The Golden Mirror: Seeing Our Own Story Through the James Webb Space Telescope

DANNY MILISAVLJEVIC
Associate Professor
Department of Physics and Astronomy
PURDUE UNIVERSITY

1

Brief Bio

Originally from Hamilton, Ontario, Canada ("Steel City", or "The Hammer"). Went to college at McMaster University for liberal arts and physics.

MSc in History and Philosophy of Science at London School of Economics. PhD at Dartmouth College in Physics and Astronomy.

Worked at Harvard University and Smithsonian Institution for 3 + 3 years.

Arrived at Purdue in 2017. Presently Associate Professor in the Department of Physics and Astronomy.

I've taught over 3000 students and have provided research projects for over undergraduate 100 students.

I study how stars live and die. I do my best to help people understand "our place in the universe."

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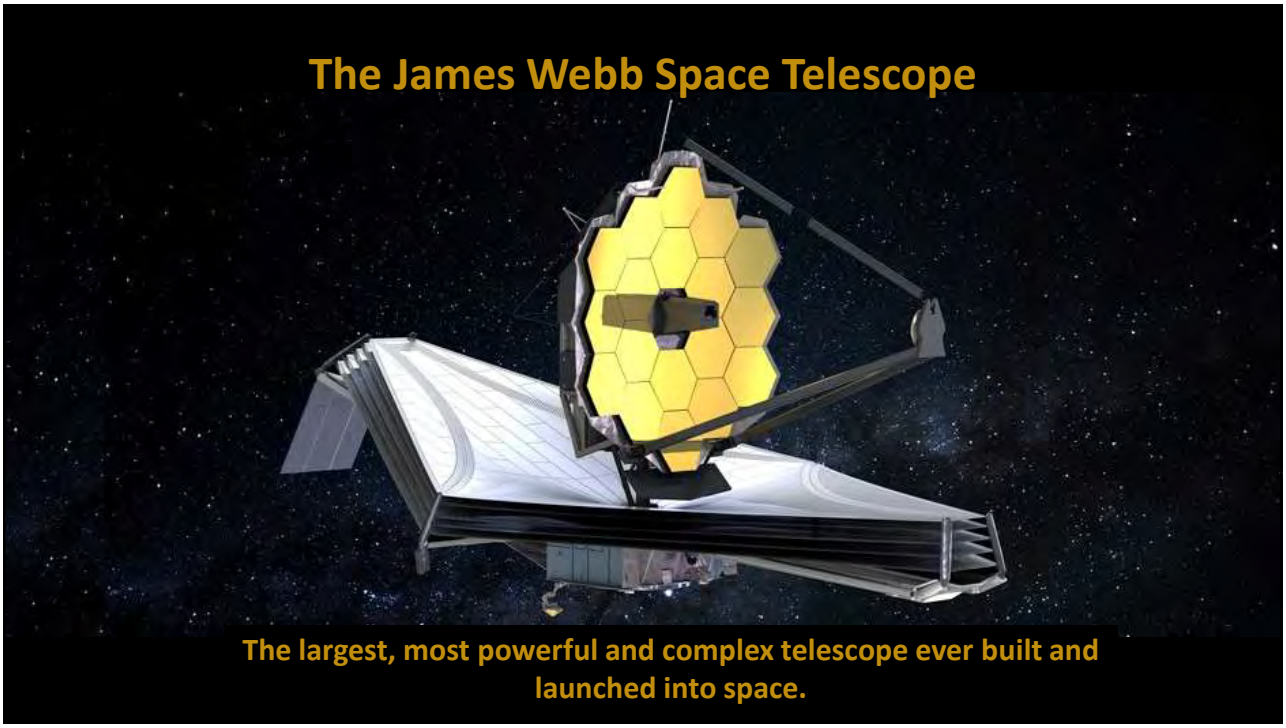
3

The James Webb Space Telescope



The largest, most powerful and complex telescope ever built and launched into space.

4

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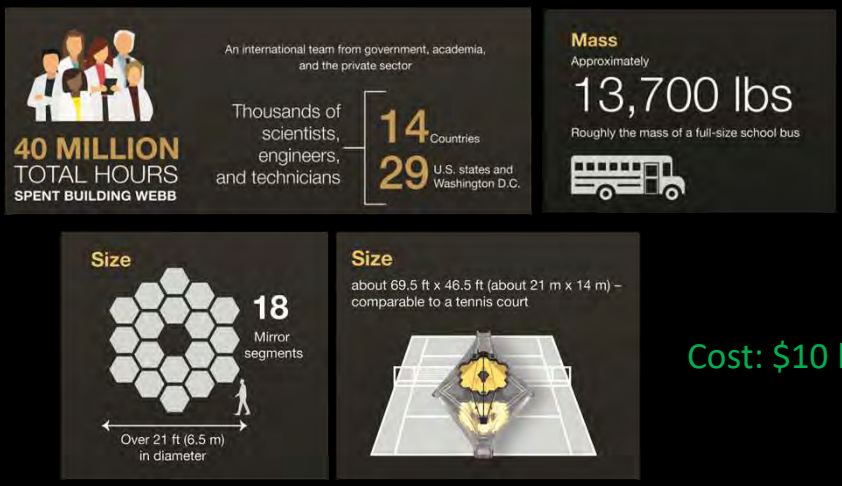
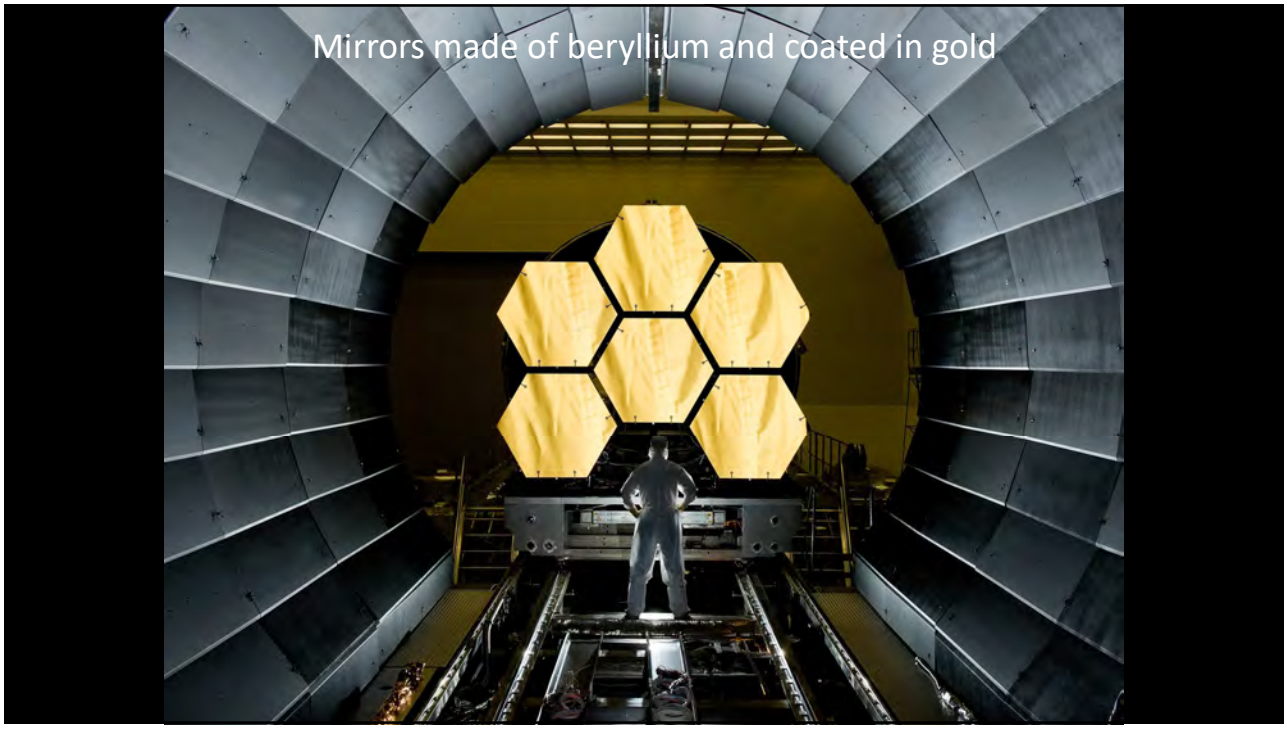


Cost: $10 billion

The largest, most powerful and complex telescope ever built and launched into space.

5



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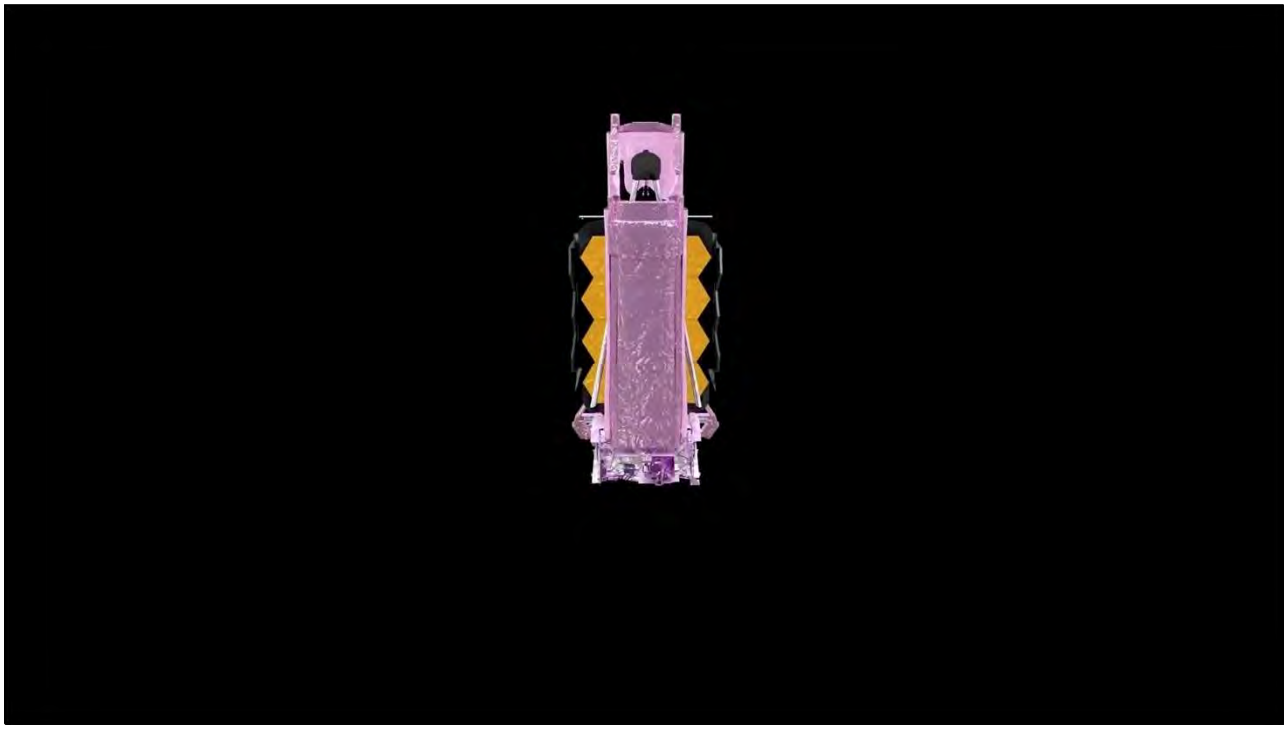
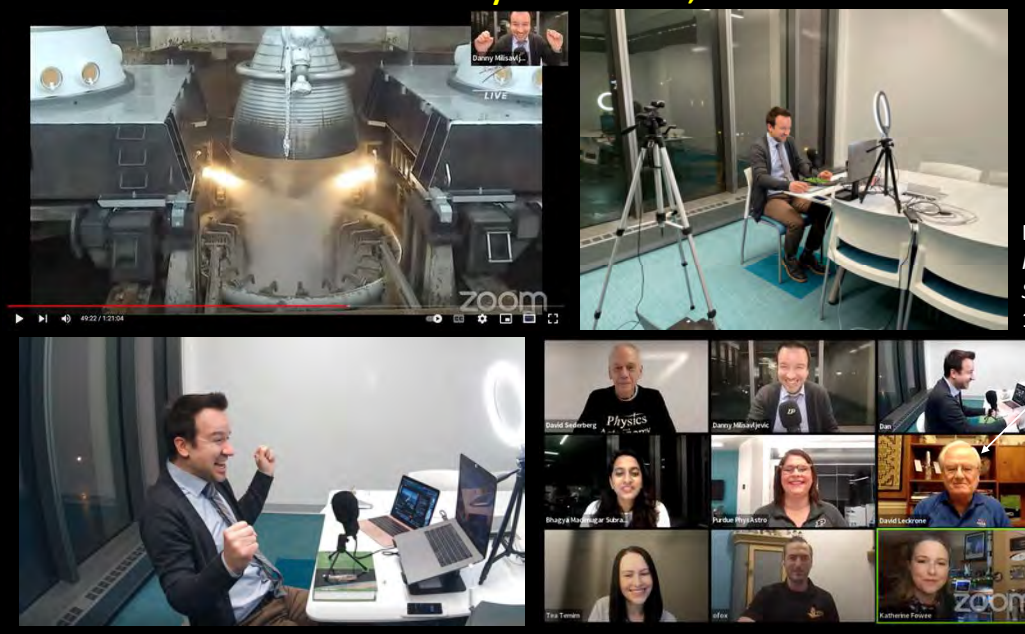


