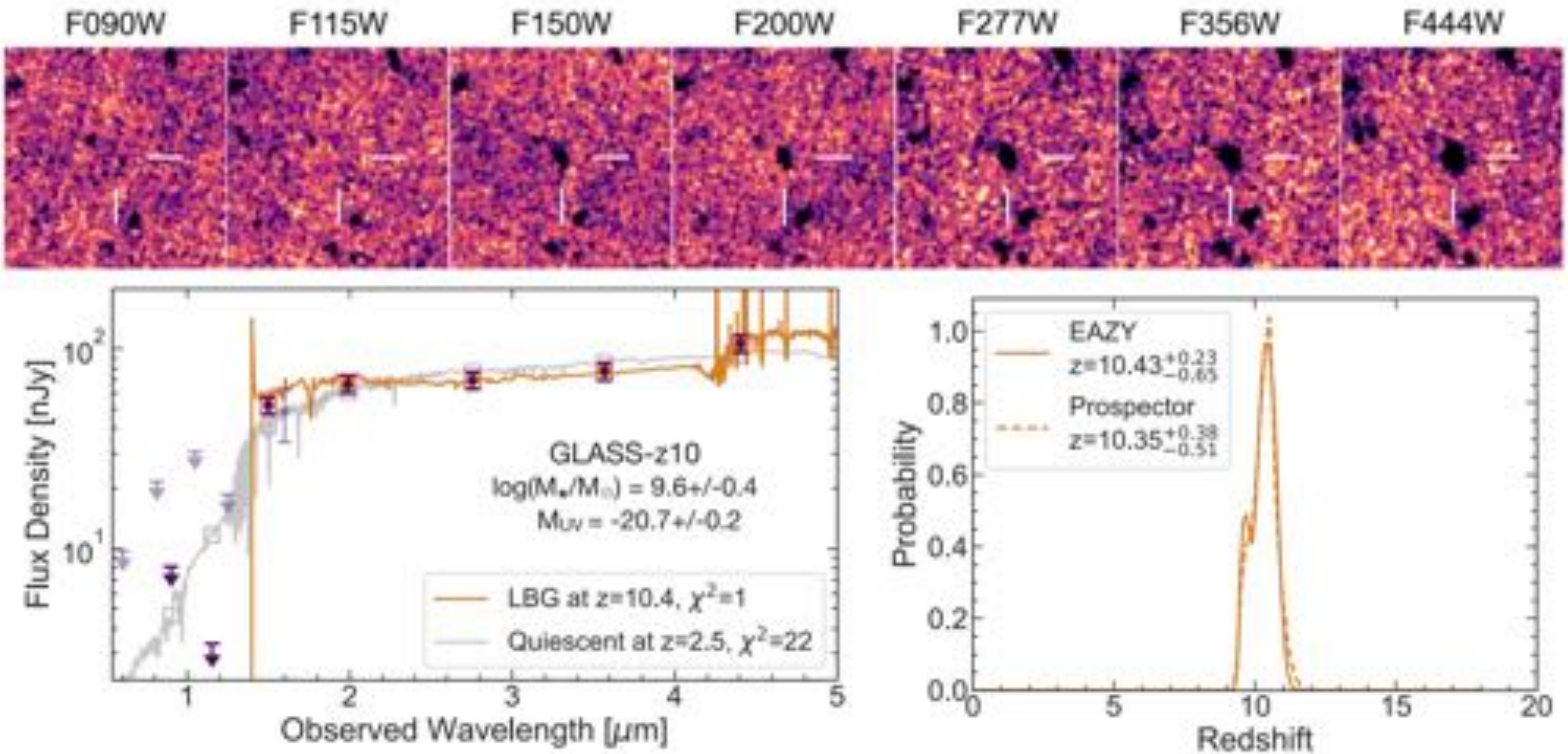
"HST-dark" galaxies could not be seen before!

