다파장 천문학
다중신호 천문학

2022 수치상대론 및 중력파 여름
학교

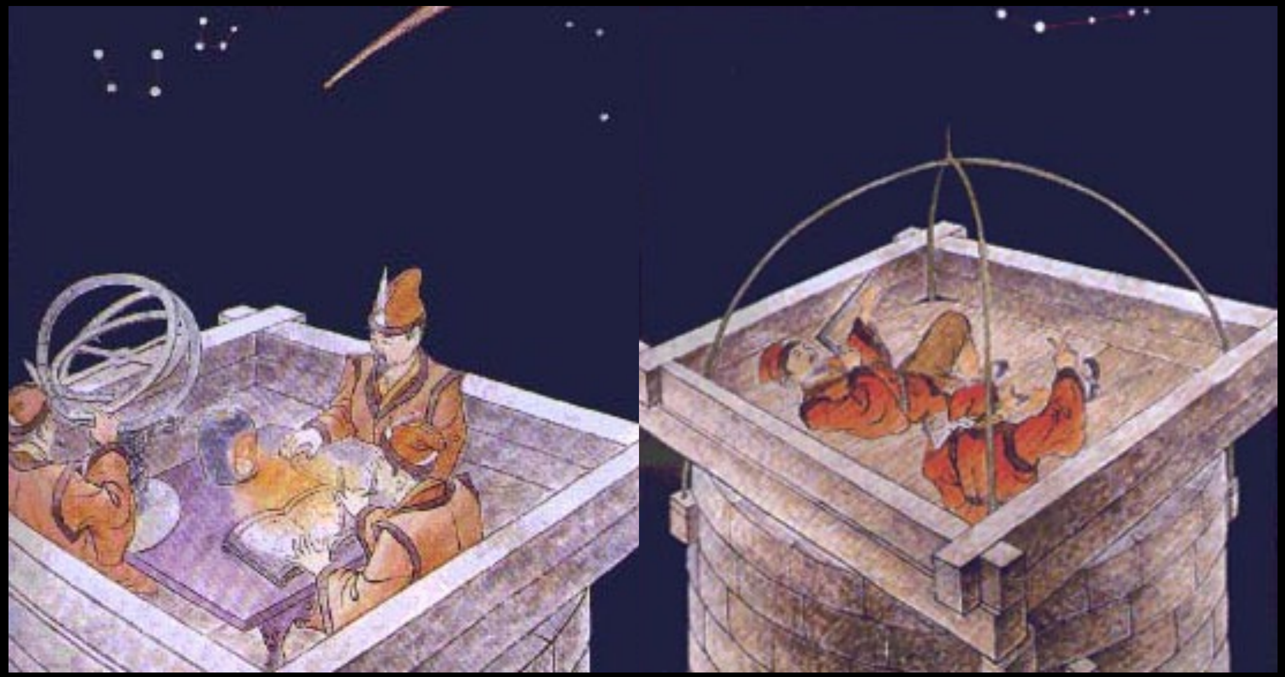
Jul.25, 2022
Lavalse hotel, Busan

한국교원대학교 손정주

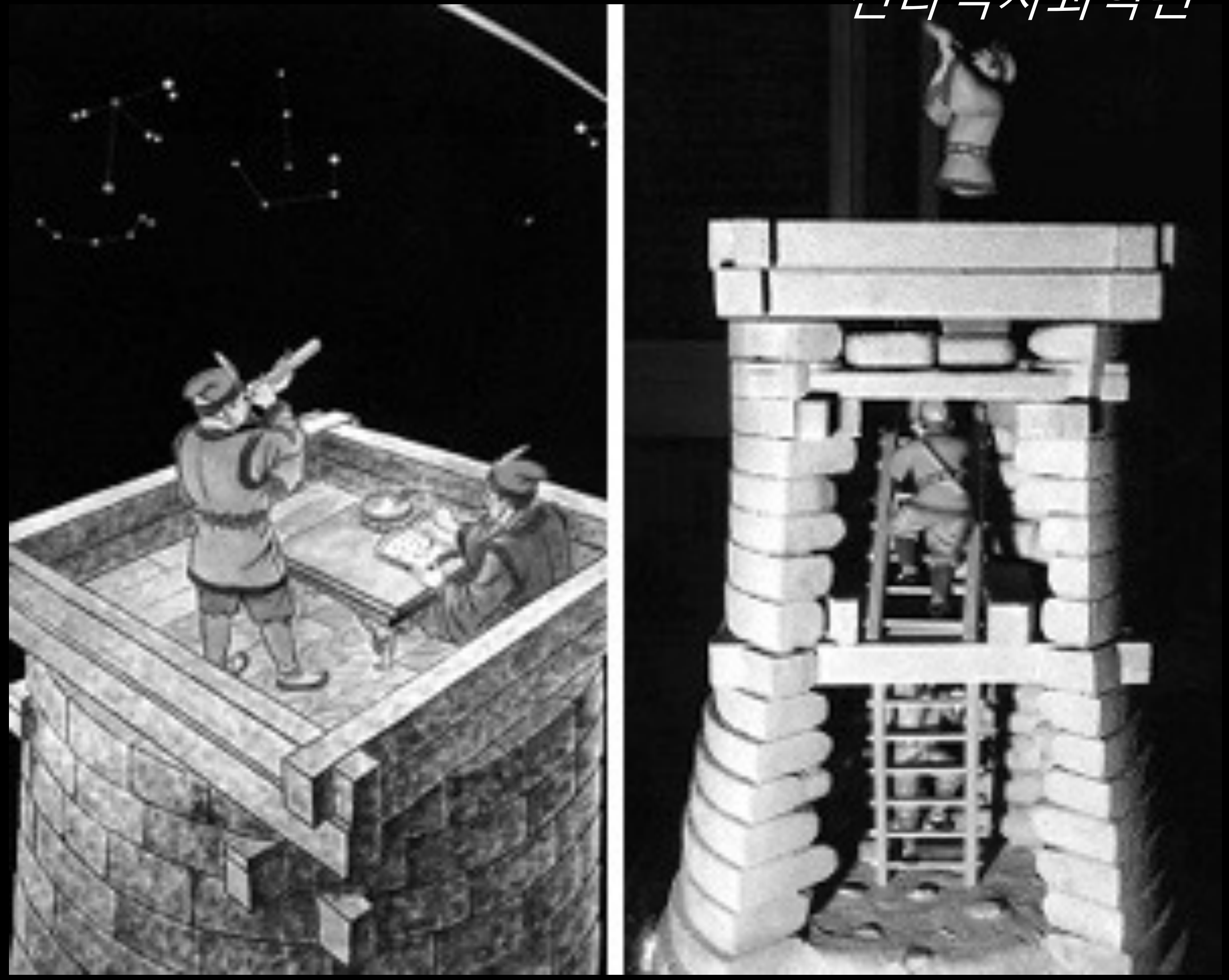
목차

어느 날 경주에서

J. Sohn



신라역사과학관



상부에서 본 첨성대 내부

첨성대 내부

신라역사과학관

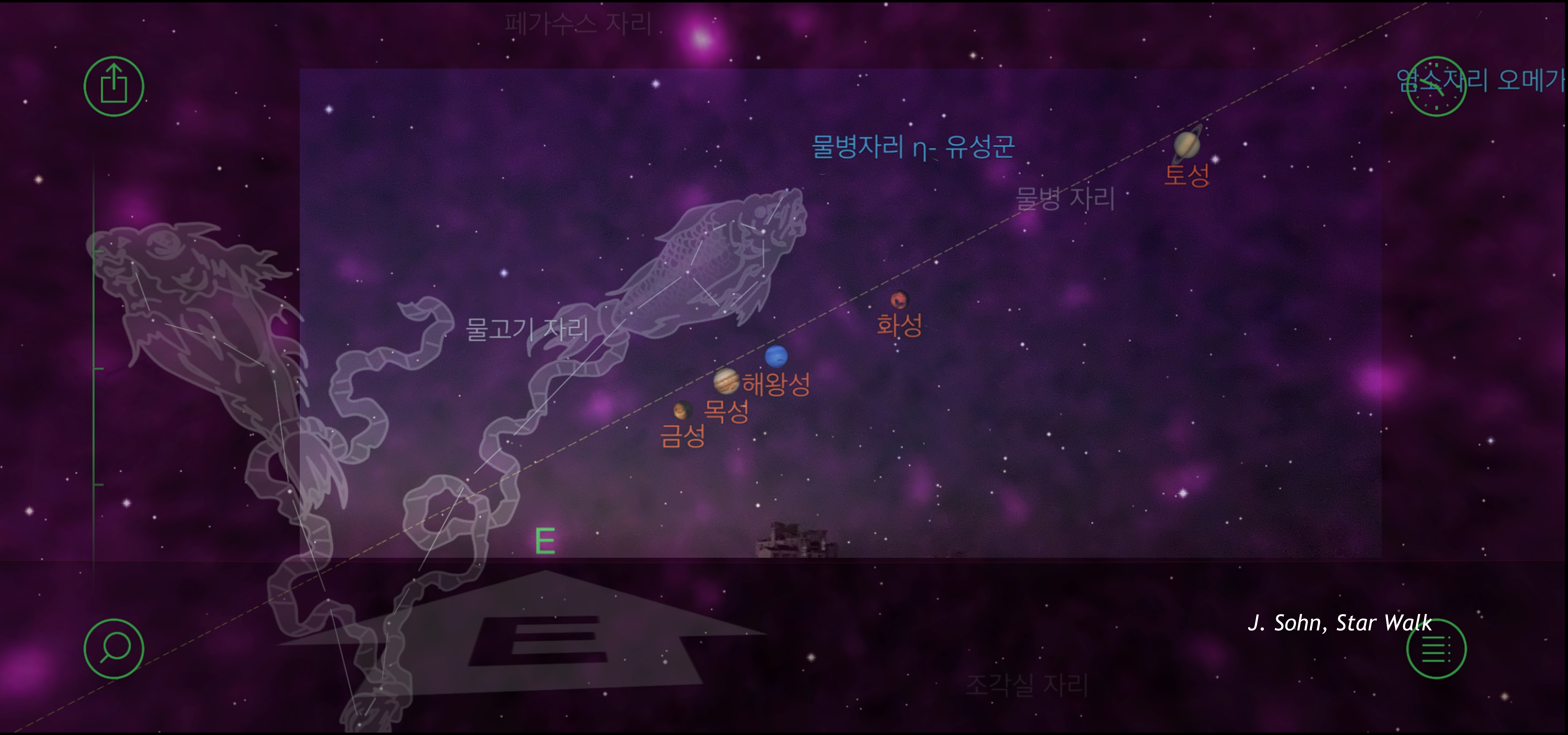
W.J. Shim

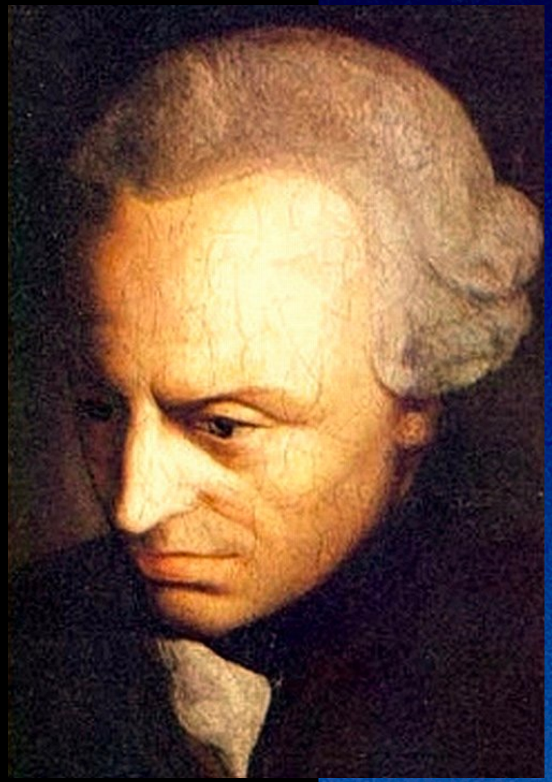
space.com

한국천문연구원

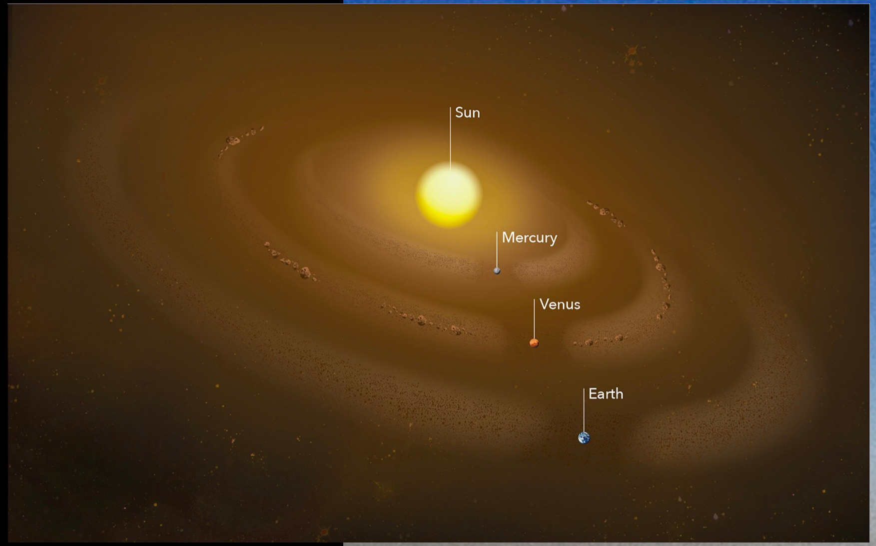

J. Sohn

J. Sohn, Star Walk

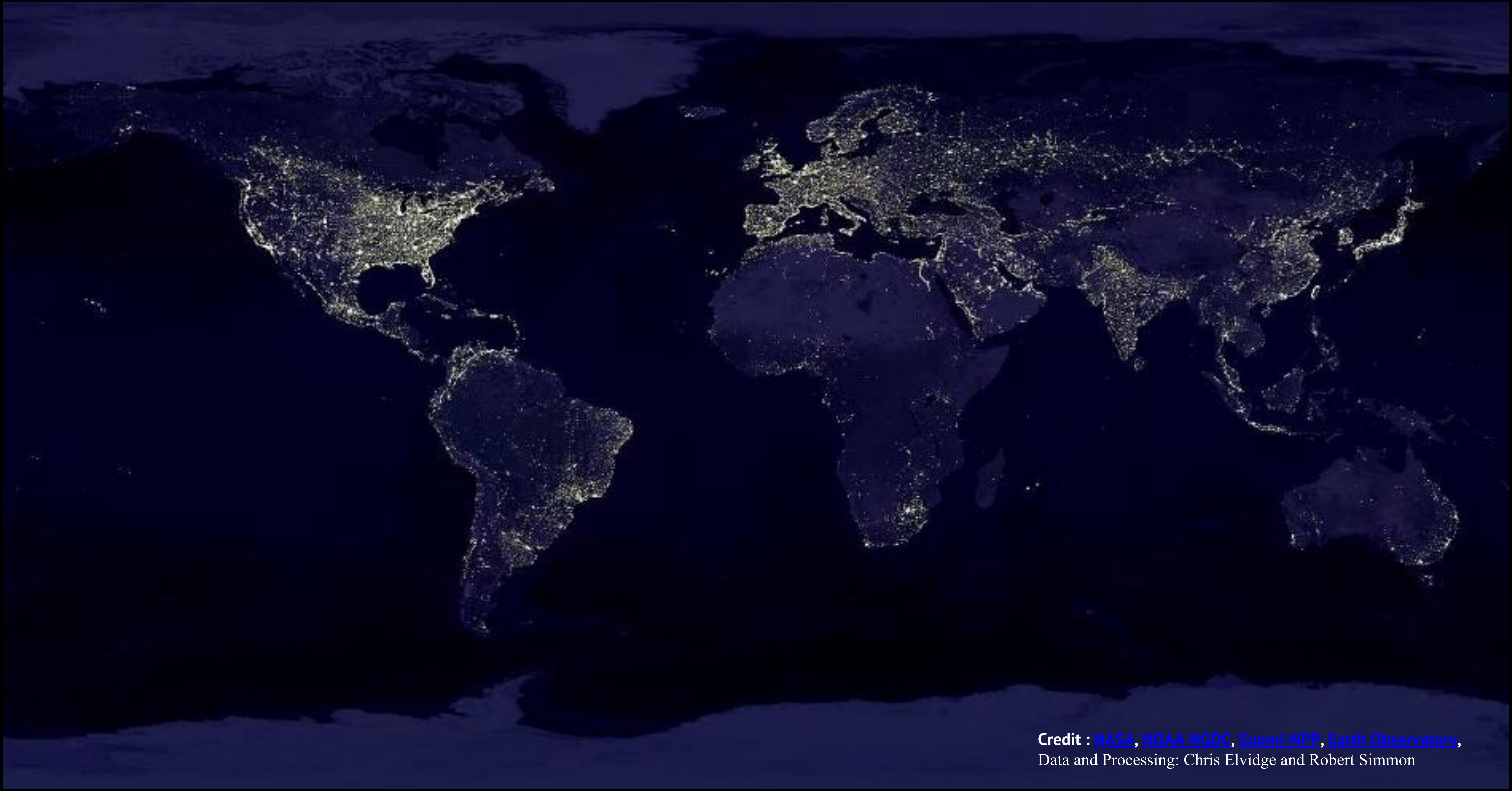

페가수스 자리
물병자리 η- 유성군
토성
물병 자리
화성
물고기 자리
해왕성
목성
금성
E
조각실 자리
J. Sohn, Star Walk



Immanel Kant (1724-1804) *Wikipedia*



NASA Sola System Exploration



Credit : NASA, NOAA NGDC, Suomi-NPP, Earth Observatory,
Data and Processing: Chris Elvidge and Robert Simmon

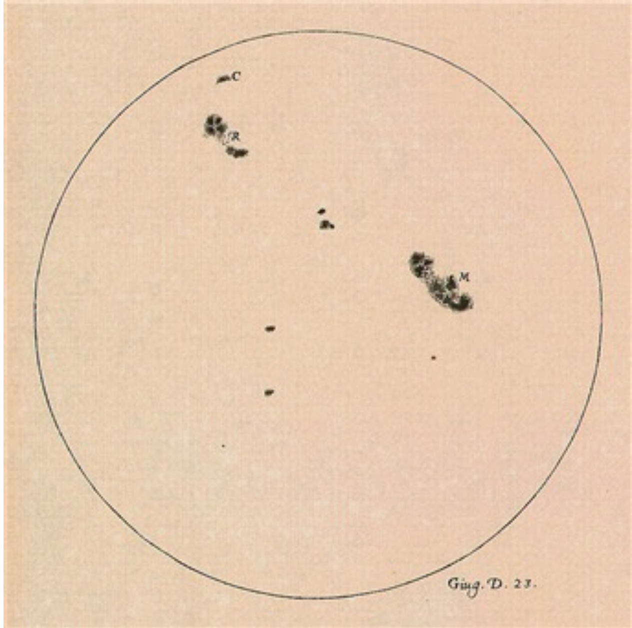
NASA's Goddard Space Flight Center

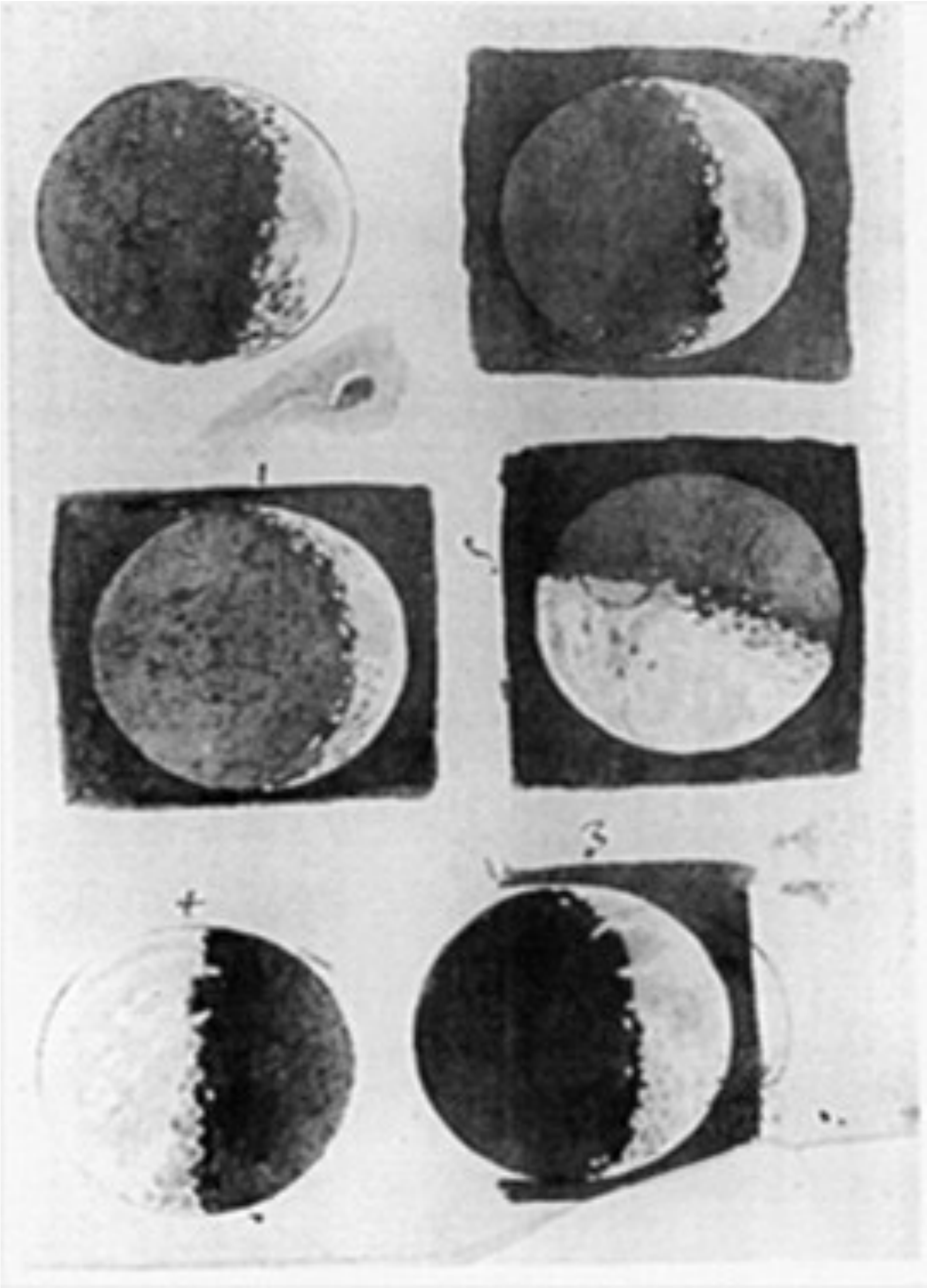
천체 관측기기의 역사

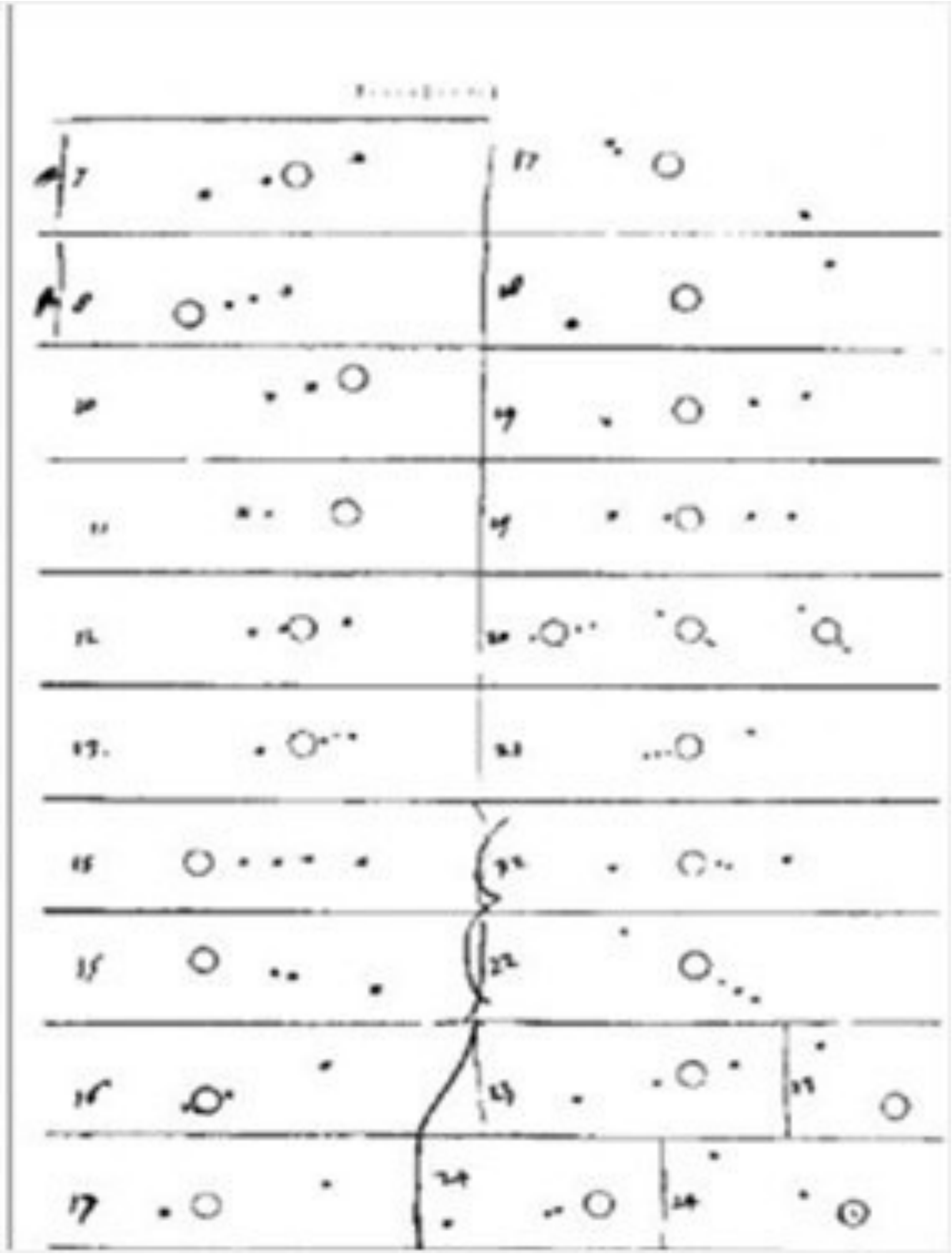
Early depiction of a "Dutch telescope" from 1624.
Wikipedia

Hans Lippershey (1570-1619) ndutch spectacle maker and inventor of telescope Lippershey with his children who according to legend helped their father discover.