8

JWST Launch Party December 25, 2021

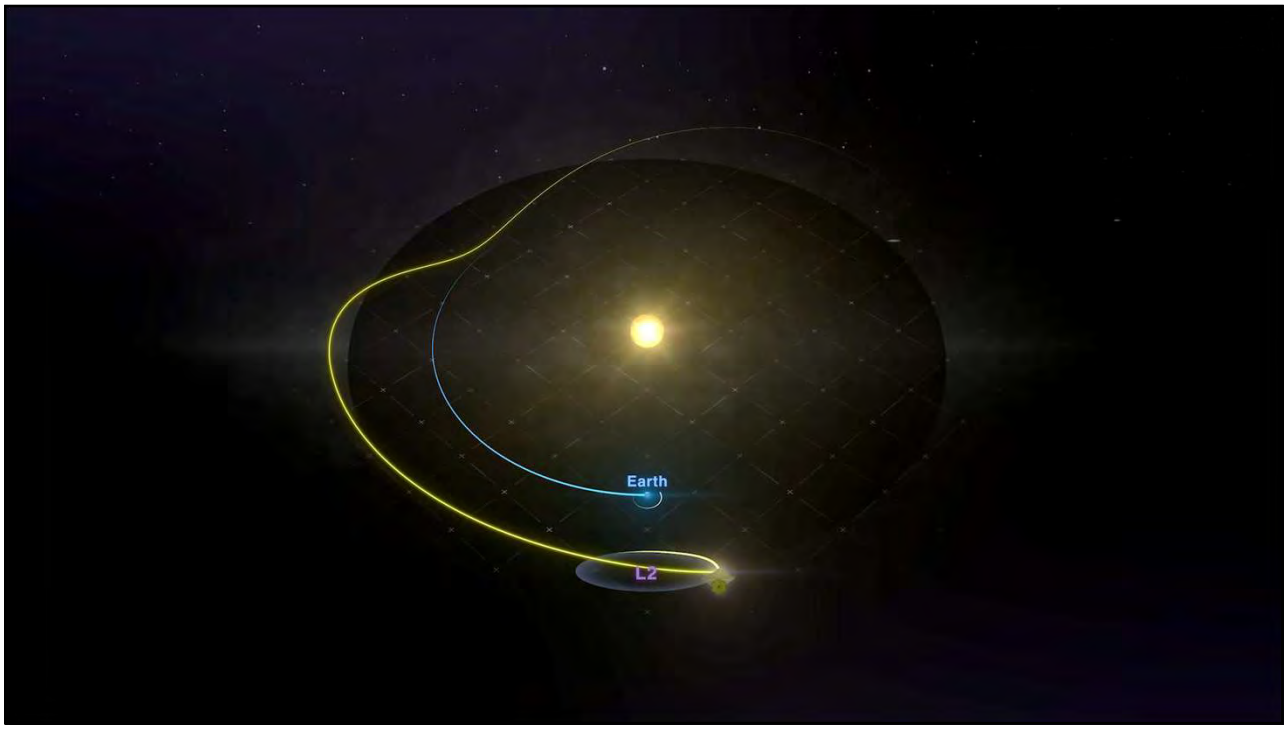


David Leckrone *Hubble Project Scientist* from 1992 – 2009

https://youtu.be/yzqsDOQoZ1w

9

10



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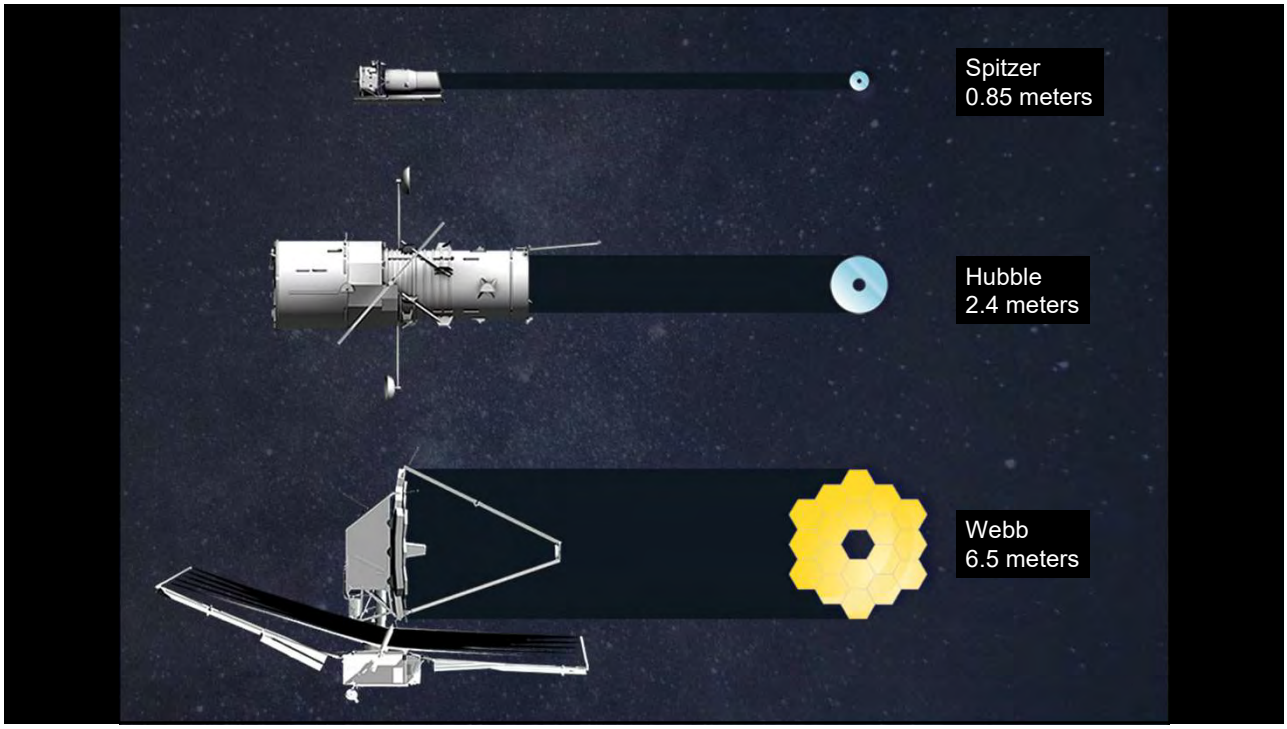

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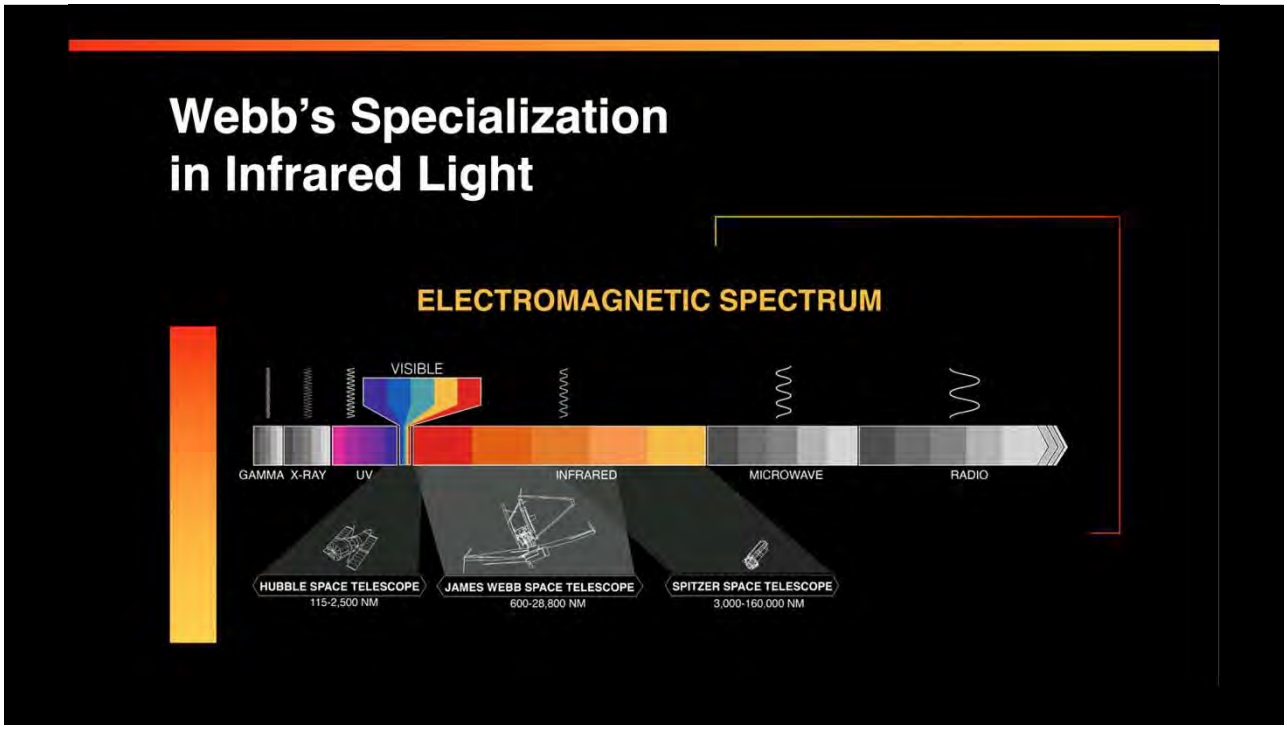
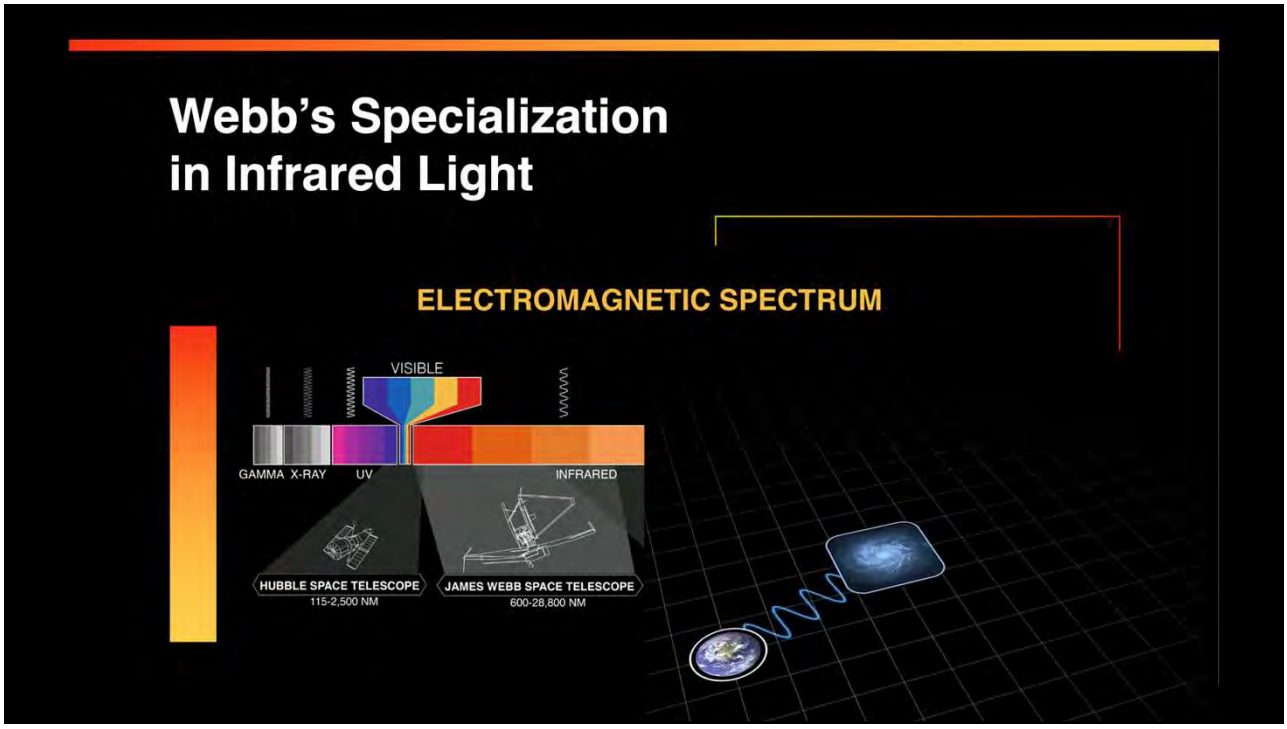

Webb's Specialization
in Infrared Light
ELECTROMAGNETIC SPECTRUM
VISIBLE
GAMMA X-RAY
UV
INFRARED
MICROWAVE
RADIO
HUBBLE SPACE TELESCOPE
115-2,500 NM
JAMES WEBB SPACE TELESCOPE
600-28,800 NM
SPITZER SPACE TELESCOPE
3,000-160,000 NM

13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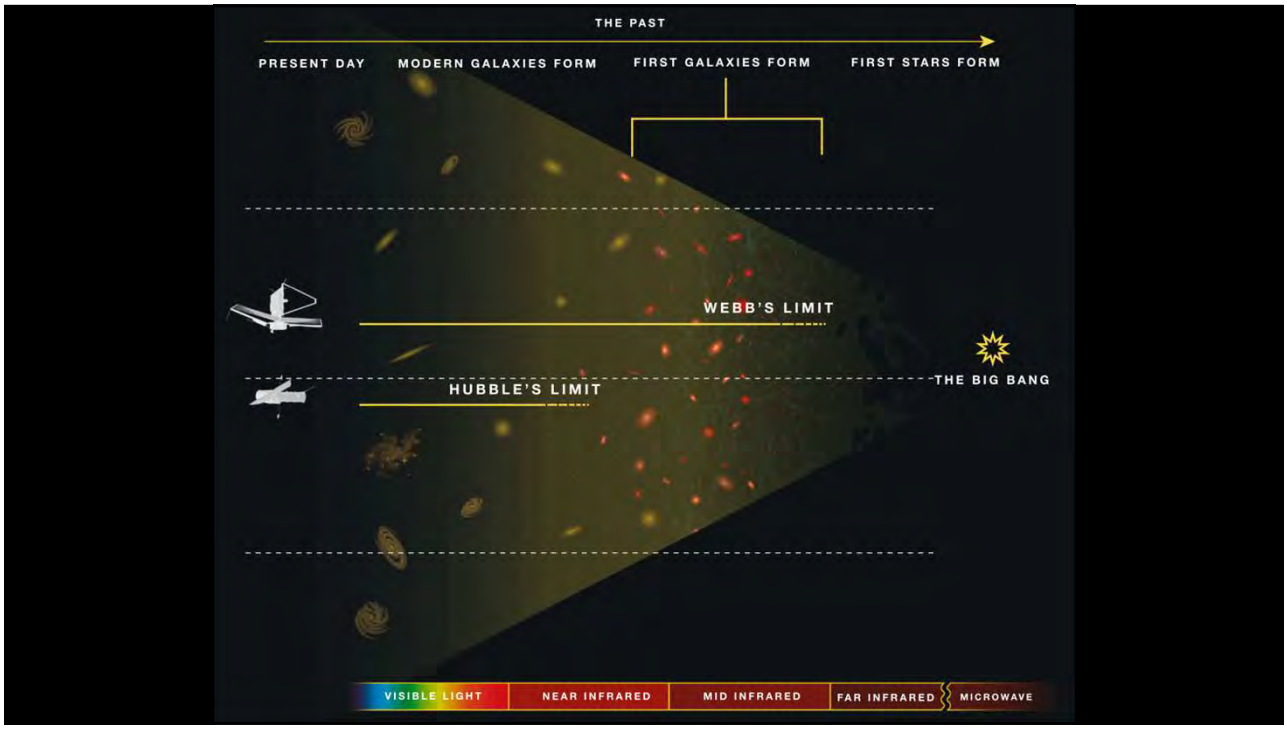
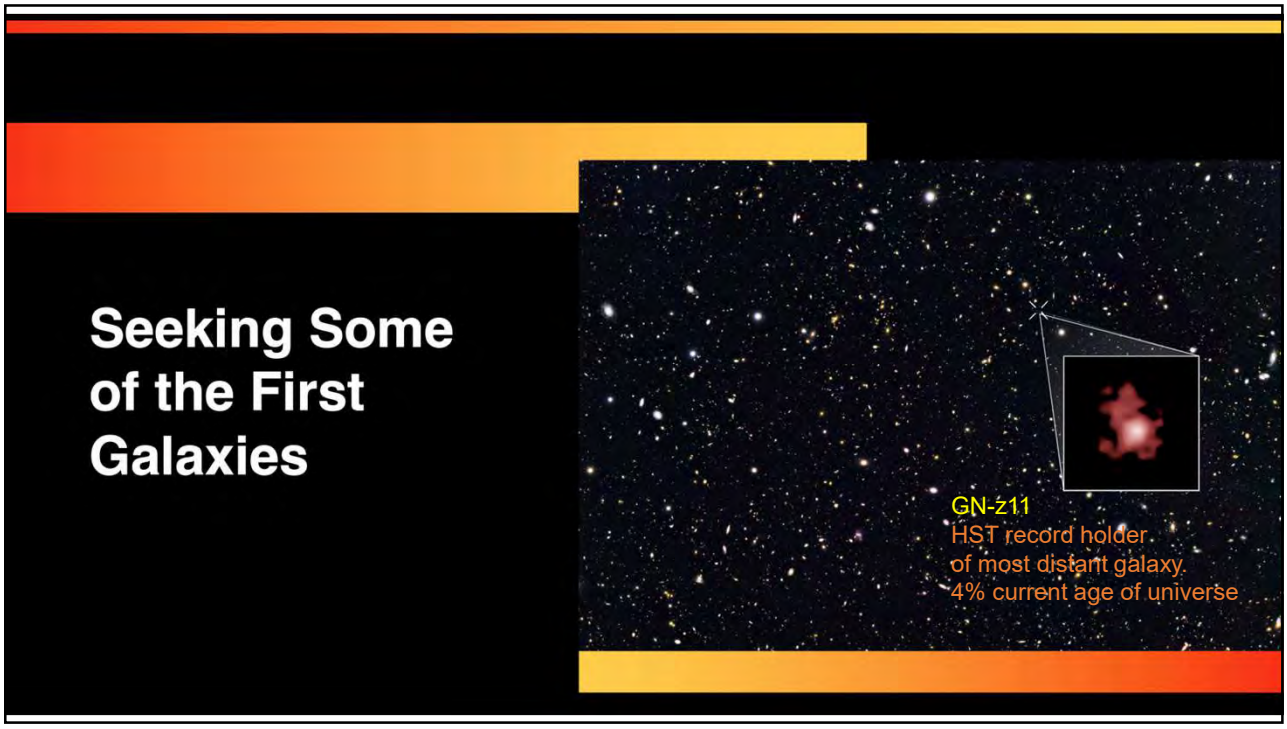
14