Nelson et al. 2022

We can characterize the emission spectrum of a galaxy by using several filters

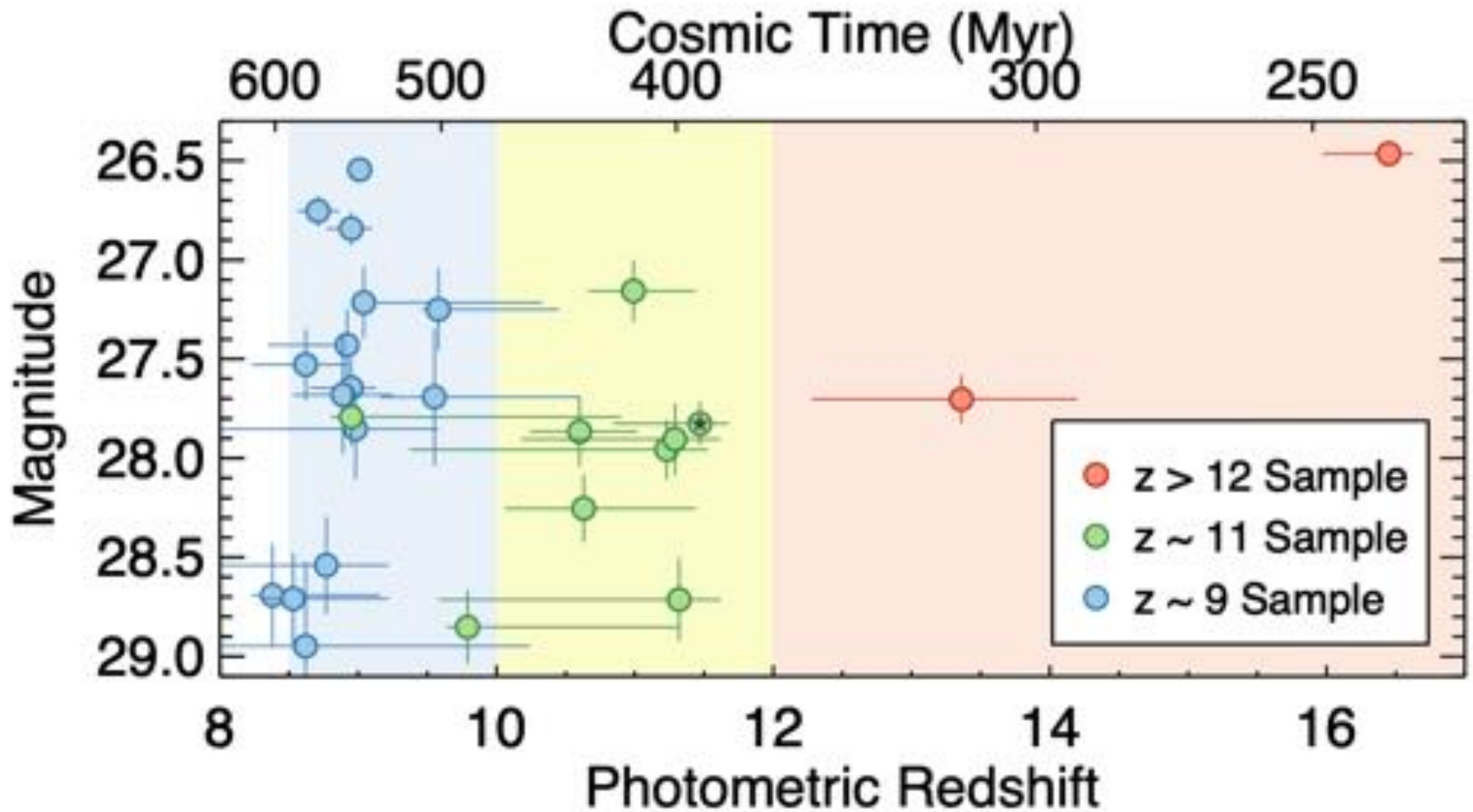


Discovery of distant galaxies:
Redshift = 9, 10, 11, 12…



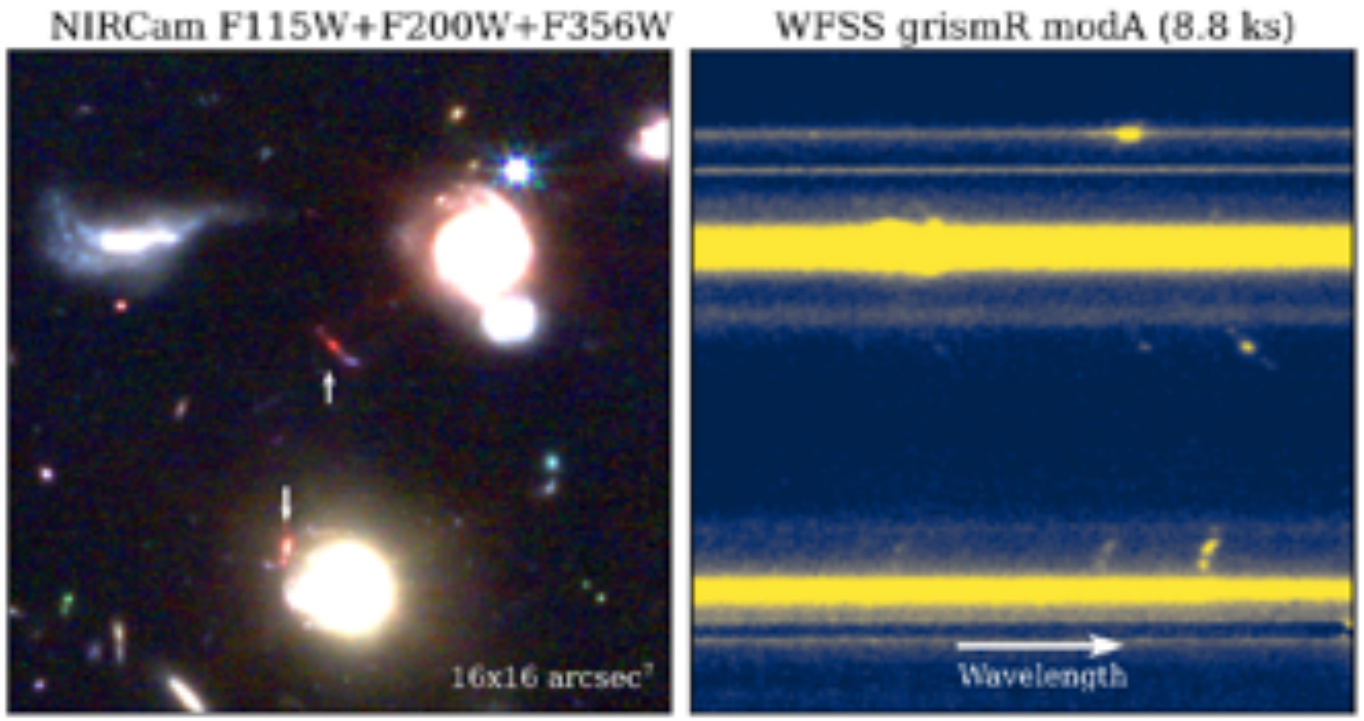
Naidu et al. 2022a

There are **a lot** of high-redshift galaxies in the first JWST images

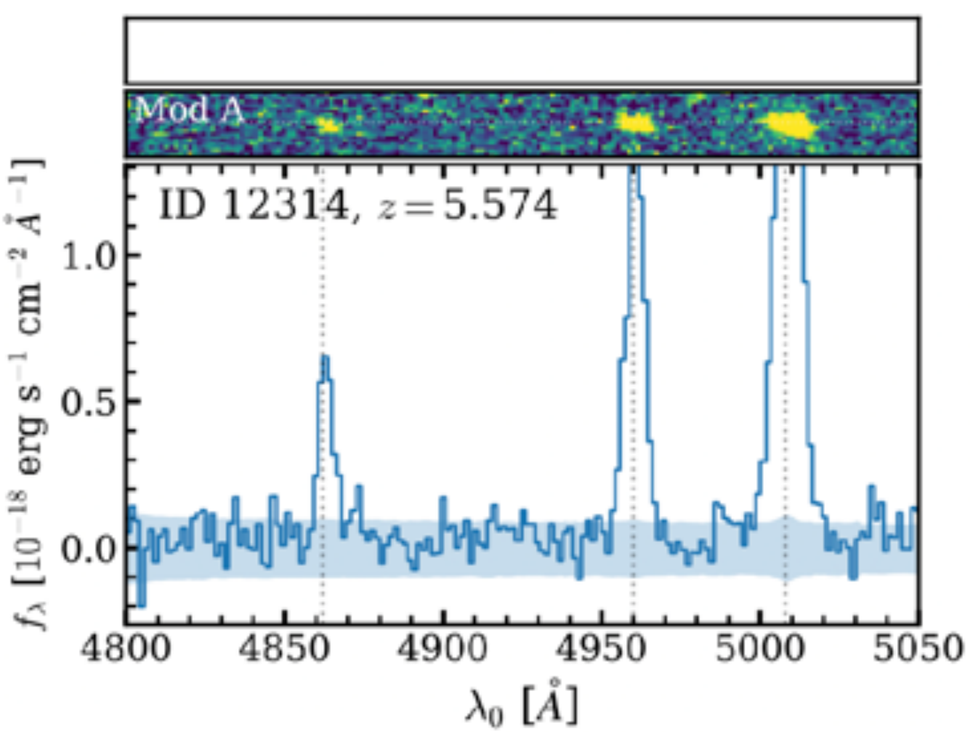


Finkelstein et al. (2022)

Wide-field slitless spectroscopy: every galaxy is dispersed

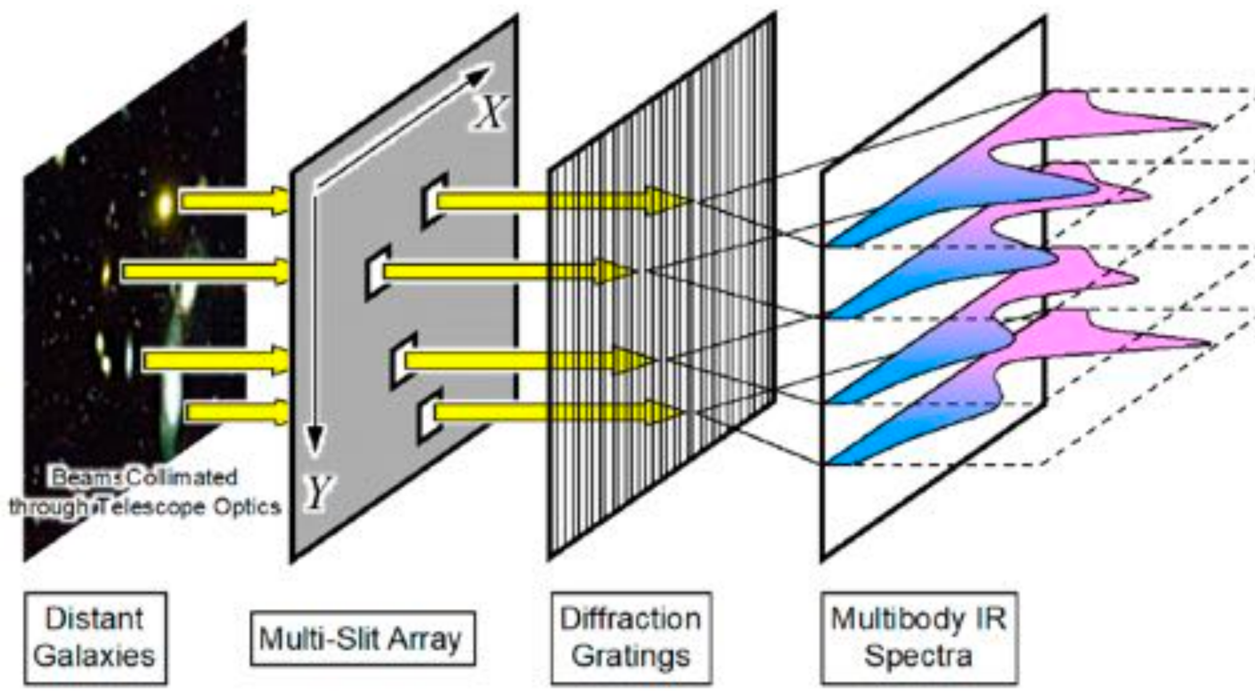


Matthee et al. (2022)

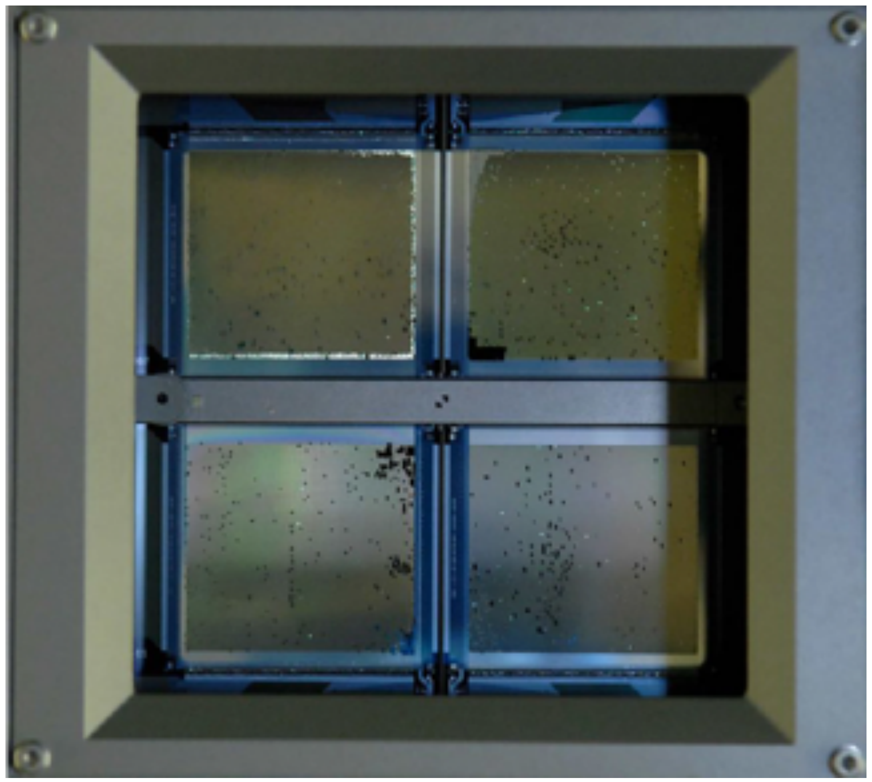


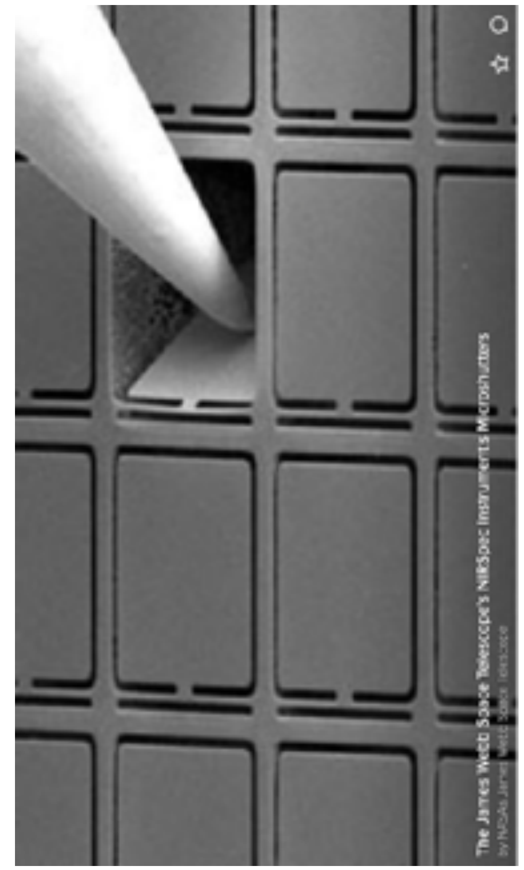
Slitless spectroscopy is noisy: we need "slits" to isolate the light from the target