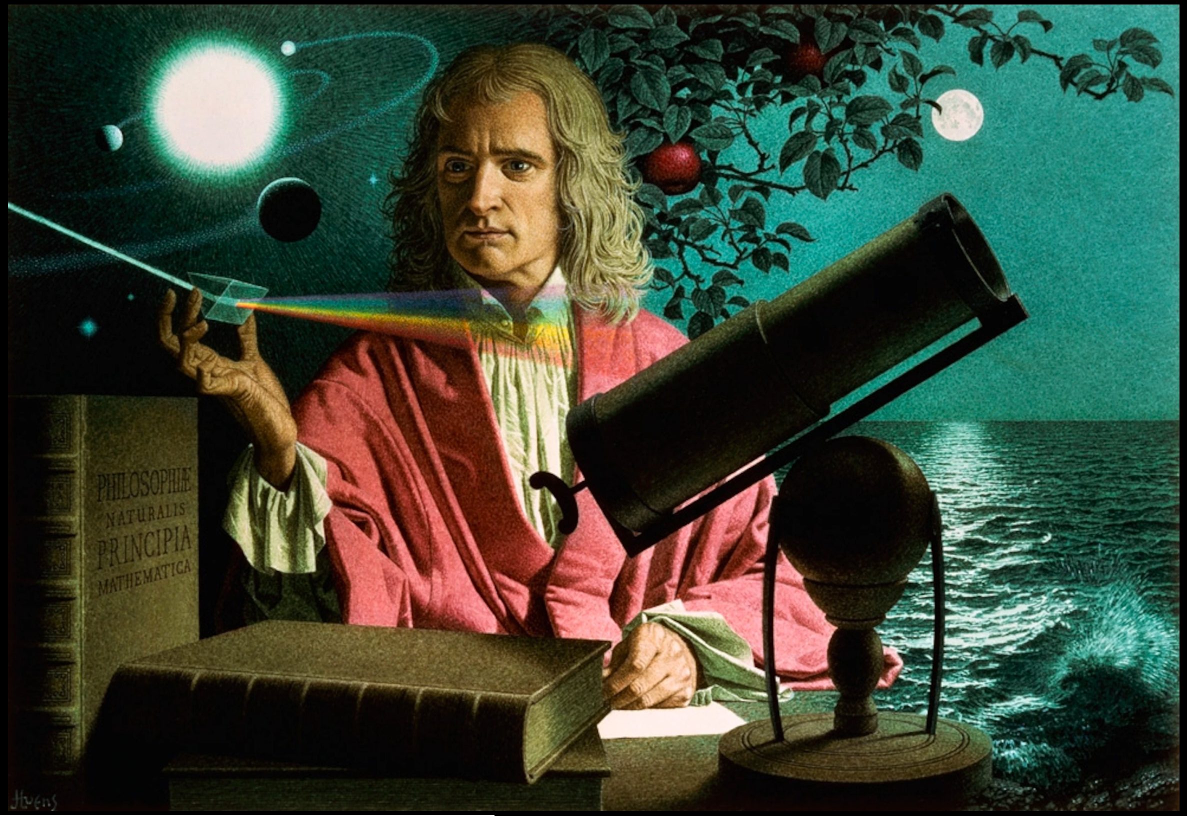
pixels.com



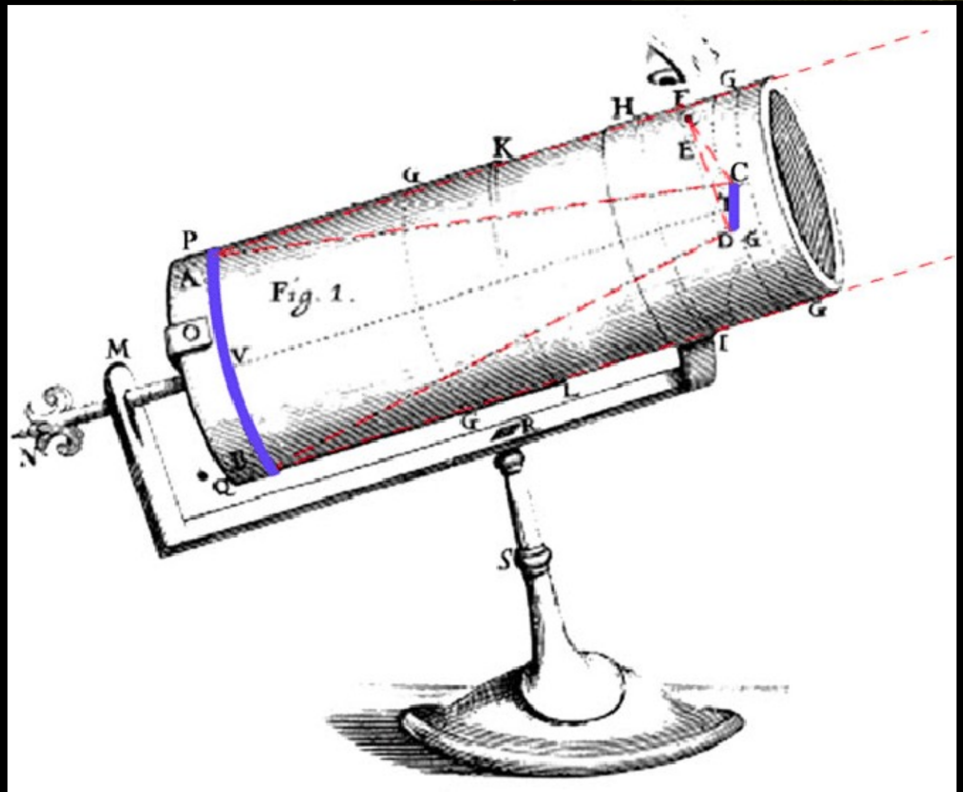


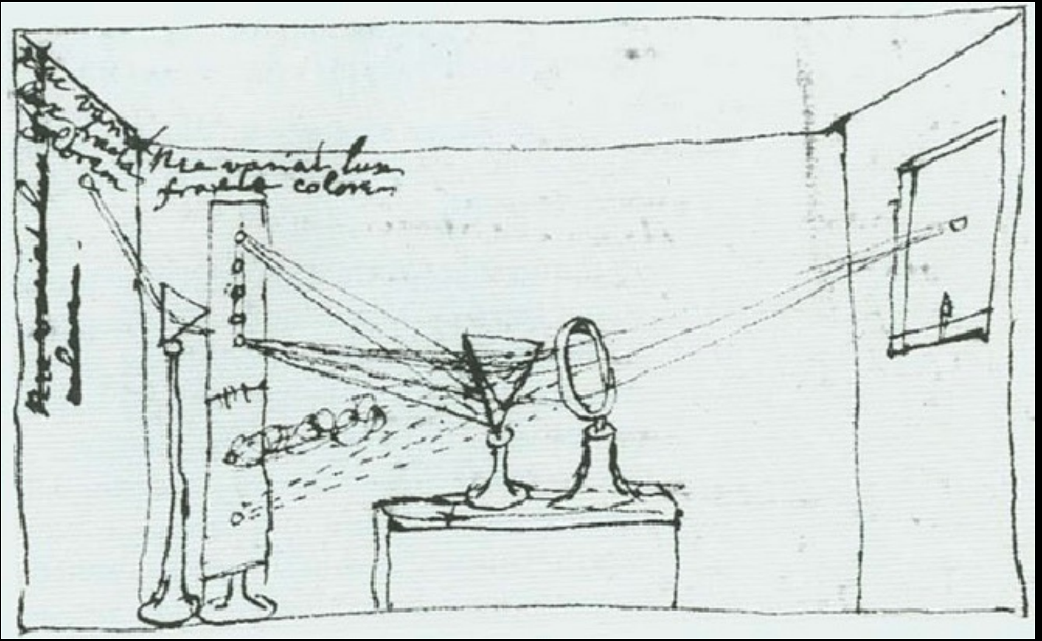


갈릴레오 갈릴레이, 갈릴레오 망원경과 스케치

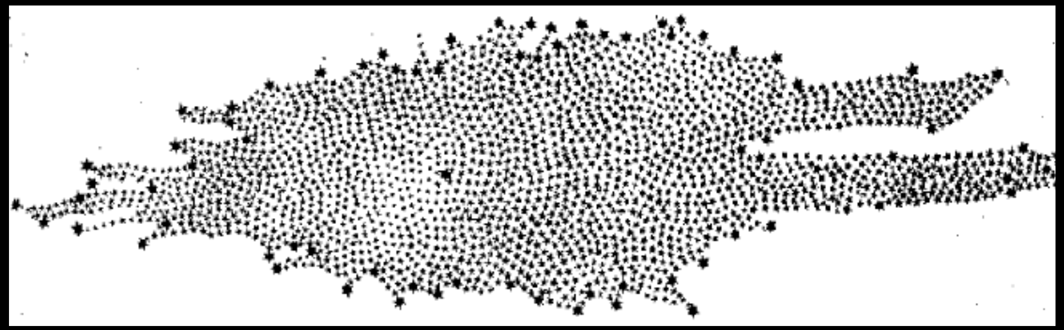


뉴턴. 출처: La Repubblica





• Philosophical Transactions of The Royal Society A Mathematical Physical and Engineering Sciences 373(2039)



Wikipedia

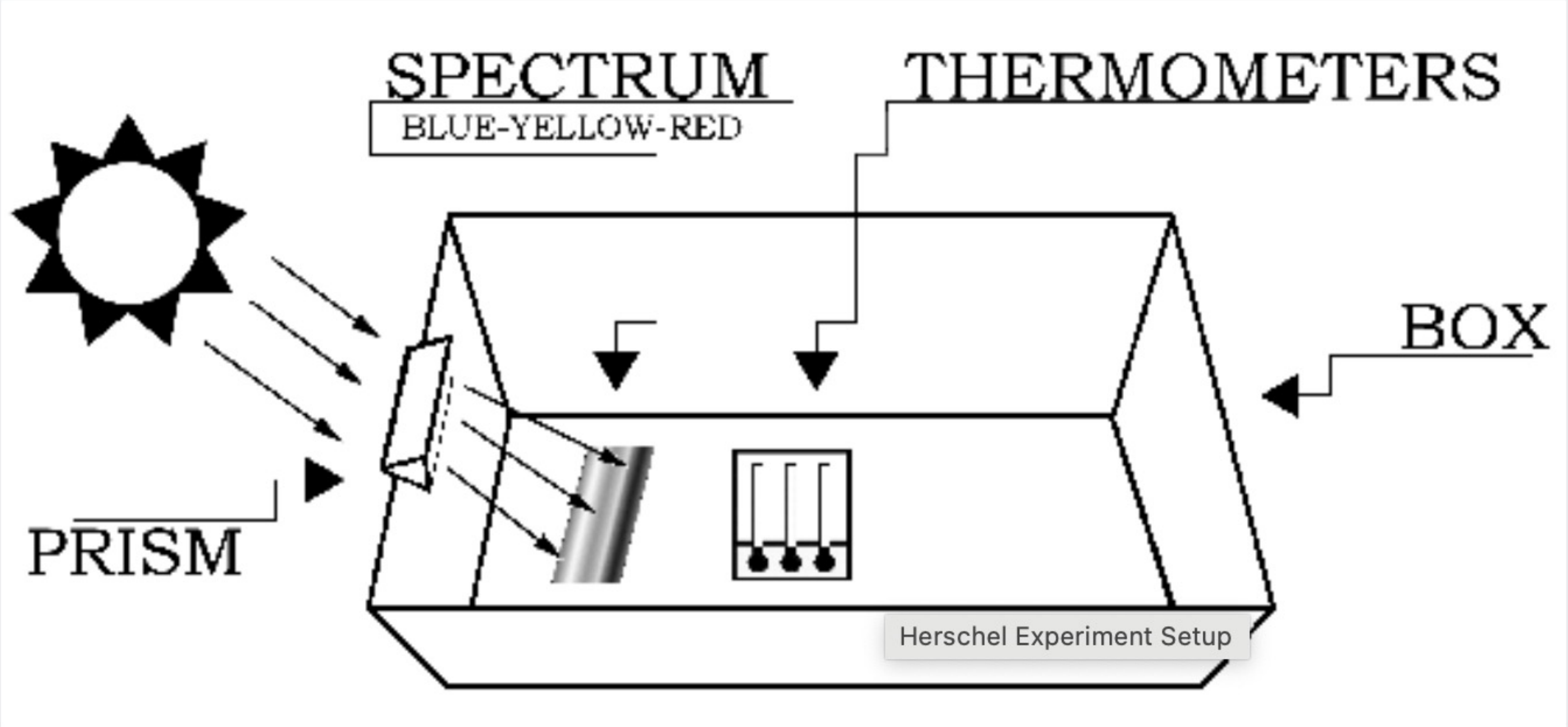
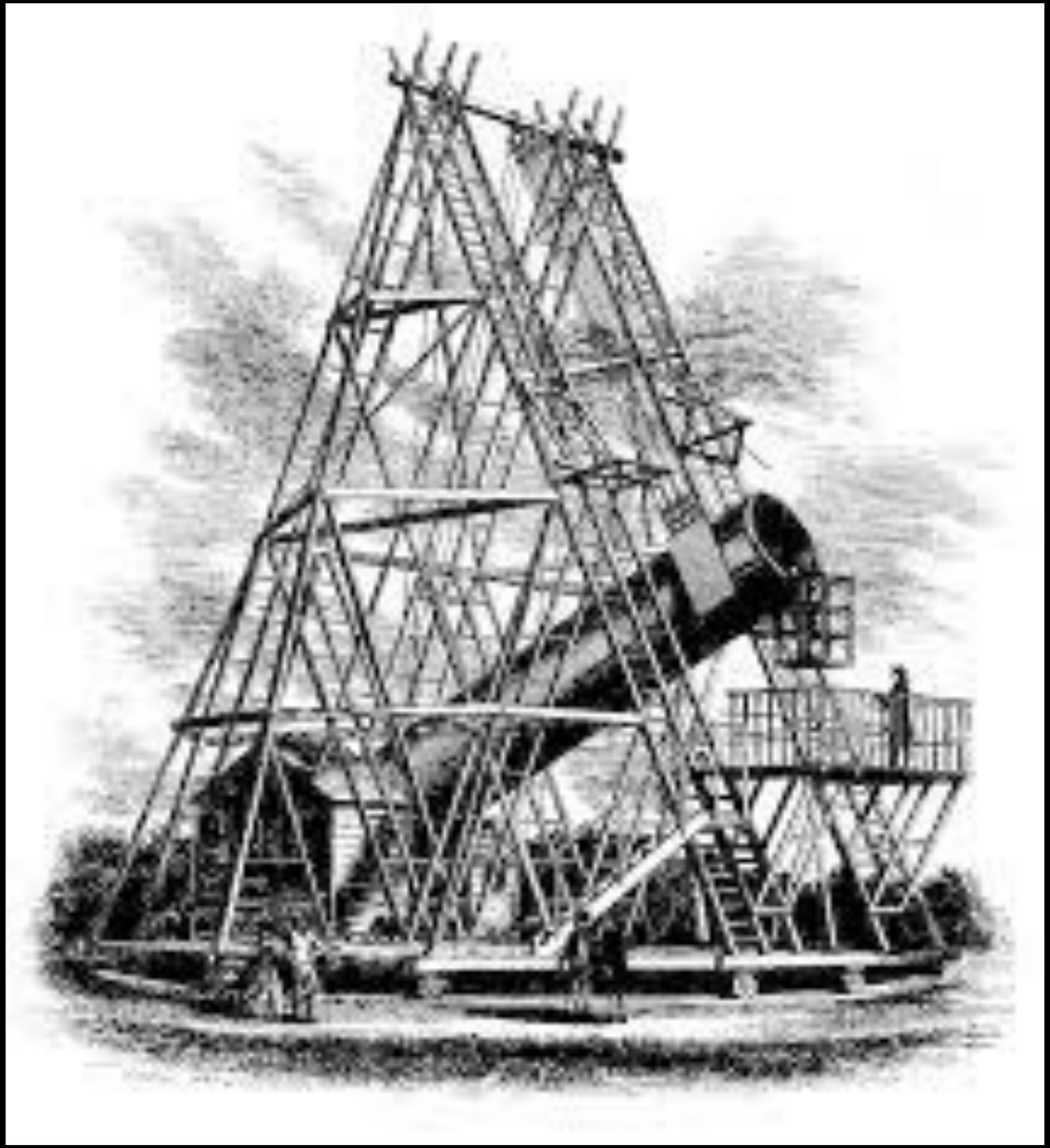
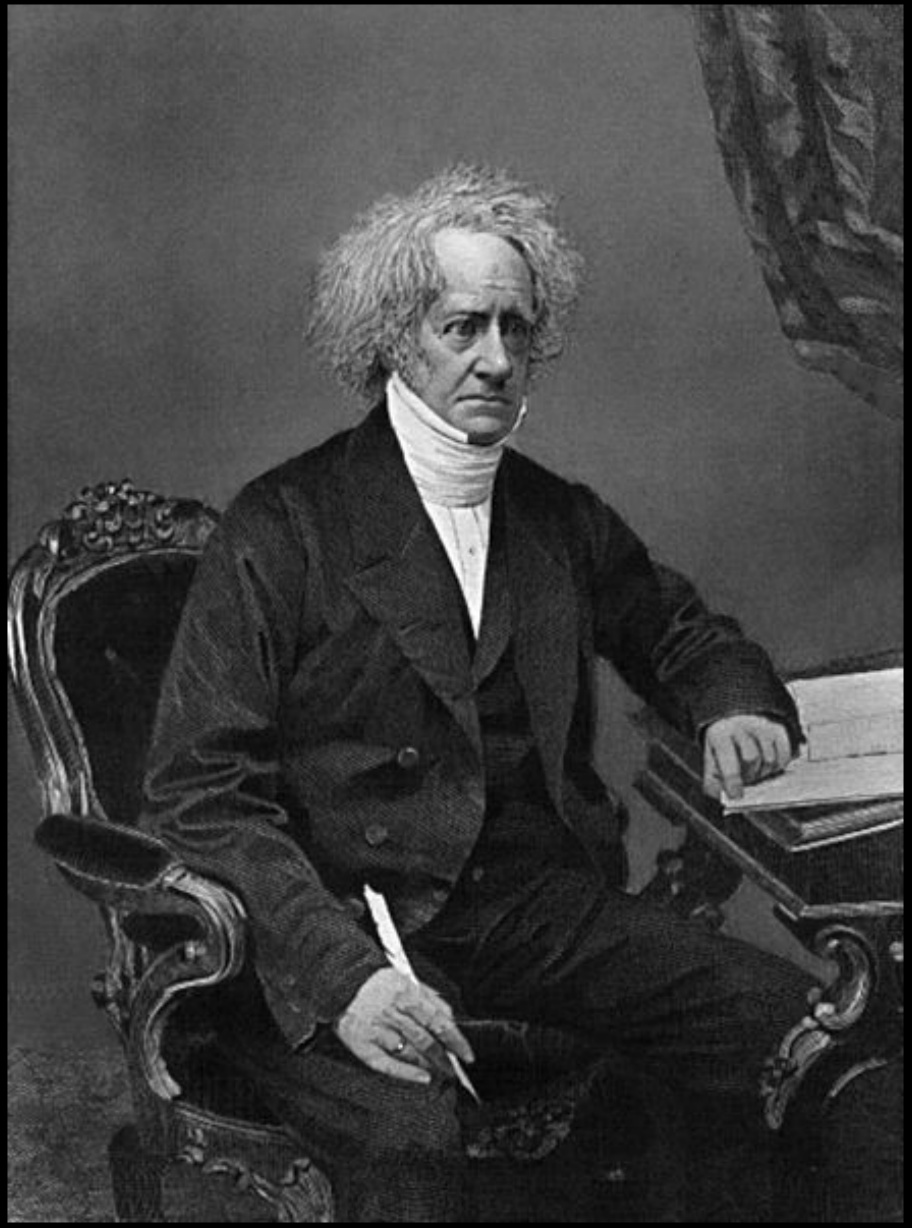


Figure 1: Herschel Experiment setup

Spitzer, Cool cosmos





Wikipedia

Cool Cosmos

INFRARED World Universe Missions Gallery Timeline

What is Infrared? Ask an Astronomer Teachers

Infrared World

The world around us looks remarkably different in infrared light. People become luminous objects as we see things by the glow of their heat rather than the light that falls upon them.

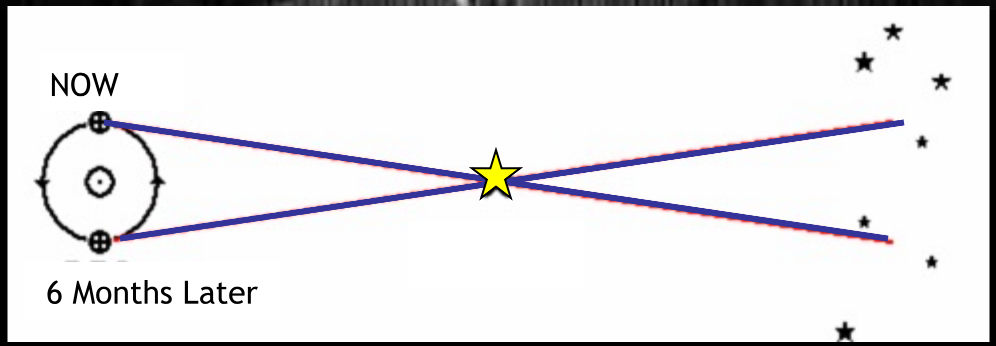
Visible Infrared

Firefighters

During a fire, it is common for the entire building to be filled with dense clouds of smoke. While firefighters can wear protective gear to supply fresh air and protect them from the heat, they still may not be able to see a thing with their own eyes.

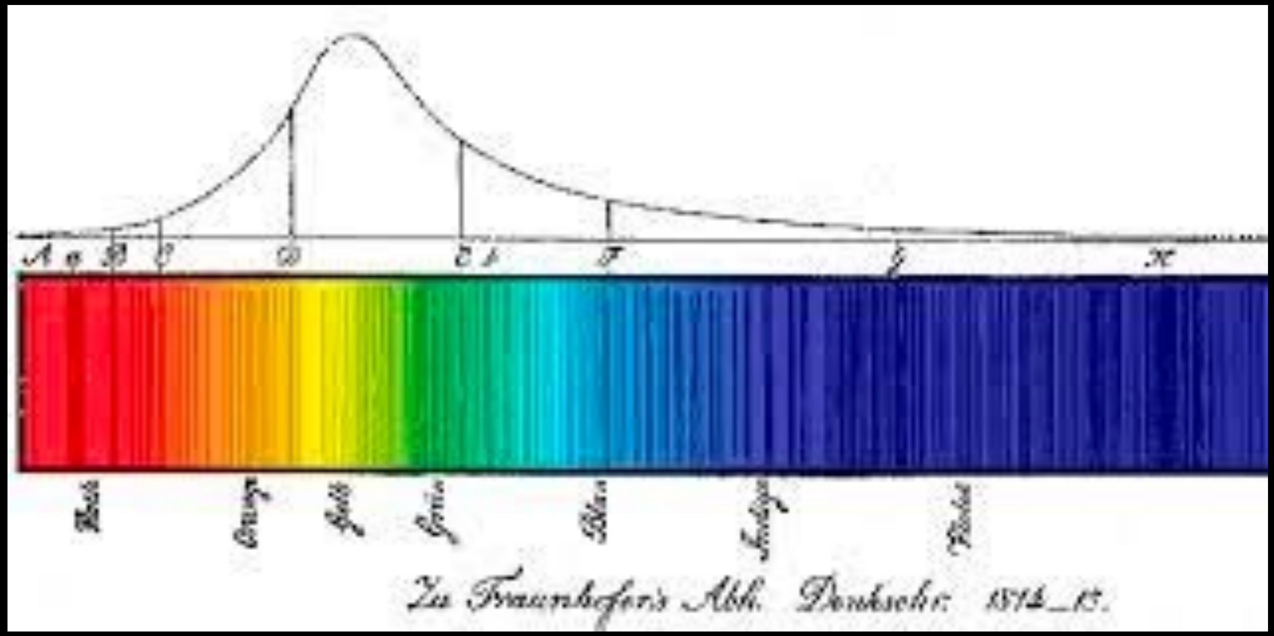
Infrared light cuts through smoke clouds to show what is hidden. Firefighters routinely use portable infrared cameras to navigate through smoky areas.

Spitzer, Cool cosmos

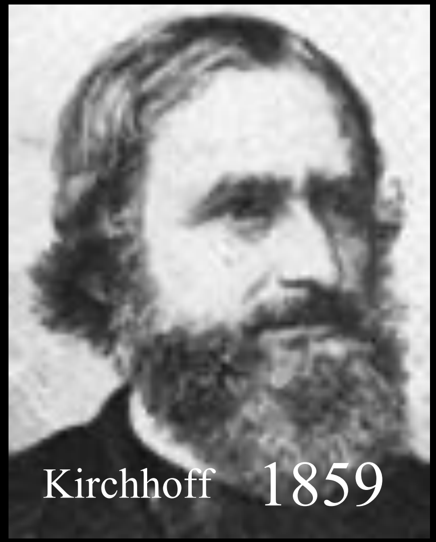


Königsberg Observatory

1838

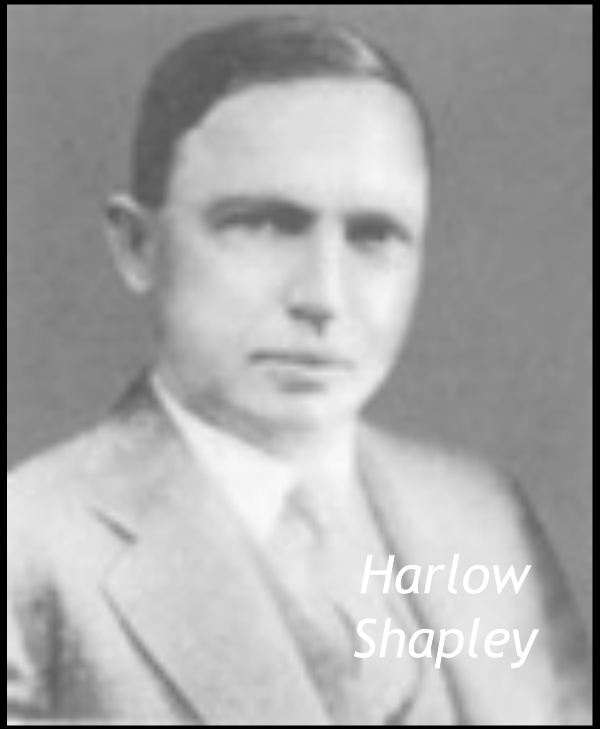


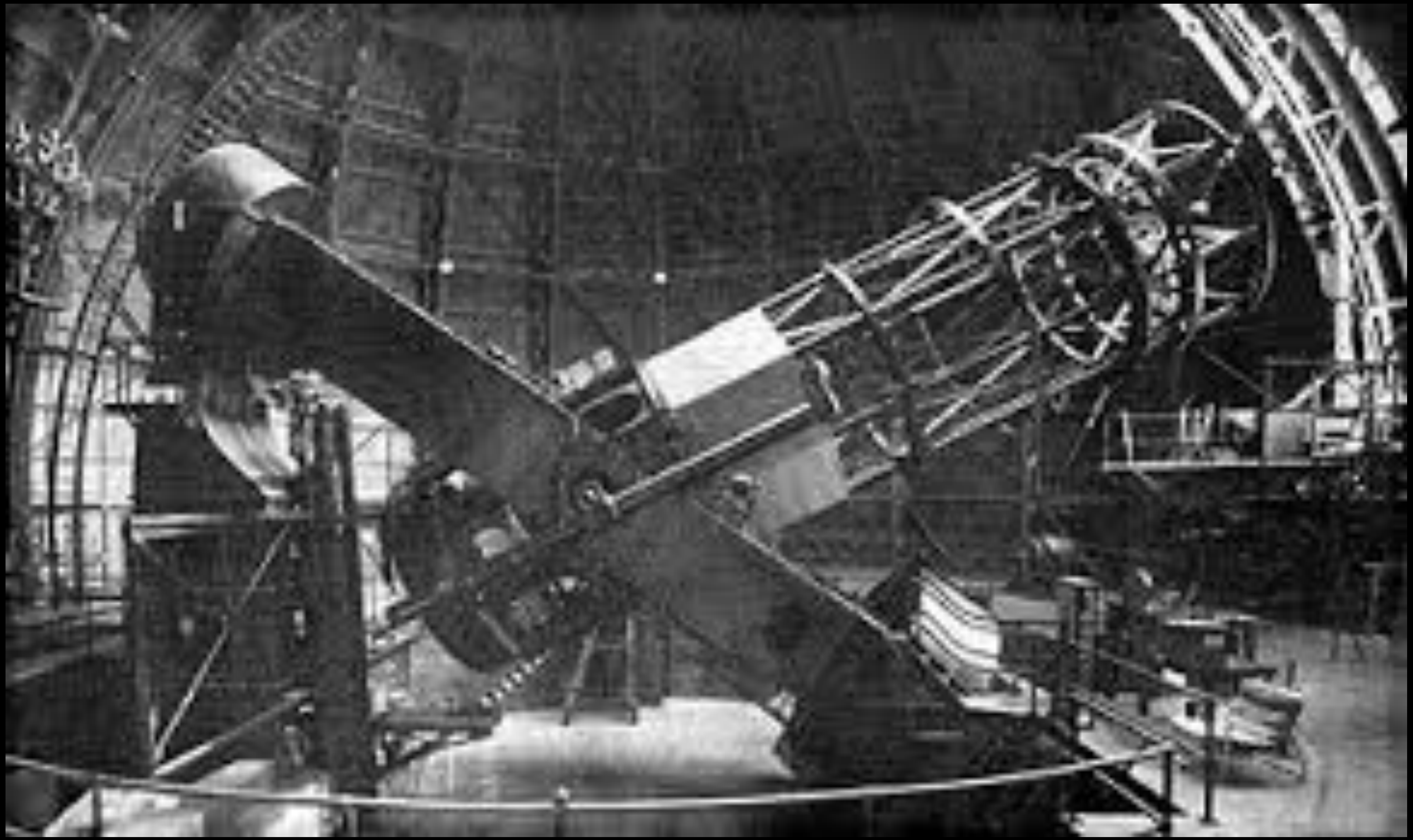
Wikipedia



‘모든 원소는 빛이 나도록 열을 주면, 각기 독특한 스펙트럼선의 빛을 낸다.’

Edwin Hubble looking through the 100-inch Hooker telescope at Mount Wilson in Southern California(US), 1929 discovers the Universe is Expanding. Credit: Margaret Bourke-White/Time & Life Pictures/Getty Images.