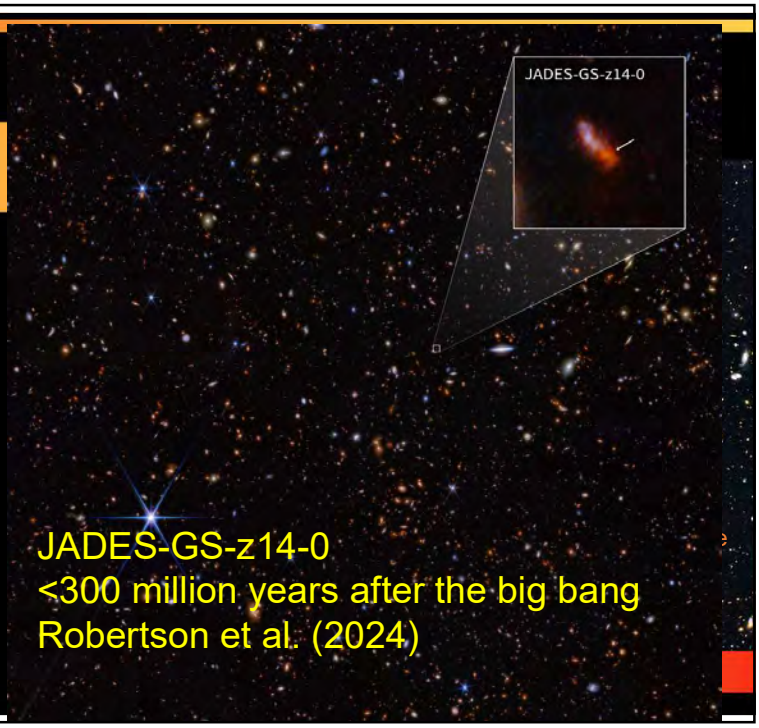

THE PAST
PRESENT DAY
MODERN GALAXIES FORM
FIRST GALAXIES FORM
FIRST STARS FORM
WEBB'S LIMIT
HUBBLE'S LIMIT
THE BIG BANG
VISIBLE LIGHT
NEAR INFRARED
MID INFRARED
FAR INFRARED
MICROWAVE

15


Seeking Some of the First Galaxies
GN-z11
HST record holder
of most distant galaxy.
4% current age of universe

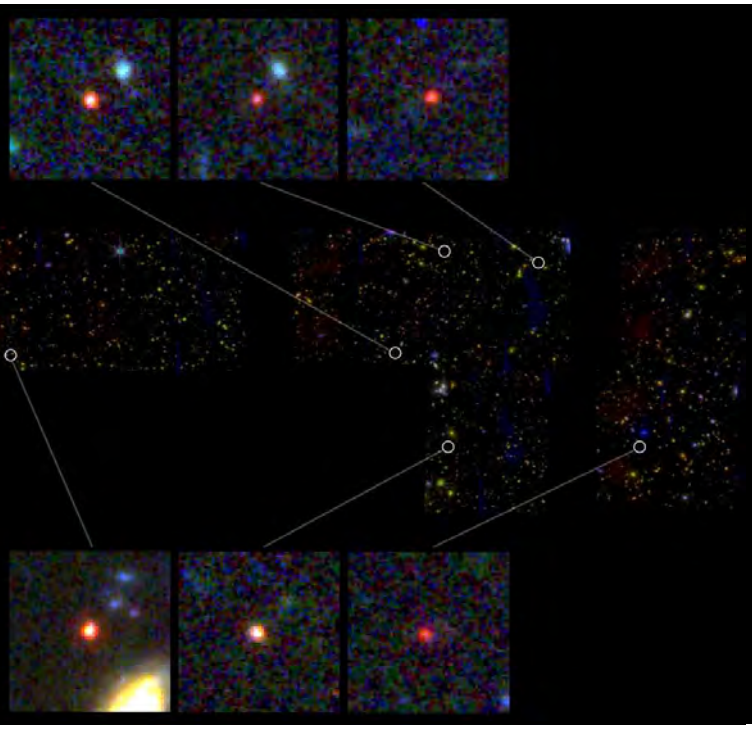
16

Seeking Some of the First Galaxies

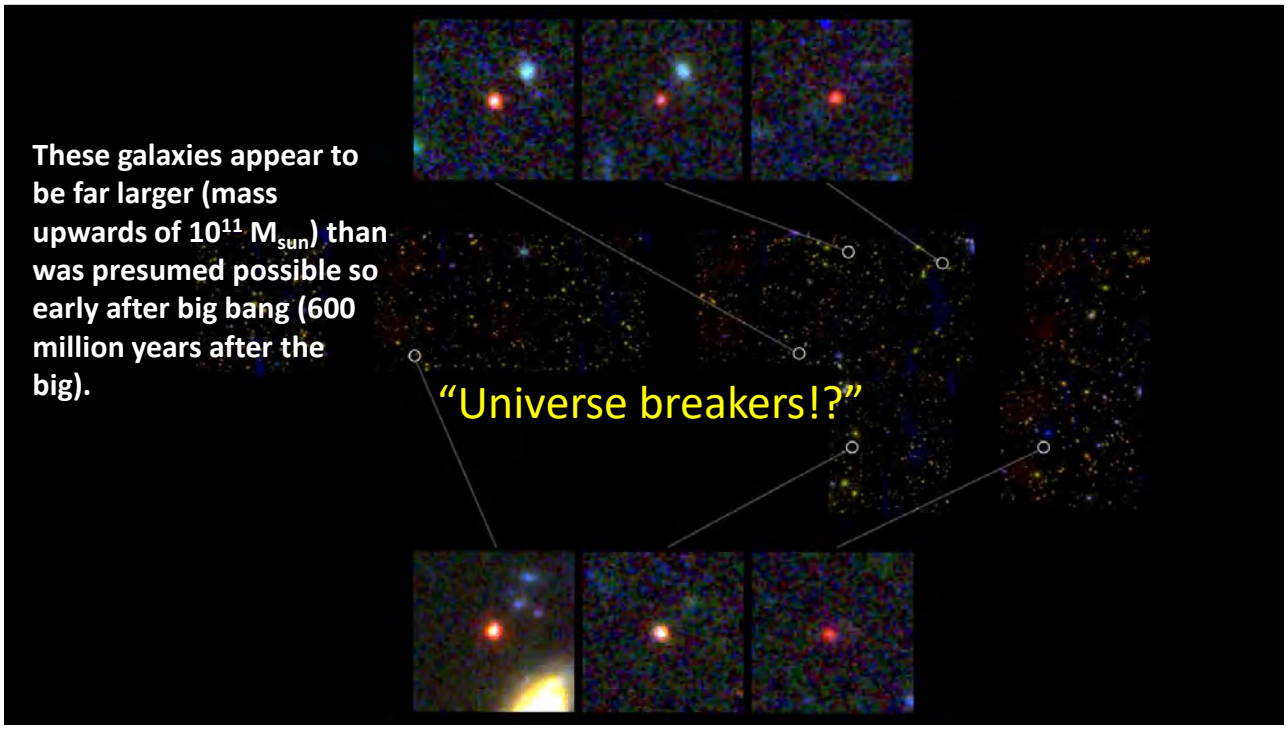


17

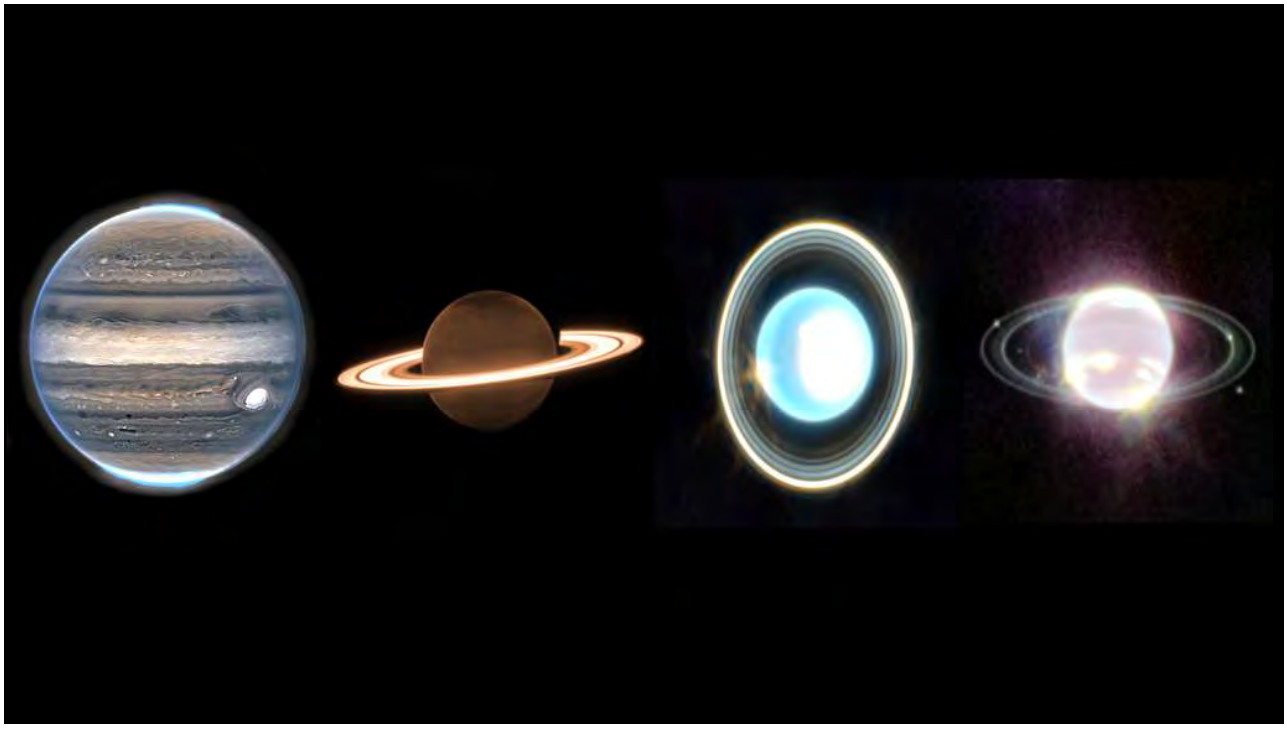
These galaxies appear to be far larger (mass upwards of 10^{11} M_{sun}) than was presumed possible so early after big bang (600 million years after the big).



18


These galaxies appear to be far larger (mass upwards of 10^{11} M_{sun}) than was presumed possible so early after big bang (600 million years after the big).
"Universe breakers!?"

19



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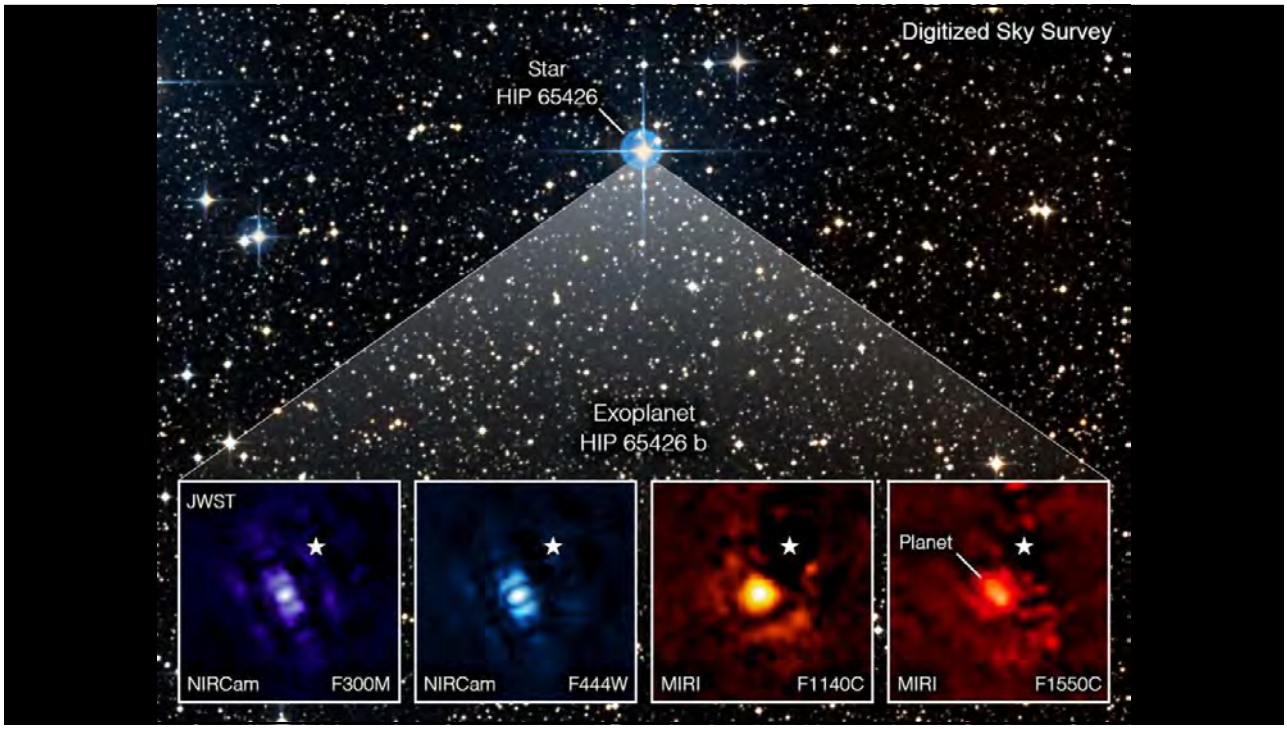
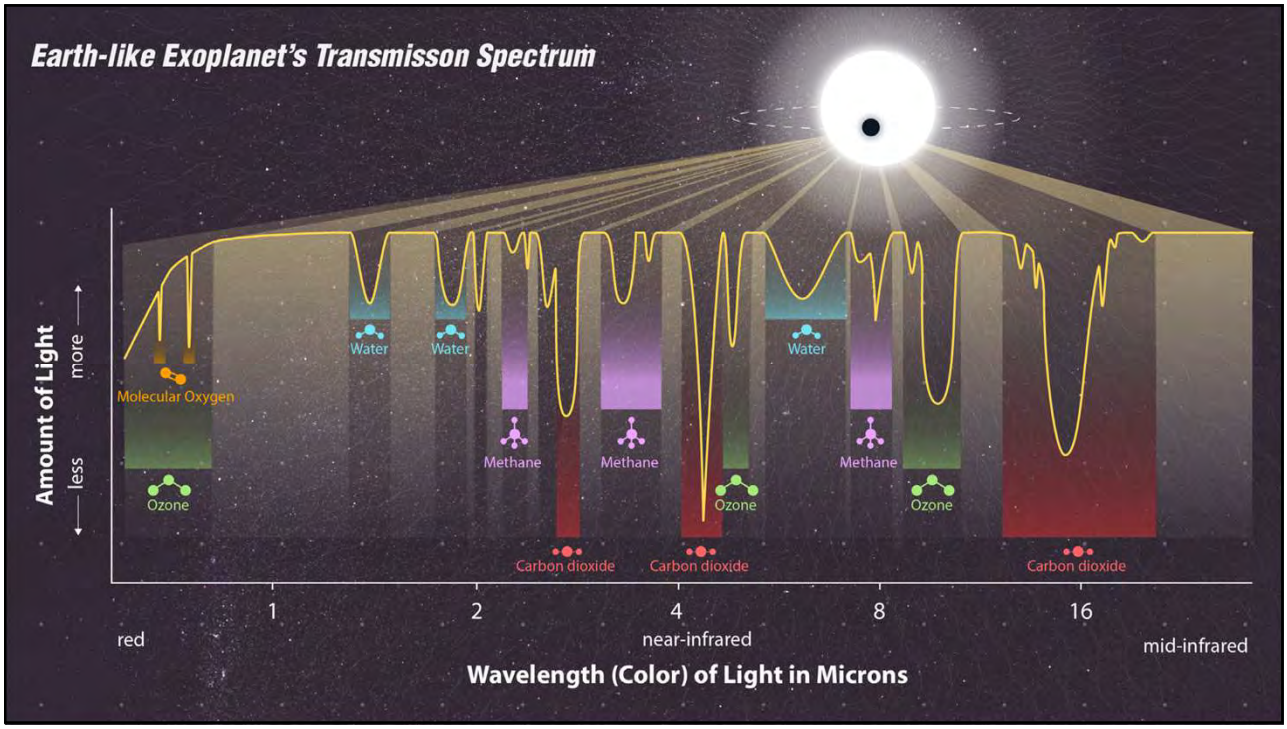