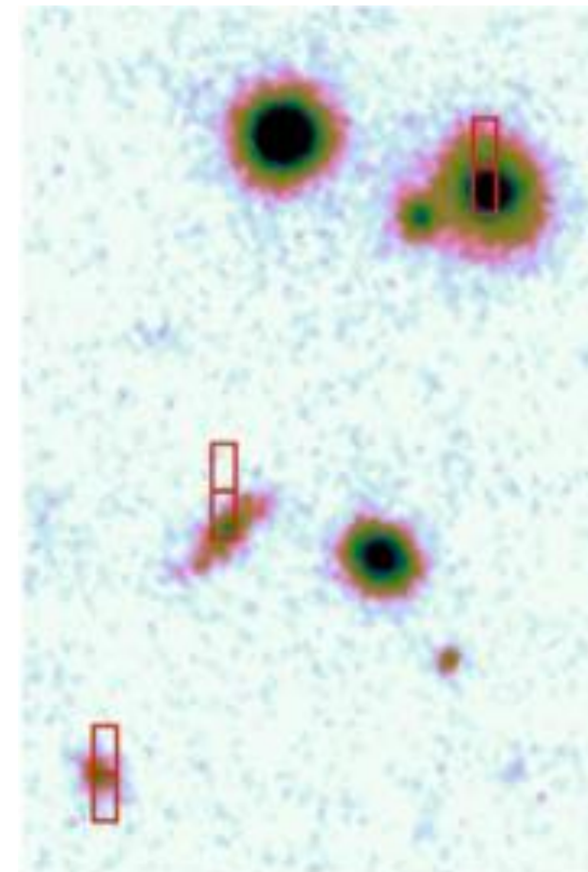
Multi-object spectroscopy (MOS)

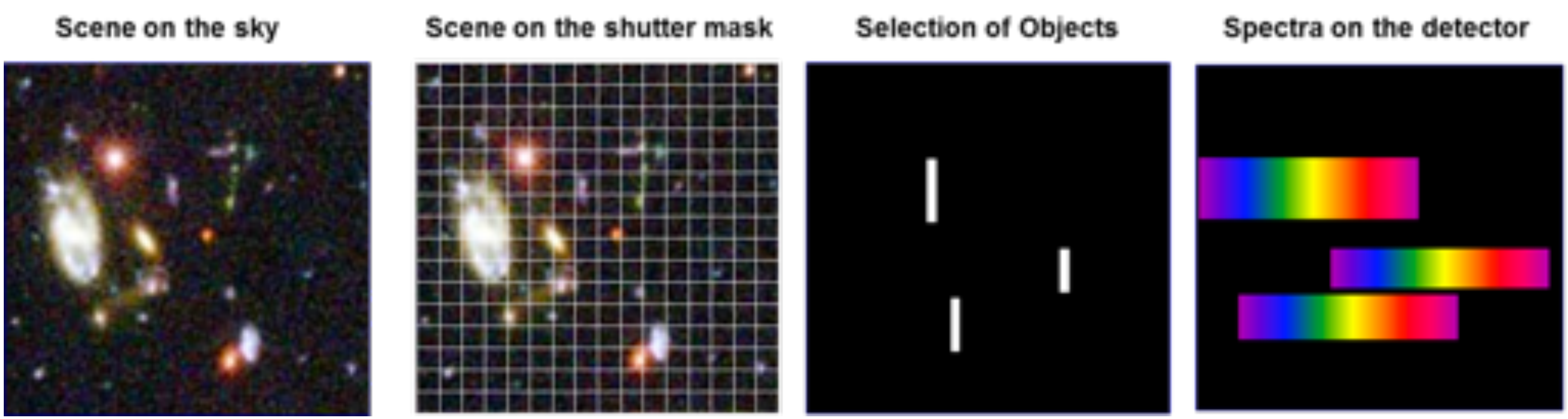


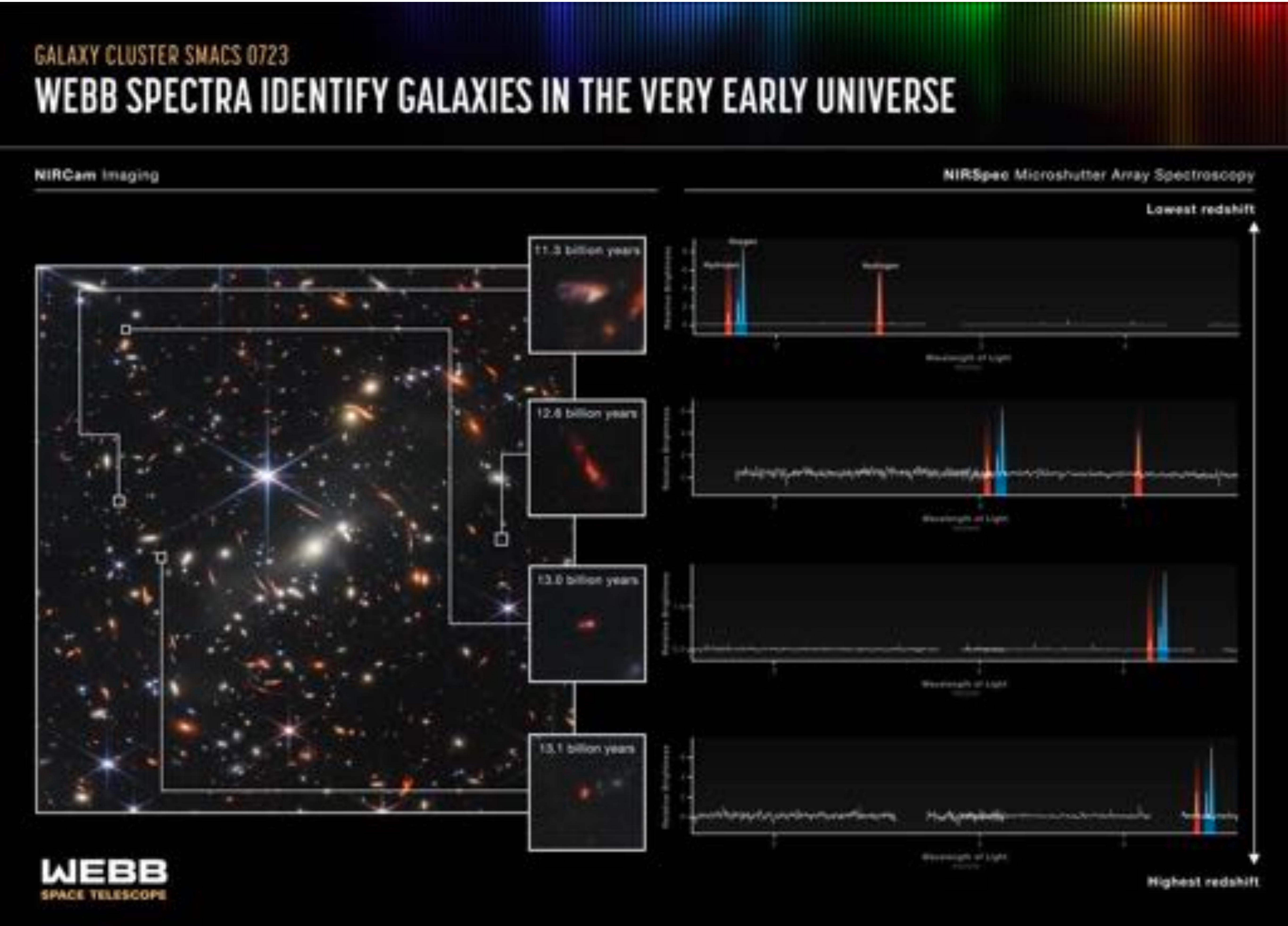
JWST NIRSpec uses a revolutionary system based on **micro-shutters**