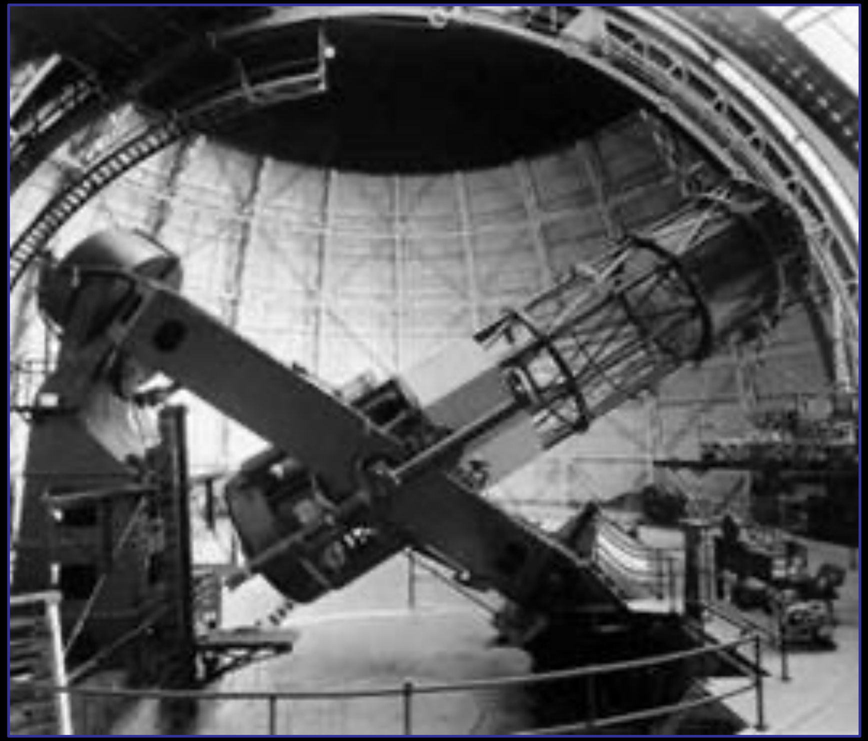




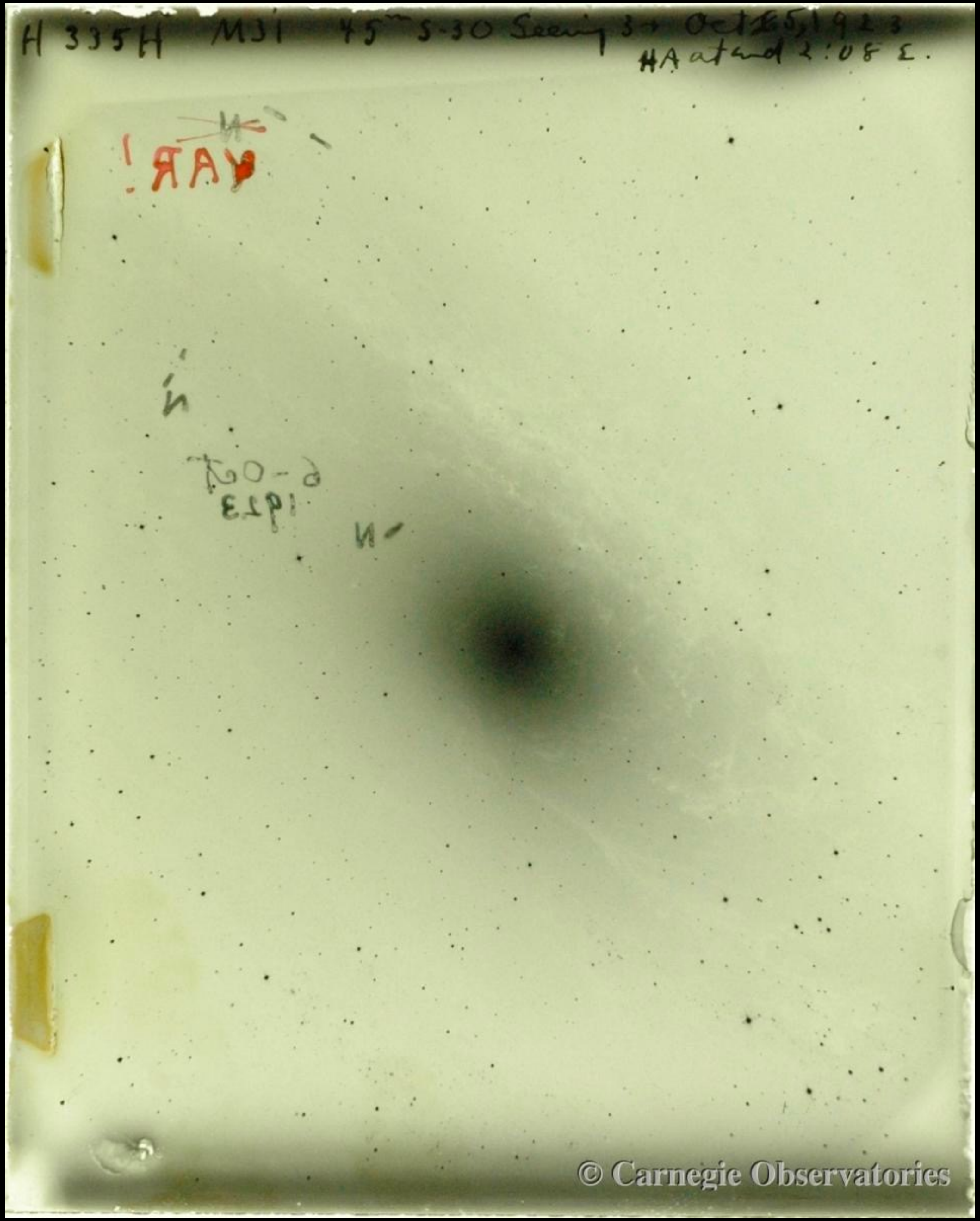
APOD NASA

에드윈 파월 허블 (1989~1953)

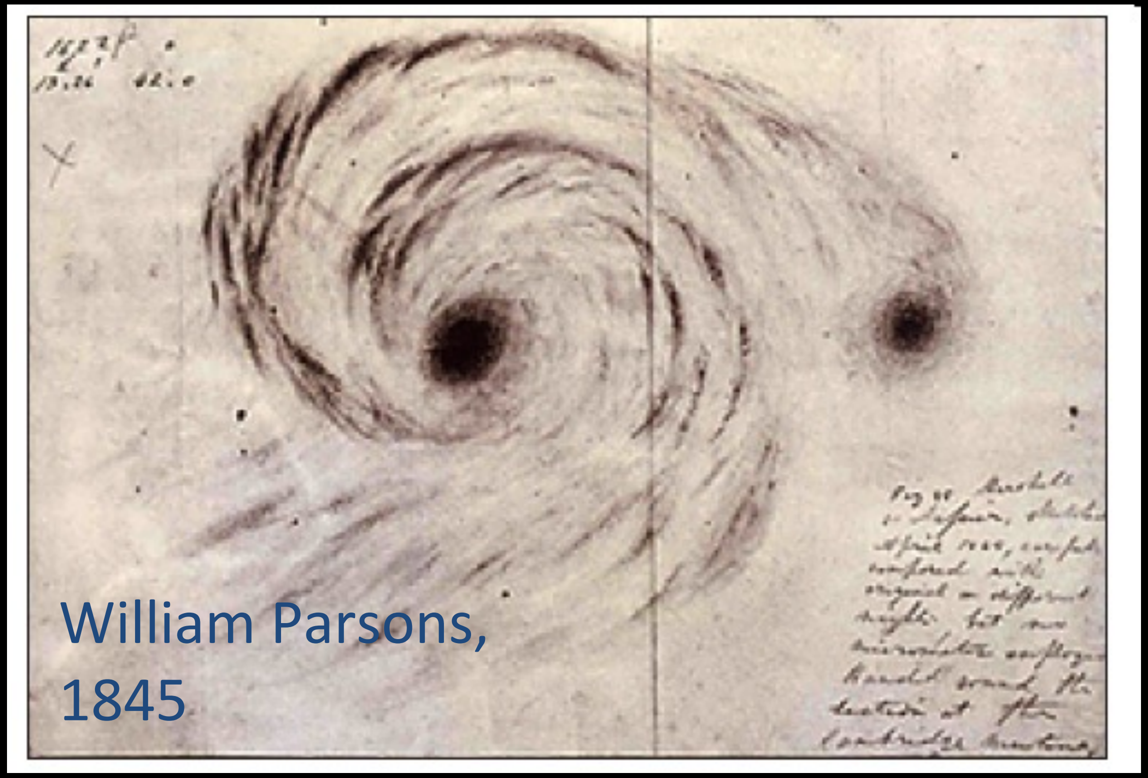
1924년 외부은하 발견
1929년 우주팽창 발견



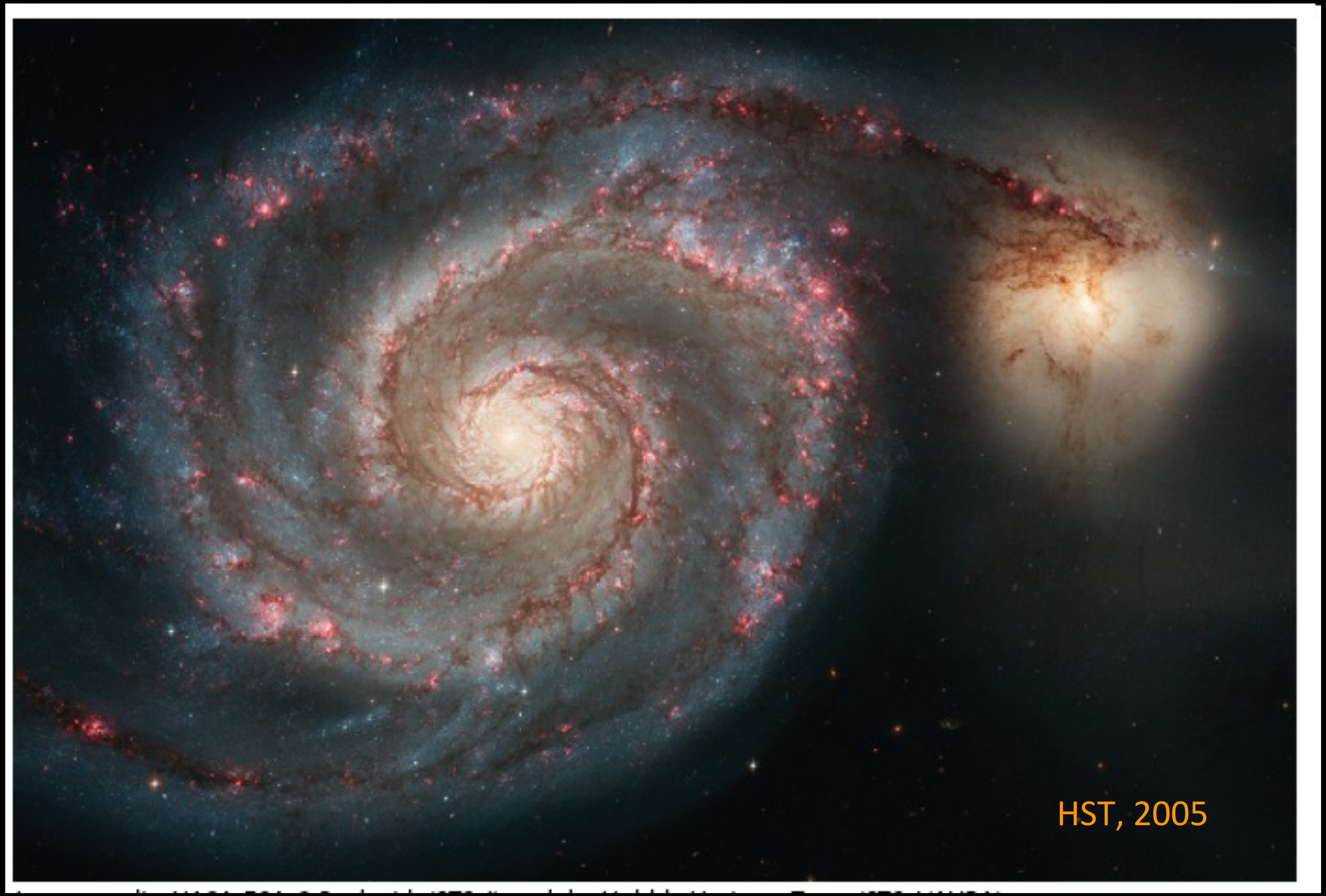
APOD NASA



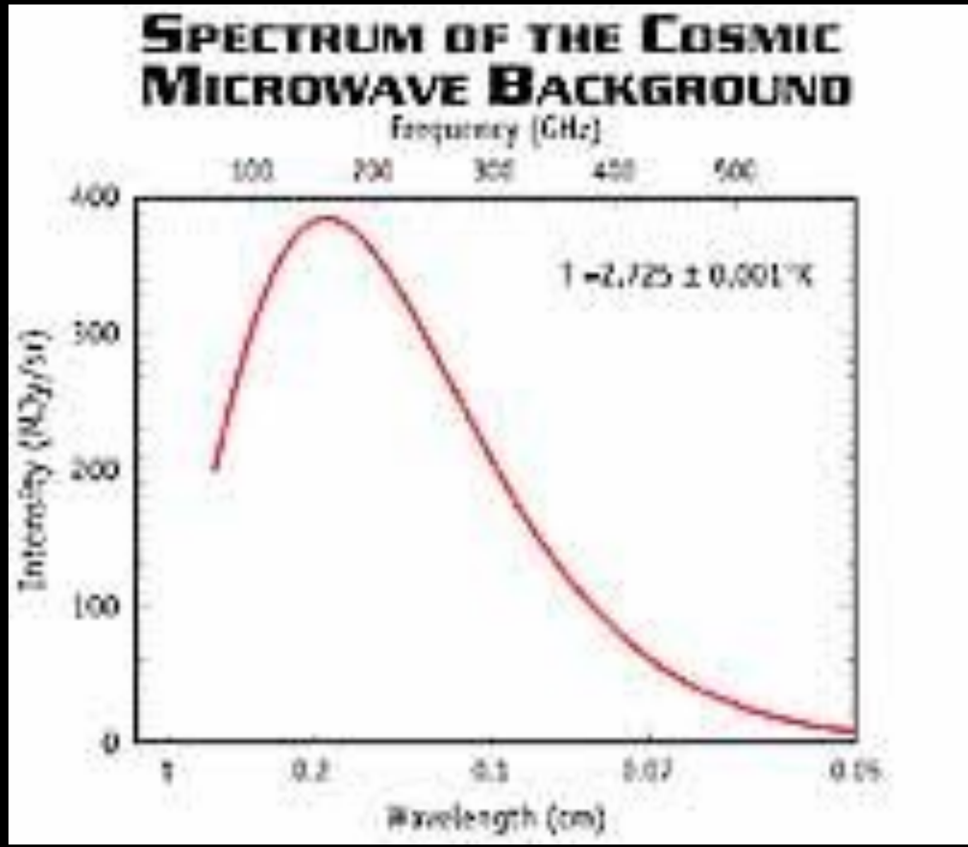
M51 Whirlpool Galaxy


William Parsons, 1845


Kitt Peqk, 2000


HST, 2005

Robert Wilson, Arno Penzias and that big antenna
(Image: Ted Thai/Time & Life Pictures/Getty Images)



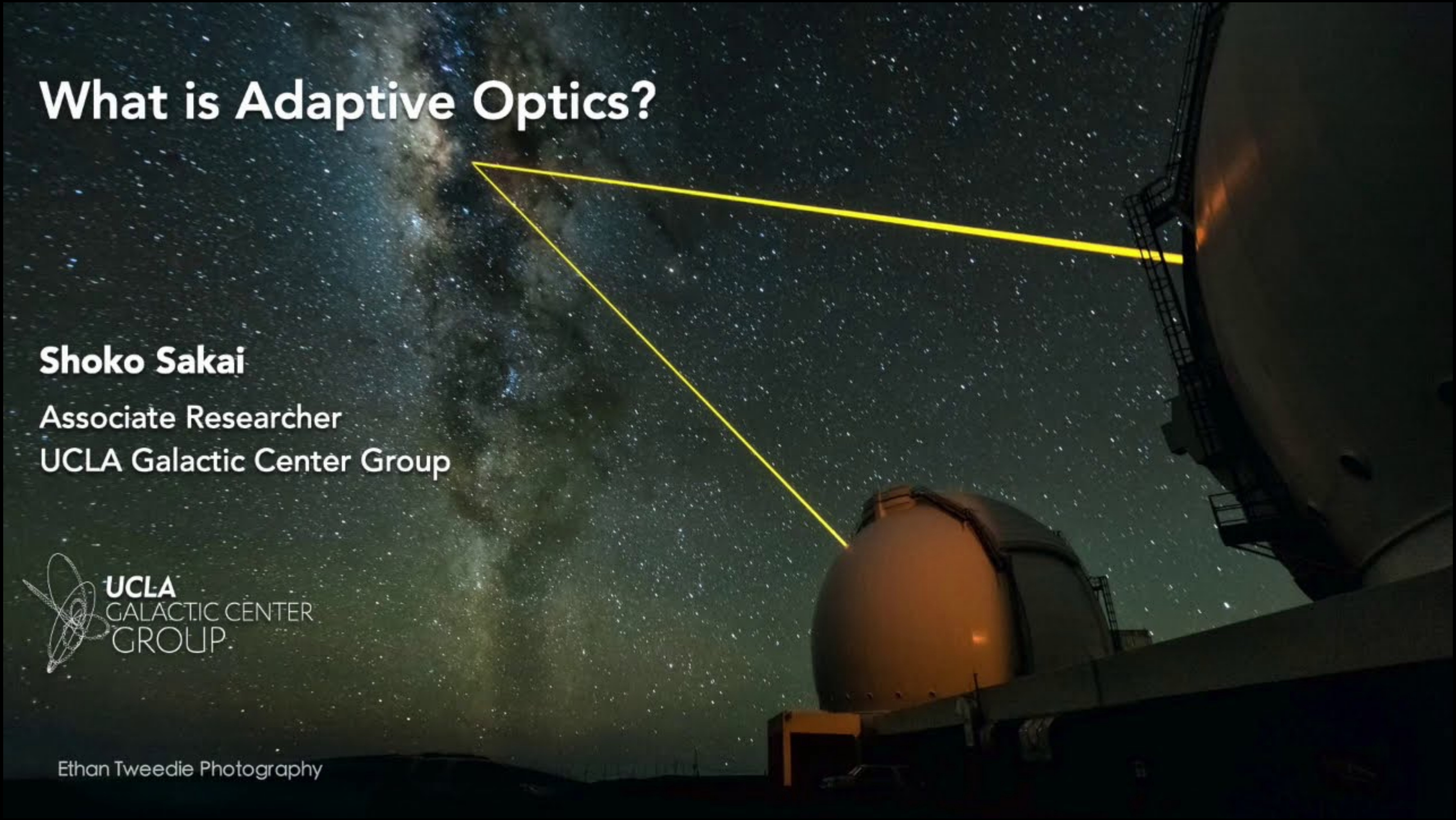
"Black body" spectrum of the cosmic microwave background radiation
(Source: NASA: http://map.gsfc.nasa.gov/universe/bb_tests_cmb.html)


Hawaii Mauna Kea
Wikipedia

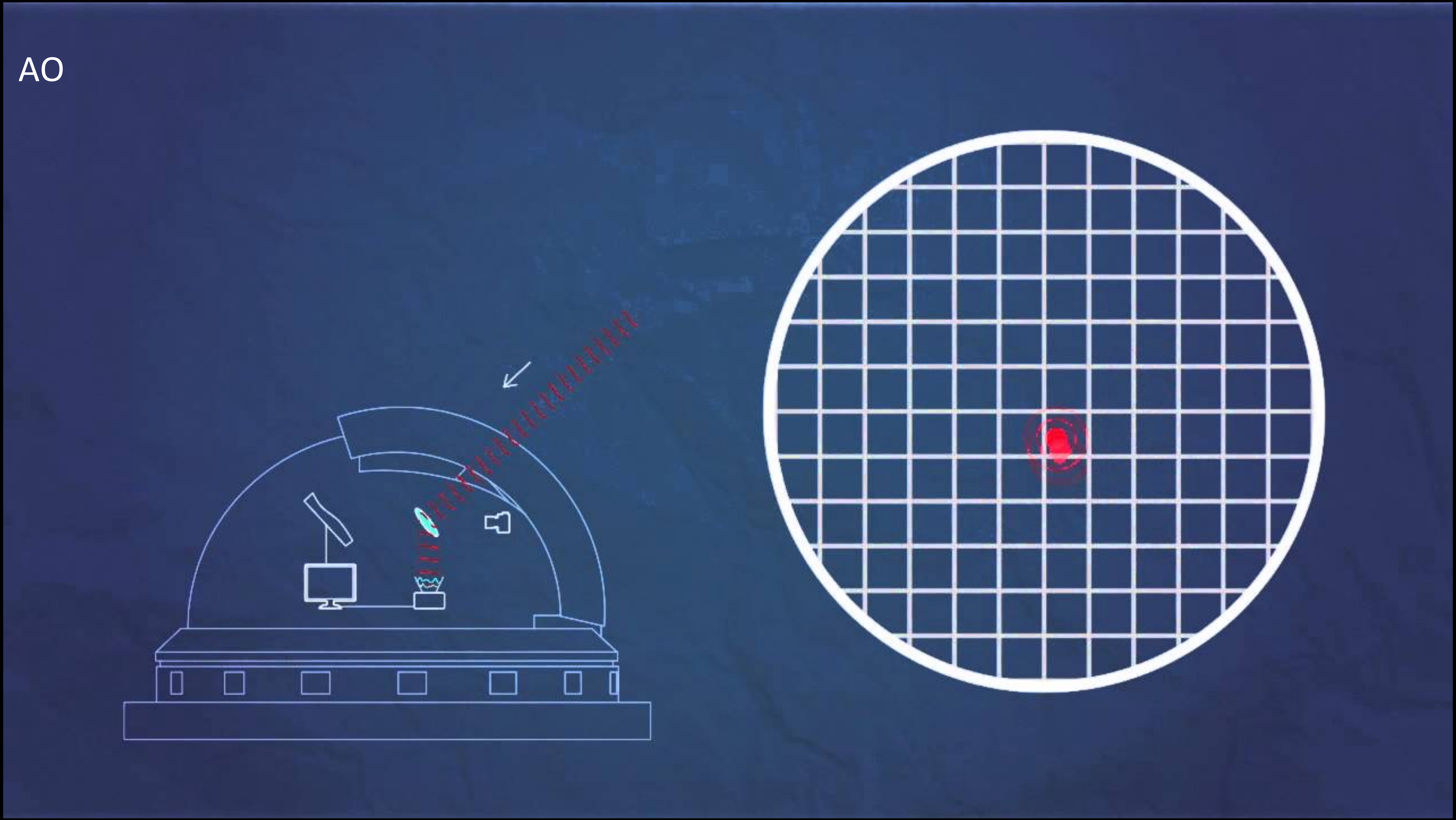
Hawaii Mauna Kea

Christopher Chan / Getty Images

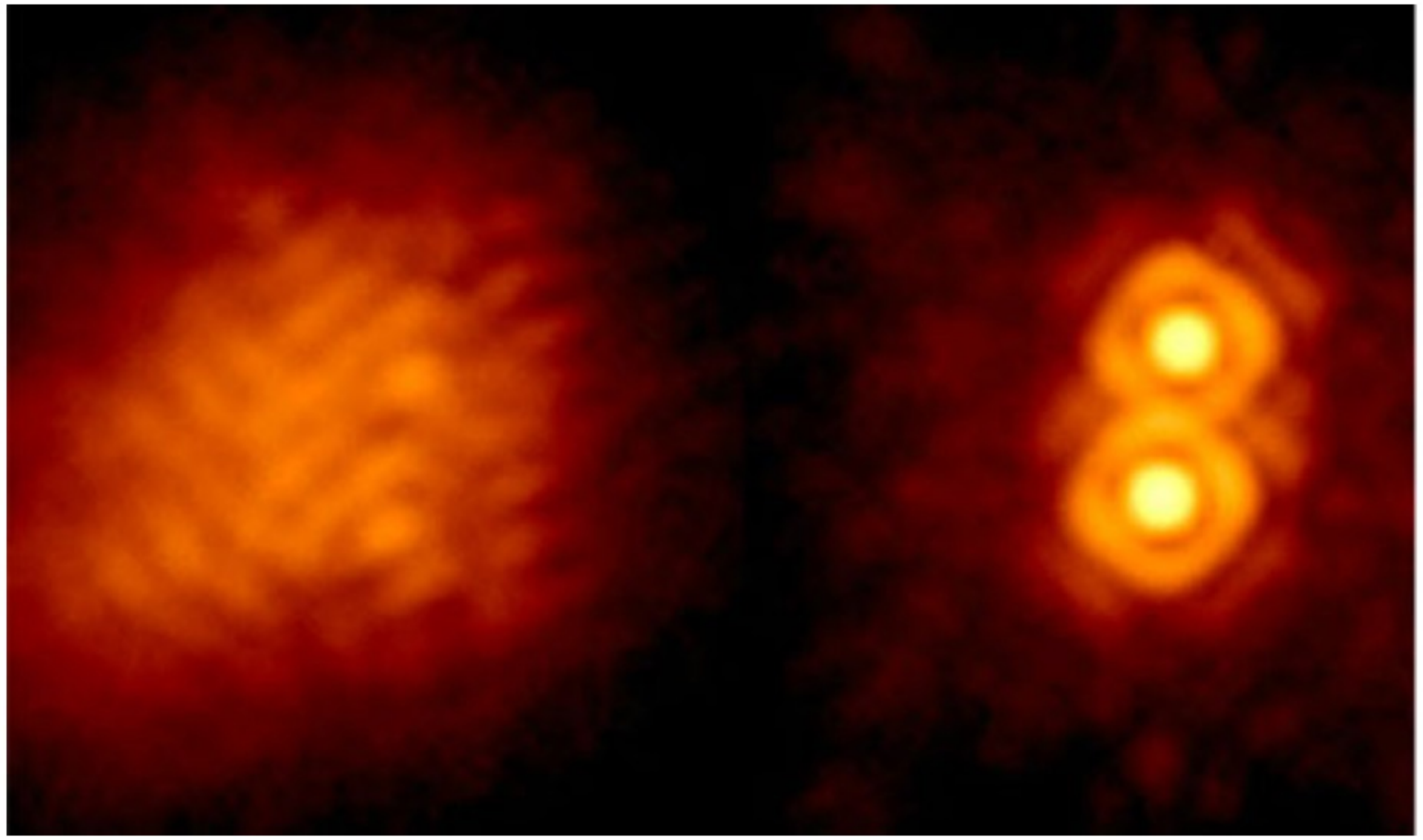
Hawaii Mauna Kea


What is Adaptive Optics?
Shoko Sakai
Associate Researcher
UCLA Galactic Center Group
UCLA
GALACTIC CENTER
GROUP
Ethan Tweedie Photography