Digitized Sky Survey
Star
HIP 65426
Exoplanet
HIP 65426 b
JWST
NIRCam F300M
NIRCam F444W
MIRI F1140C
Planet
MIRI F1550C

21


Earth-like Exoplanet's Transmisson Spectrum
Amount of Light
more
less
Molecular Oxygen
Ozone
Water
Water
Methane
Methane
Carbon dioxide
Carbon dioxide
Ozone
Water
Methane
Ozone
Carbon dioxide
1
2
4
8
16
red
near-infrared
mid-infrared
Wavelength (Color) of Light in Microns

22

Reexamining How Stars Form, Live, and Die

23

24

25

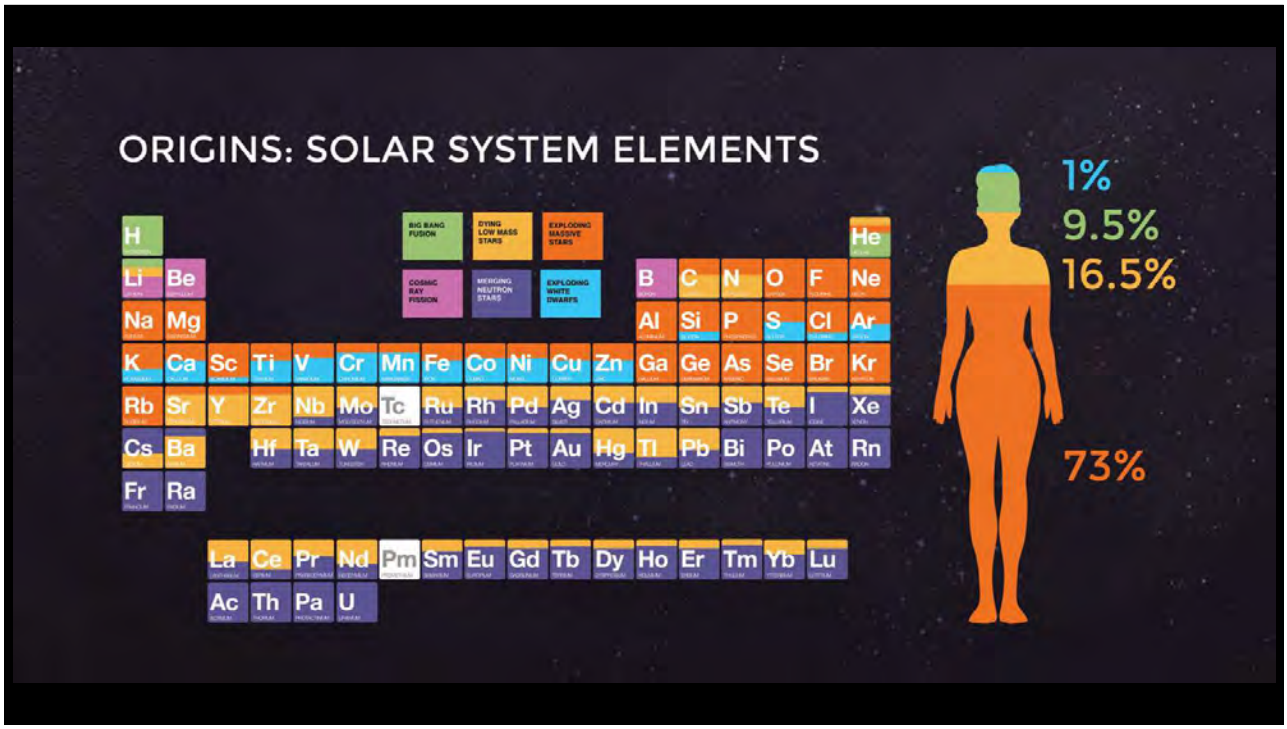
Tycho Brahe observing the supernova of 1572

Massive stars end their lives as *supernova explosions* that drive cosmic evolution and make raw materials for life.

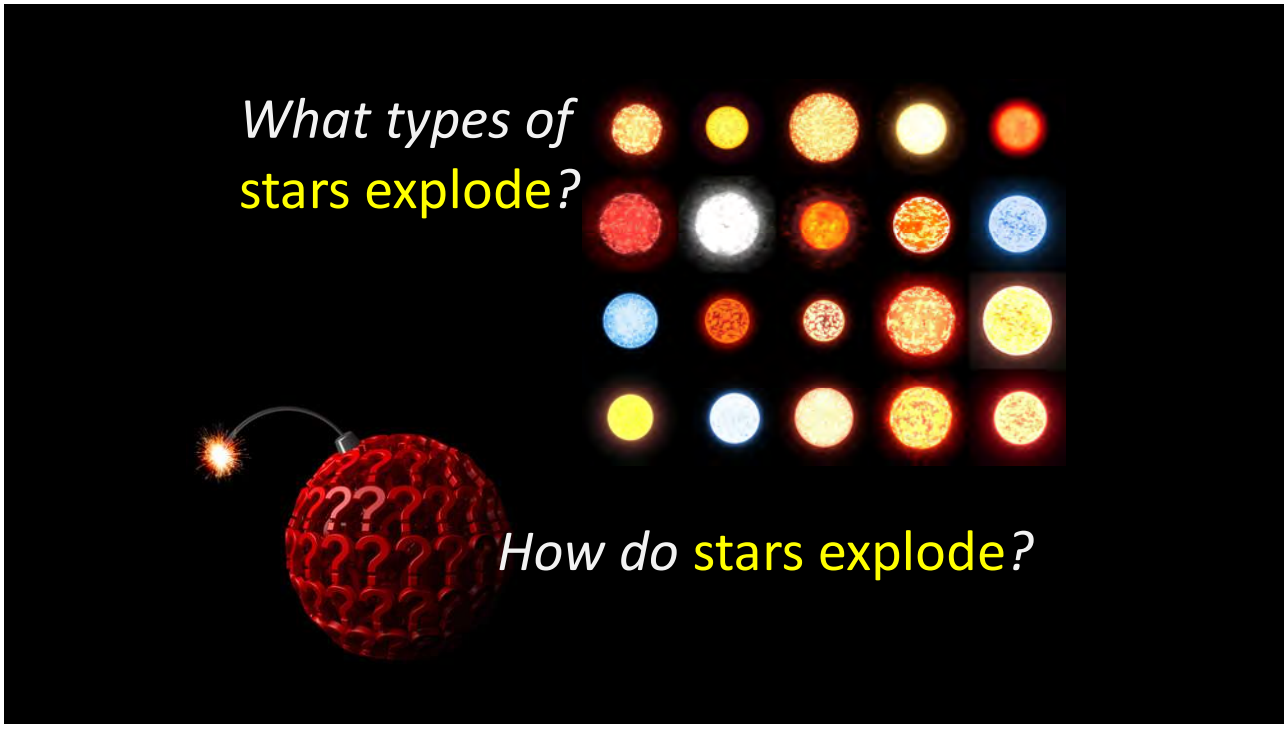
When these explosions happen in our own Milky Way galaxy, they can sometimes be seen with the naked eye – even during the day.

SN 1987A

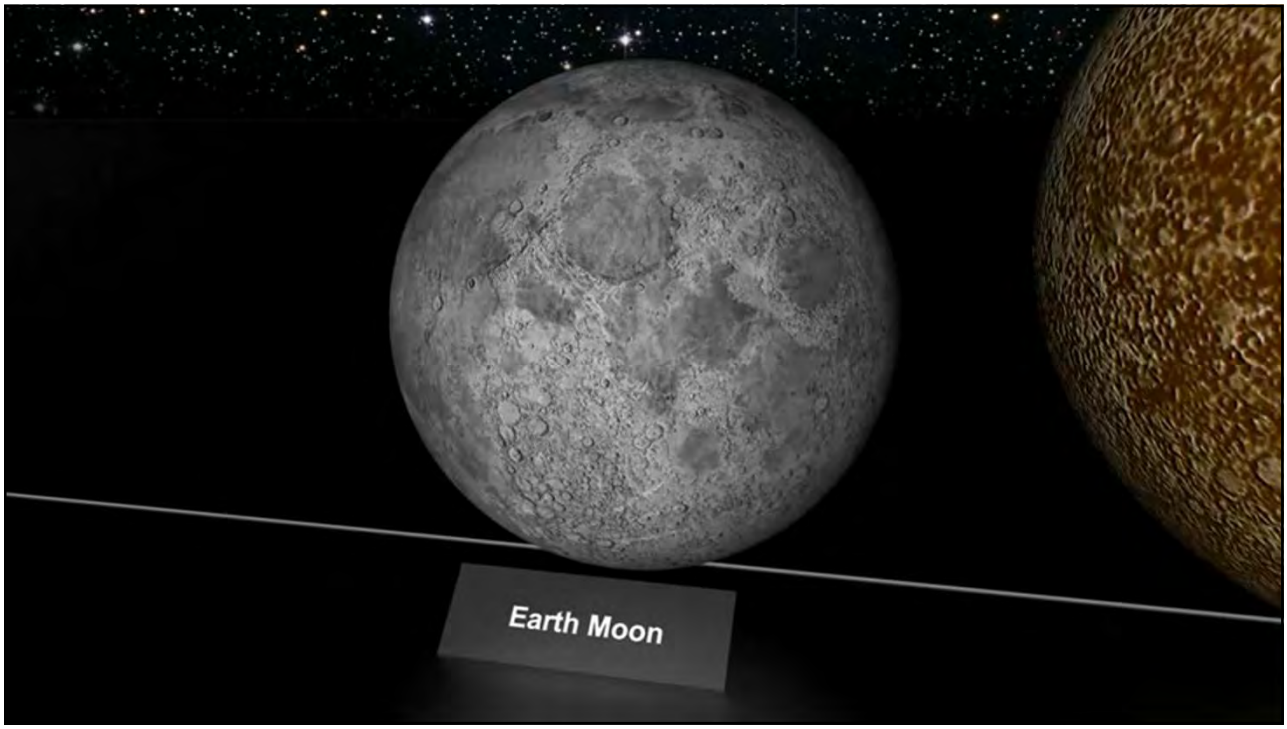
26


ORIGINS: SOLAR SYSTEM ELEMENTS
BIG BANG FUSION
DYING LOW MASS STARS
EXPLODING MASSIVE STARS
COSMIC RAY FISSION
MERGING NEUTRON STARS
EXPLODING WHITE DWARFS
H
He
Li Be
B C N O F Ne
Na Mg
Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Ac Th Pa U
1%
9.5%
16.5%
73%

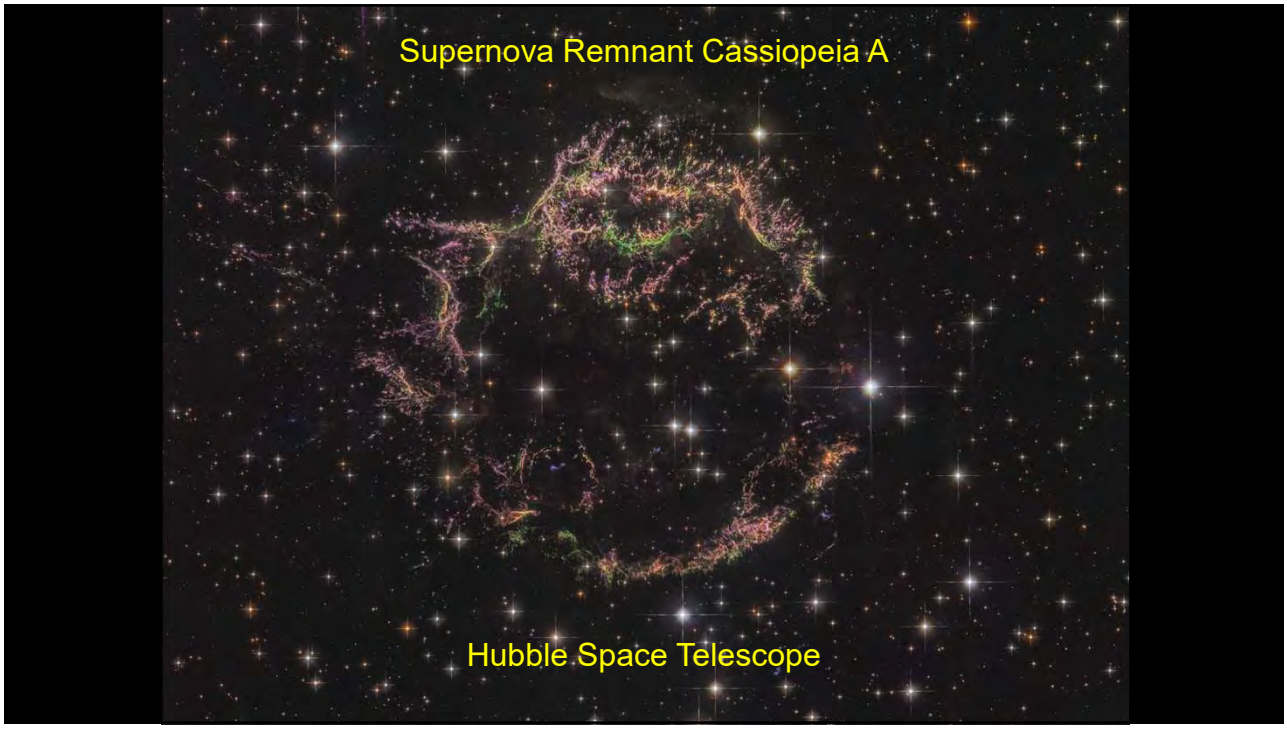
27


What types of stars explode?
How do stars explode?