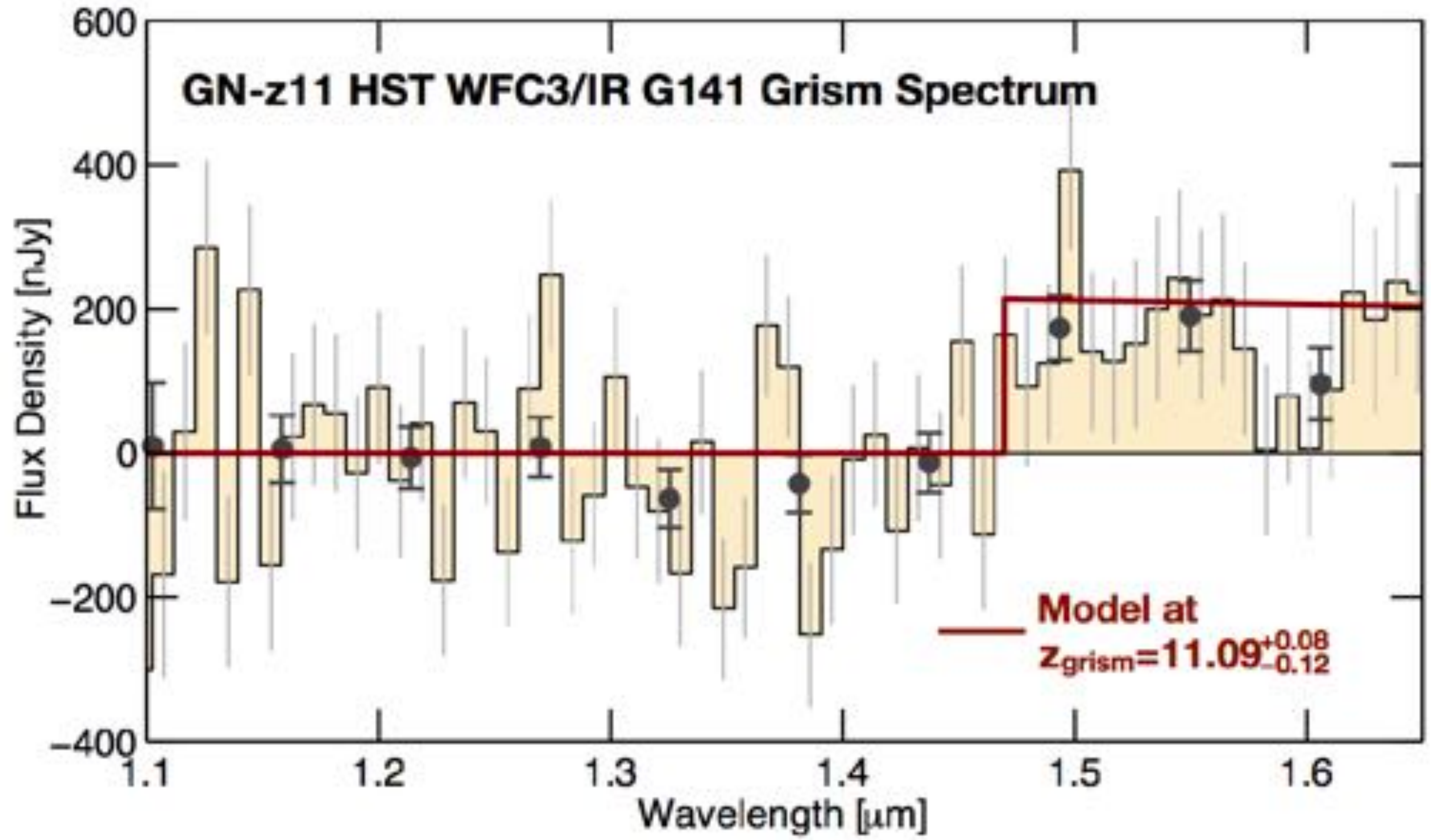




GALAXY CLUSTER SMACS 0723
WEBB SPECTRA IDENTIFY GALAXIES IN THE VERY EARLY UNIVERSE
NIRCam Imaging
NIRSpec Microshutter Array Spectroscopy
Lowest redshift
11.3 billion years
12.6 billion years
13.0 billion years
13.1 billion years
Highest redshift
WEBB
SPACE TELESCOPE

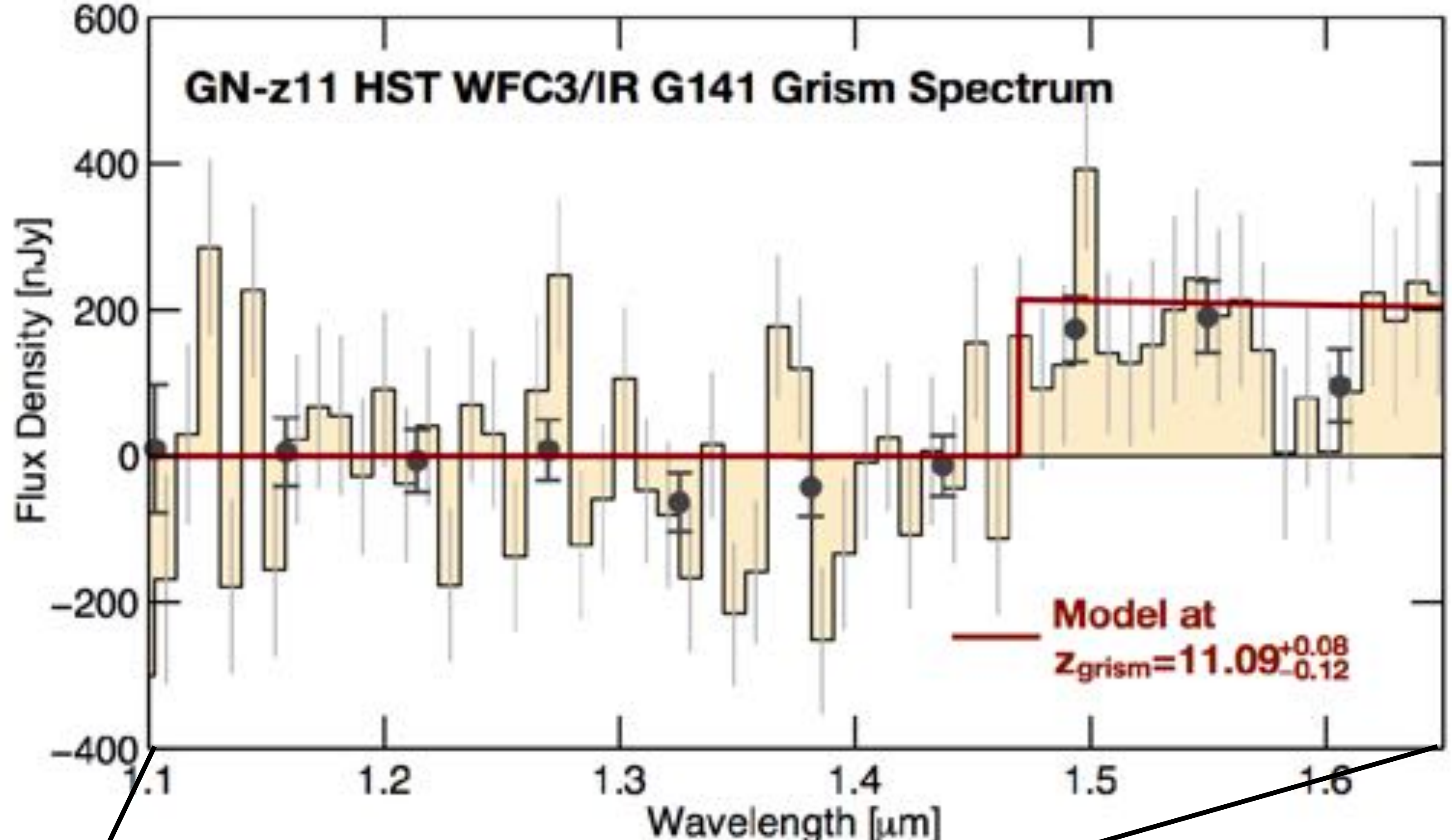
Before JWST

(Oesch et al. 2016)



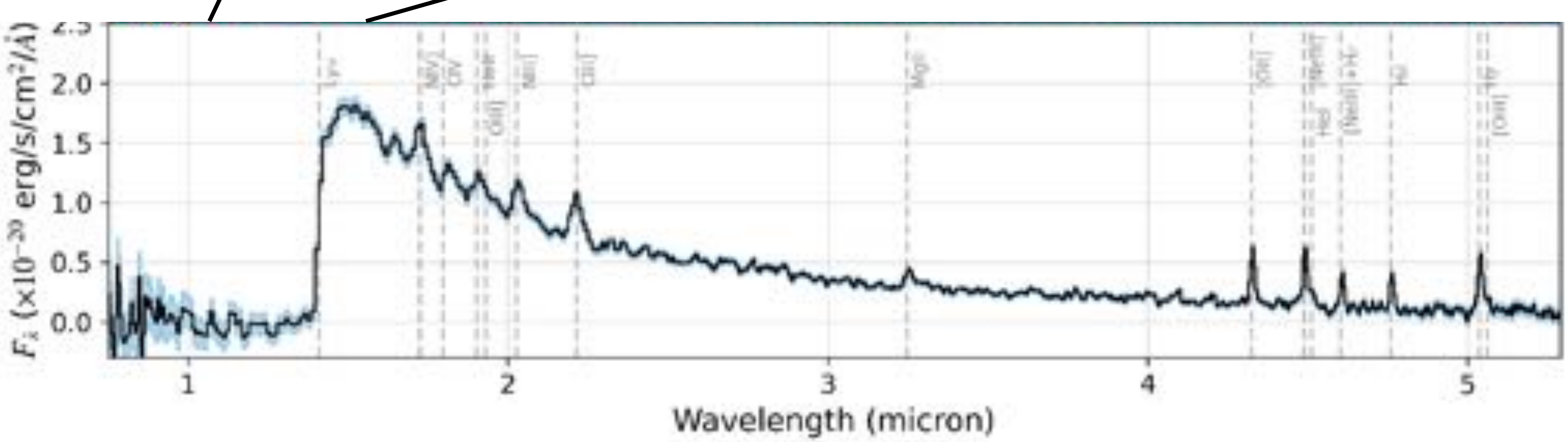
Before JWST

(Oesch et al. 2016)



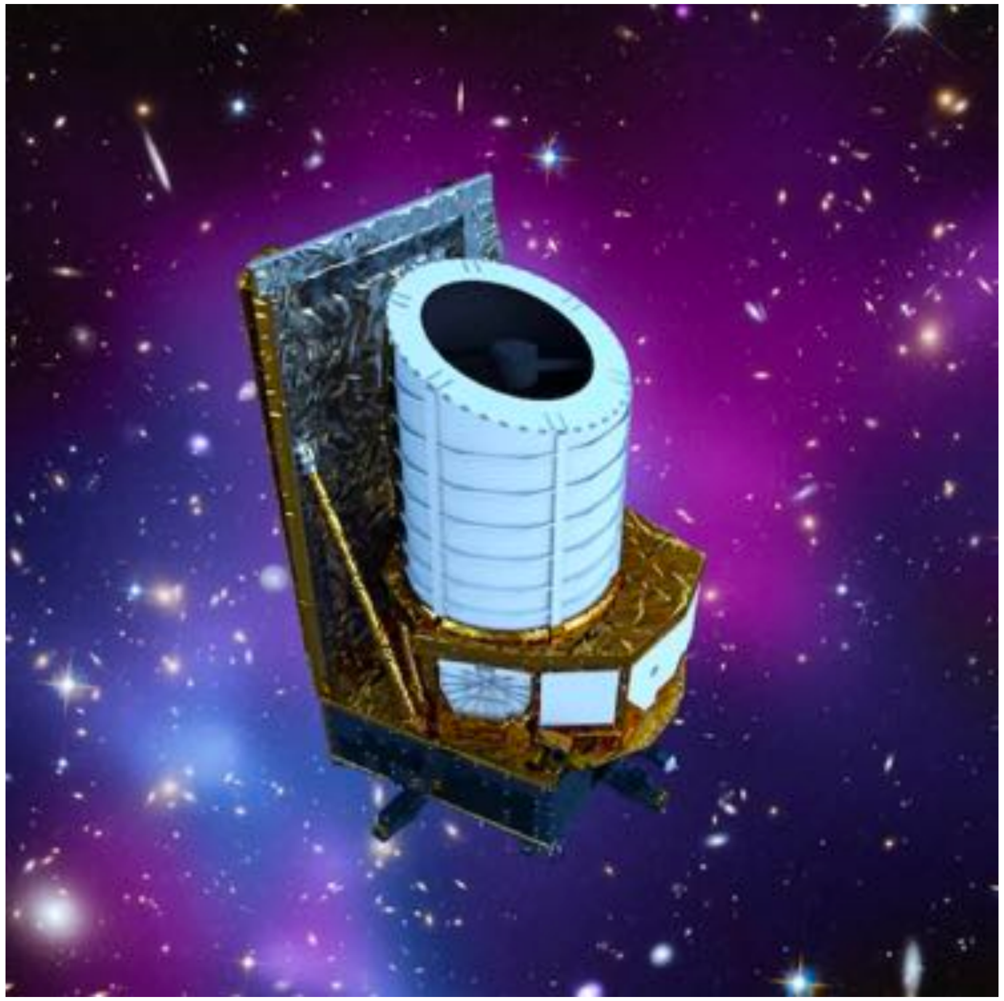
With JWST

(Bunker et al. 2023)