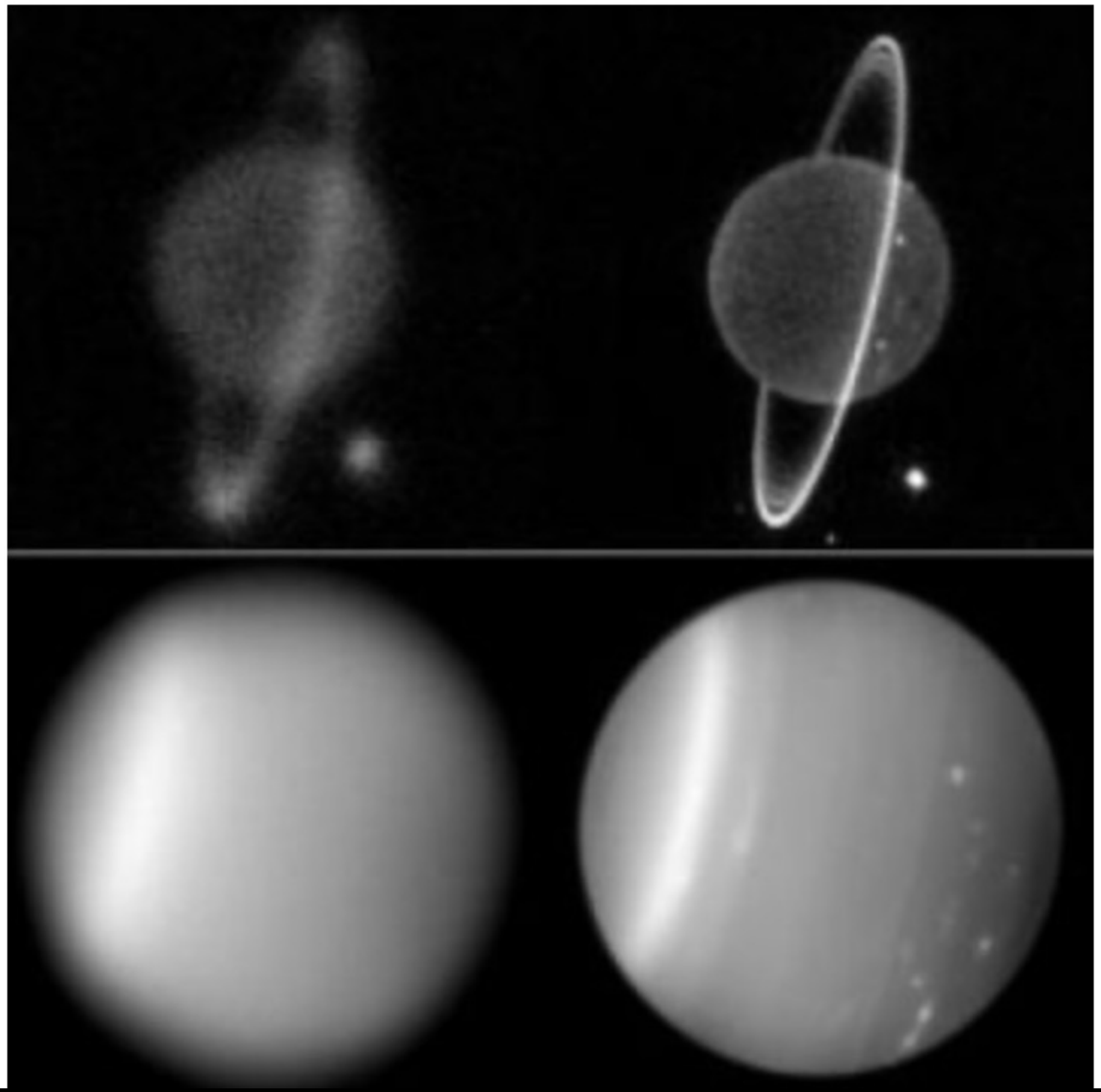
AO



https://www.youtube.com/watch?v=gDGvNyVApgg

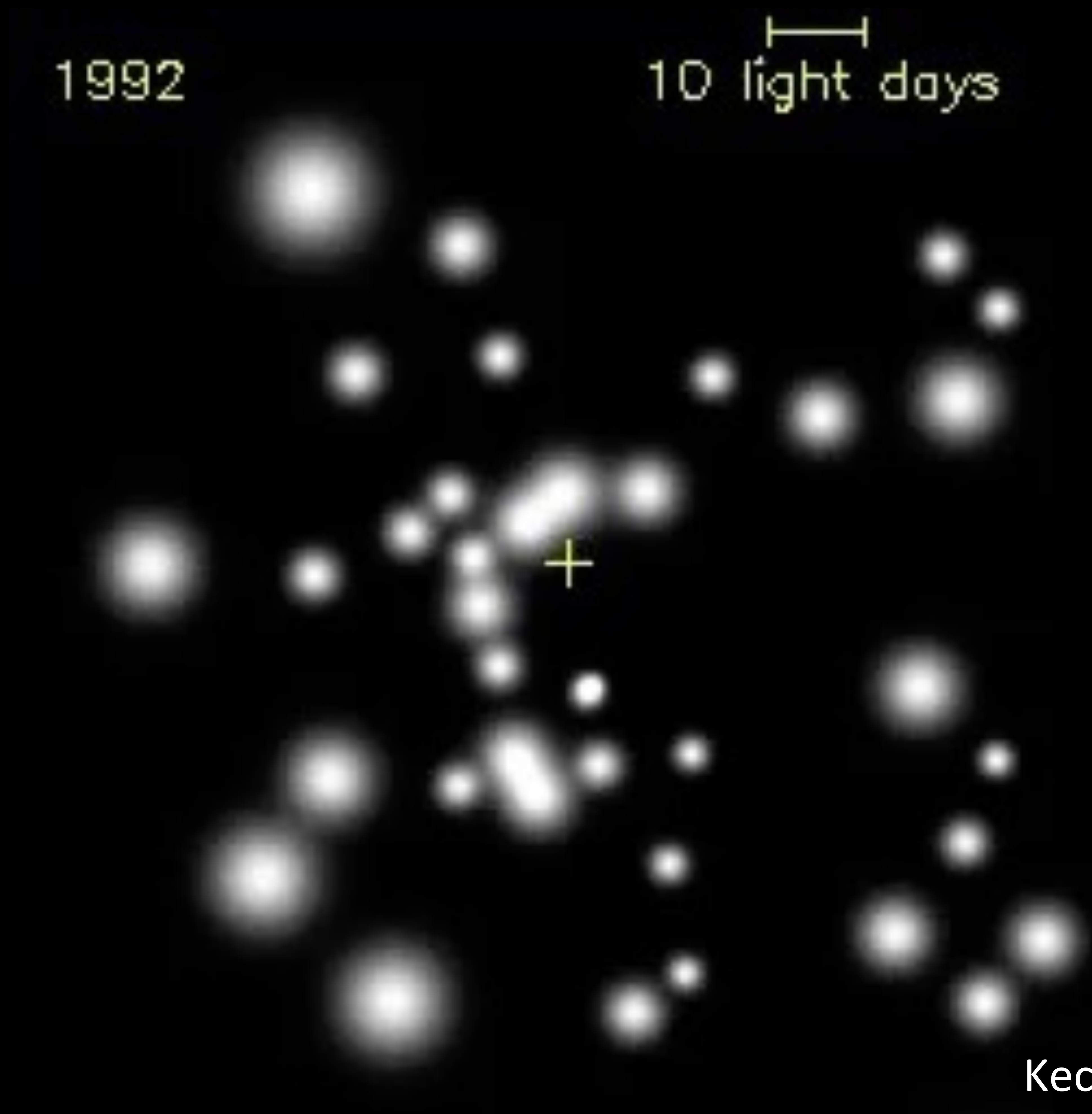


Palomar Observatory / NASA-JPL



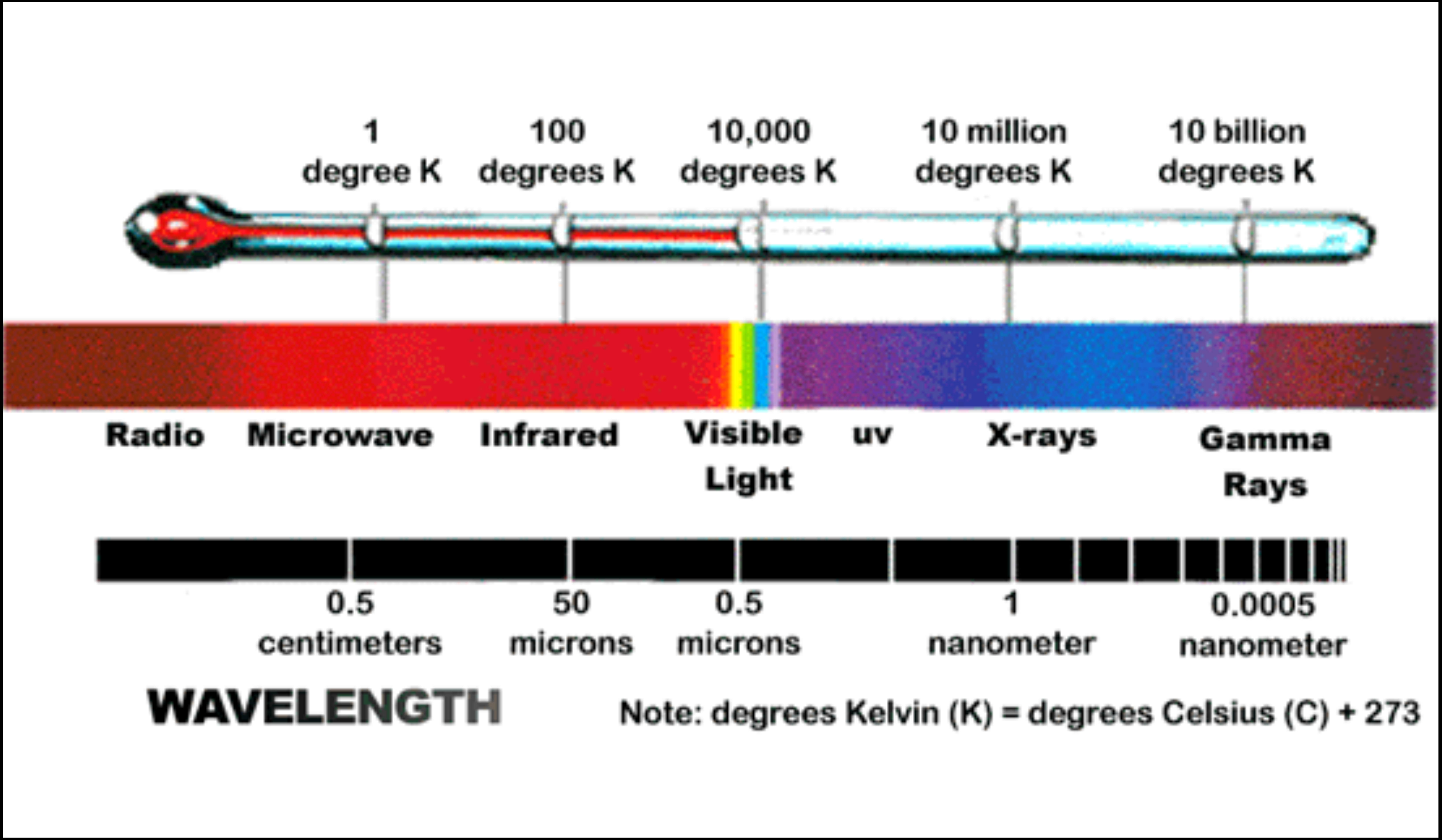
Heidi B. Hammel and Imke de Pater

우리은하 중심에 위치한 블랙홀



Keck, UCLA

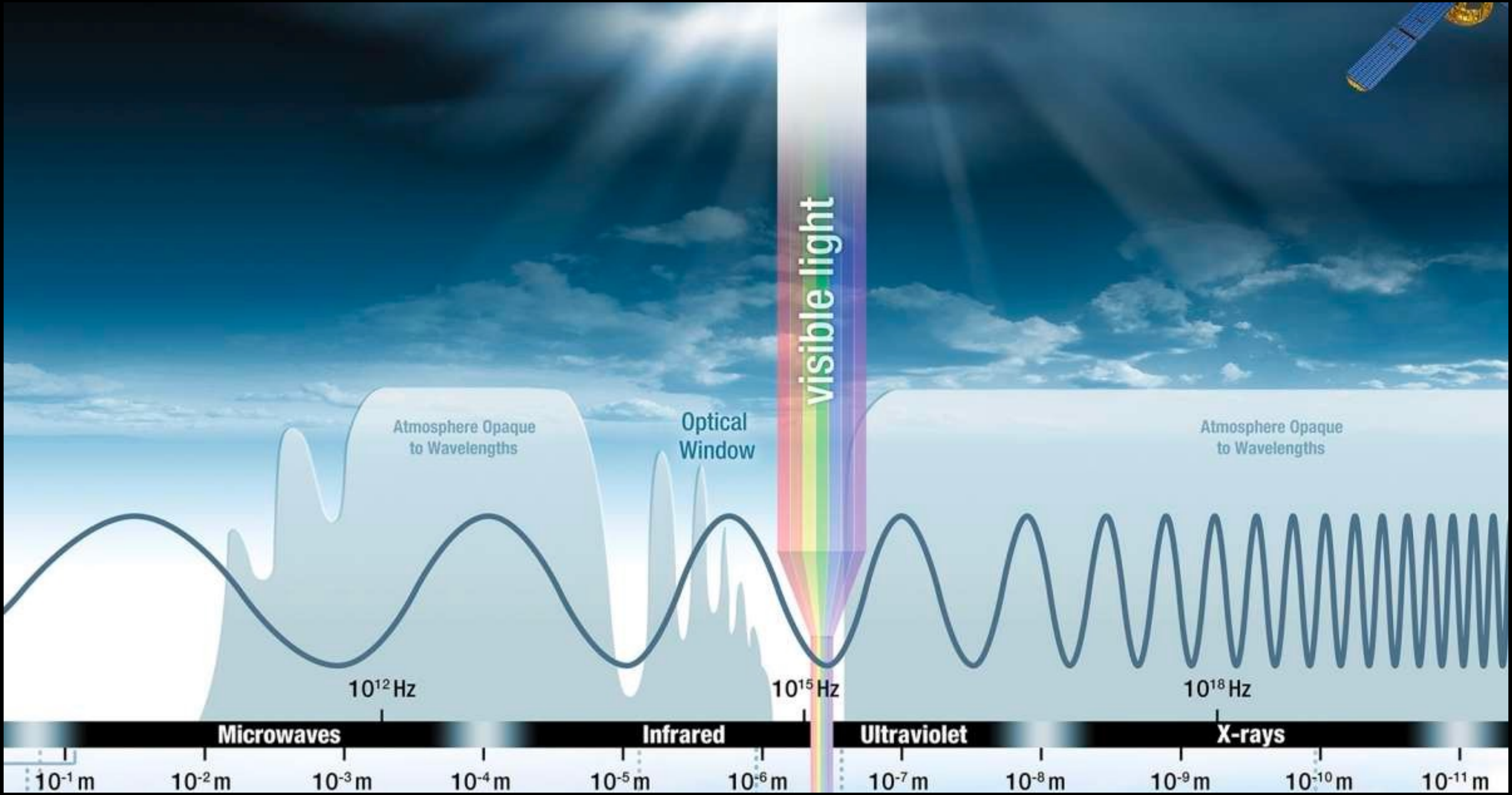
다파장 천문학과 우주망원경


1 degree K
100 degrees K
10,000 degrees K
10 million degrees K
10 billion degrees K
Radio
Microwave
Infrared
Visible Light
uv
X-rays
Gamma Rays
0.5 centimeters
50 microns
0.5 microns
1 nanometer
0.0005 nanometer
WAVELENGTH
Note: degrees Kelvin (K) = degrees Celsius (C) + 273

NASA

Waveband	Wavelength /Energy	Temperature	What can be studied
Gamma rays	100keV-100MeV	$>10^8$K	accretion disks, gamma-ray bursts
X-rays	<1-100keV	10^6-10^8K	Hot gas in clusters of galaxies, stellar coronae, accretion disks,
Ultra-violet	900-3000A	10^4-10^6K	Hot stars, white dwarfs, instellar gas
Optical	3000-10,000A	10^3-10^4K	Sun-like stars.
Infra-red	1-100 micron	10-10^3K	Dust, planets, brown dwarfs
Microwave	1cm	<10K	Background radiation of the Universe (remnant of Big Bang)
Radio	>1m	<10K	Radiation from electrons moving in a magnetic field: pulsars

NASA


visible light
Atmosphere Opaque to Wavelengths
Optical Window
Atmosphere Opaque to Wavelengths
10¹² Hz
10¹⁵ Hz
10¹⁸ Hz
Microwaves
Infrared
Ultraviolet
X-rays
10⁻¹ m
10⁻² m
10⁻³ m
10⁻⁴ m
10⁻⁵ m
10⁻⁶ m
10⁻⁷ m
10⁻⁸ m
10⁻⁹ m
10⁻¹⁰ m
10⁻¹¹ m

NASA

Kuiper Airborne Observatory

Stratospheric Observatory For Infrared Astronomy (SOFIA)

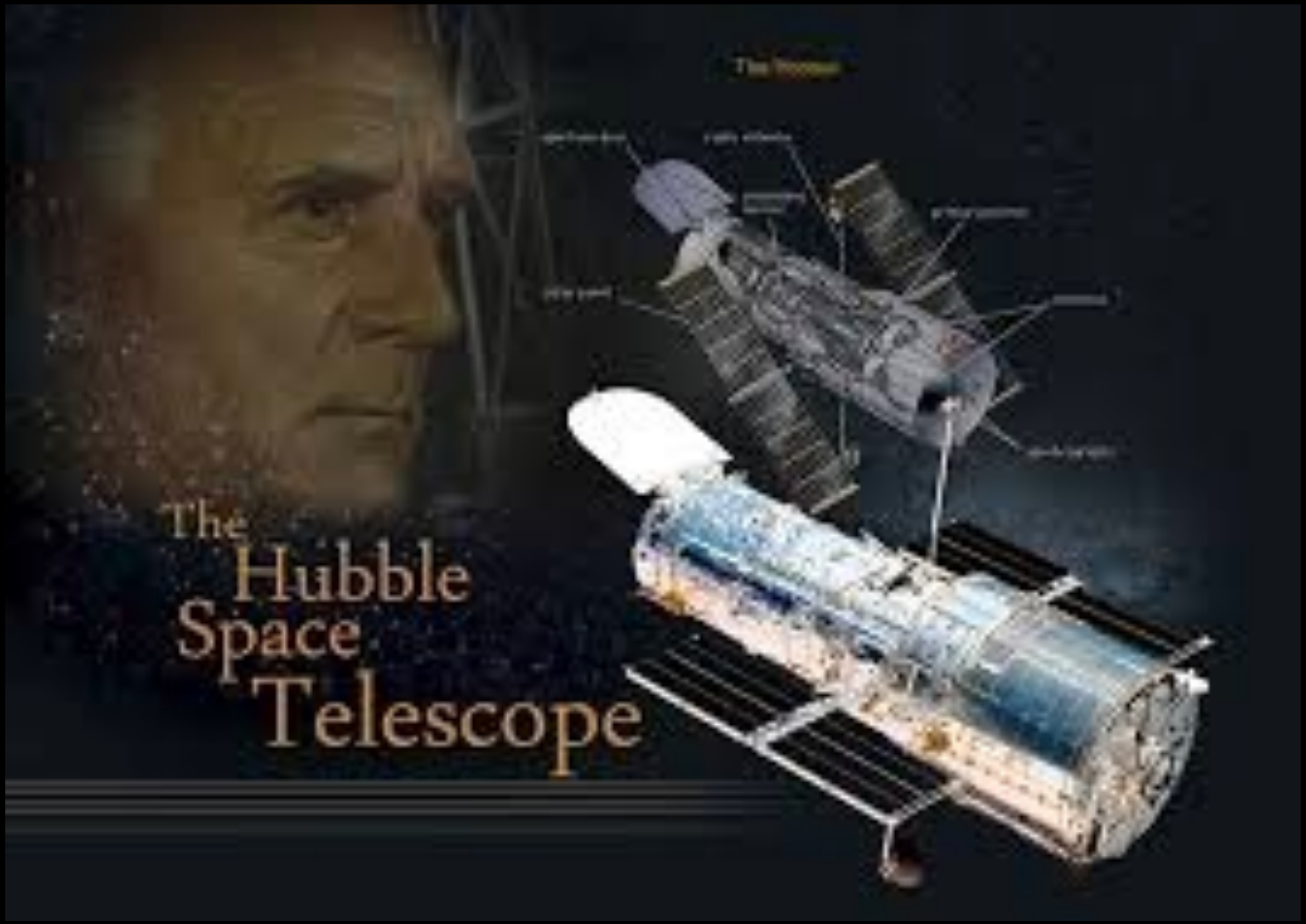
NASA

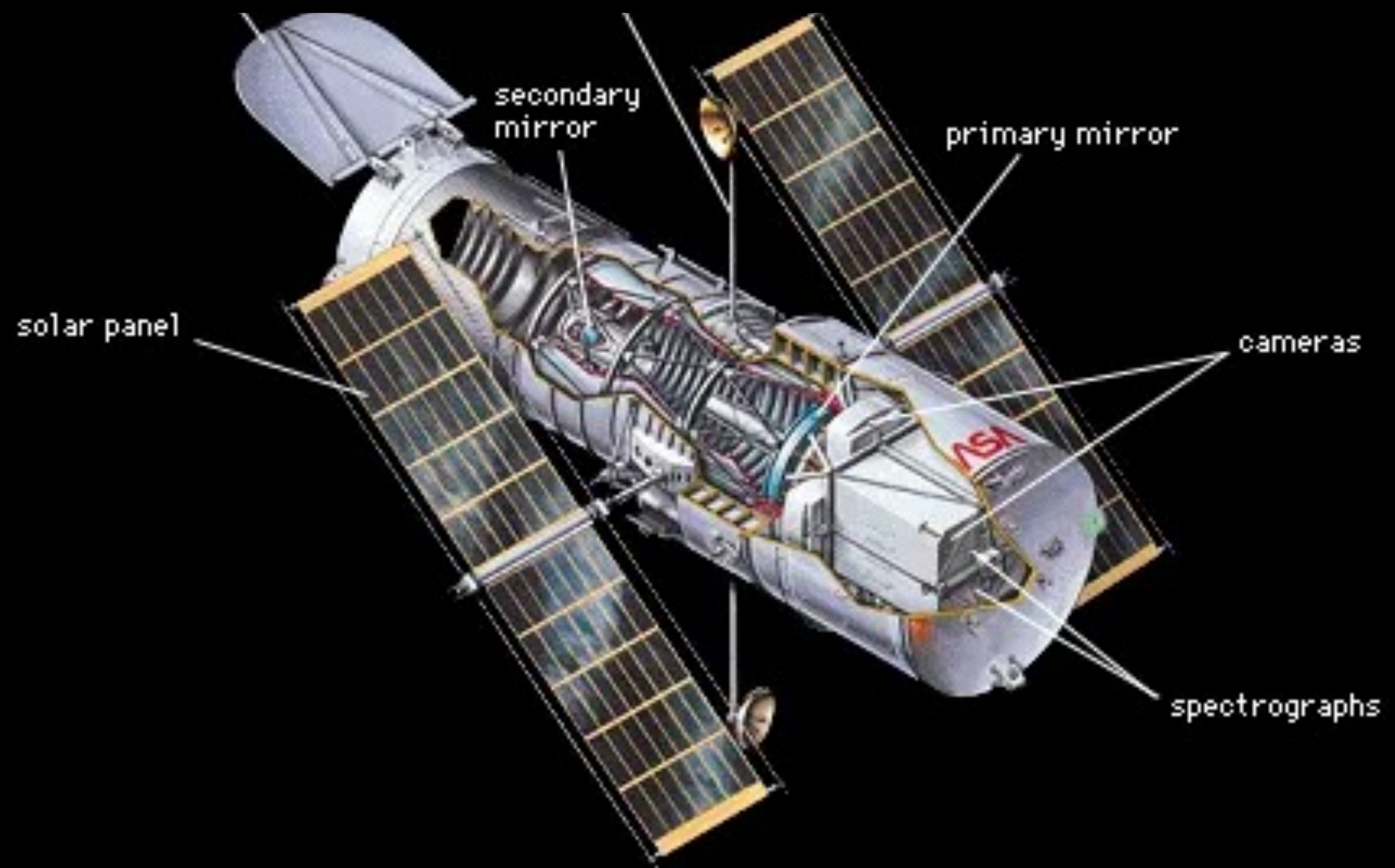
+ SMEX/MO (2025), MIDEX/MO (2028), etc.
Spitzer 8/25/2003
Formulation
Implementation
Primary Ops
Extended Ops
WFIRST Mid 2020s
Euclid (ESA) 2022
SXG (RSA) 7/13/2019
Webb 2021
Ariel (ESA) 2028
Chandra 7/23/1999
XMM-Newton (ESA) 12/10/1999
TESS 4/18/2018
NuSTAR 6/13/2012
Swift 11/20/2004
Fermi 6/11/2008
IXPE 2021
XRISM (JAXA) 2022
SPHEREx 2023
Hubble 4/24/1990
ISS-NICER 6/3/2017
GUSTO 2021
SOFIA Full Ops 5/2014
Revised November 24, 2019
+ Athena (early 2030s), LISA (early 2030s)
NASA

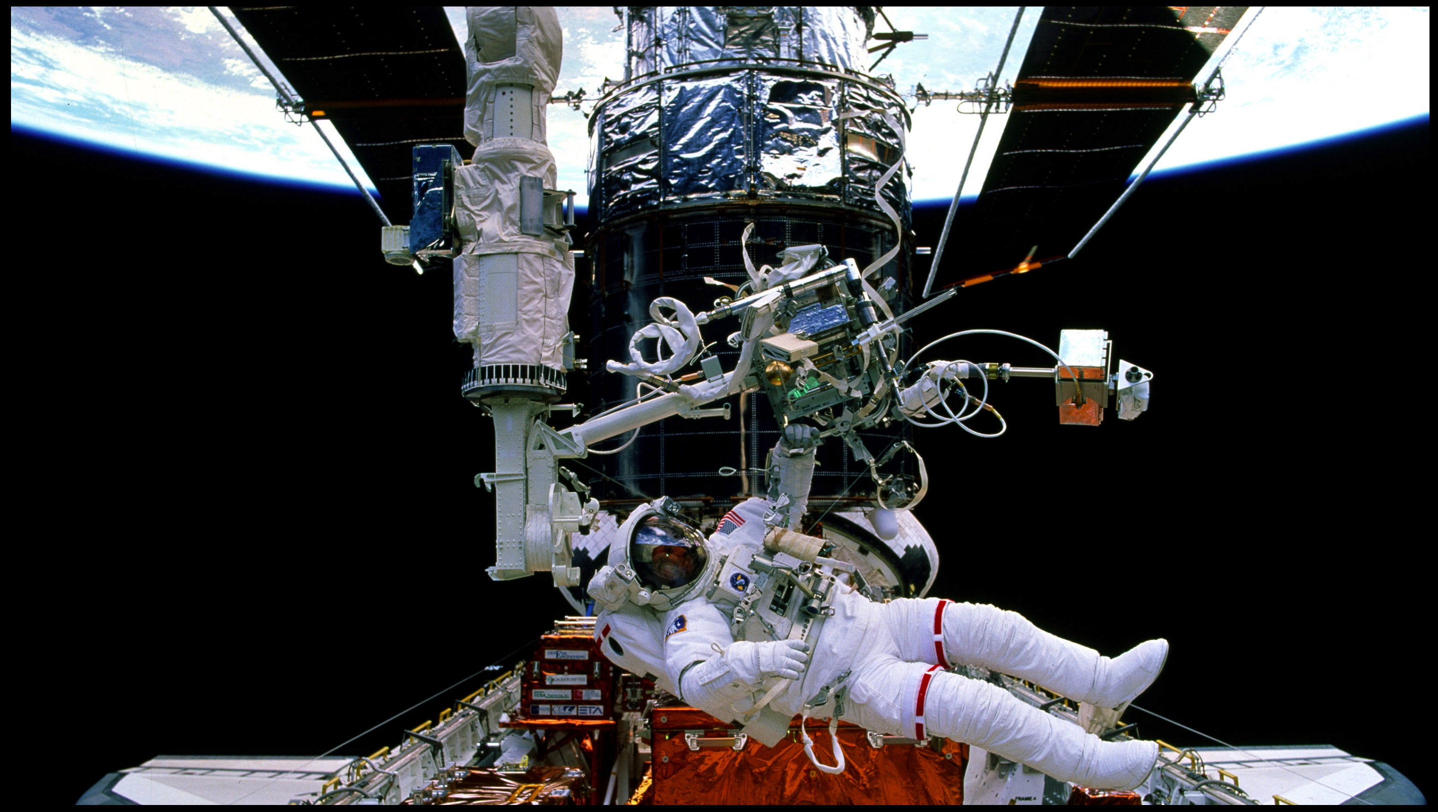
4.6 billion light years away | **10 feet away security cam**