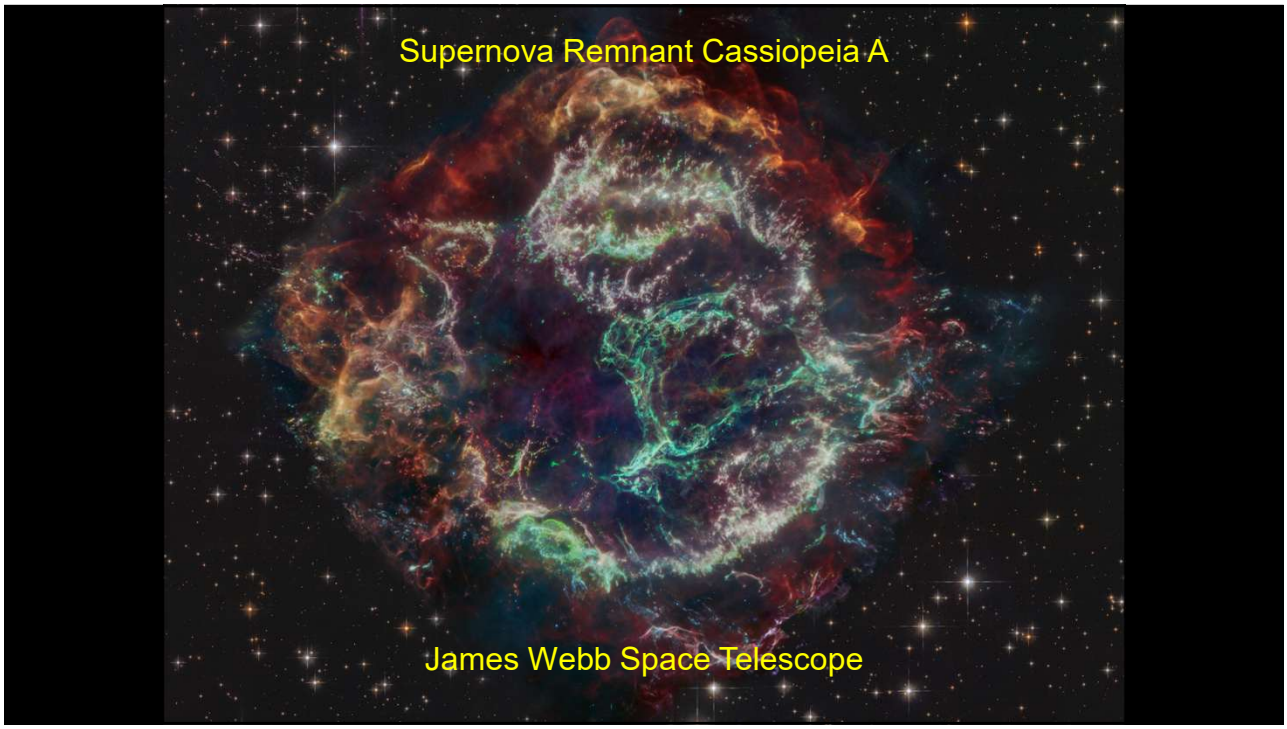
28


Earth Moon

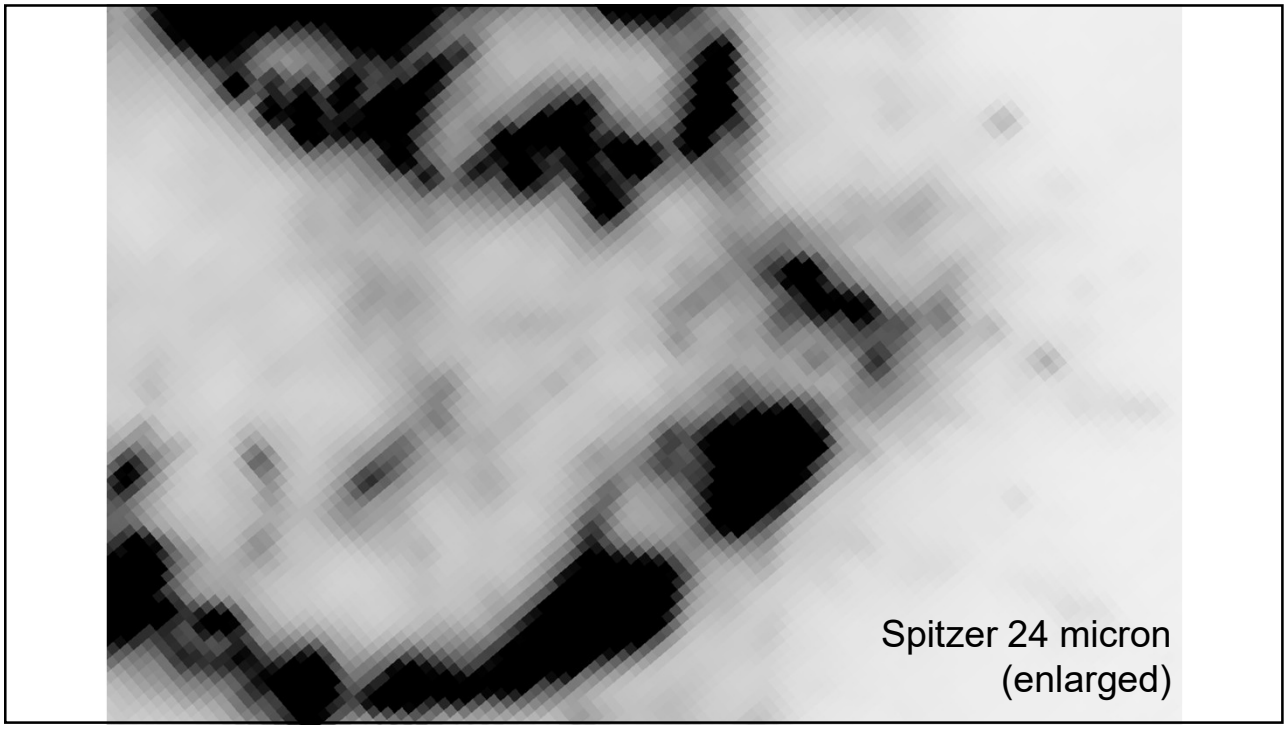
29


Supernova Remnant Cassiopeia A
Hubble Space Telescope

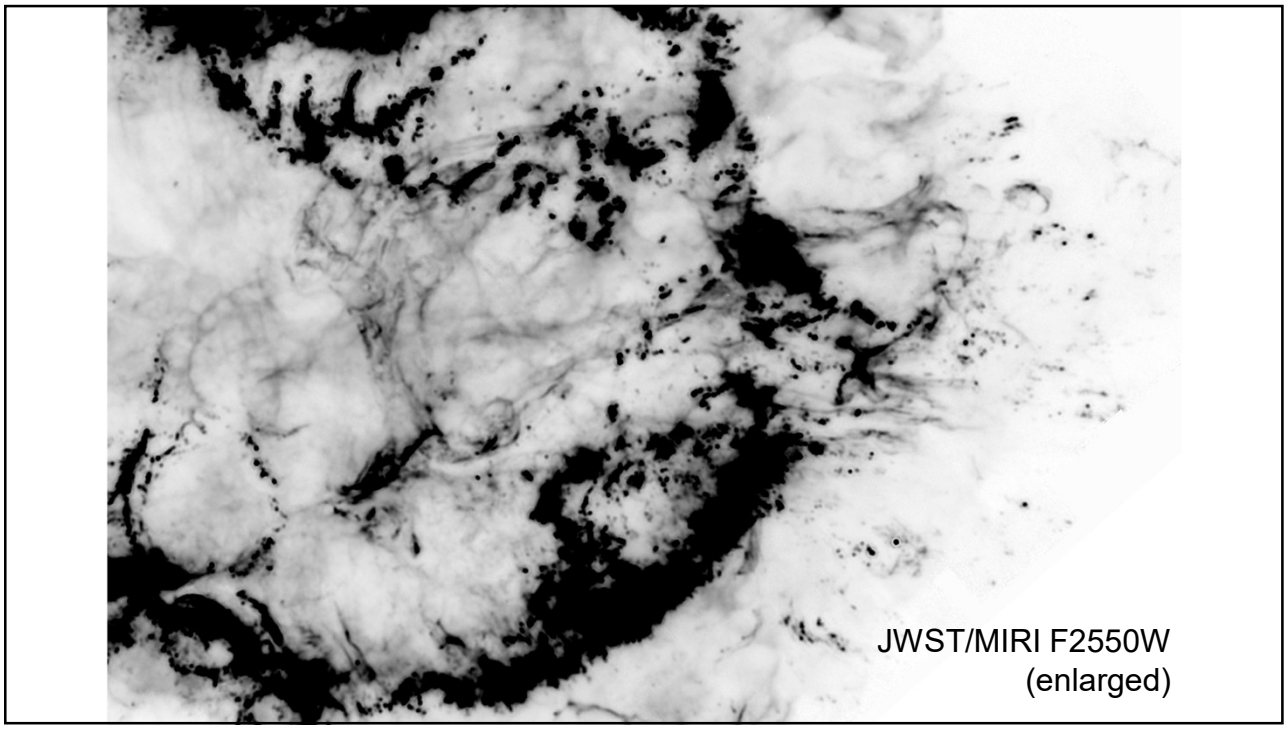
30


Supernova Remnant Cassiopeia A
James Webb Space Telescope

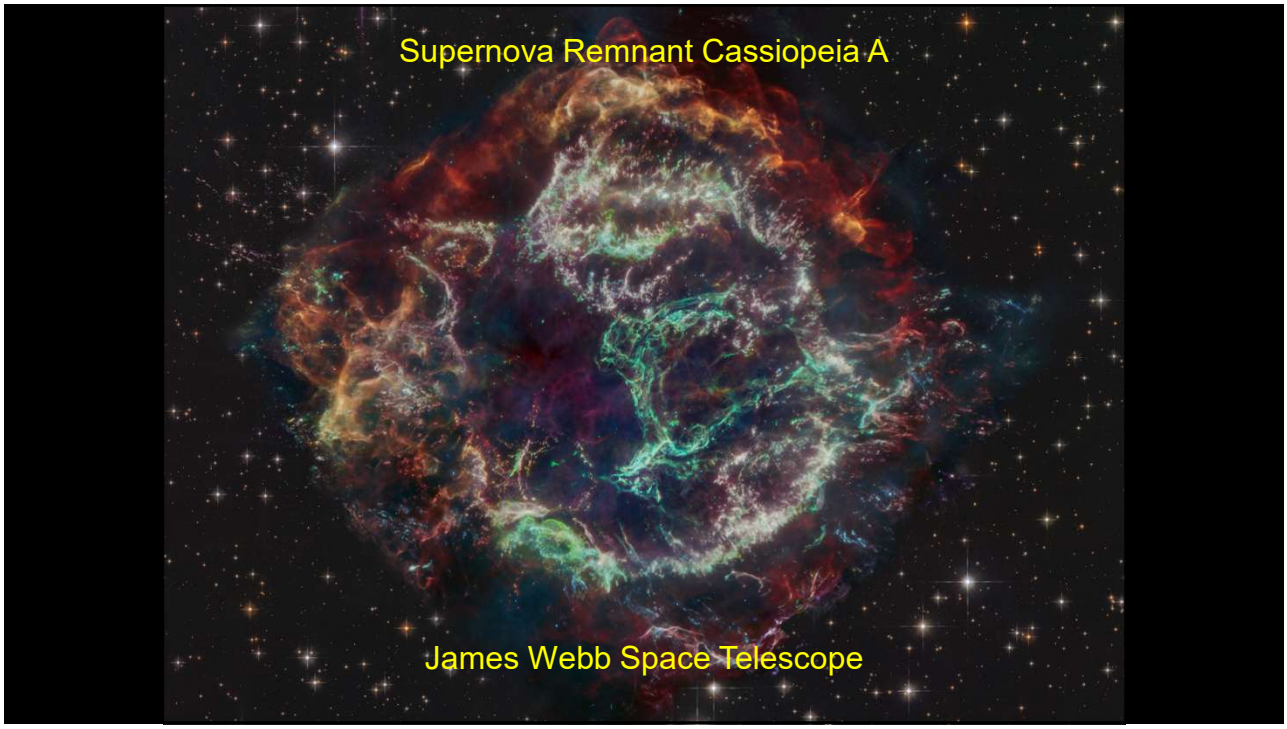
31


Spitzer 24 micron
(enlarged)

32


JWST/MIRI F2550W
(enlarged)

33

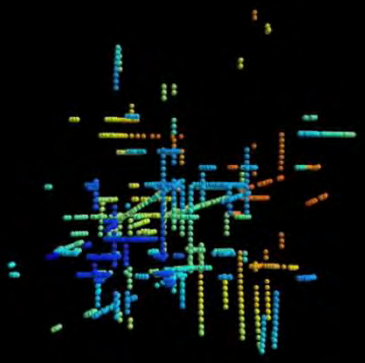

Supernova Remnant Cassiopeia A
James Webb Space Telescope

34

35

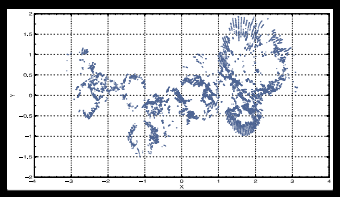
36

3D Reconstruction of a SN Debris Field



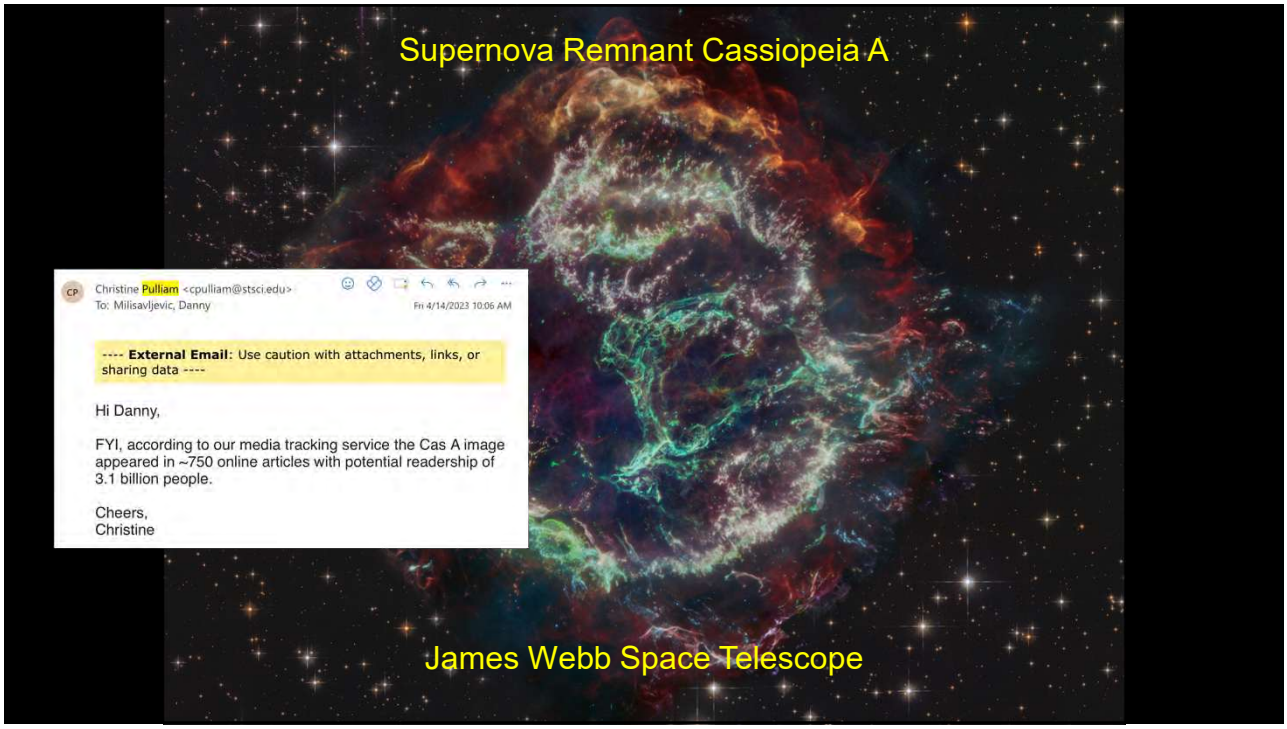
Milisavljevic & Fesen (2015, *Science*)

Ejecta distribution exhibits large-scale coherent structure that was imprinted early in the explosion



Mercator projection of reverse-shocked O+S-rich material
Milisavljevic & Fesen (2013)