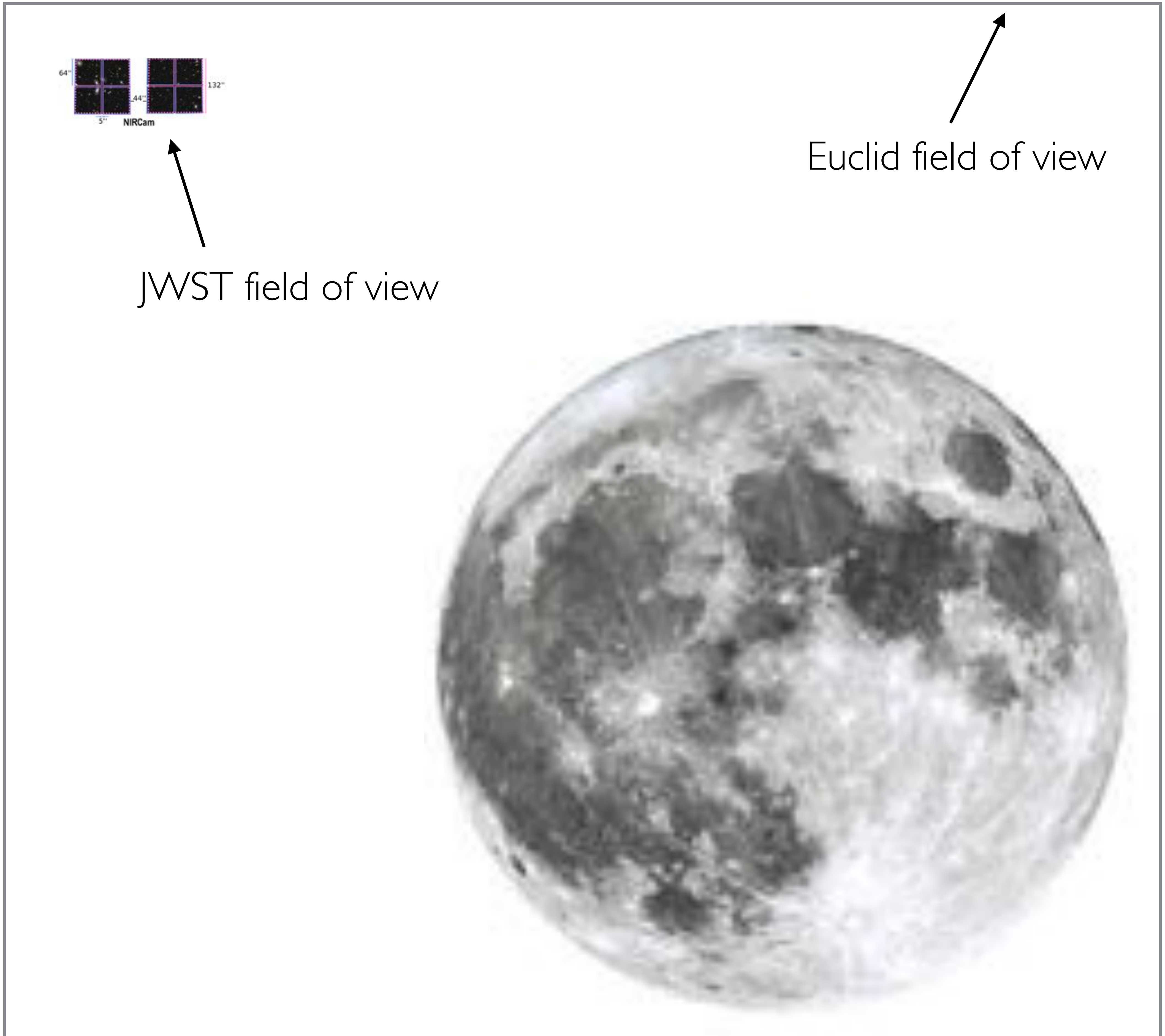


Euclid

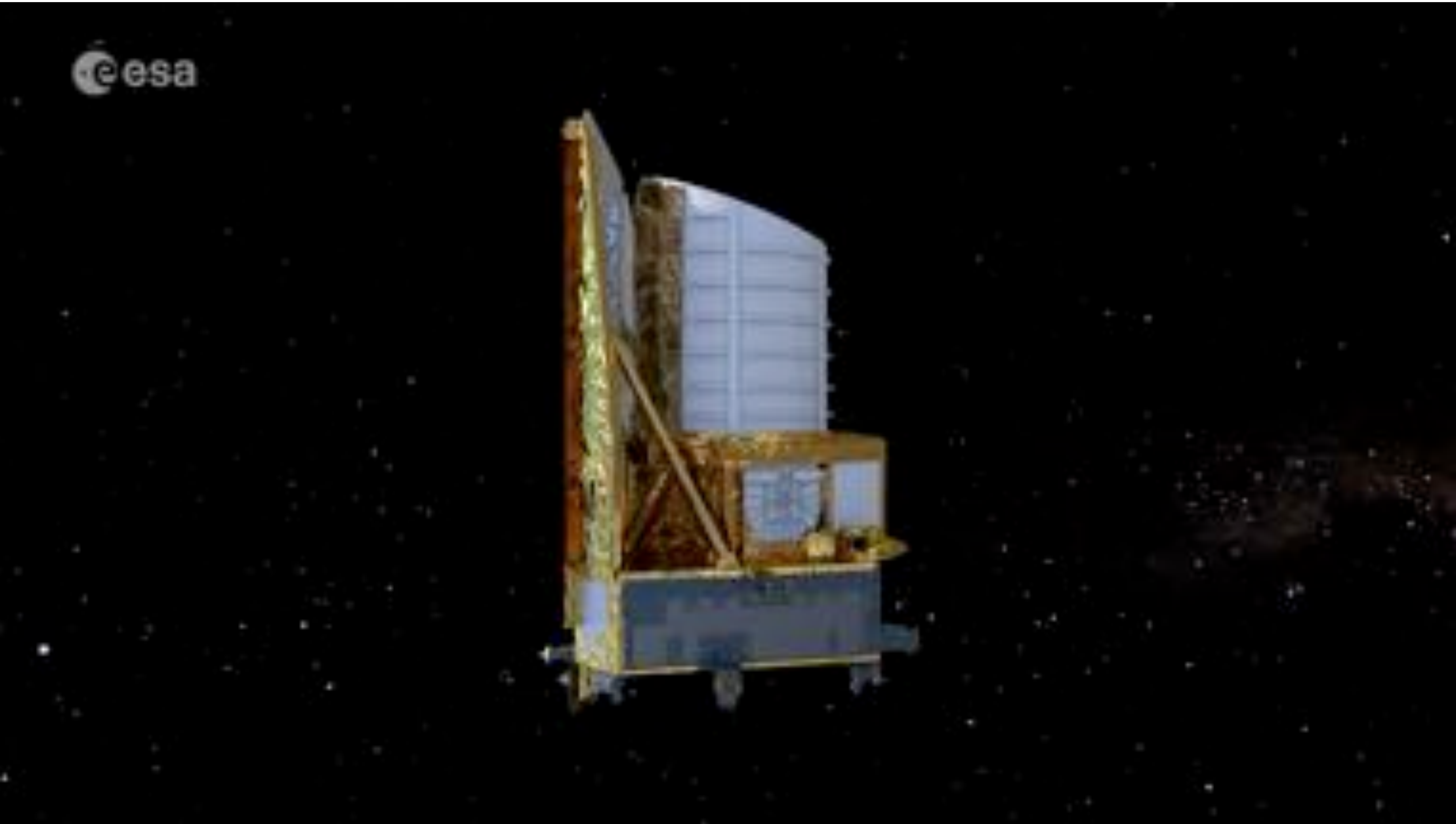
1.2-meter (launched July 1st, 2023)



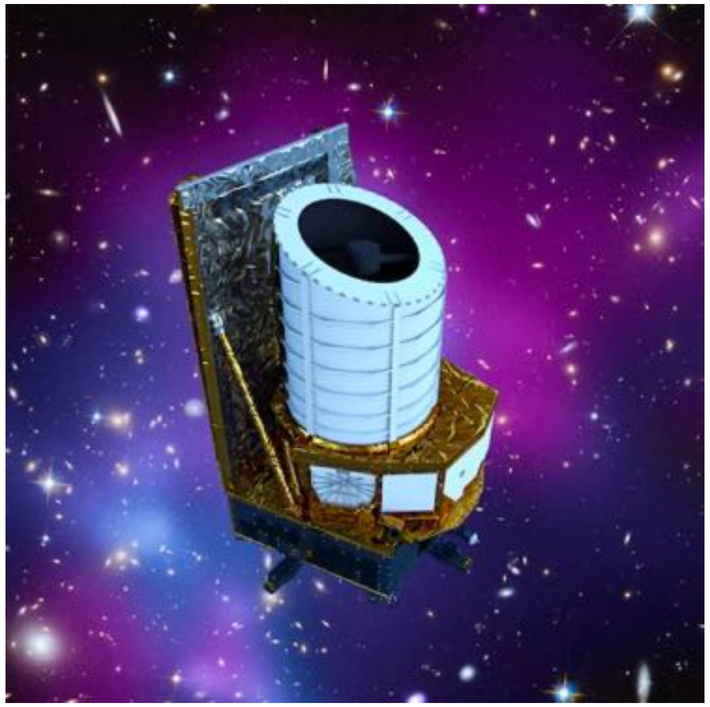
- Smaller mirror than JWST
- Less infrared wavelength coverage
- Less advanced spectroscopic capabilities
- …much, much bigger field of view!