Syed Wali Shah ▸ James Webb Space Telescope (JWST) & Astronomical Discoveries

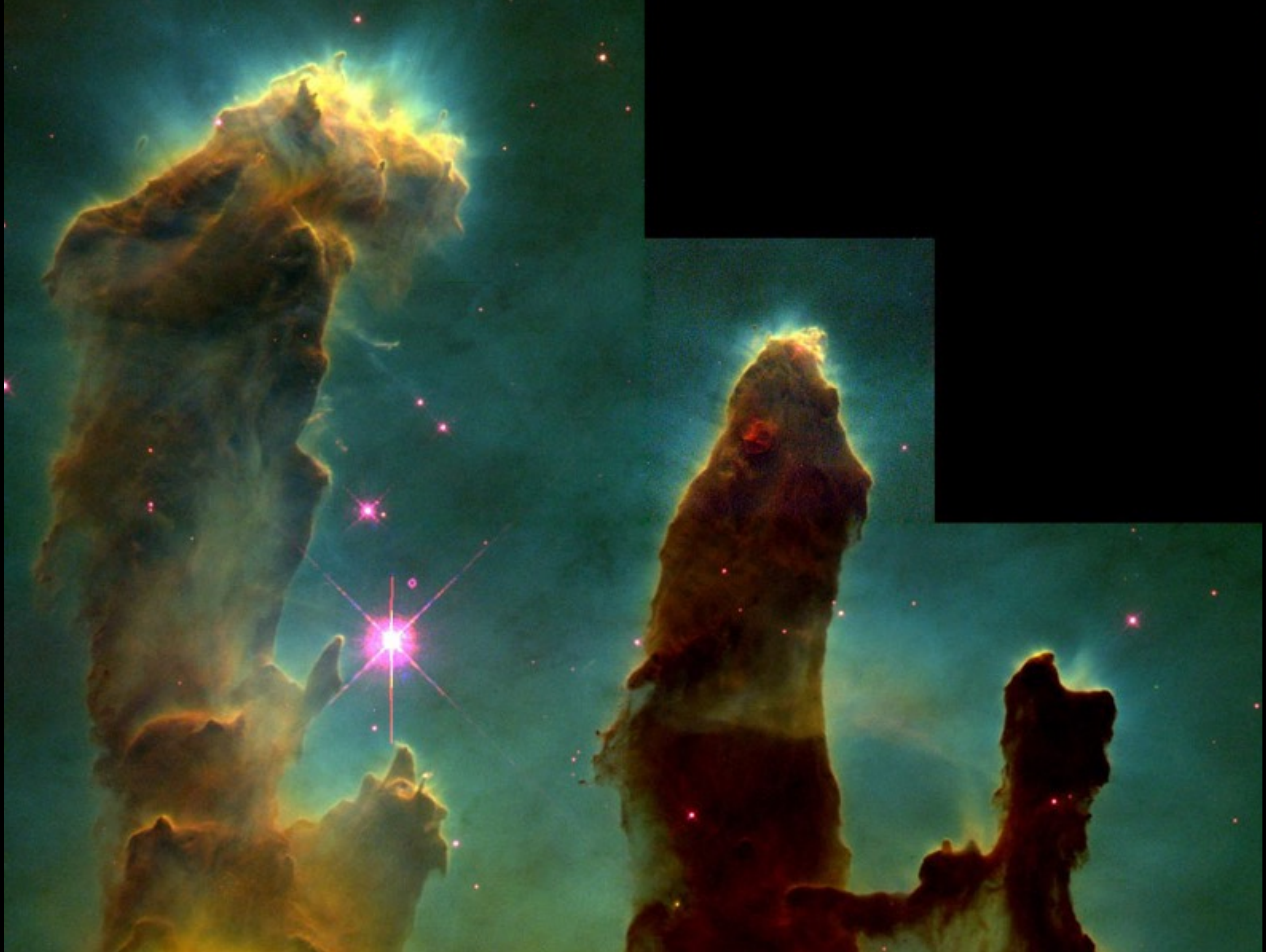
HUBBLE SPACE TELESCOPE


The Hubble Space Telescope

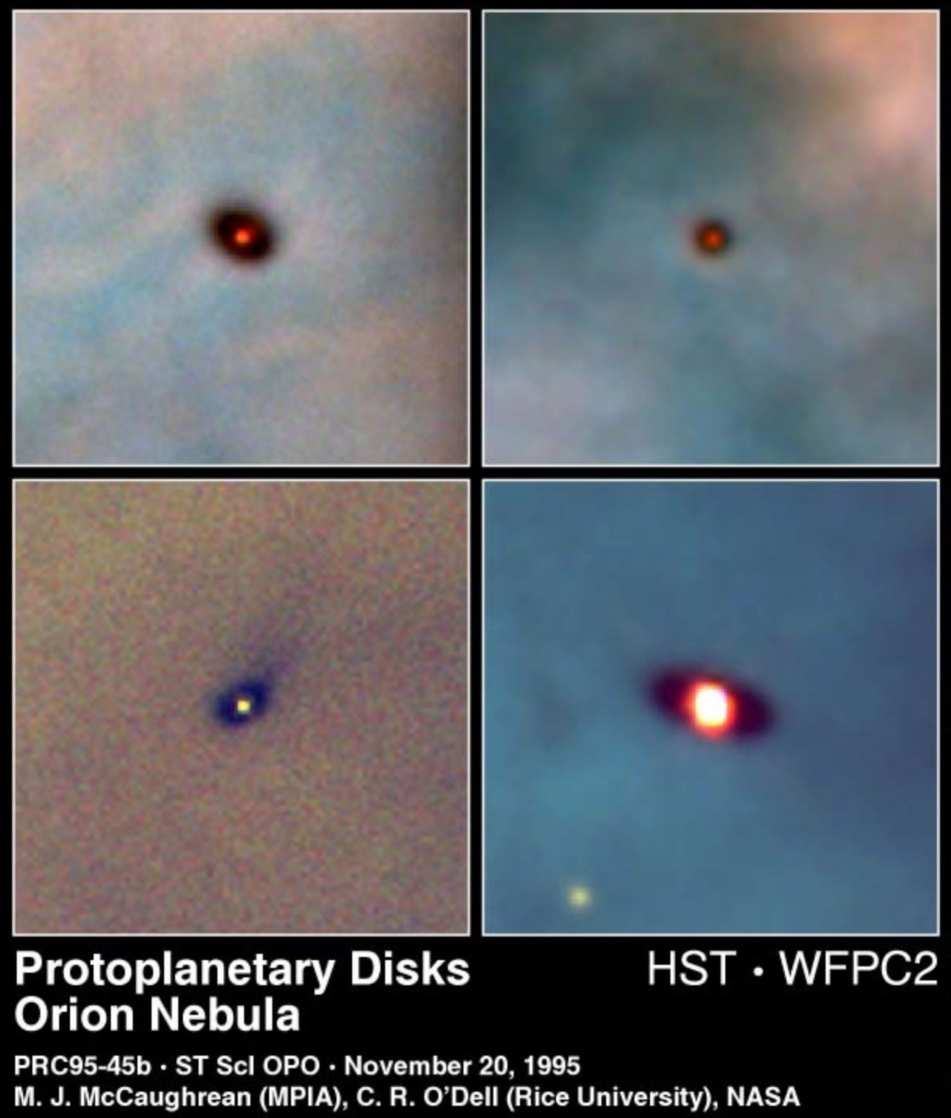

secondary mirror
primary mirror
solar panel
cameras
spectrographs

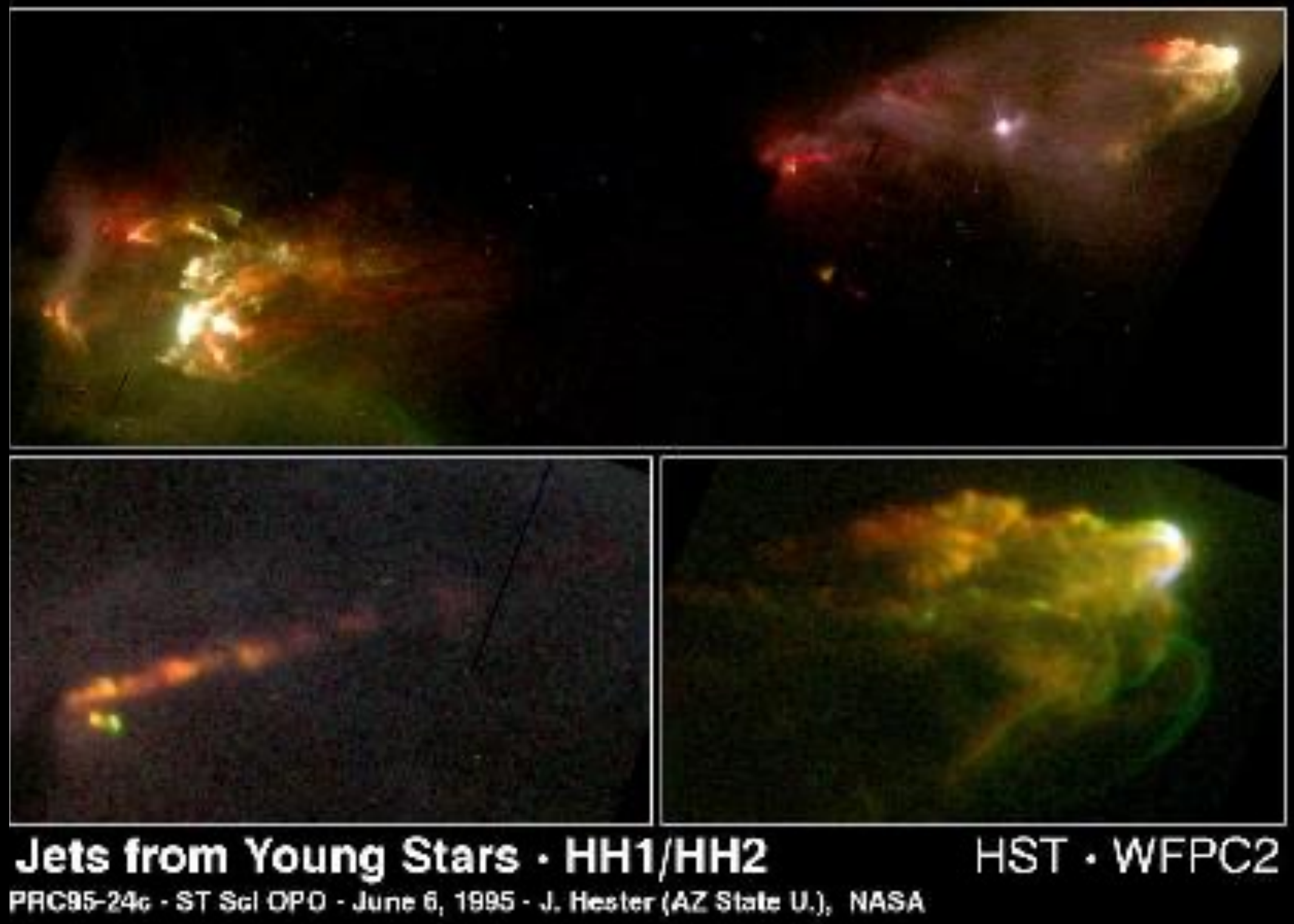


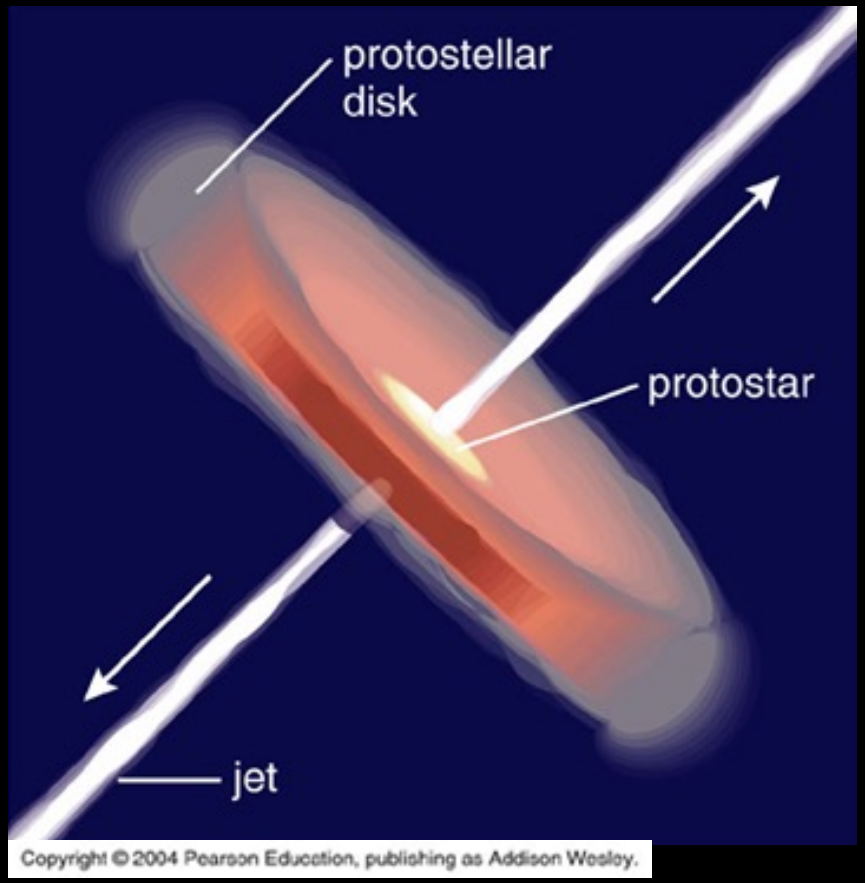
NASA

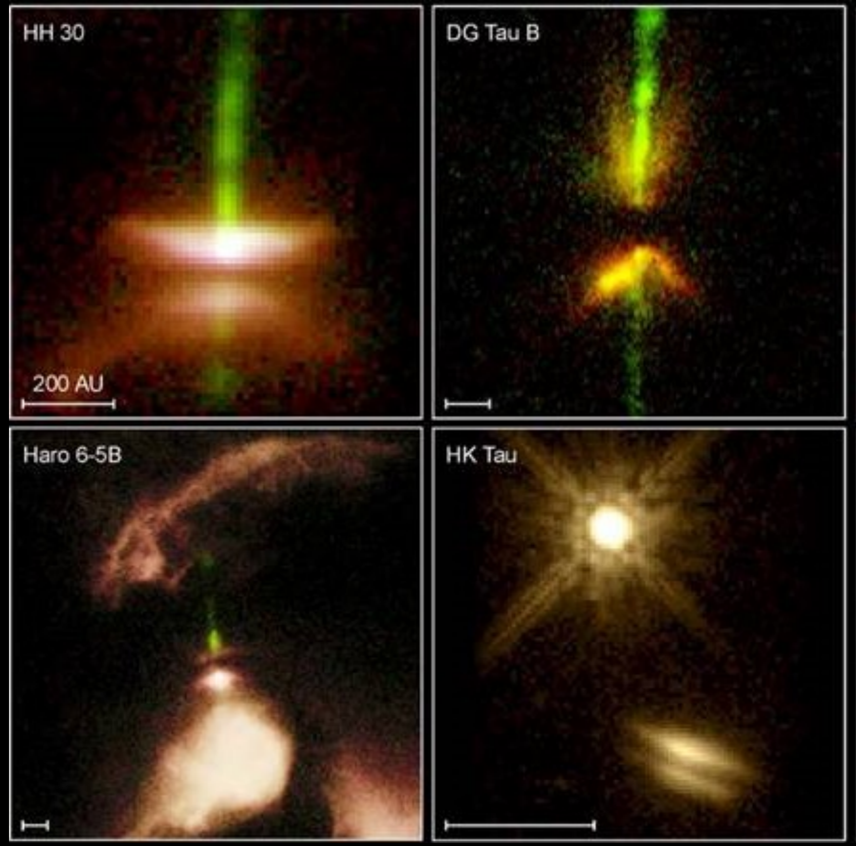


NASA/ESA


Protoplanetary Disks
Orion Nebula
HST • WFPC2
PRC95-45b • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

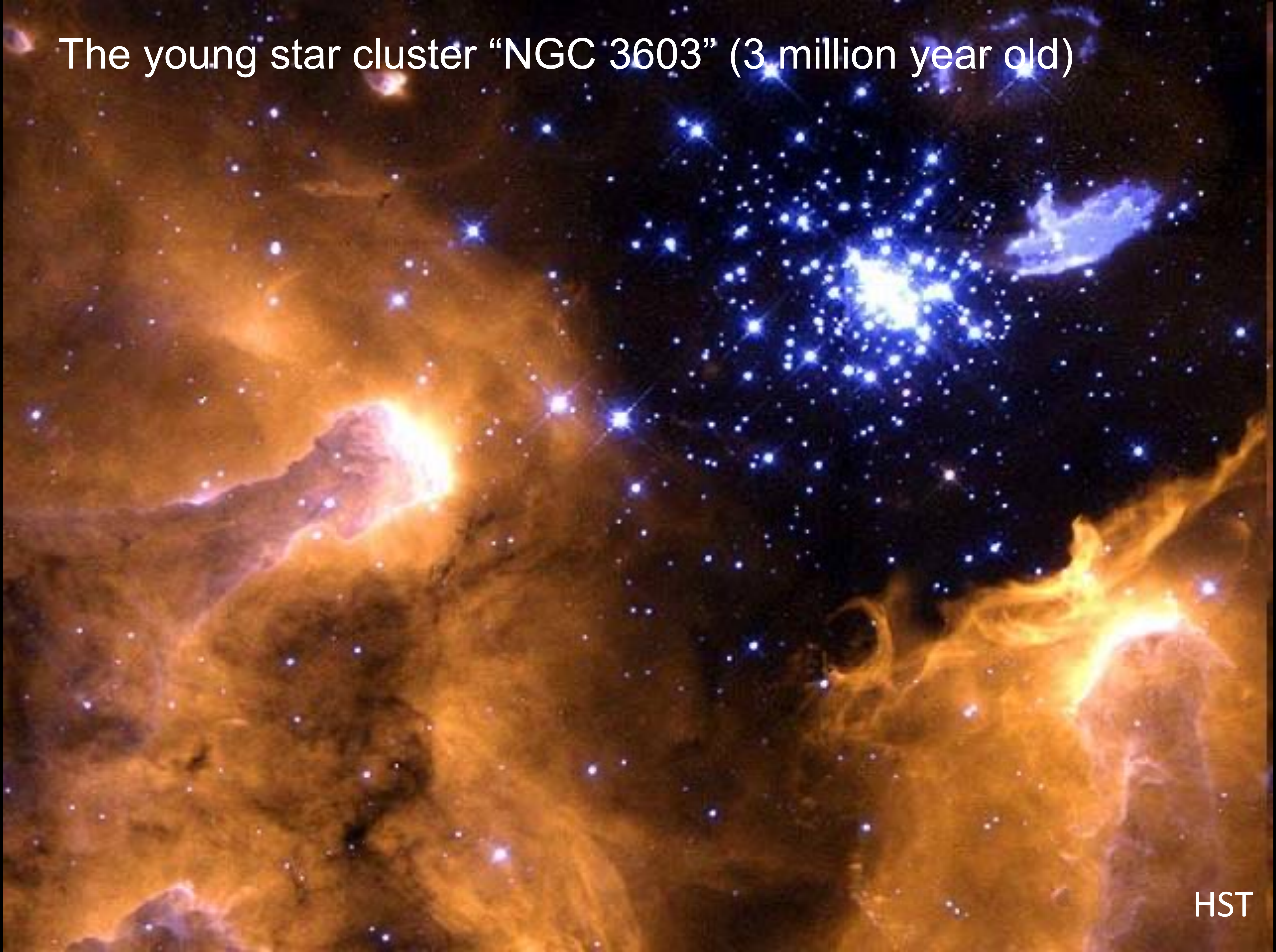

Jets from Young Stars • HH1/HH2
HST • WFPC2
PRC95-24c • ST ScI OPO • June 6, 1995 • J. Hester (AZ State U.), NASA


protostellar
disk
protostar
jet
Copyright © 2004 Pearson Education, publishing as Addison Wesley.


HH 30
DG Tau B
200 AU
Haro 6-5B
HK Tau

HST

The young star cluster “NGC 602” (3 million year old)


The young star cluster “NGC 3603” (3 million year old)
HST

The open star cluster “Pleiades” (100 million year old)

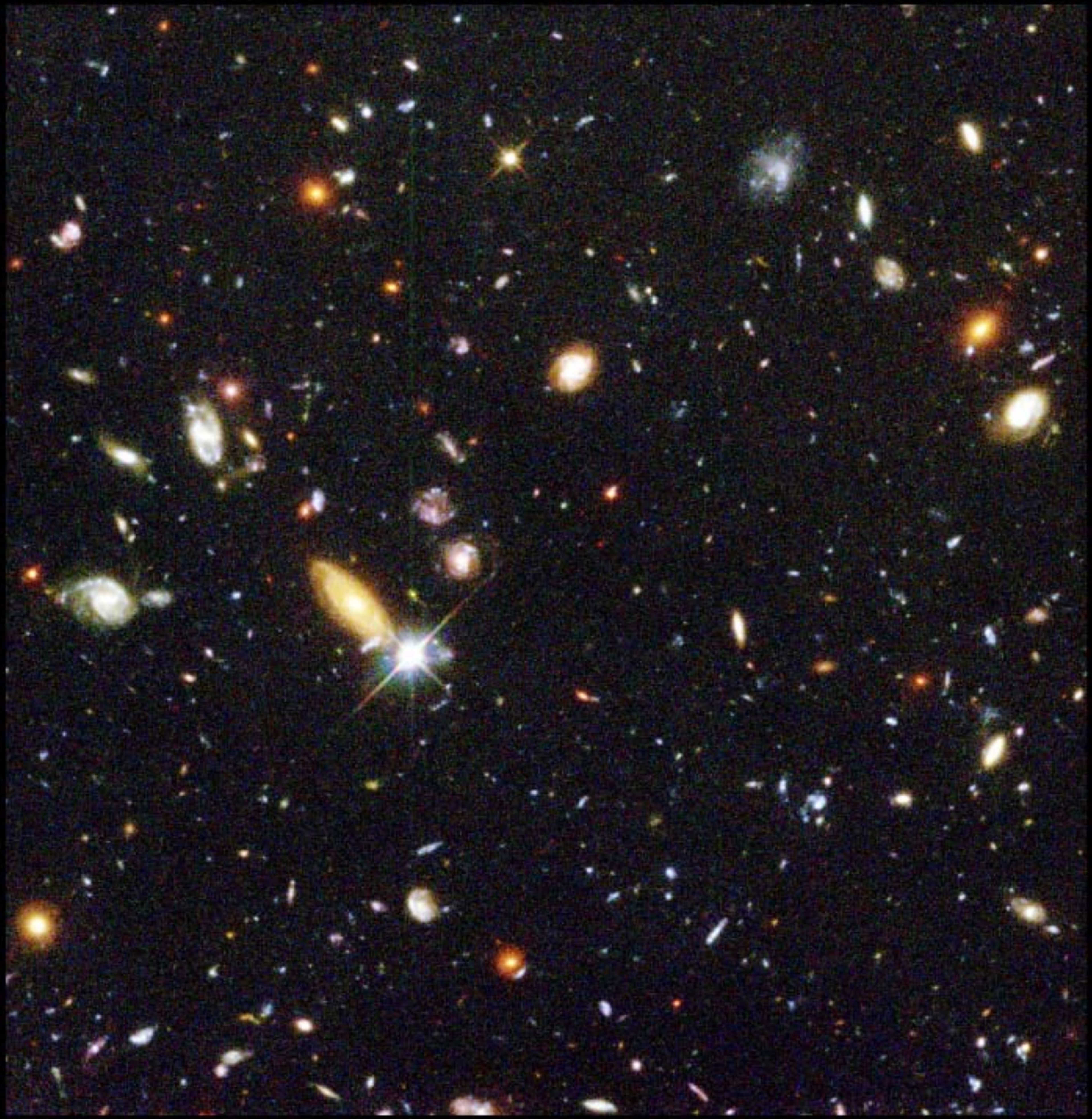
HST


The globular cluster “Omega Centauri” (10 billion year old)
HST


digitalblasphemy.com

Many new star clusters in the Antennae Galaxies

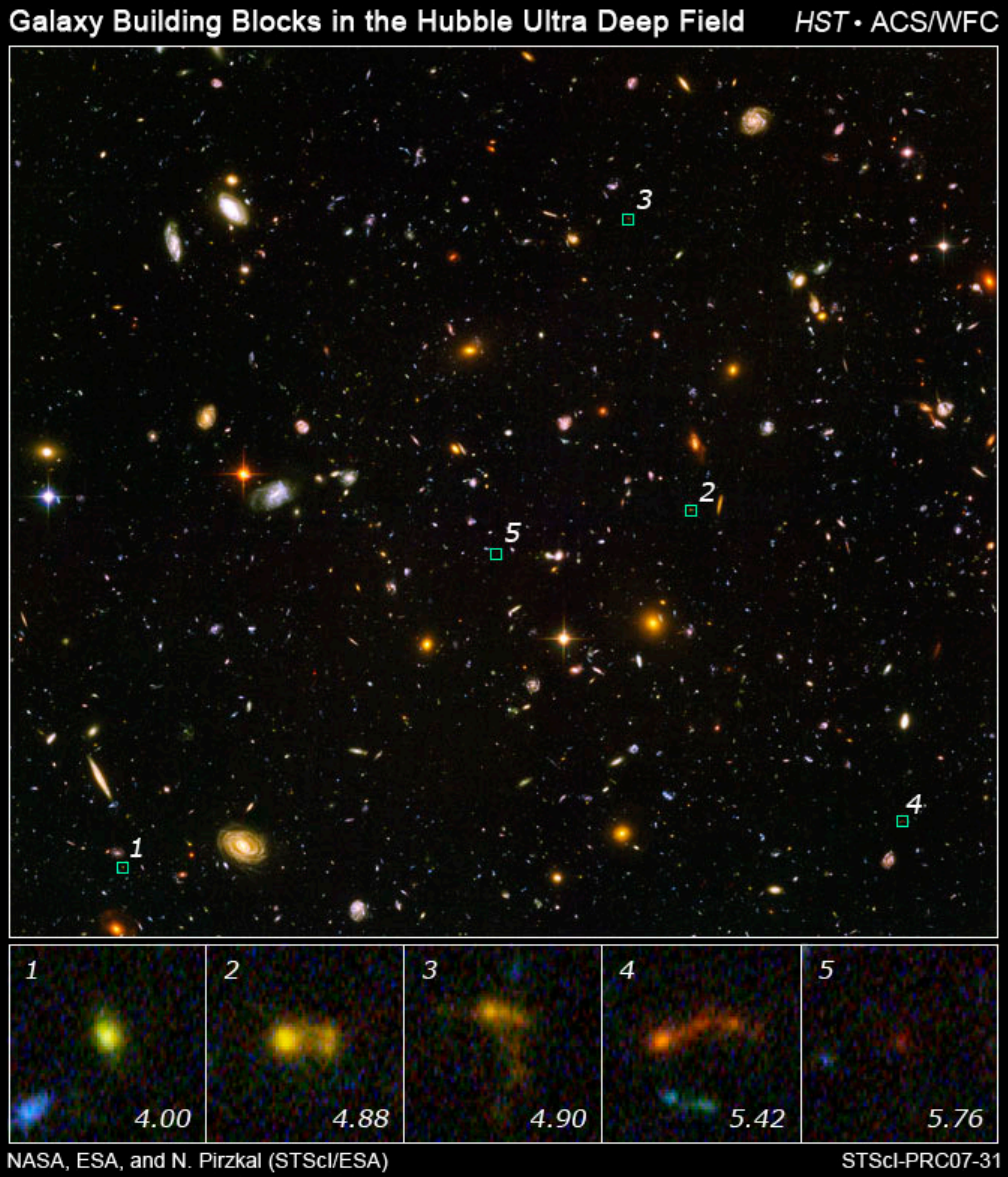
HST



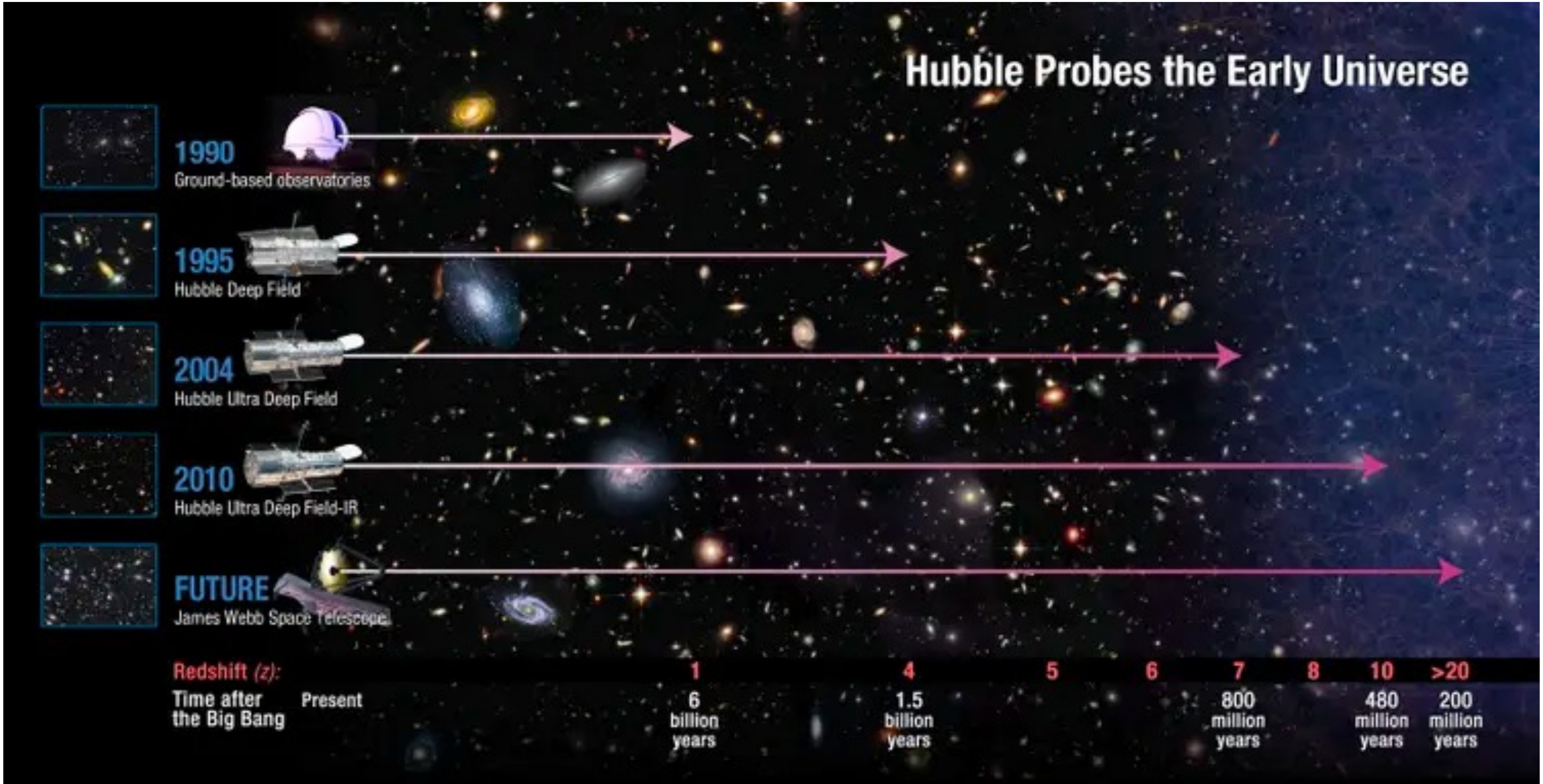
Hubble Deep Field HST • WFPC2

PRC96-01a • ST ScI OPO • January 15, 1996 • R. Williams (ST ScI), NASA

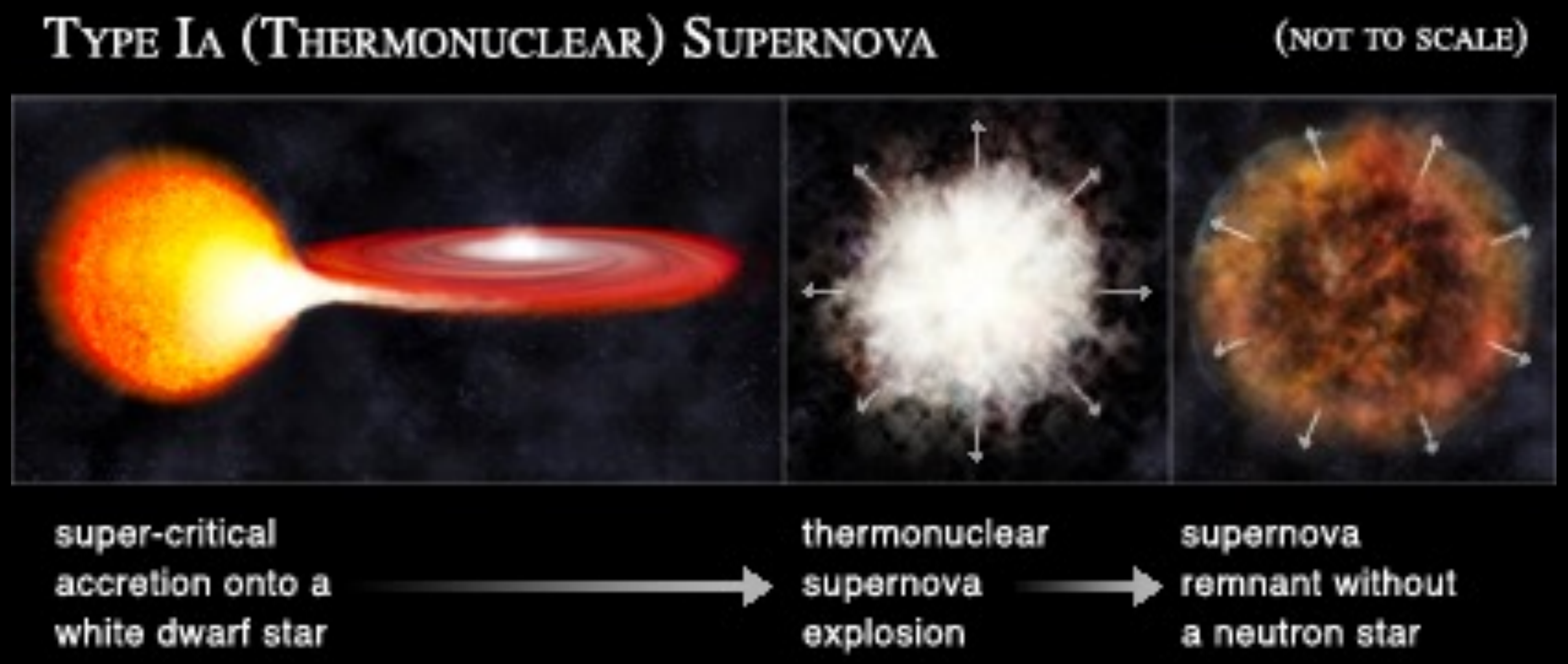
HST


Galaxy Building Blocks in the Hubble Ultra Deep Field
HST • ACS/WFC
3
2
5
4
1
1
4.00
2
4.88
3
4.90
4
5.42
5
5.76
NASA, ESA, and N. Pirzkal (STScI/ESA)
STScI-PRC07-31