37



38

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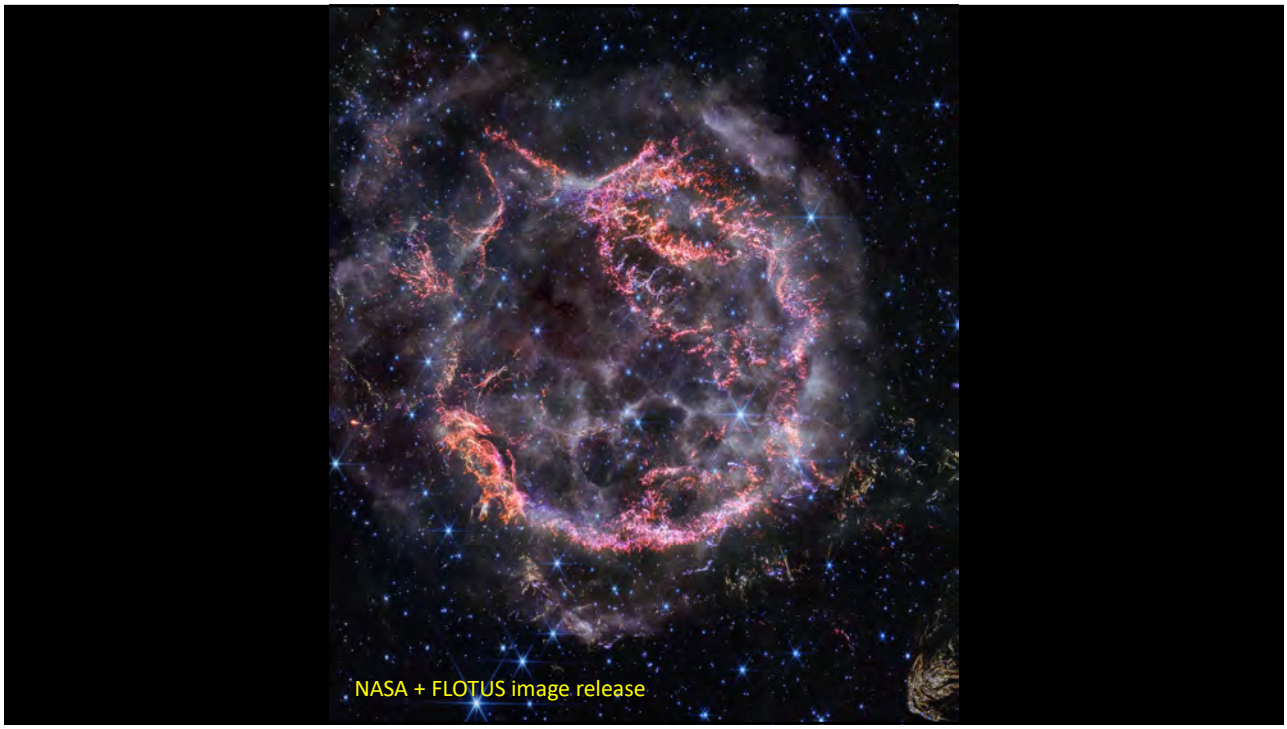
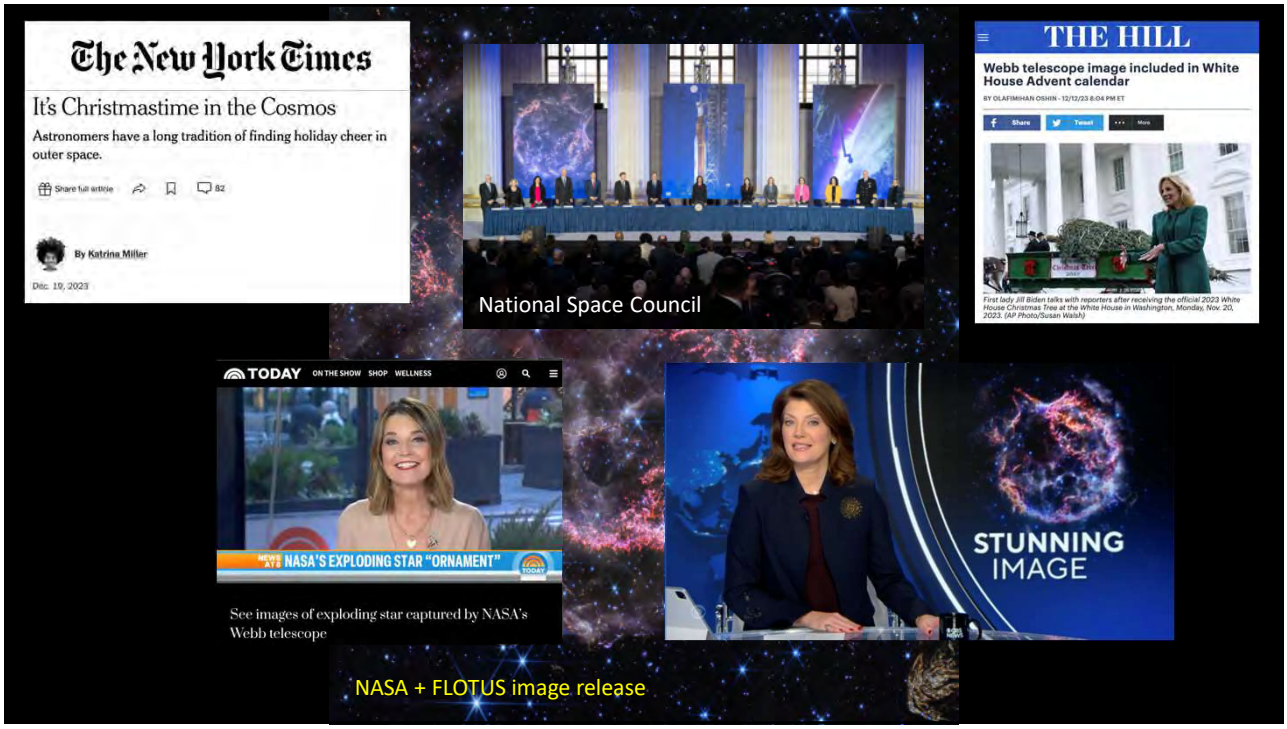
40


NASA + FLOTUS image release

41


The New York Times
It's Christmastime in the Cosmos
Astronomers have a long tradition of finding holiday cheer in outer space.
Share full article
82
By Katrina Miller
Dec. 19, 2023
National Space Council
THE HILL
Webb telescope image included in White House Advent calendar
BY OLAFIMIHAN OSHIN - 12/12/23 8:04 PM ET
Share
Tweet
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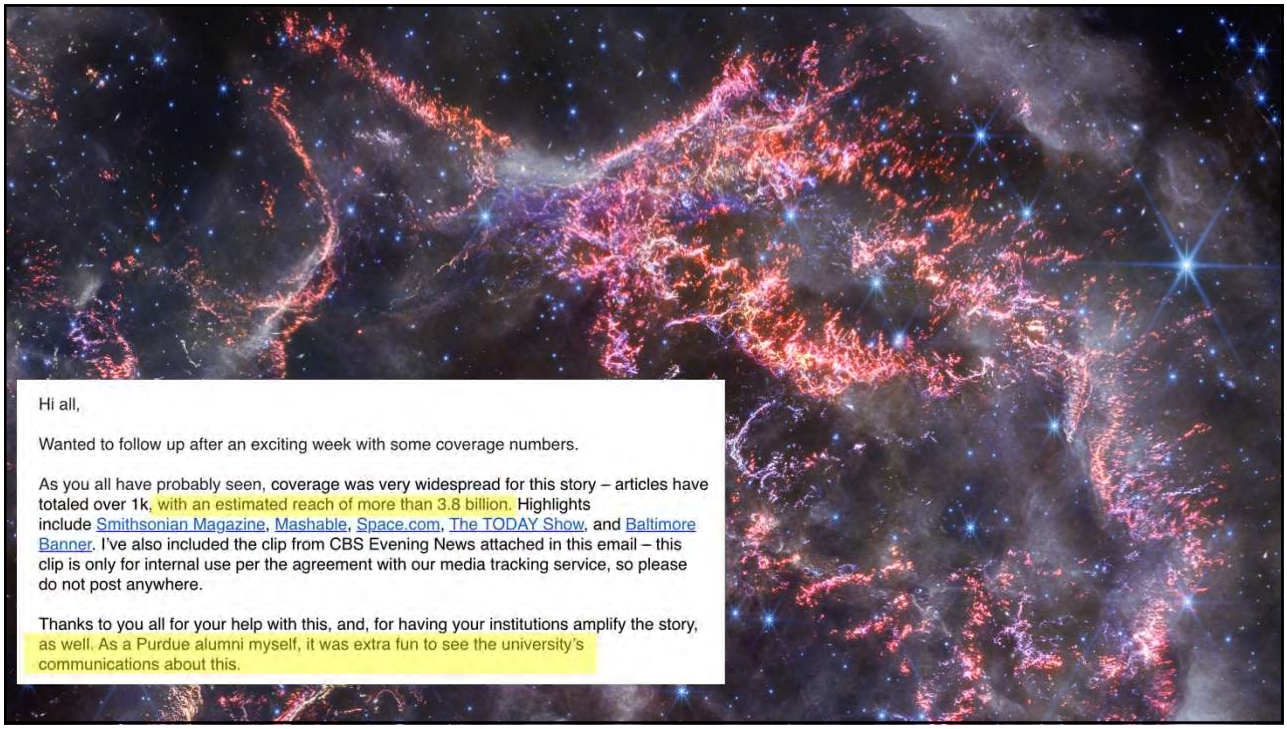
First lady Jill Biden talks with reporters after receiving the official 2023 White House Christmas Tree at the White House in Washington, Monday, Nov. 20, 2023. (AP Photo/Susan Walsh)
TODAY
ON THE SHOW
SHOP
WELLNESS
NASA'S EXPLODING STAR "ORNAMENT"
See images of exploding star captured by NASA's Webb telescope
STUNNING IMAGE
NASA + FLOTUS image release

42

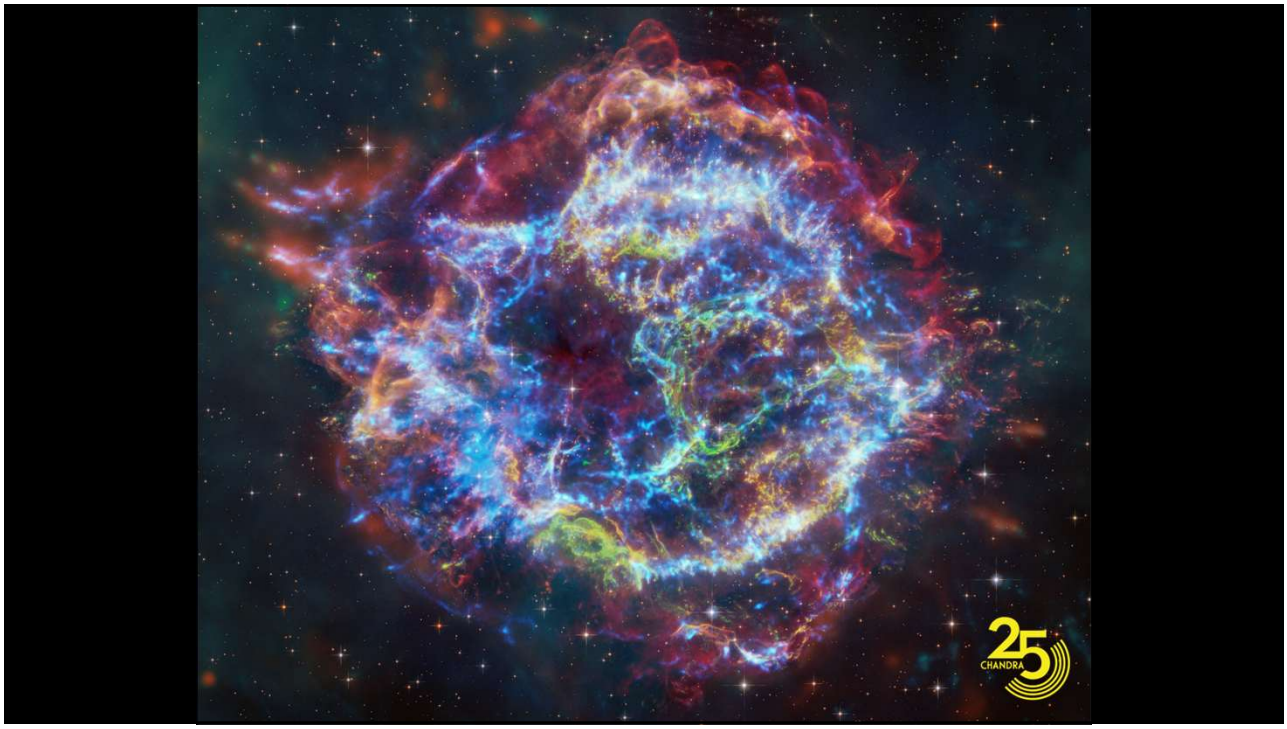

STUNNING
IMAGE
CBS NEWS
For Internal Use Only

43


Hi all,
Wanted to follow up after an exciting week with some coverage numbers.
As you all have probably seen, coverage was very widespread for this story – articles have totaled over 1k, with an estimated reach of more than 3.8 billion. Highlights include Smithsonian Magazine, Mashable, Space.com, The TODAY Show, and Baltimore Banner. I've also included the clip from CBS Evening News attached in this email – this clip is only for internal use per the agreement with our media tracking service, so please do not post anywhere.
Thanks to you all for your help with this, and, for having your institutions amplify the story, as well. As a Purdue alumni myself, it was extra fun to see the university's communications about this.

44

45



46


NATIONAL GEOGRAPHIC
Learn Why We're Going Back to the Moon
Join the Search for Clues to Alien Life
MYSTERIES OF
SPACE
Explore the Depths of the Universe
Supernova Cassiopeia A as seen by the James Webb Space Telescope