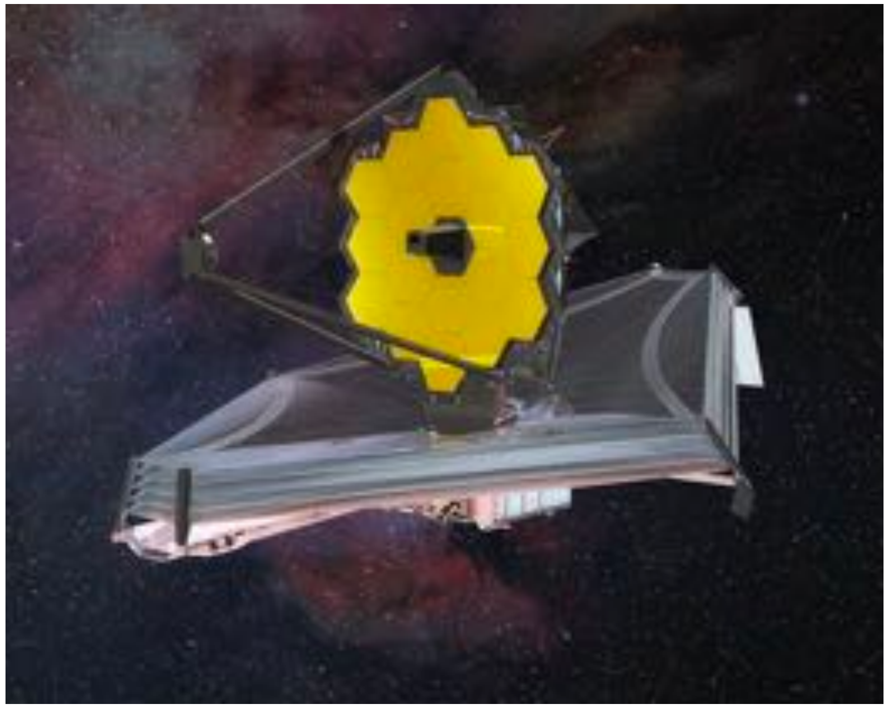

64''
132''
44''
5''
NIRCam
JWST field of view
Euclid field of view

EUCLID




esa





Euclid

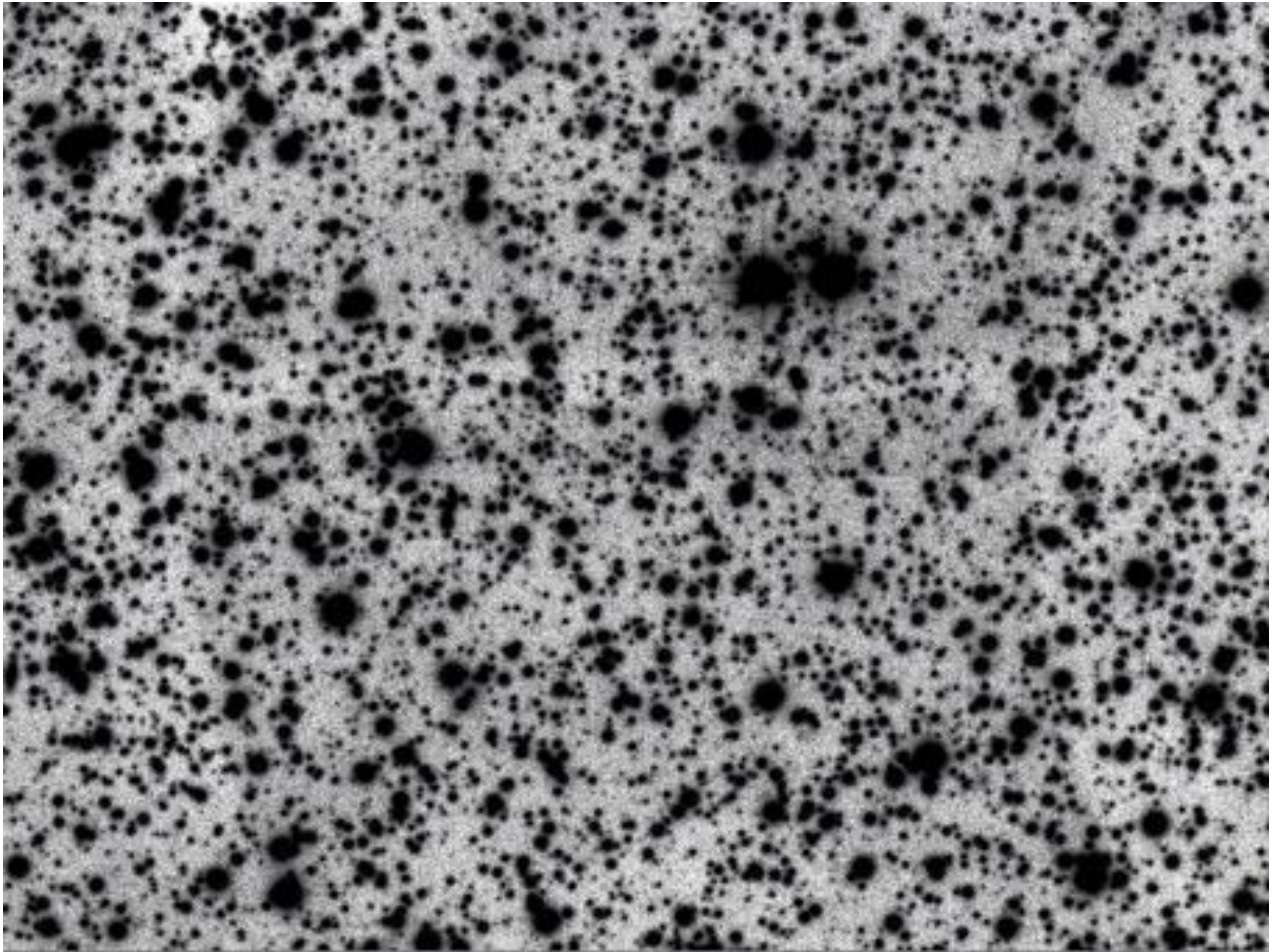
- Will observe one third of the entire sky
- Mostly useful for cosmology and galaxy evolution
- One large team, one long observation

JWST

- Will observe only small, targeted parts of the sky
- Useful to study everything, from planets to galaxies
- Anyone can apply and obtain observations