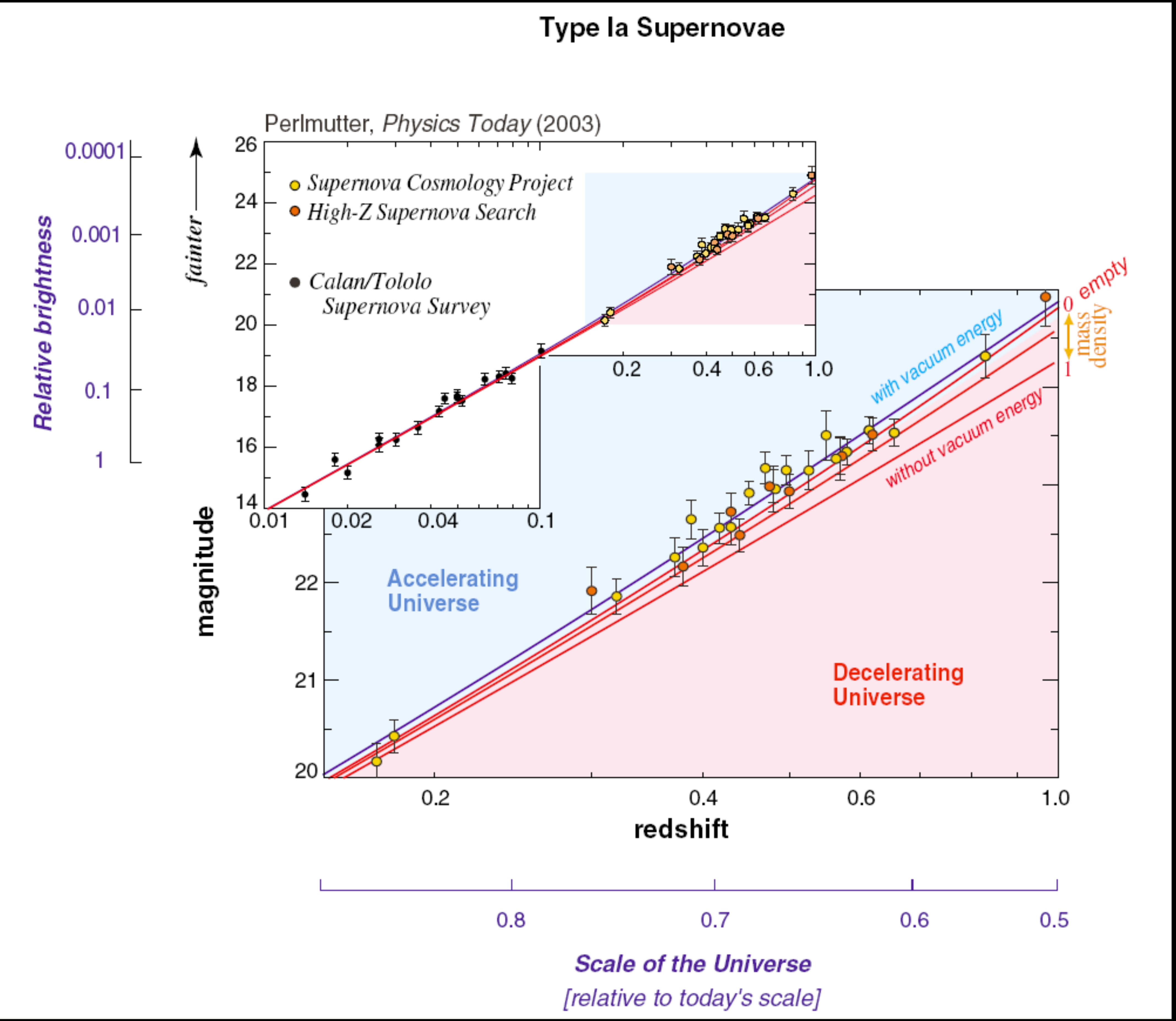
HST


Hubble Probes the Early Universe
1990
Ground-based observatories
1995
Hubble Deep Field
2004
Hubble Ultra Deep Field
2010
Hubble Ultra Deep Field-IR
FUTURE
James Webb Space Telescope
Redshift (z):
1
4
5
6
7
8
10
>20
Time after the Big Bang
Present
6 billion years
1.5 billion years
800 million years
480 million years
200 million years

NASA

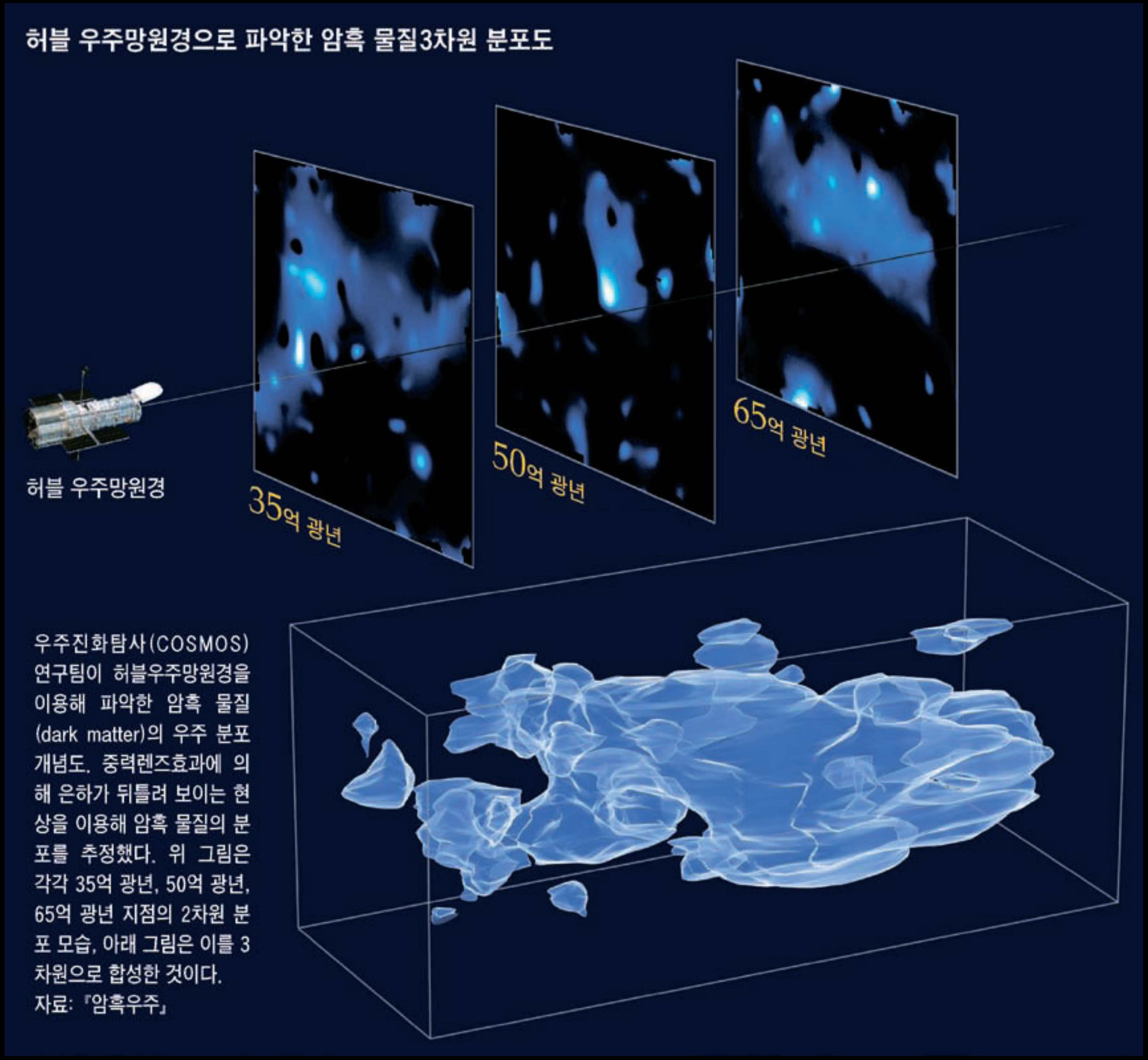


Chandra



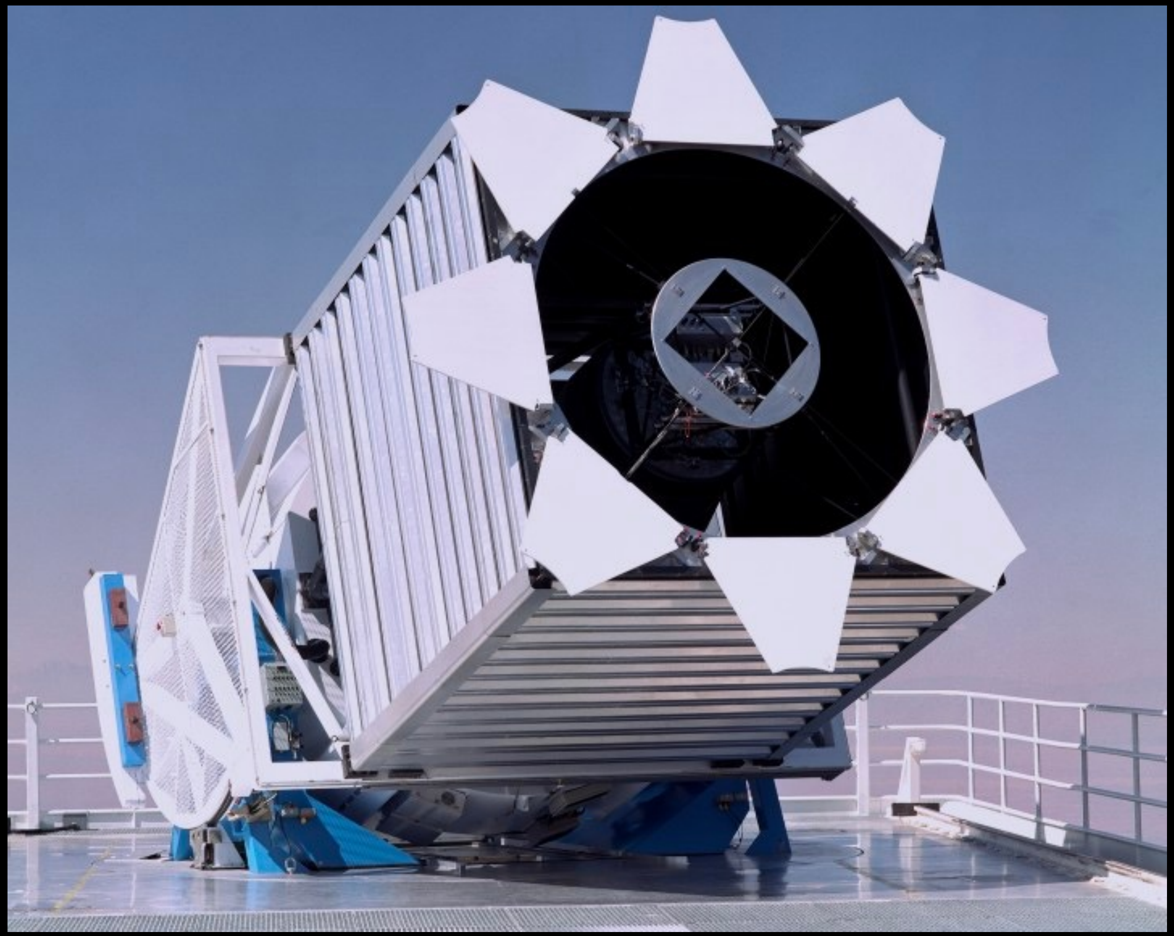
Pulmutter et al.
Nature 391, 51
1998, ApJ 517, 565

베라 루빈 (1928-2016)