47

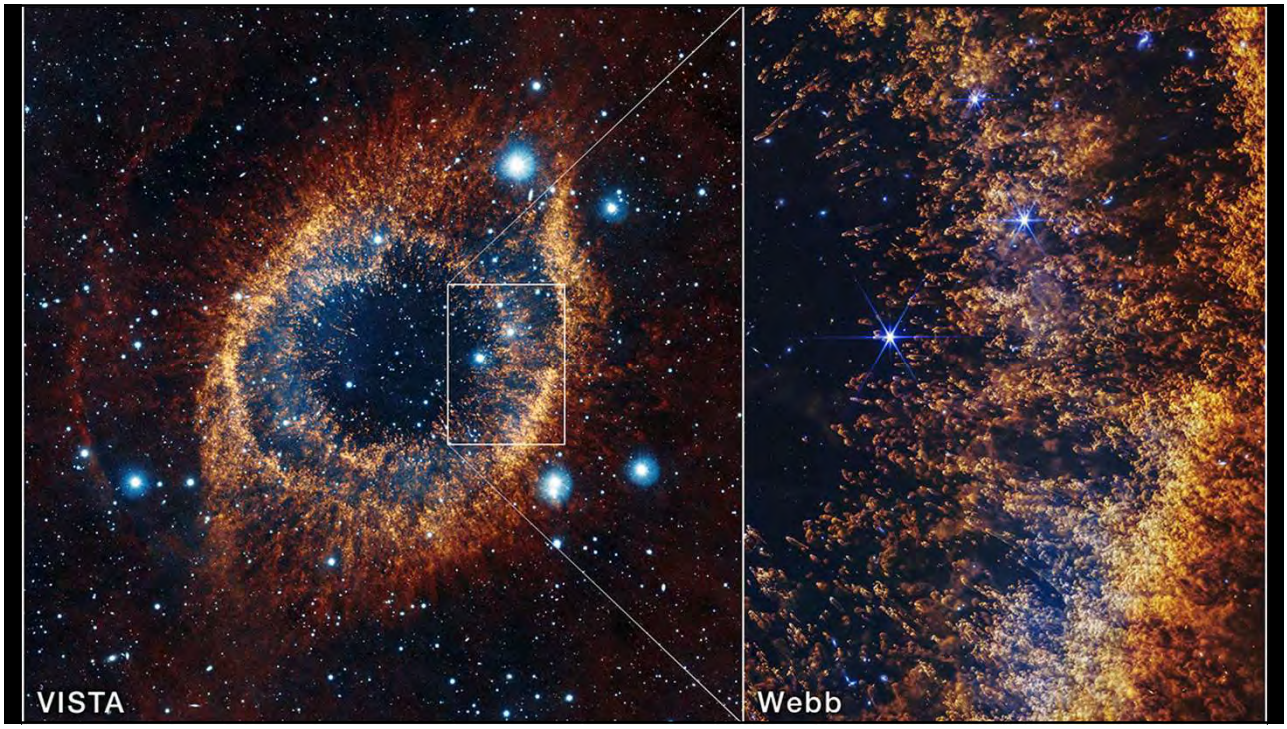

THE WHOLE STORY
WITH ANDERSON COOPER
The James Webb Telescope: Are We Alone?
CNN

48

49

50

51



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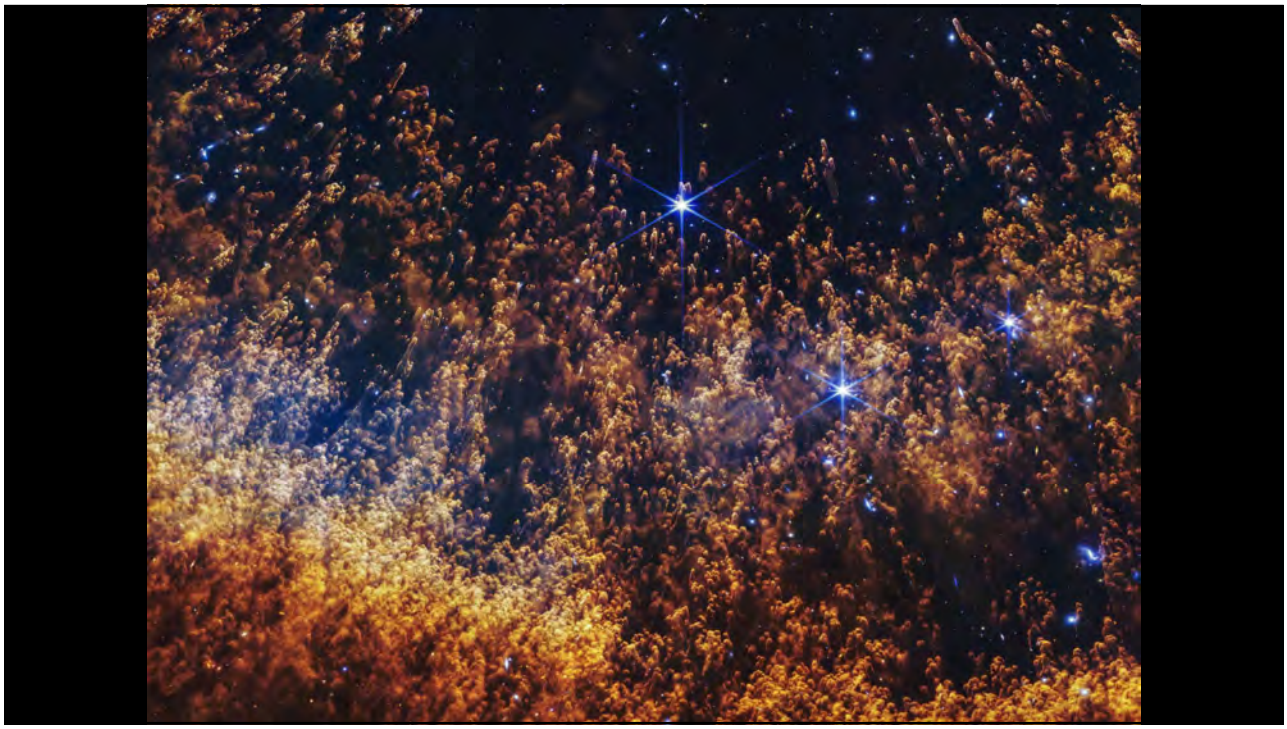


53

54

55

The bridge between a galaxy 10 billion light-years away and a tumor in a human lung is shorter than you think. Both astronomers and doctors share a fundamental problem: **they are trying to see something faint, distant, or hidden against a noisy background.**

Astronomical Origin	Medical Application	Benefit
Adaptive Optics	Retinal Imaging	Detection of eye disease at cellular levels.
Galaxy Clustering Algs	Mammography	Higher accuracy in spotting early-stage tumors.
CCD Refinement	Digital X-Rays	Lower radiation doses and instant results.
Radio Interferometry	MRI / CT Scans	High-resolution 3D internal imaging.

56

Several of the most important advances in how we scan, visualize, and diagnose the human body ***originated from techniques developed to study the cosmos***.

Image Reconstruction Algorithms (CT & MRI)

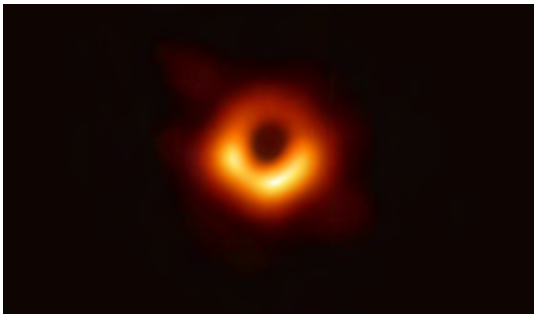
Astronomers often collect *incomplete* or *indirect* data—radio telescopes detect signals across sparse baselines, and X-ray telescopes reconstruct images from limited photons.

To deal with this, astronomy pioneered **Fourier-transform–based image reconstruction** and **tomographic techniques**.

57

Several of the most important advances in how we scan, visualize, and diagnose the human body ***originated from techniques developed to study the cosmos***.

Image Reconstruction Algorithms (VLBI image reconstruction of supermassive black hole in M87)



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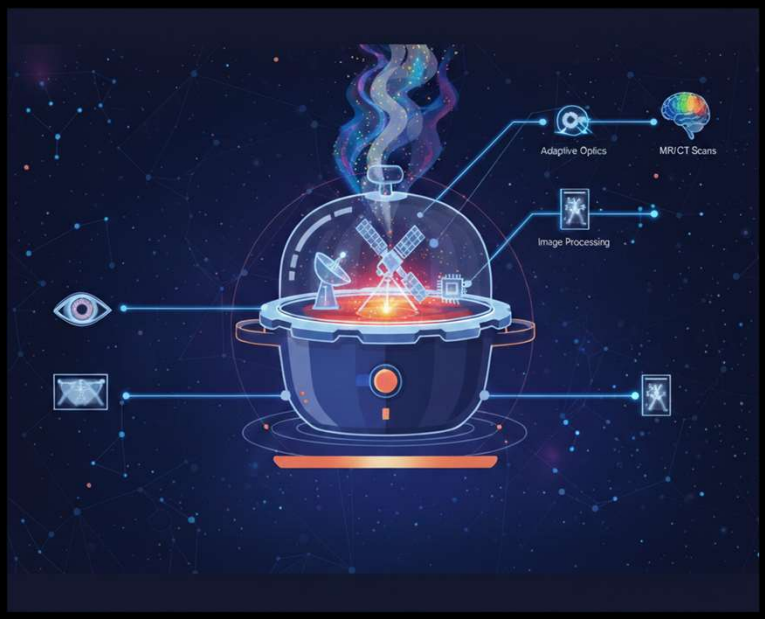
58

Augmented reality platform CollabXR developed at Purdue for astronomy, but being used for everything from nursing to archeology

59



Astronomy is a kind of **innovation pressure cooker:** a discipline where scientists are forced to invent entirely new ways of *seeing*.

When astronomers design a better way to observe the universe, those inventions can also observe *us* more clearly.

60

Yūgen 幽玄 – An awareness of the universe that triggers an emotional response too deep and powerful for words.

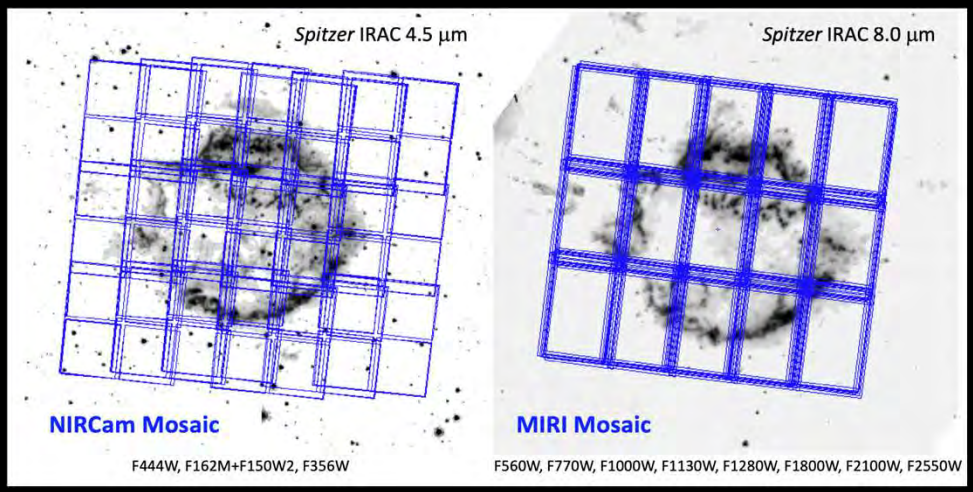
"The cosmos is within us. We are made of star-stuff. *We are a way for the universe to know itself.*"
-Carl Sagan

PURDUE UNIVERSITY

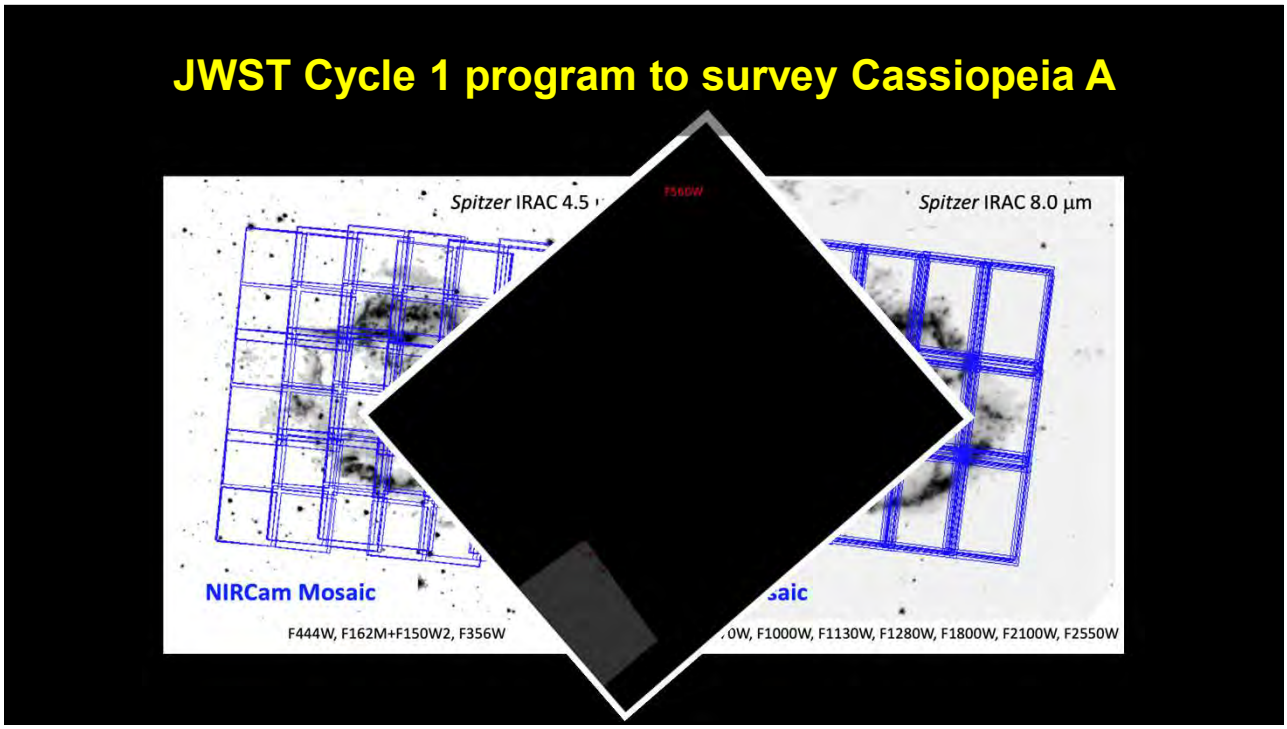
Thank you!

61

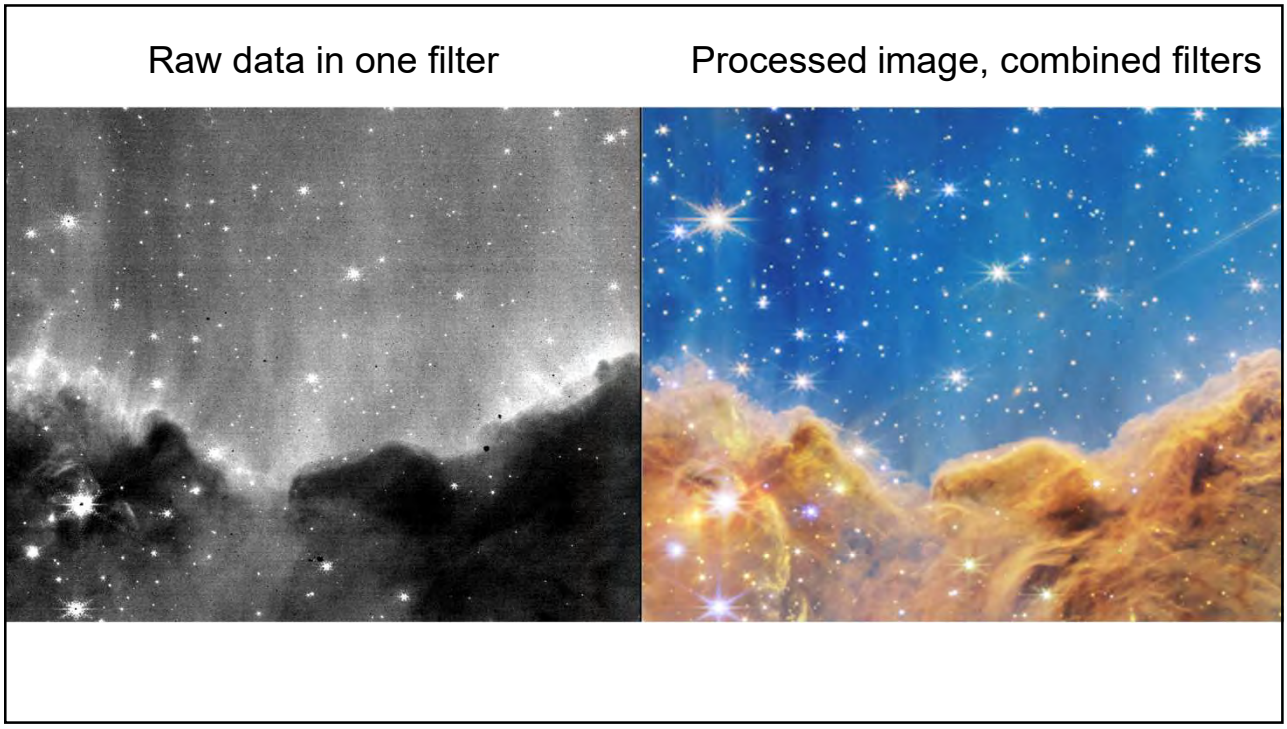
JWST Cycle 1 program to survey Cassiopeia A