Euclid launch on July 1st

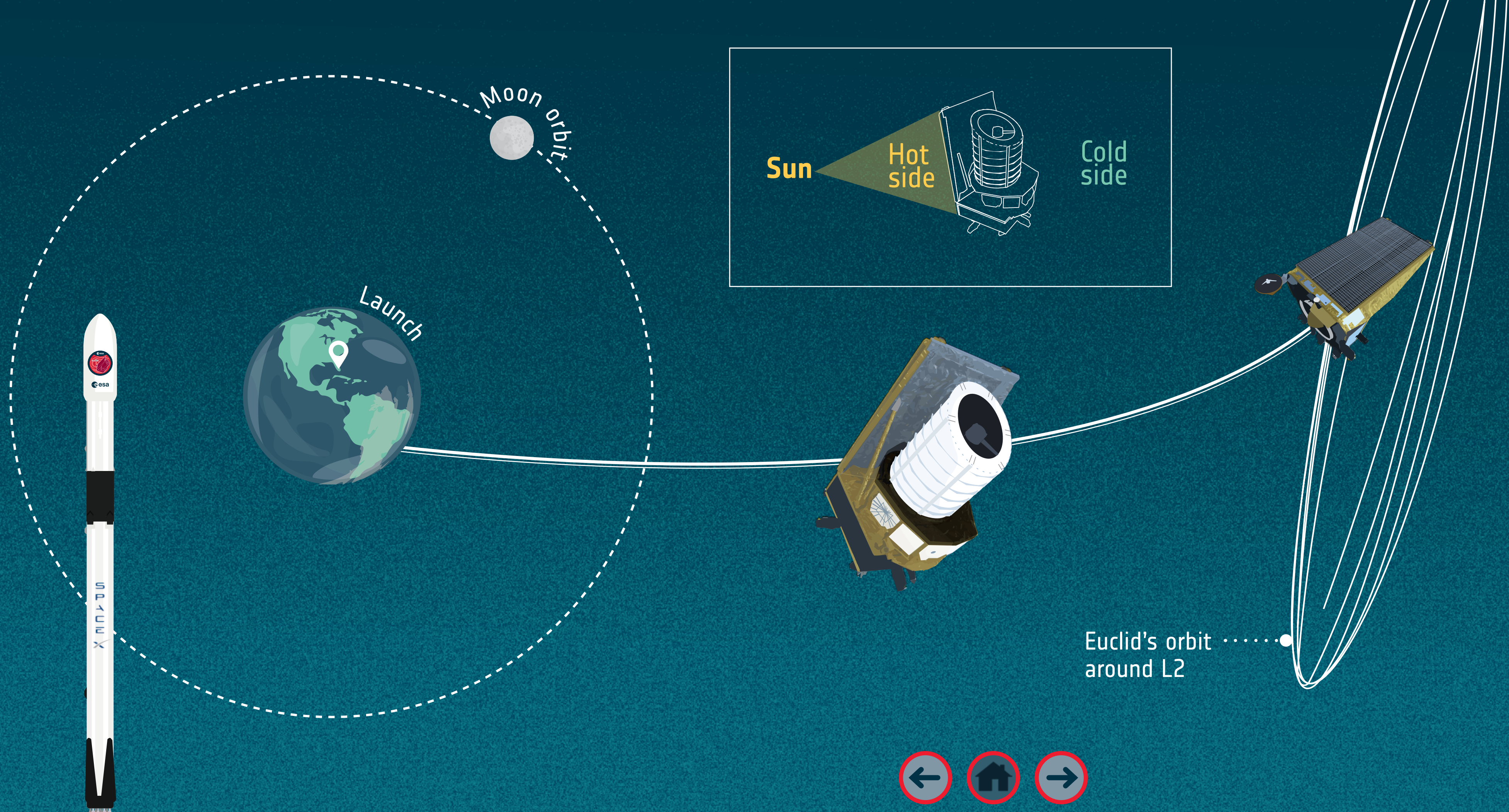
SpaceX Falcon 9 booster landing



Euclid moving to L2 by CFHT-MegaCam / 12-07-2023

EUCLID'S JOURNEY TO L2

Euclid will orbit the second Lagrange point (L2), 1.5 million kilometres from Earth in the opposite direction from the Sun. L2 is an equilibrium point of the Sun-Earth system that follows the Earth around the Sun. In its orbit at L2, Euclid's sunshield can always block the light from the Sun, Earth and Moon while pointing its telescope towards deep space, ensuring a high level of stability for its instruments.

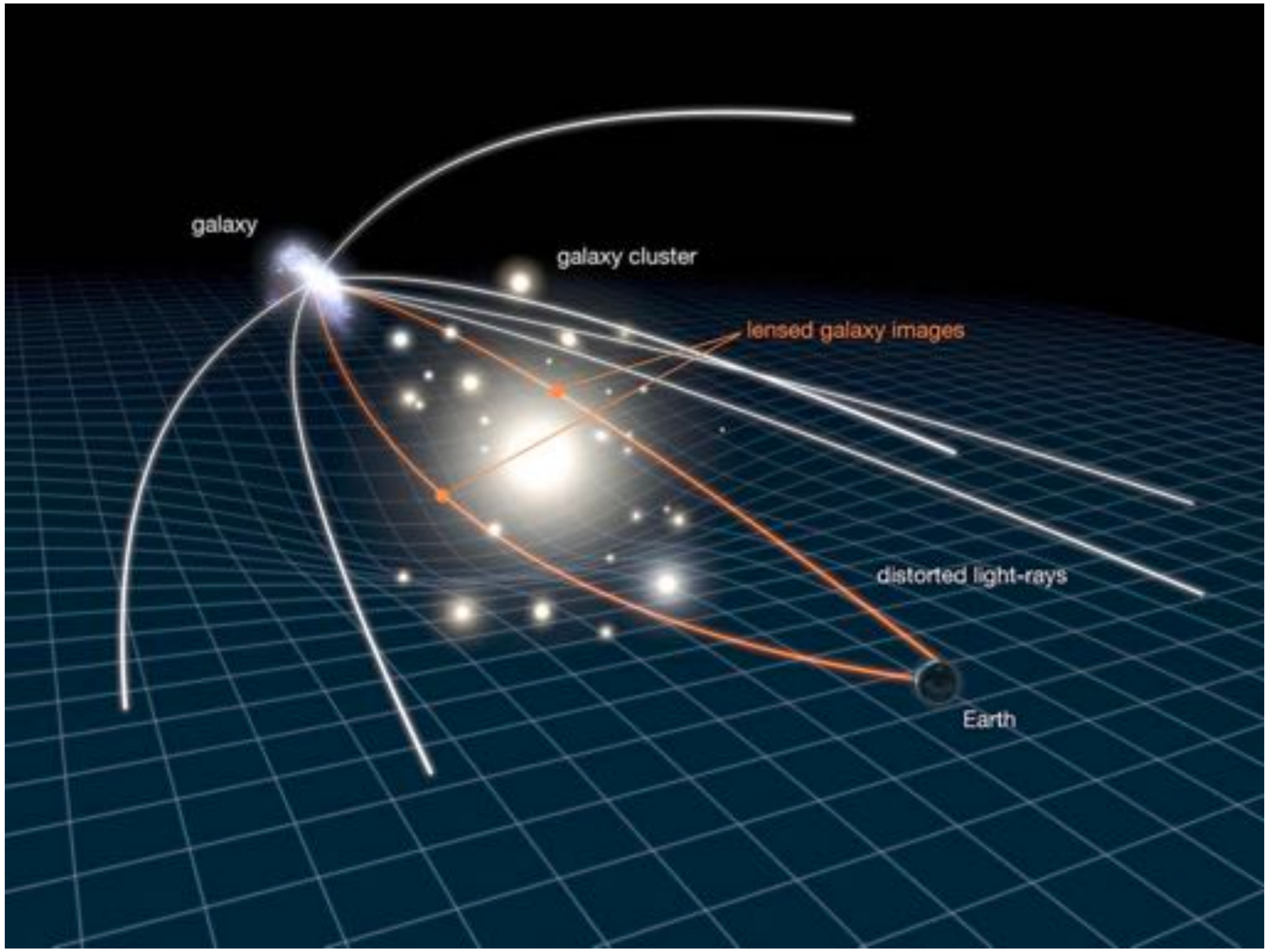


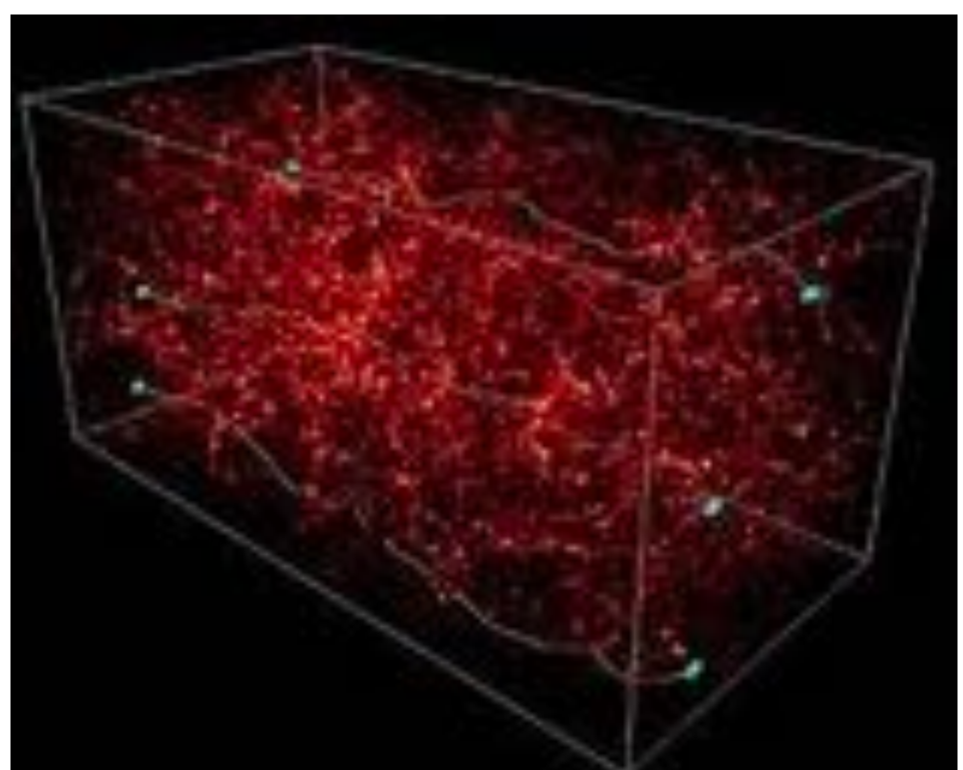
- **Launch (L)**
- **L+2 days:** Euclid is on its way to L2
- **L+2 weeks:** Euclid cool-down is complete
- **L+4 weeks:** Euclid in orbit around L2
- **L+4 weeks:** Telescope aligned and all instruments turned on
- **L+1–3 months:** Testing of scientific performance and readiness for science
- **L+3 months:** Euclid begins its survey

Euclid will be able to measure the geometry of the universe using two methods:

Gravitational Lensing

Baryonic Acoustic Oscillations

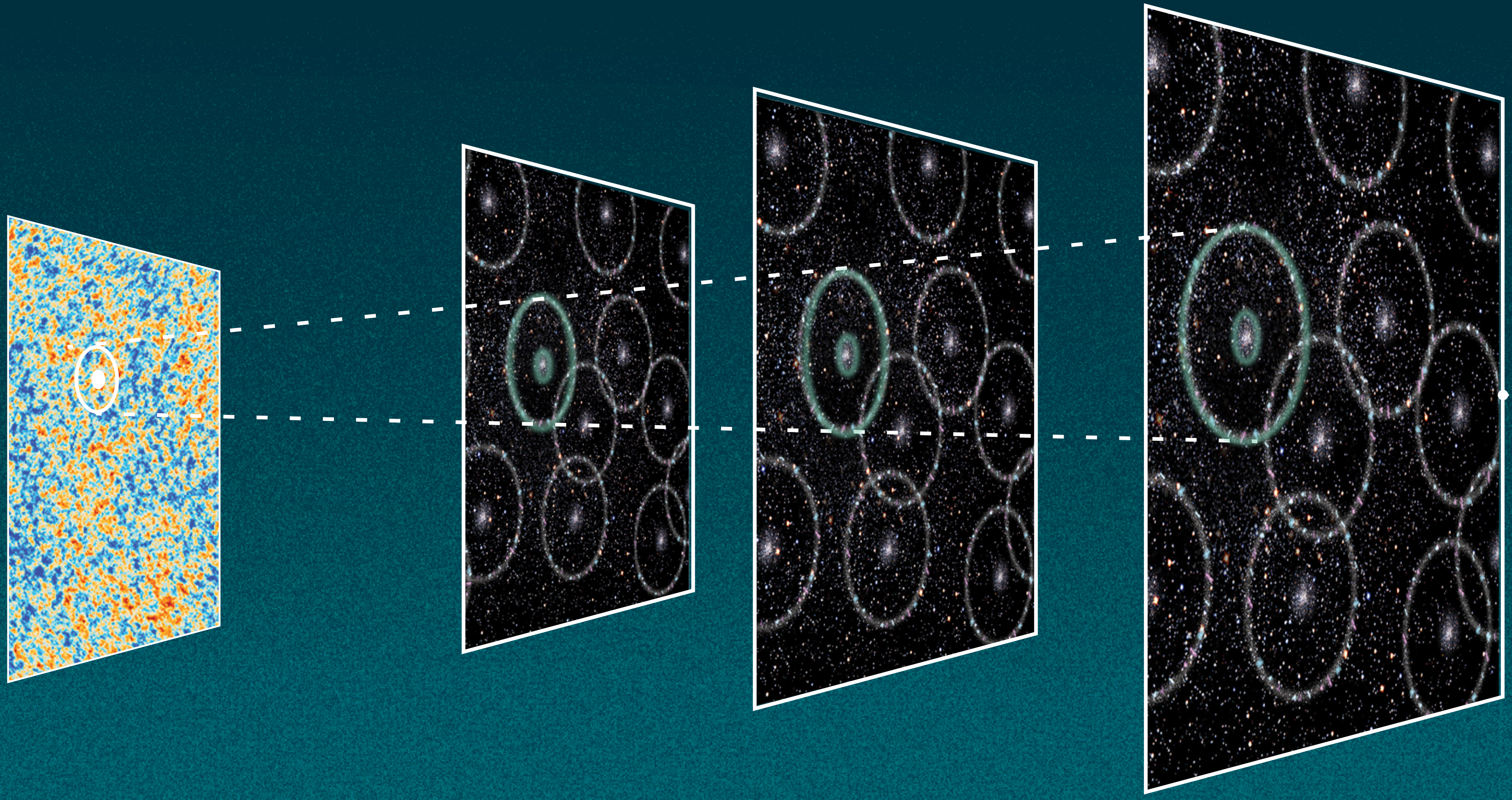




Euclid will be able to map the distribution of dark matter

WHAT EUCLID WILL MEASURE: BARYONIC ACOUSTIC OSCILLATIONS

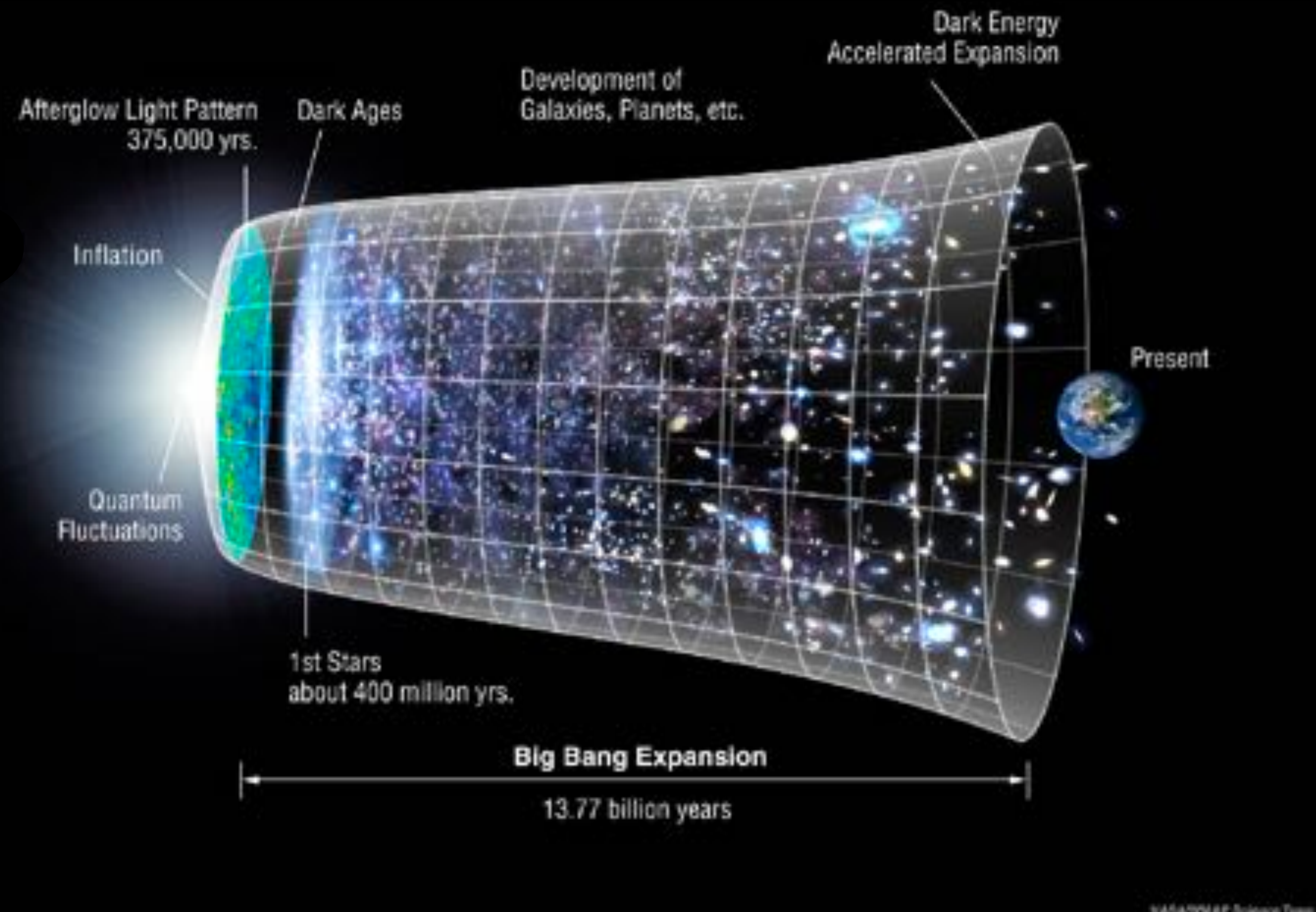
During the first 300 000 years after the Big Bang, density fluctuations in the hot plasma (of protons, neutrons, electrons and photons) behaved as sound waves (bubbles) that rippled through this primordial particle-radiation soup. At the end of this period, slightly more galaxies formed in clusters along the frozen ripples. The ripples stretched as the Universe expanded, increasing the distance between galaxies. Euclid will study the distribution of galaxies over immense distances, teasing out these ripple patterns and determining their size. This enables us to measure accurately the accelerated expansion of the Universe and teaches us about the nature of dark energy and dark matter.

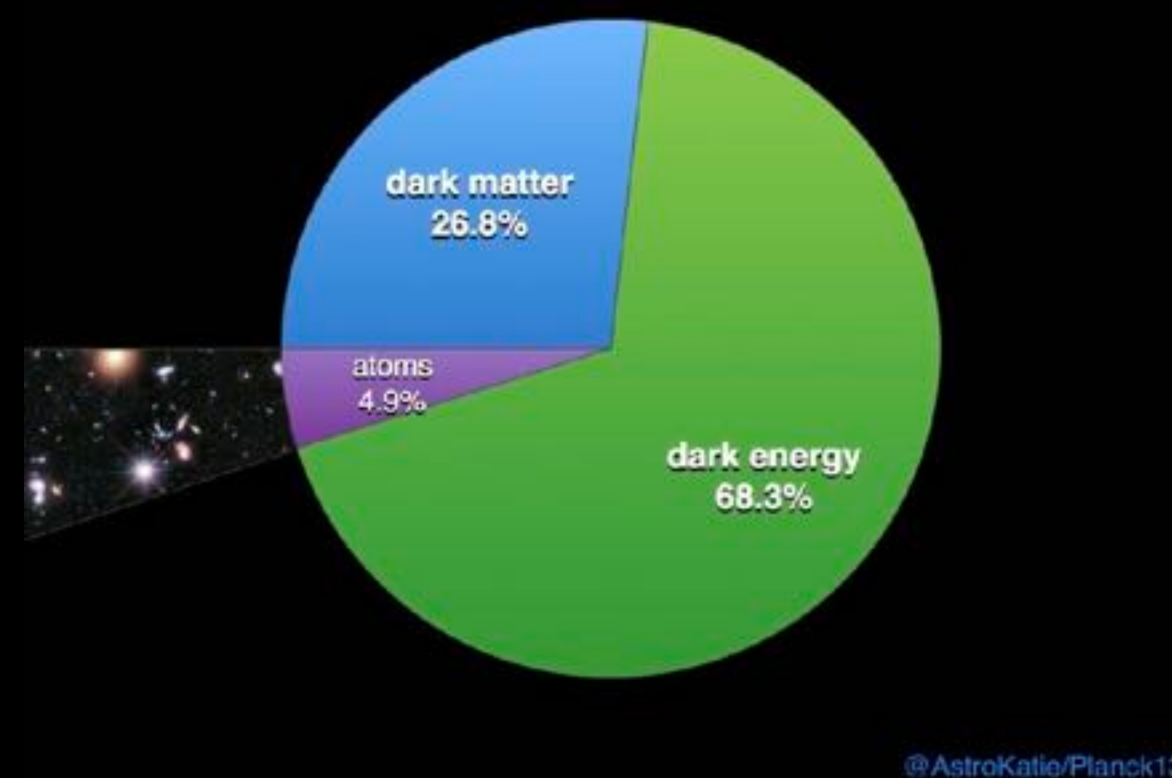


Artist's impression of the pattern of baryonic acoustic oscillations imprinted on the large-scale distribution of galaxies (exaggerated)

Source: ESA and the Planck Collaboration / Gabriela Secara / Perimeter Institute

ΛCDM = Dark energy (Λ) + Cold Dark Matter





Can we go beyond the current "standard model" for cosmology?

What are the constituents of our universe?