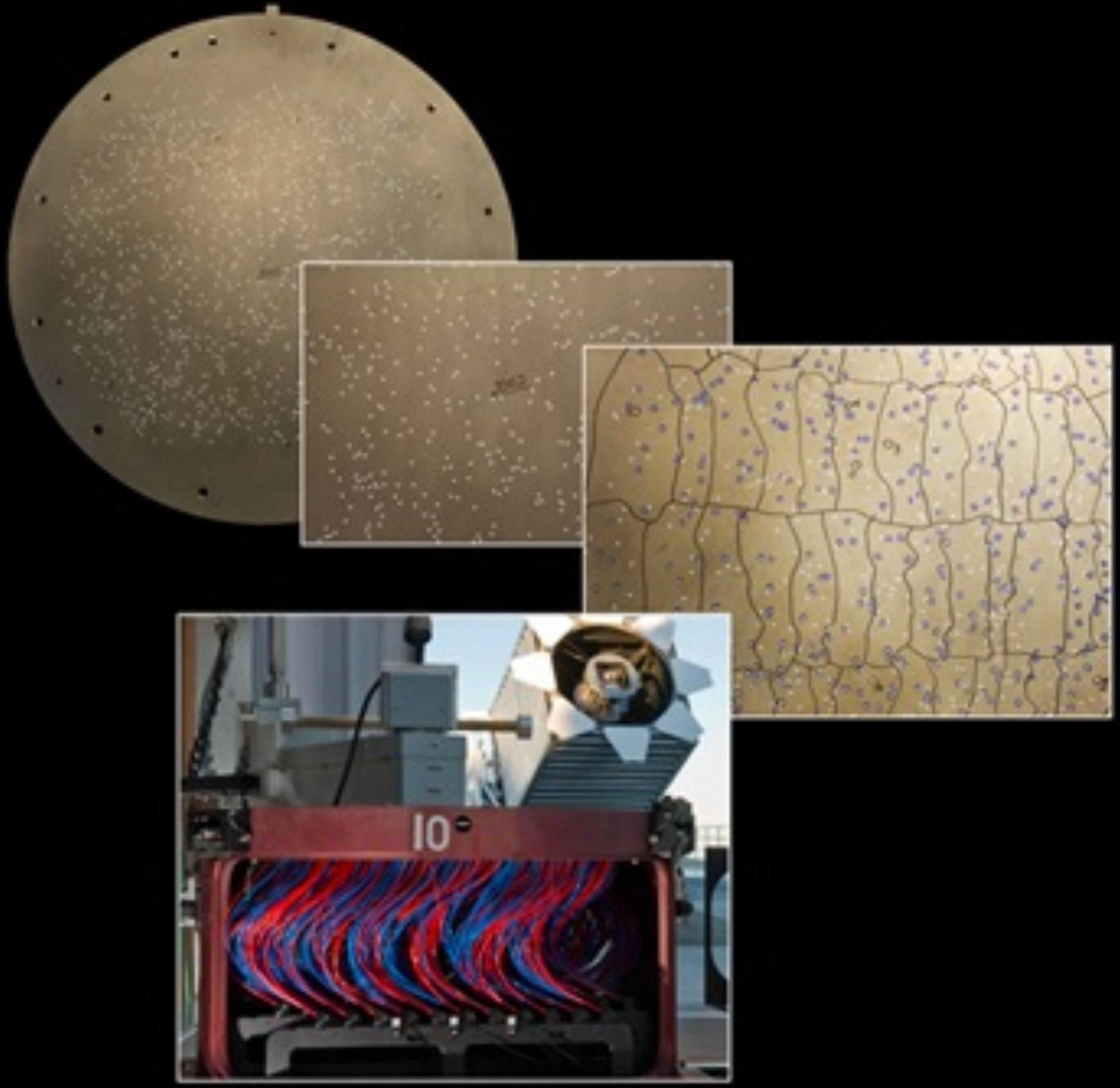


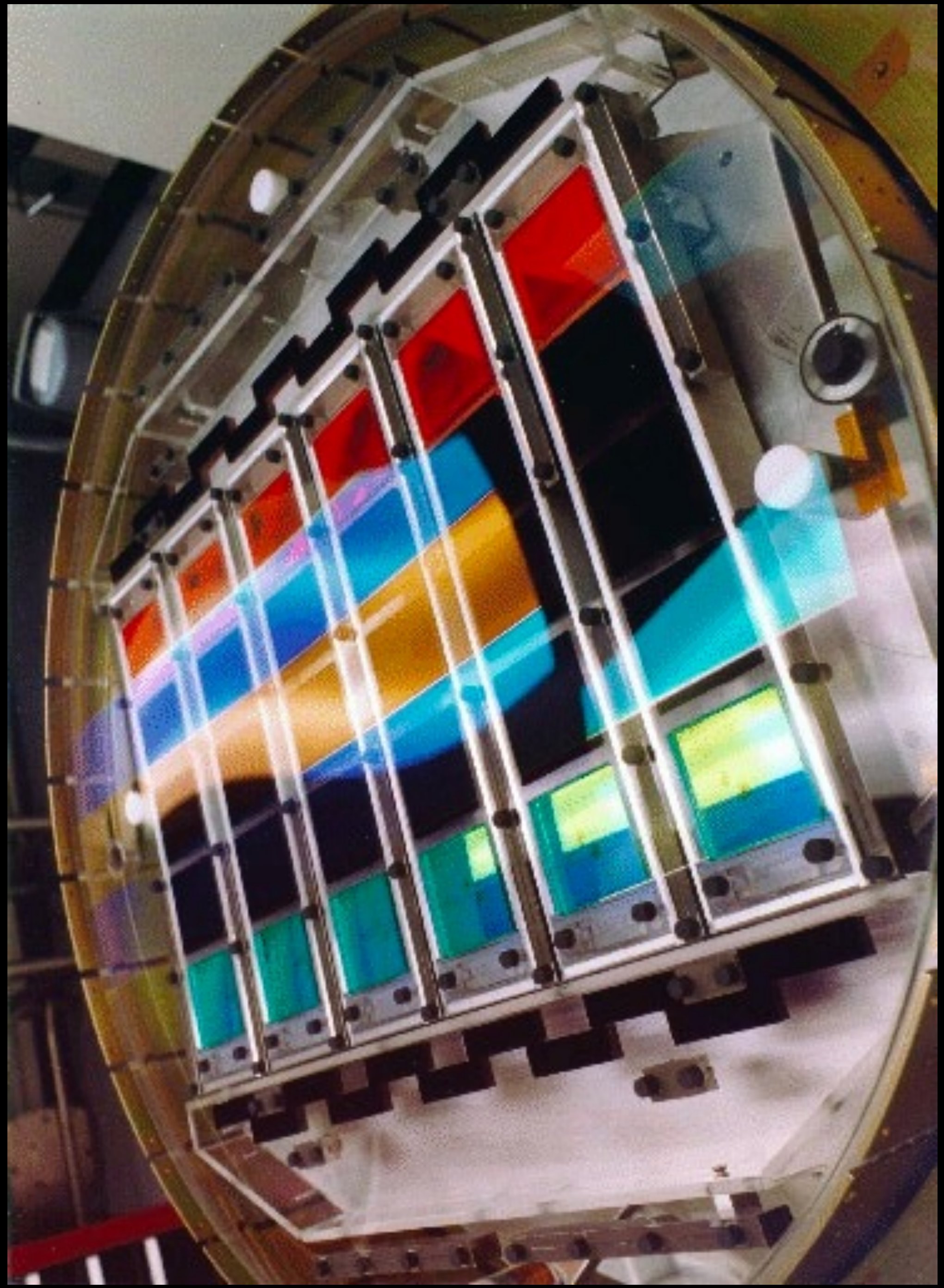
HST

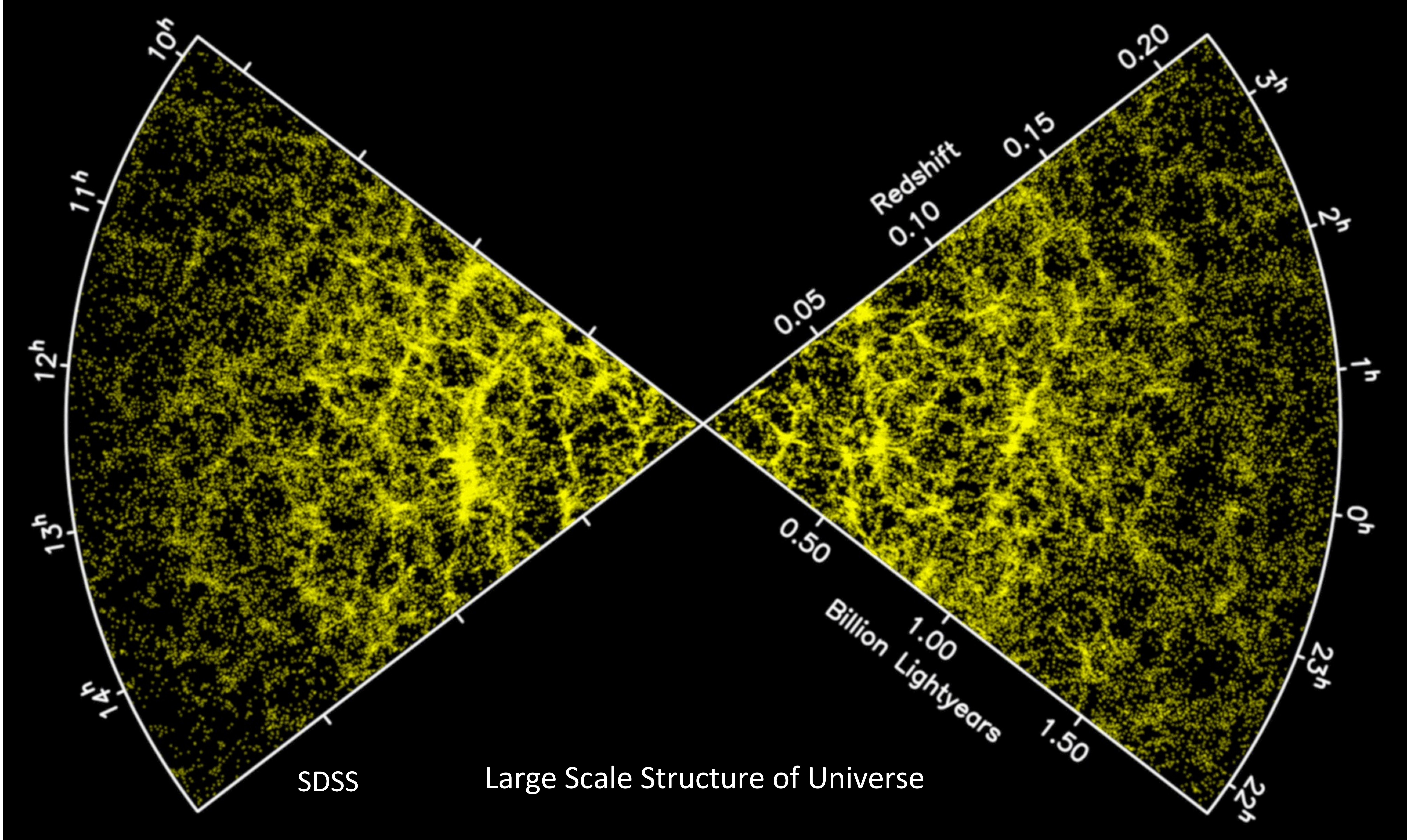
Sloan Digital Sky Survey



SDSS





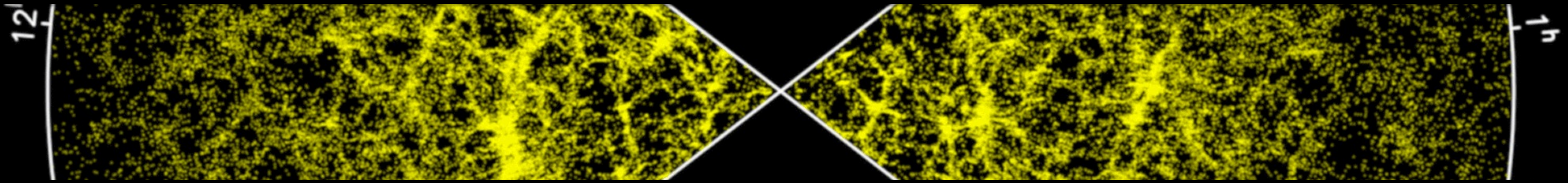


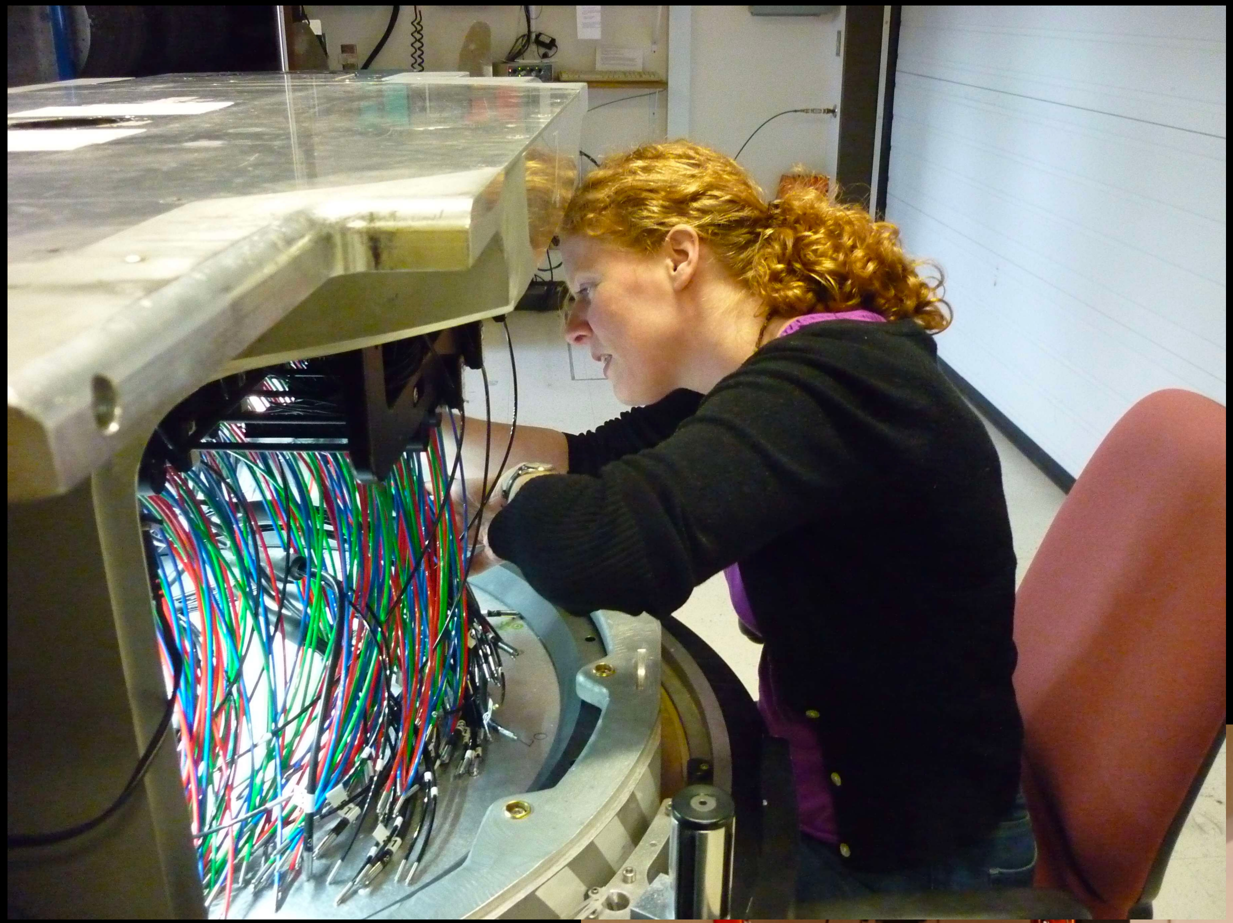
SDSS

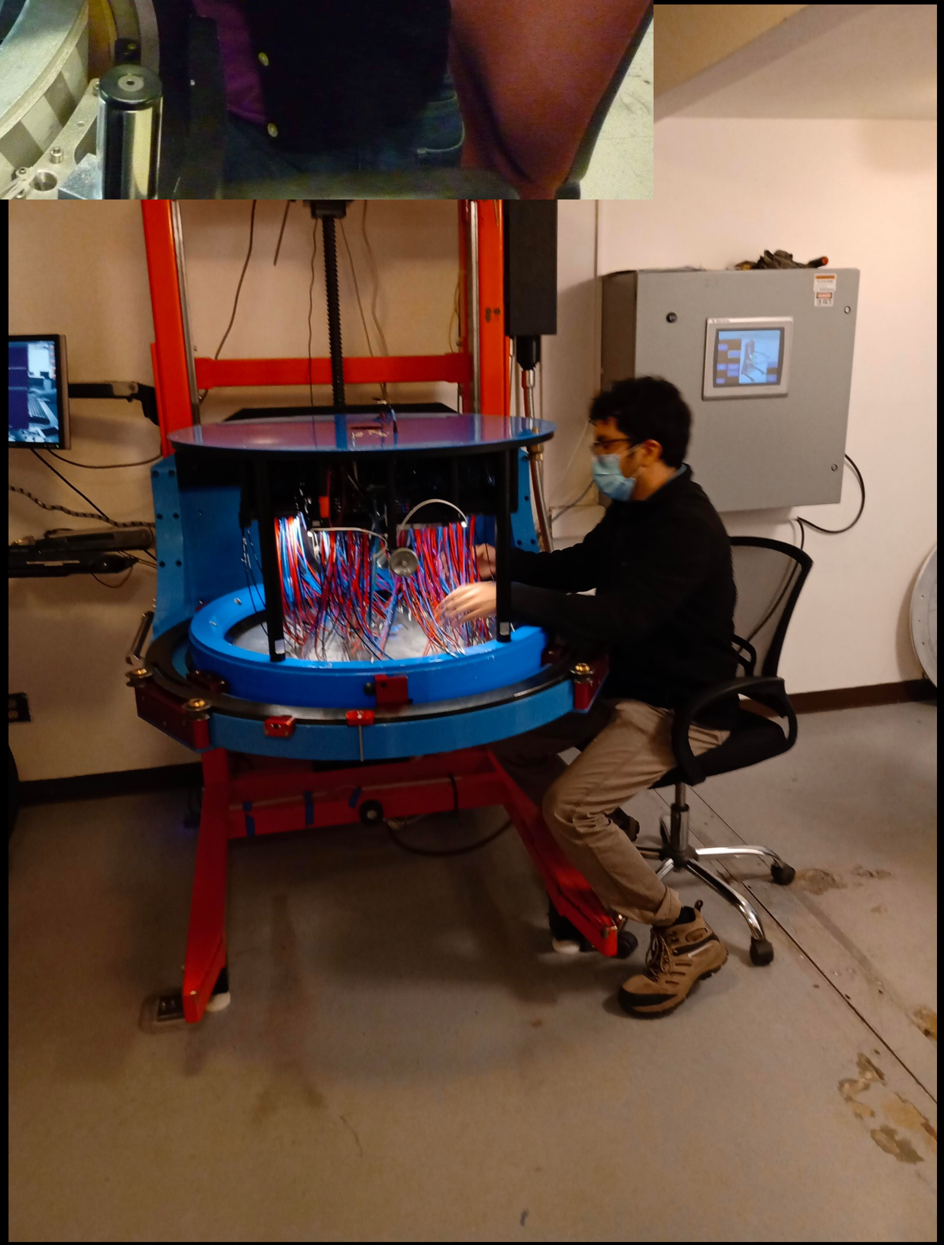
Large Scale Structure of Universe

Sloan Digital Sky Survey SDSS

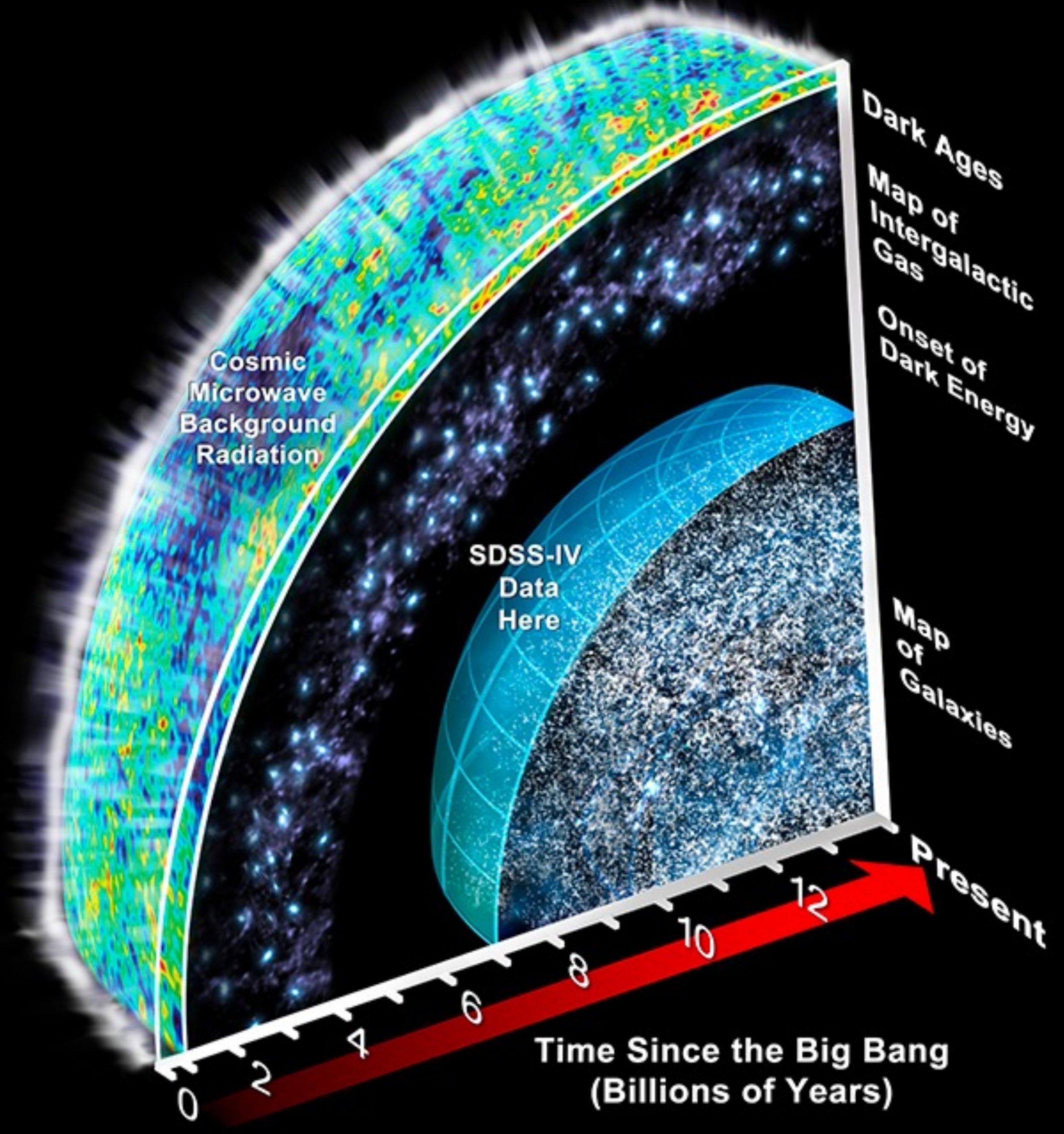
Large Scale Structure of Universe



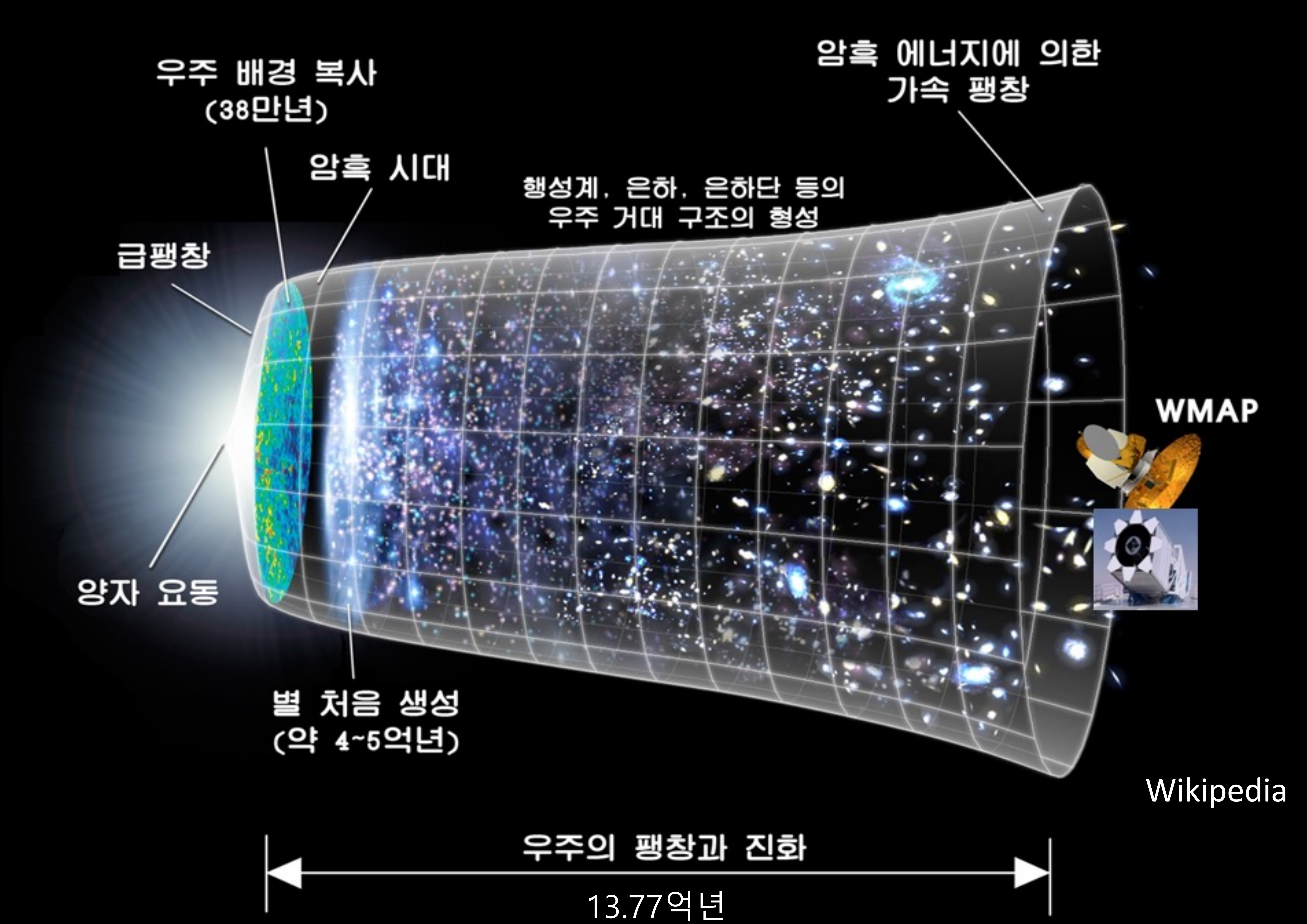




SDSS-IV Catches the Rise of Dark Energy

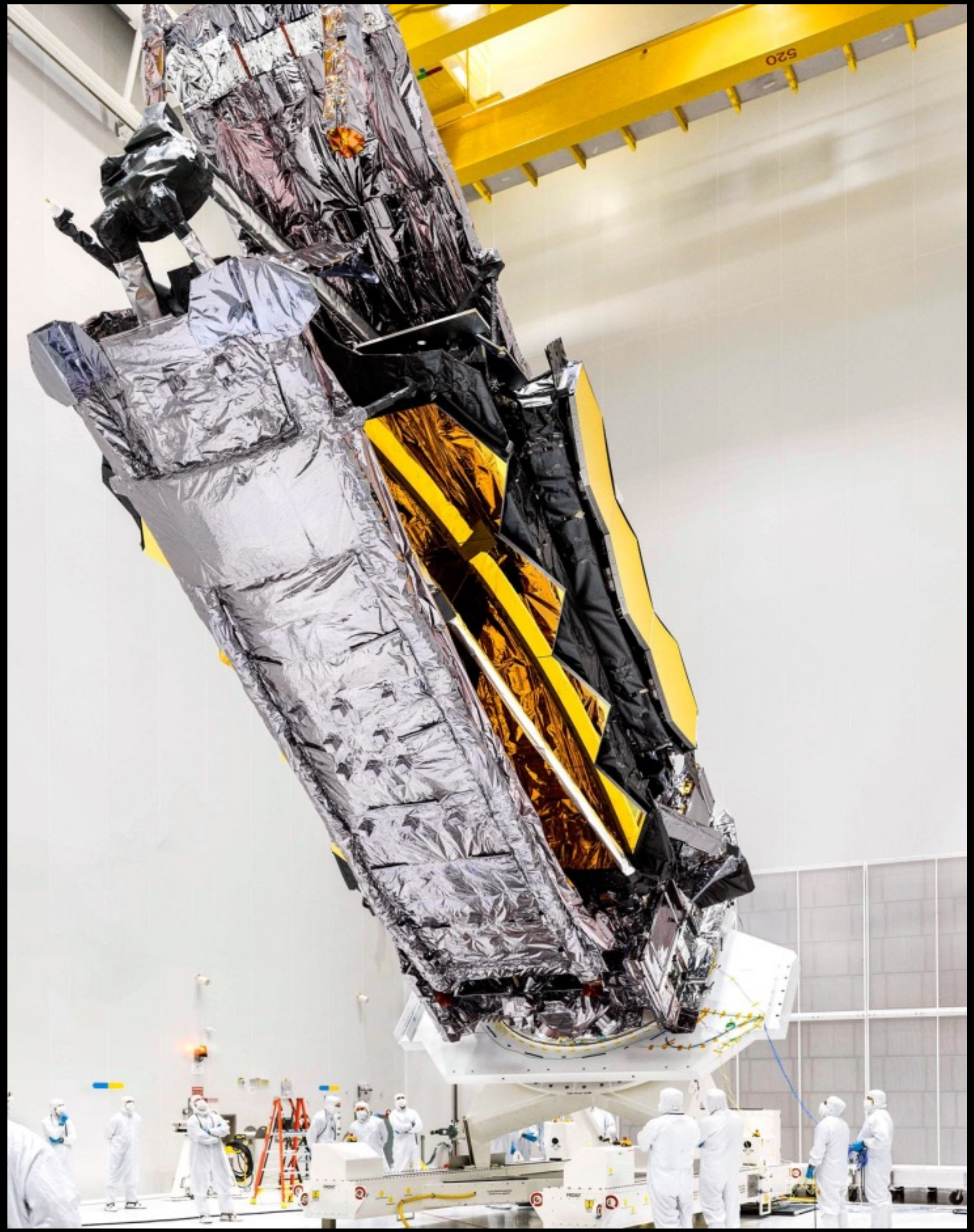


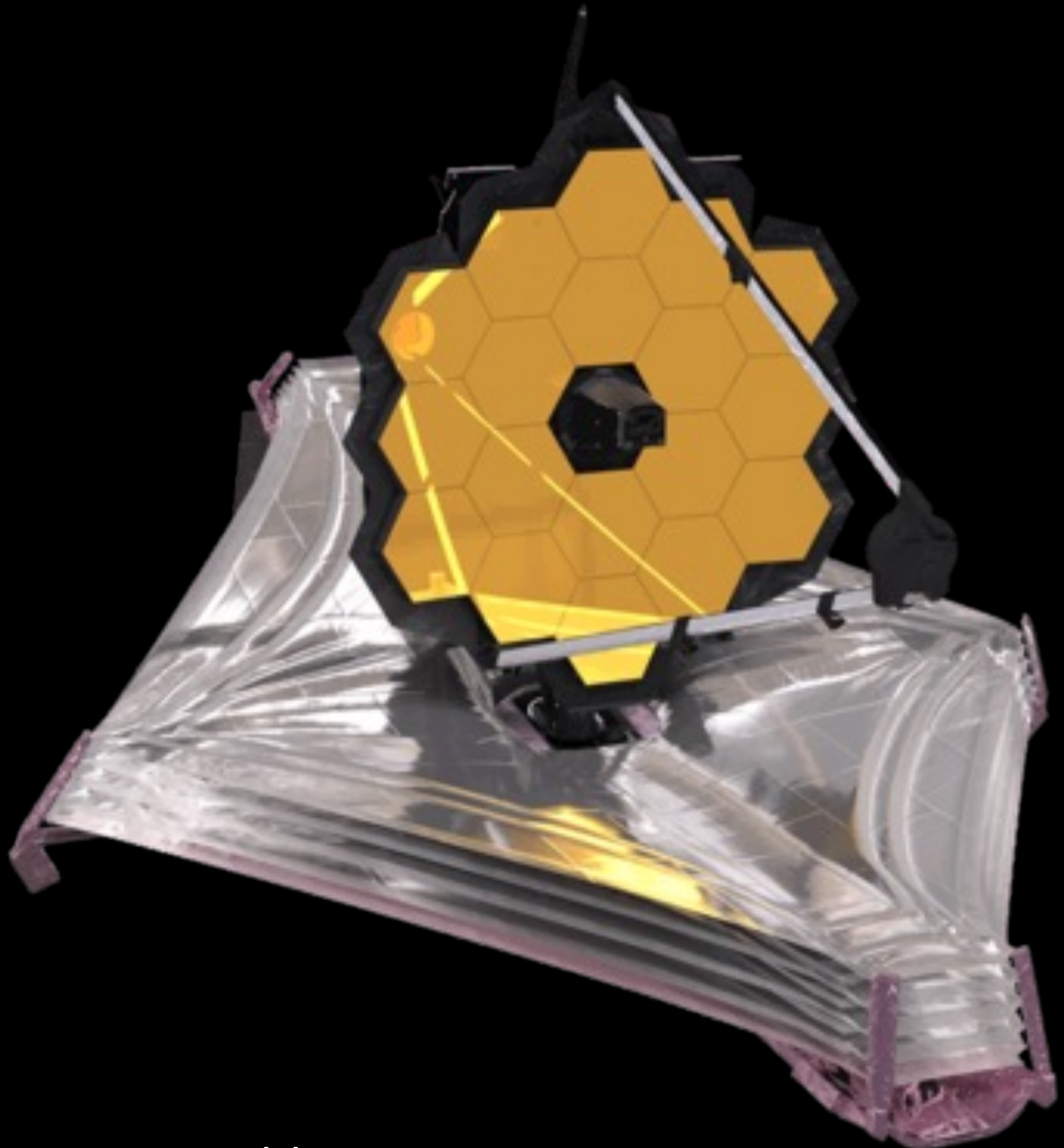
SDSS


우주 배경 복사
(38만년)
암흑 에너지에 의한
가속 팽창
암흑 시대
행성계, 은하, 은하단 등의
우주 거대 구조의 형성
급팽창
양자 요동
별 처음 생성
(약 4~5억년)
WMAP
우주의 팽창과 진화
13.77억년