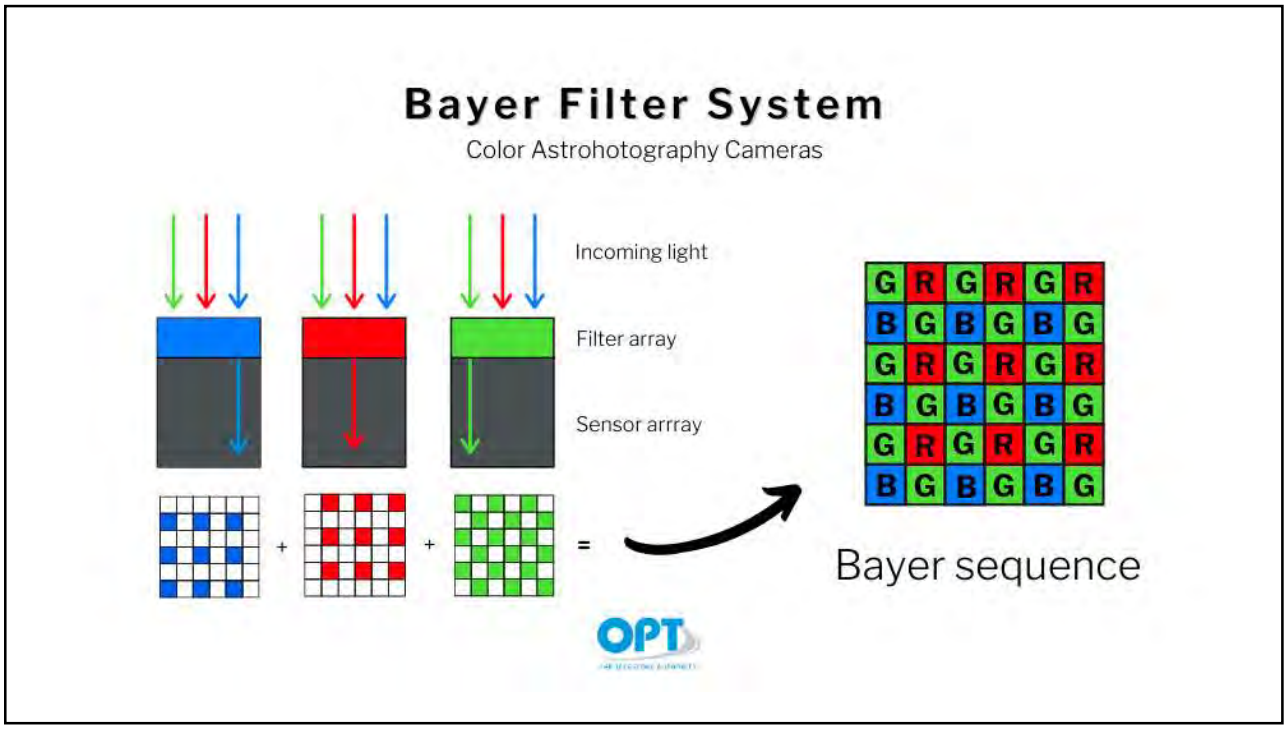
62


JWST Cycle 1 program to survey Cassiopeia A
Spitzer IRAC 4.5
Spitzer IRAC 8.0 μm
NIRCam Mosaic
F444W, F162M+F150W2, F356W

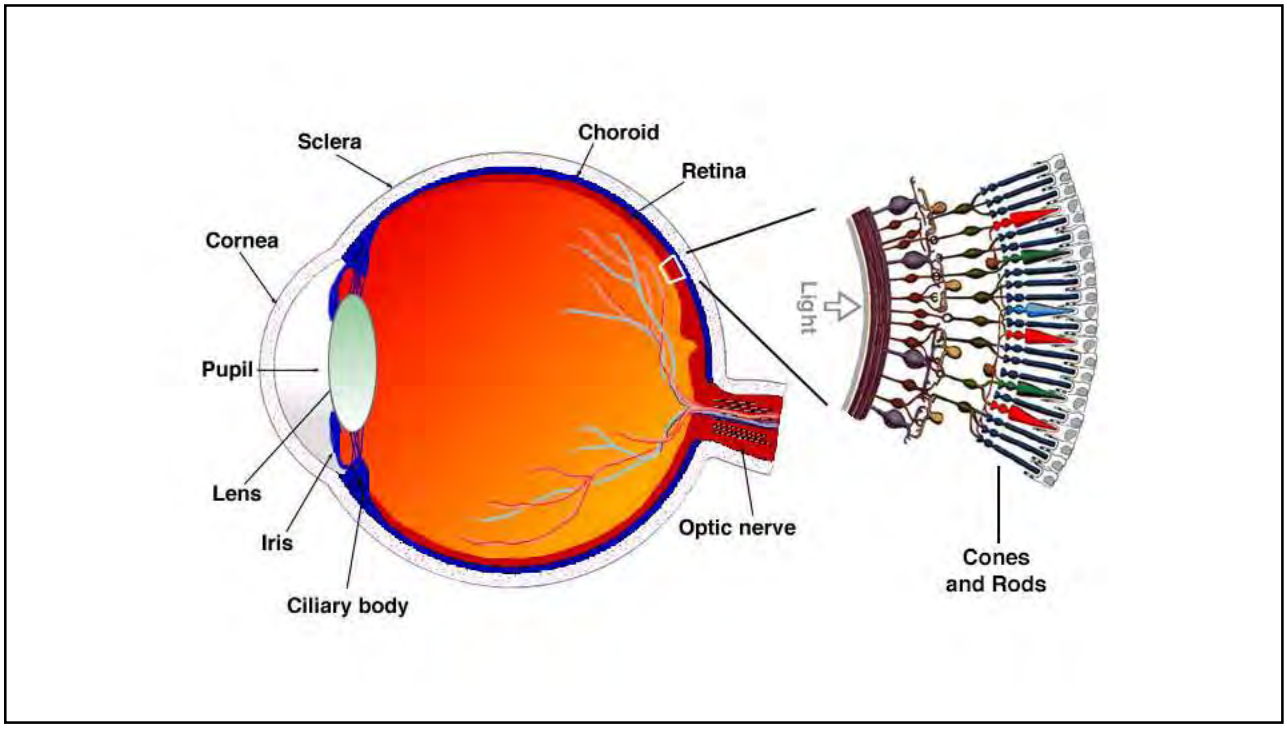
63


Raw data in one filter
Processed image, combined filters

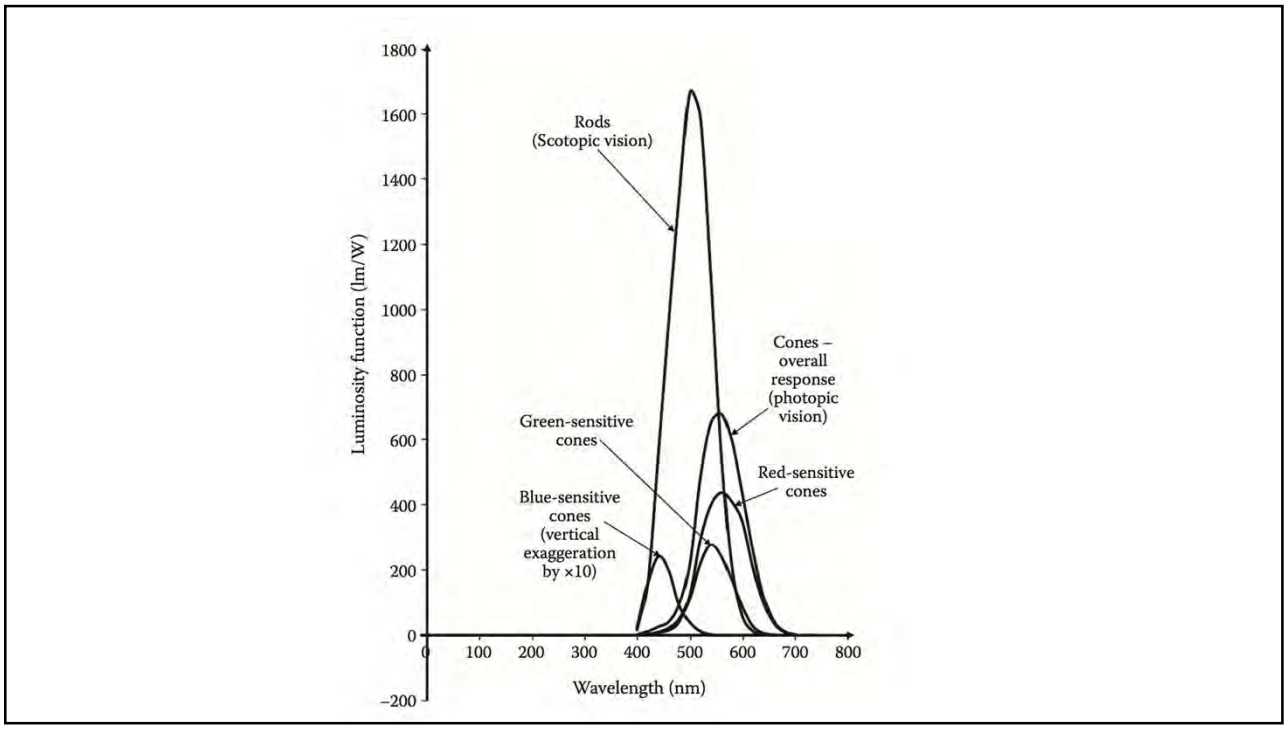
64


Bayer Filter System
Color Astrohotography Cameras
Incoming light
Filter array
Sensor arrray
Bayer sequence
OPT

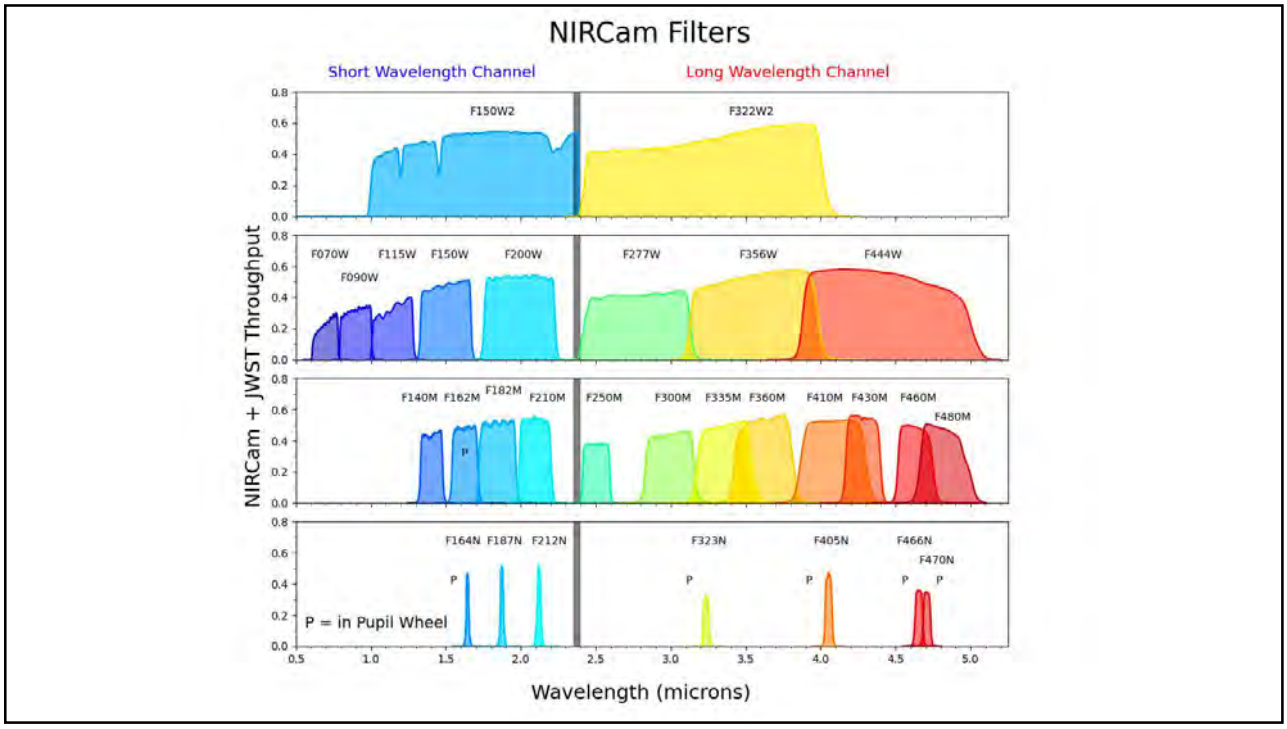
65


Sclera
Choroid
Retina
Cornea
Pupil
Lens
Iris
Ciliary body
Optic nerve
Light
Cones
and Rods

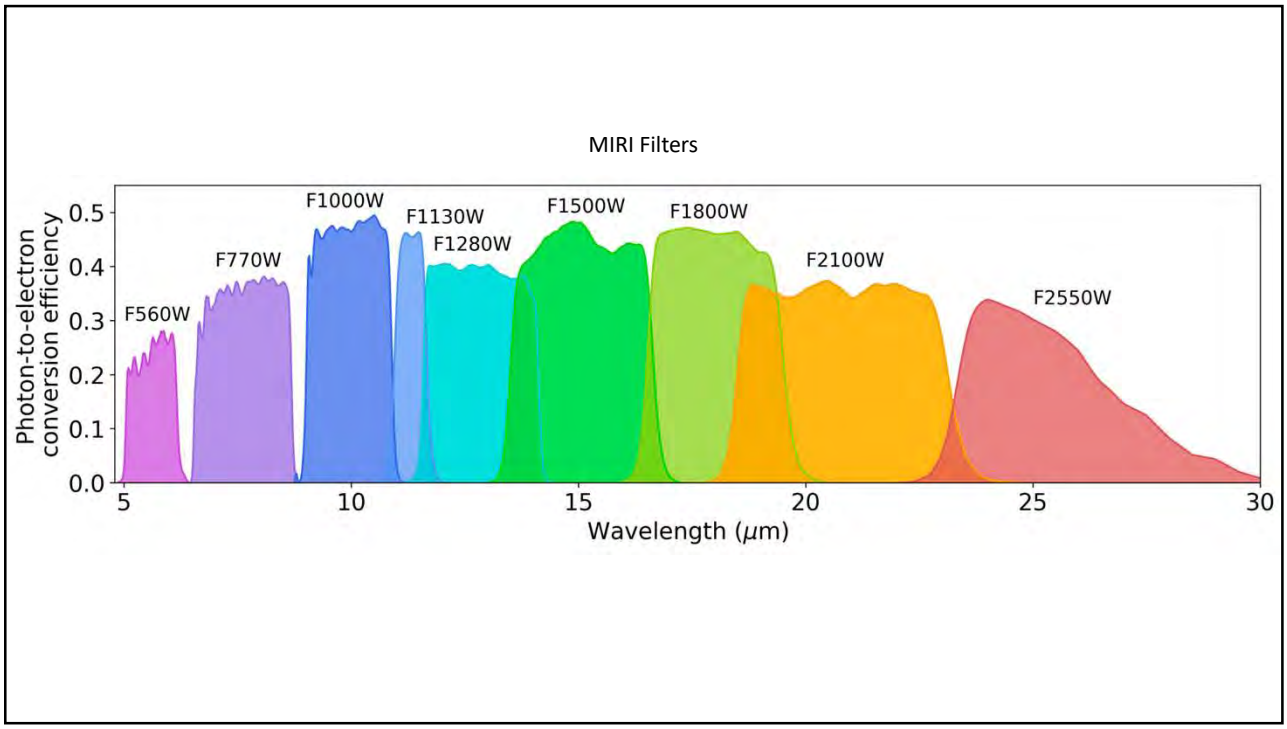
66


Luminosity function (lm/W)
Wavelength (nm)
Rods
(Scotopic vision)
Cones –
overall
response
(photopic
vision)
Green-sensitive
cones
Red-sensitive
cones
Blue-sensitive
cones
(vertical
exaggeration
by ×10)

67

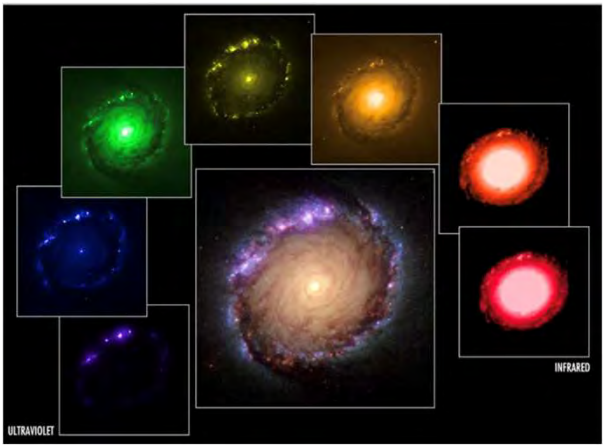

NIRCam Filters
Short Wavelength Channel
Long Wavelength Channel
NIRCam + JWST Throughput
Wavelength (microns)
F150W2
F322W2
F070W
F090W
F115W
F150W
F200W
F277W
F356W
F444W
F140M
F162M
F182M
F210M
F250M
F300M
F335M
F360M
F410M
F430M
F460M
F480M
F164N
F187N
F212N
F323N
F405N
F466N
F470N
P = in Pupil Wheel

68



69

Why does it look like that?



Images are obtained in filters sensitive to different wavelengths of light. Then, there are arbitrary decisions on how to assign colors, adjust the relative intensities, and blend together. This is where science meets art.

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70