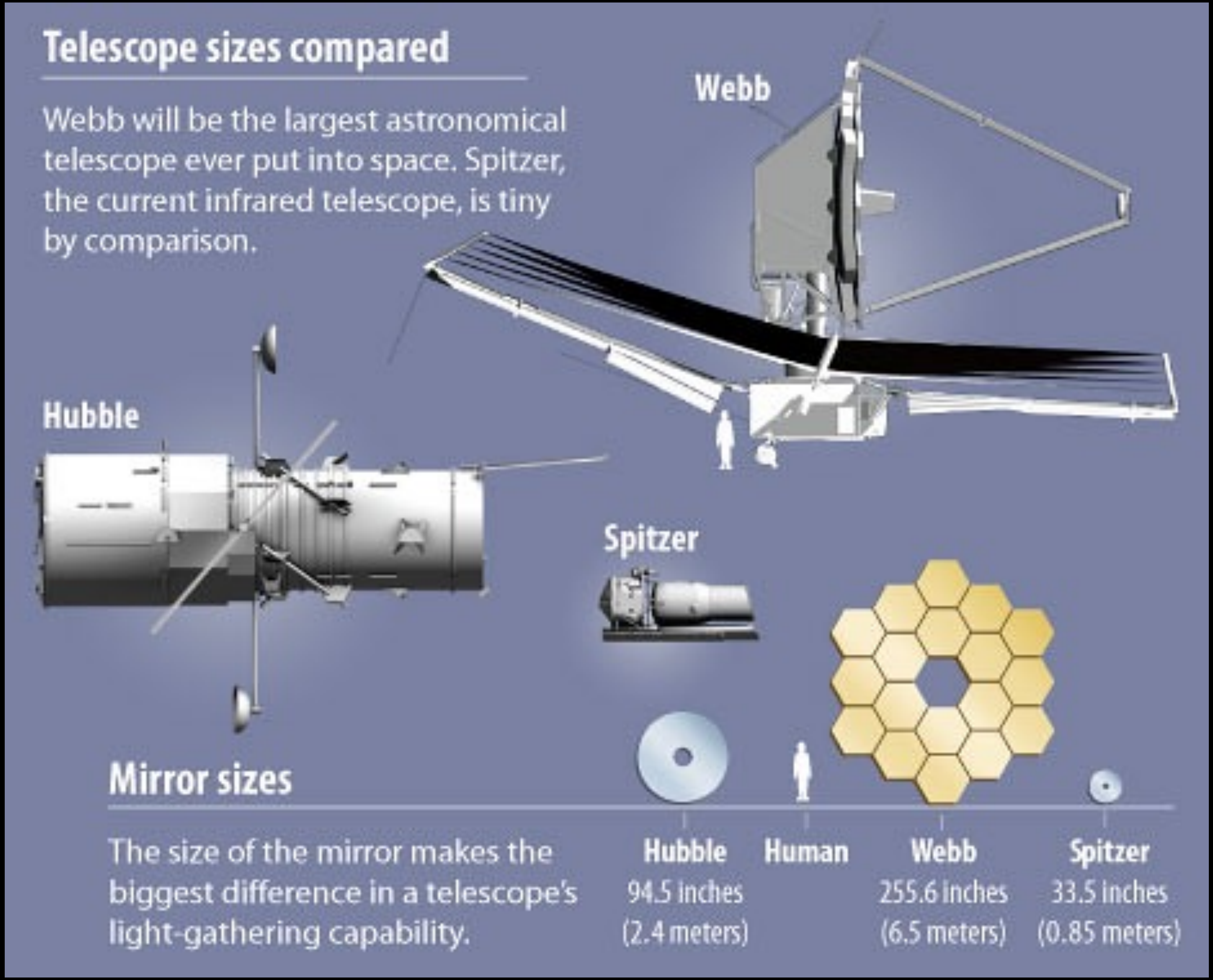
Wikipedia

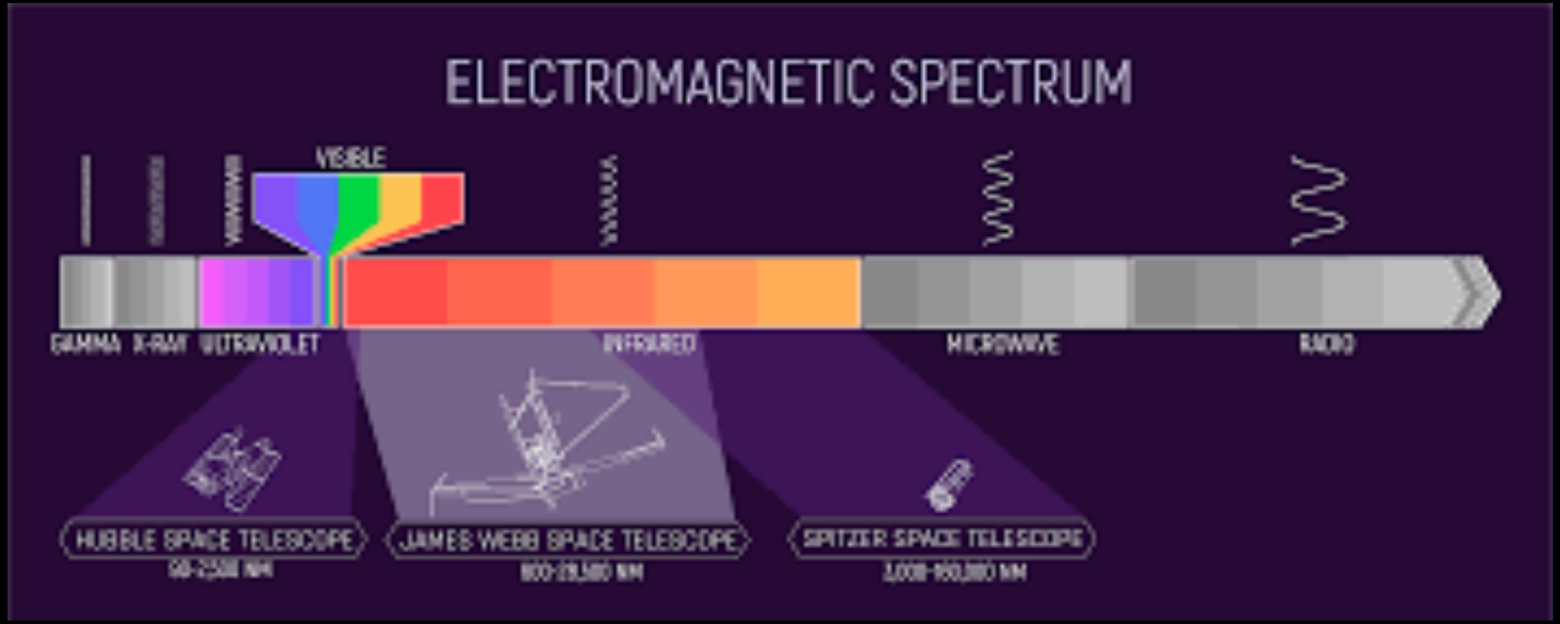
JAMES WEEB SPACE TELESCOPE



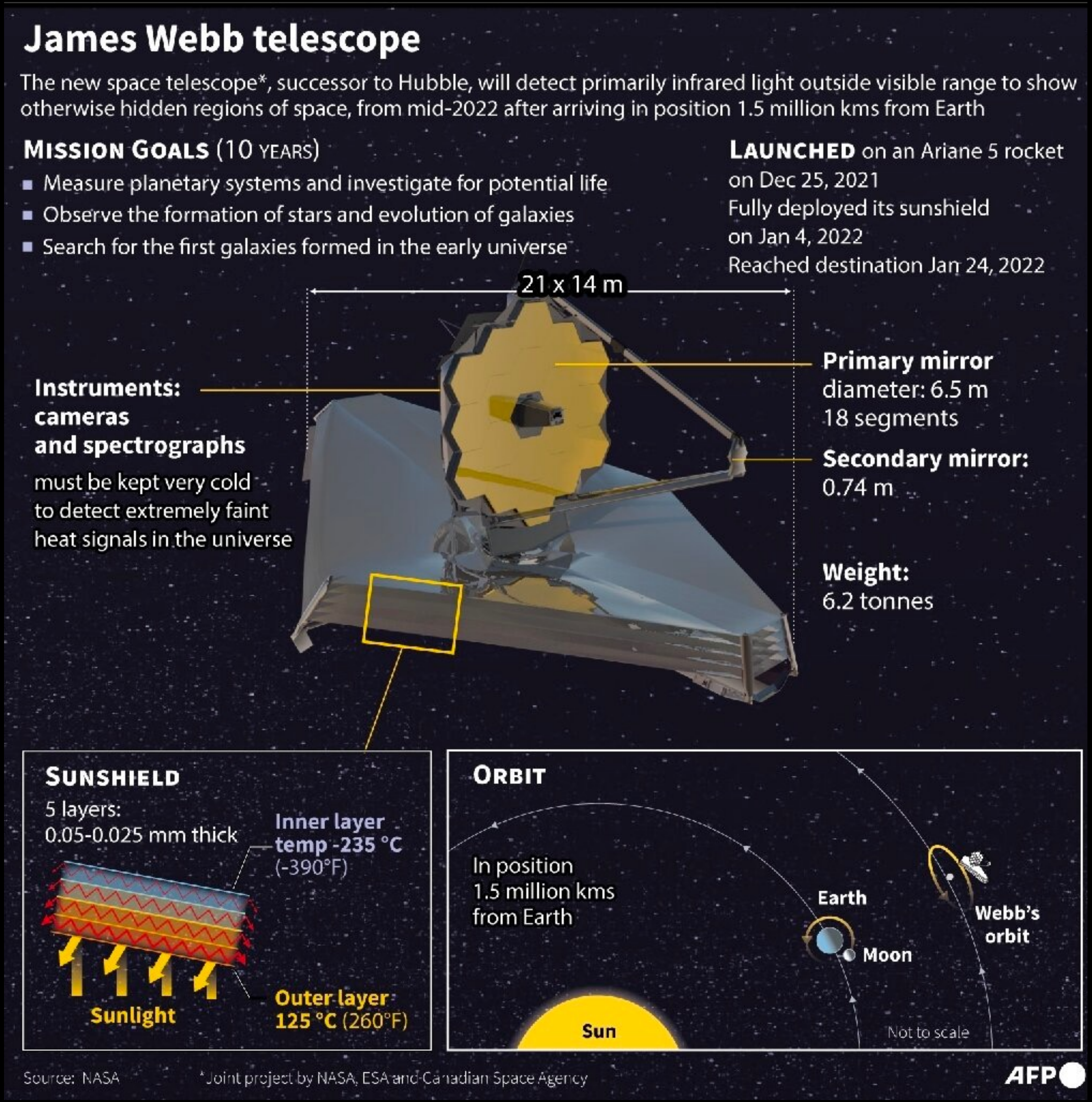


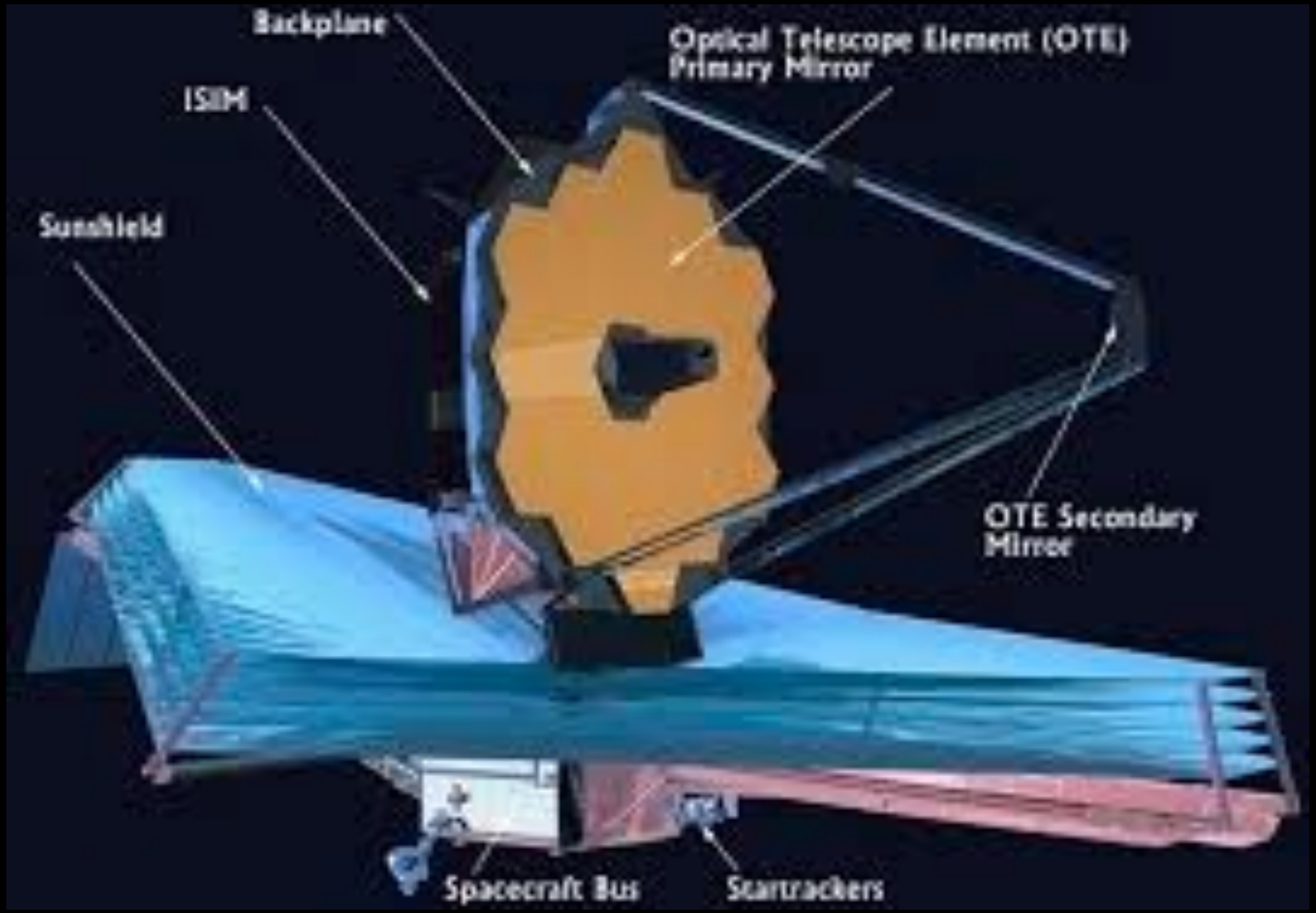
James Webb Space Telescope





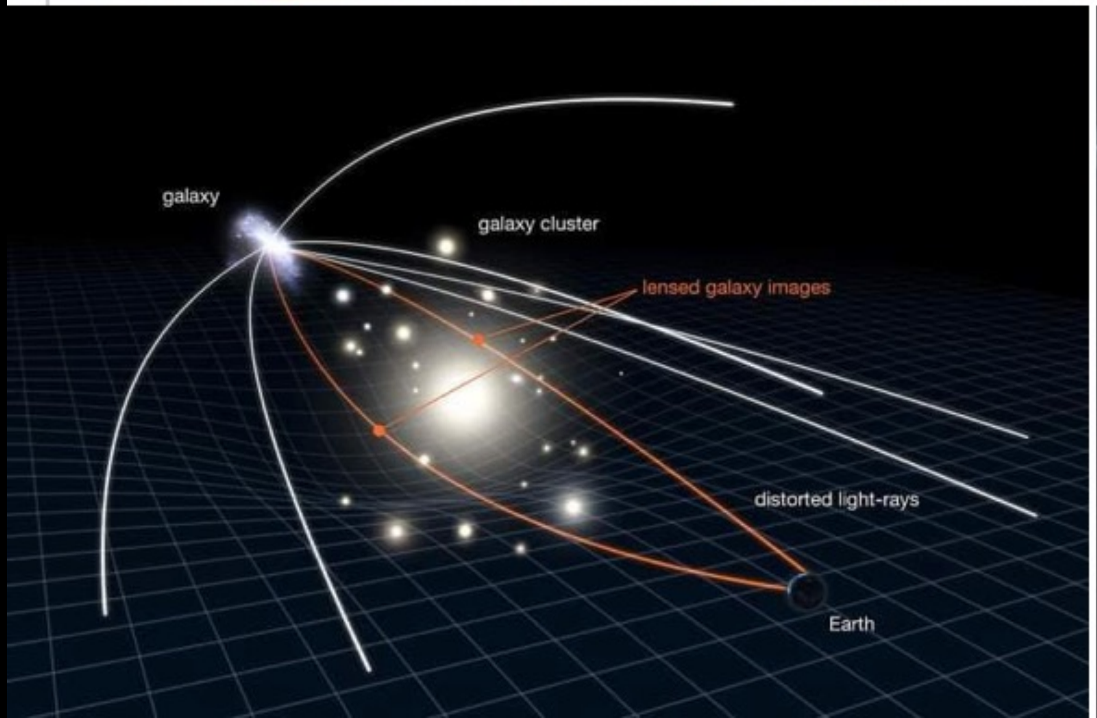
James Webb Space Telescope


James Webb telescope
The new space telescope*, successor to Hubble, will detect primarily infrared light outside visible range to show otherwise hidden regions of space, from mid-2022 after arriving in position 1.5 million kms from Earth
Mission Goals (10 years)
Measure planetary systems and investigate for potential life
Observe the formation of stars and evolution of galaxies
Search for the first galaxies formed in the early universe
Launched on an Ariane 5 rocket on Dec 25, 2021
Fully deployed its sunshield on Jan 4, 2022
Reached destination Jan 24, 2022
21 x 14 m
Instruments: cameras and spectrographs
must be kept very cold to detect extremely faint heat signals in the universe
Primary mirror
diameter: 6.5 m
18 segments
Secondary mirror:
0.74 m
Weight:
6.2 tonnes
Sunshield
5 layers:
0.05-0.025 mm thick
Inner layer temp -235 °C (-390°F)
Outer layer 125 °C (260°F)
Sunlight
Orbit
In position 1.5 million kms from Earth
Earth
Moon
Webb's orbit
Sun
Not to scale
Source: NASA
*Joint project by NASA, ESA and Canadian Space Agency
AFP


Backplane
Optical Telescope Element (OTE) Primary Mirror
ISIM
Sunshield
OTE Secondary Mirror
Spacecraft Bus
Startrackers

JWST

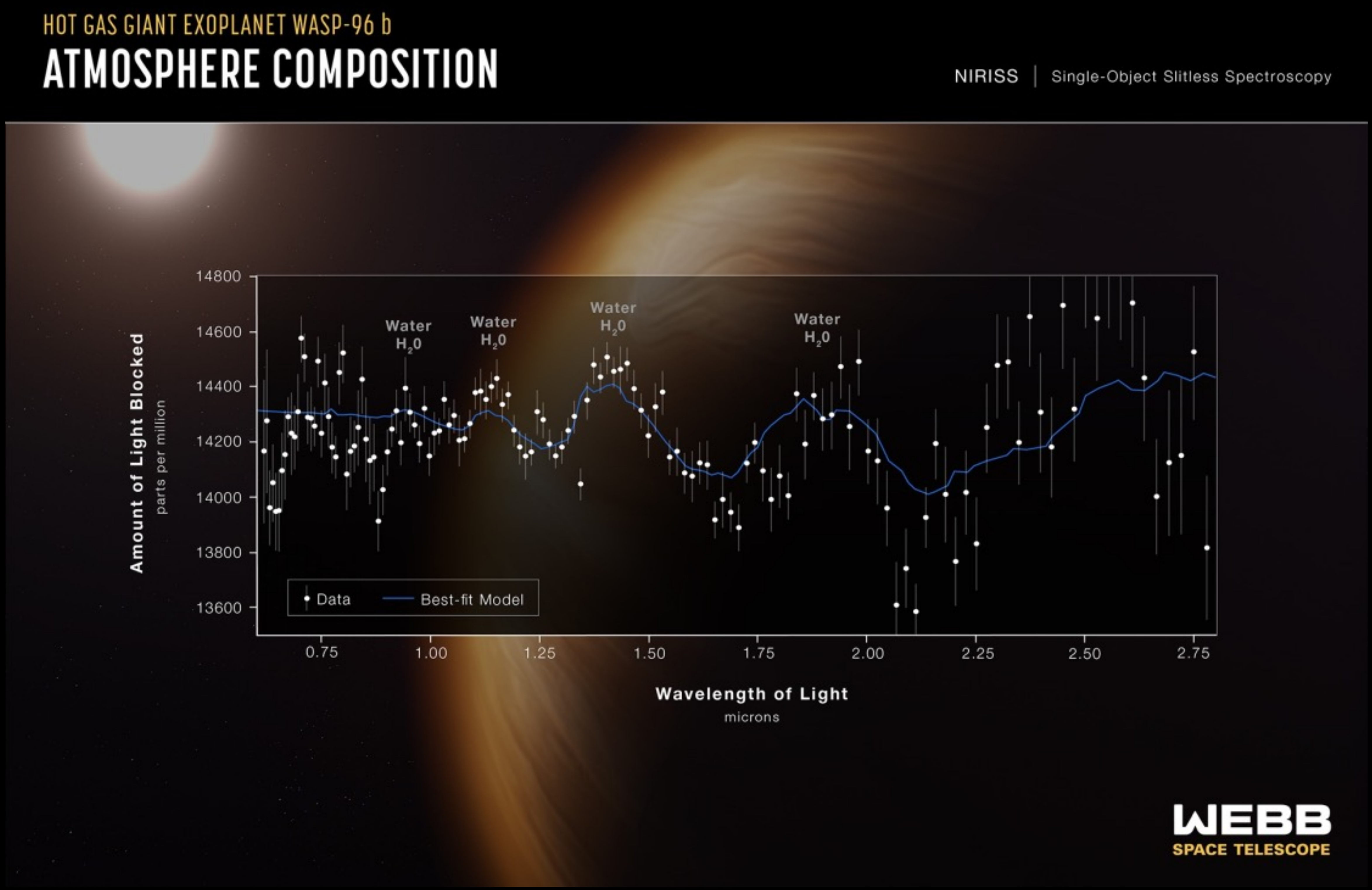
JWST


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

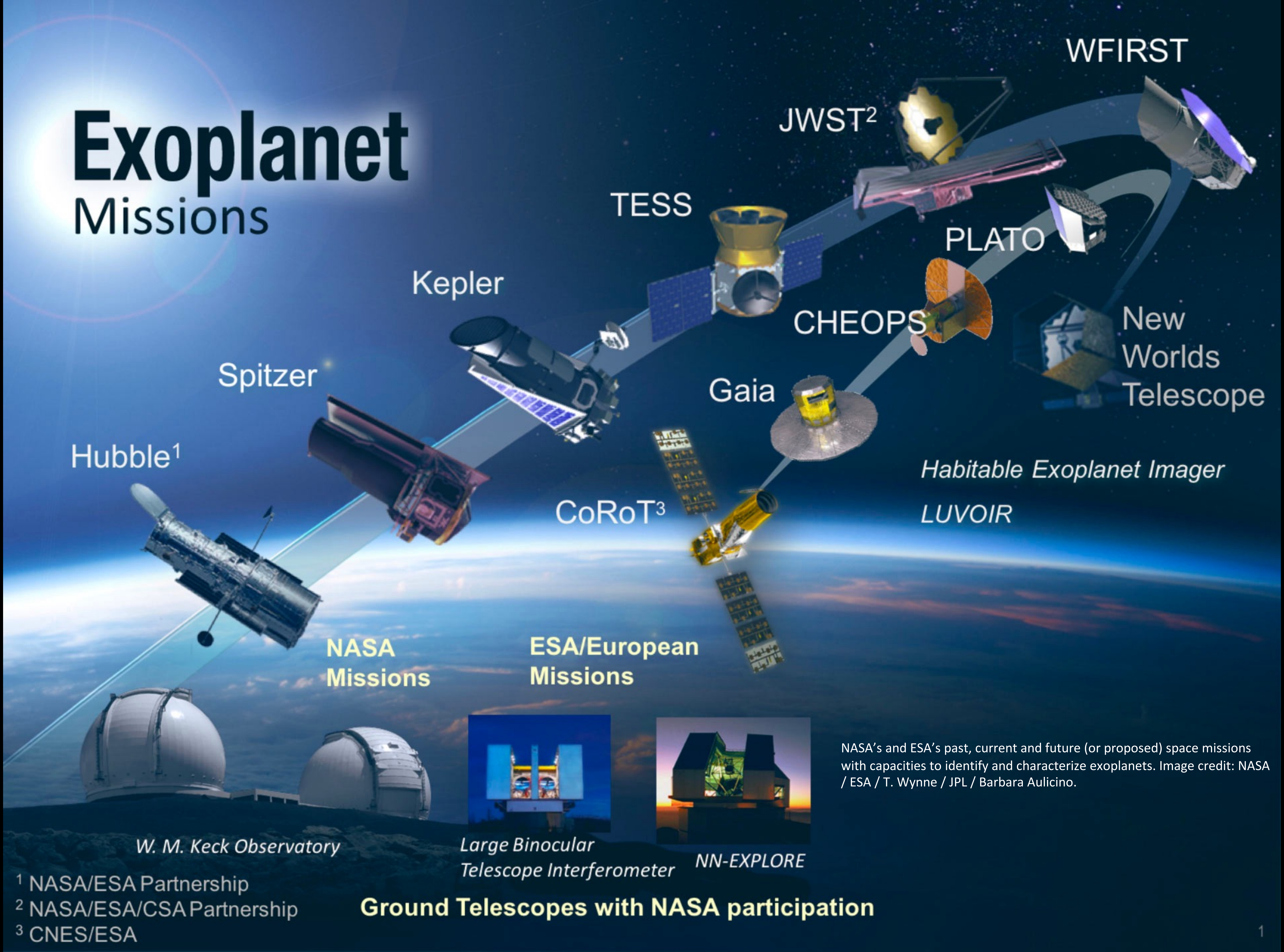

FOREGROUND GALAXY
WITH FOUR QUASAR IMAGES
HUBBLE

JWST

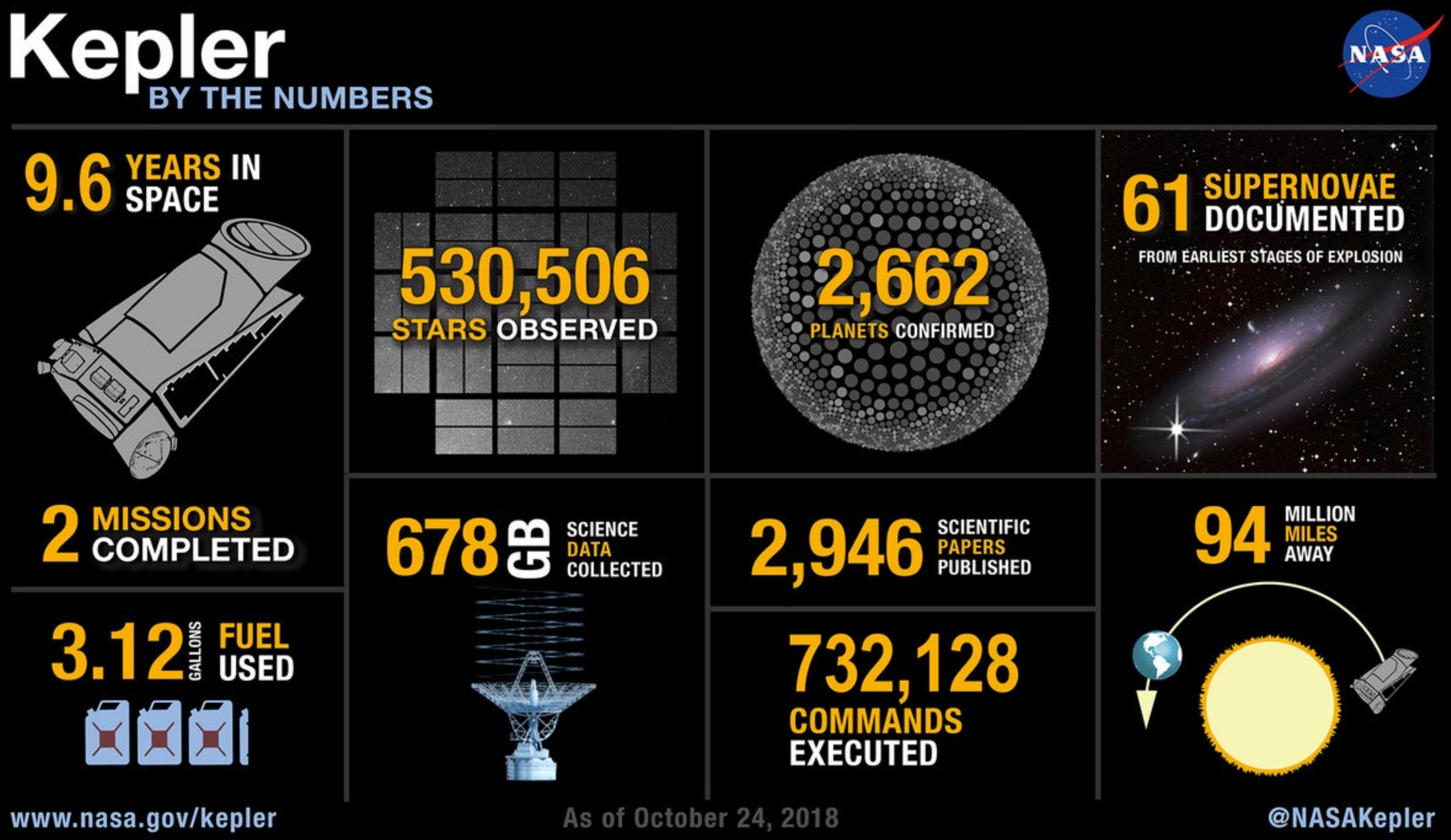
WASP-96b



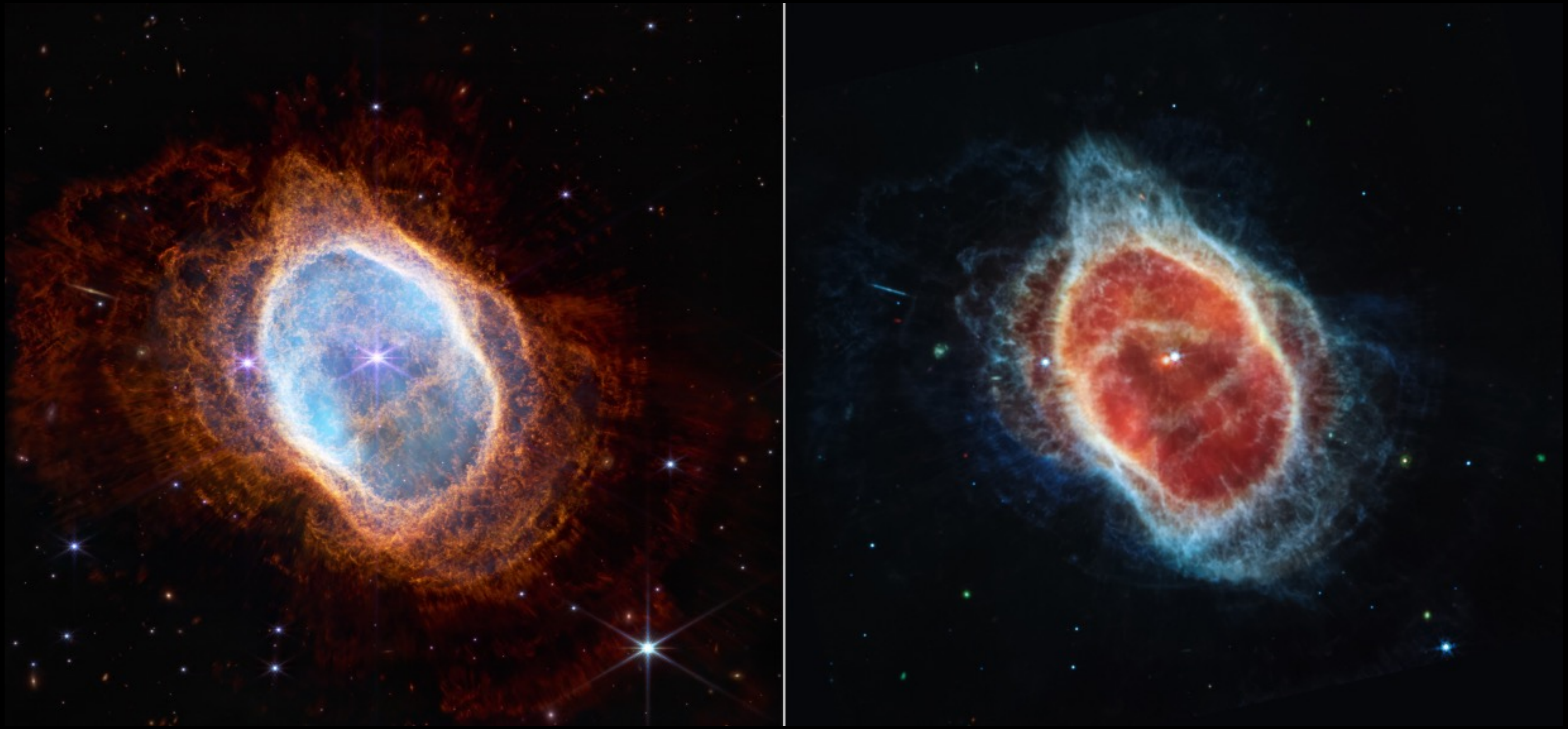
JWST



NASA's and ESA's past, current and future (or proposed) space missions with capacities to identify and characterize exoplanets. Image credit: NASA / ESA / T. Wynne / JPL / Barbara Aulicino.


Kepler
BY THE NUMBERS
9.6 YEARS IN SPACE
530,506 STARS OBSERVED
2,662 PLANETS CONFIRMED
61 SUPERNOVAE DOCUMENTED
FROM EARLIEST STAGES OF EXPLOSION
2 MISSIONS COMPLETED
678 GB SCIENCE DATA COLLECTED
2,946 SCIENTIFIC PAPERS PUBLISHED
94 MILLION MILES AWAY
3.12 GALLONS FUEL USED
732,128 COMMANDS EXECUTED
www.nasa.gov/kepler
As of October 24, 2018
@NASAKepler

Southern Ring Nebula



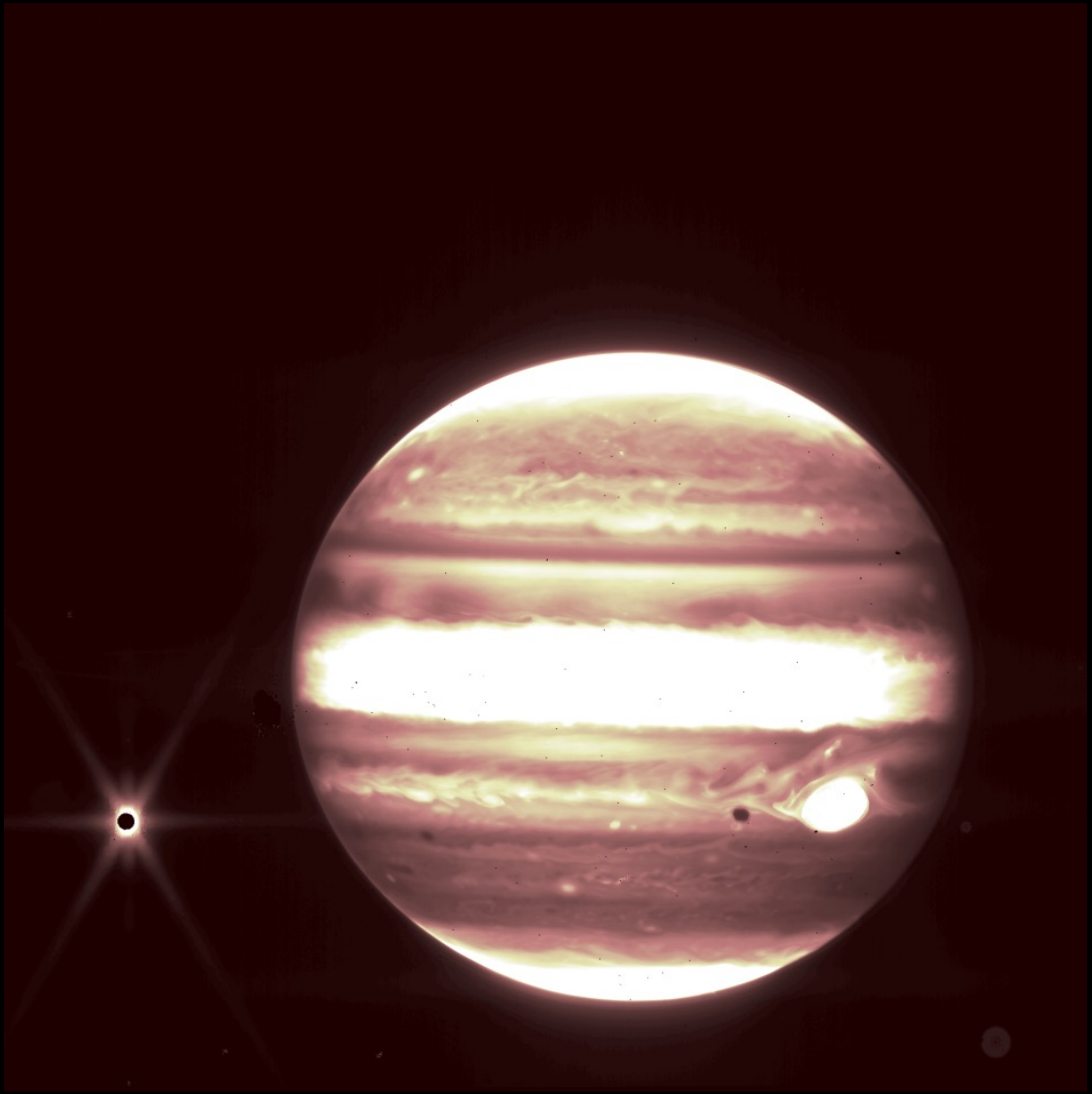
JWST

Stephan's Quintet

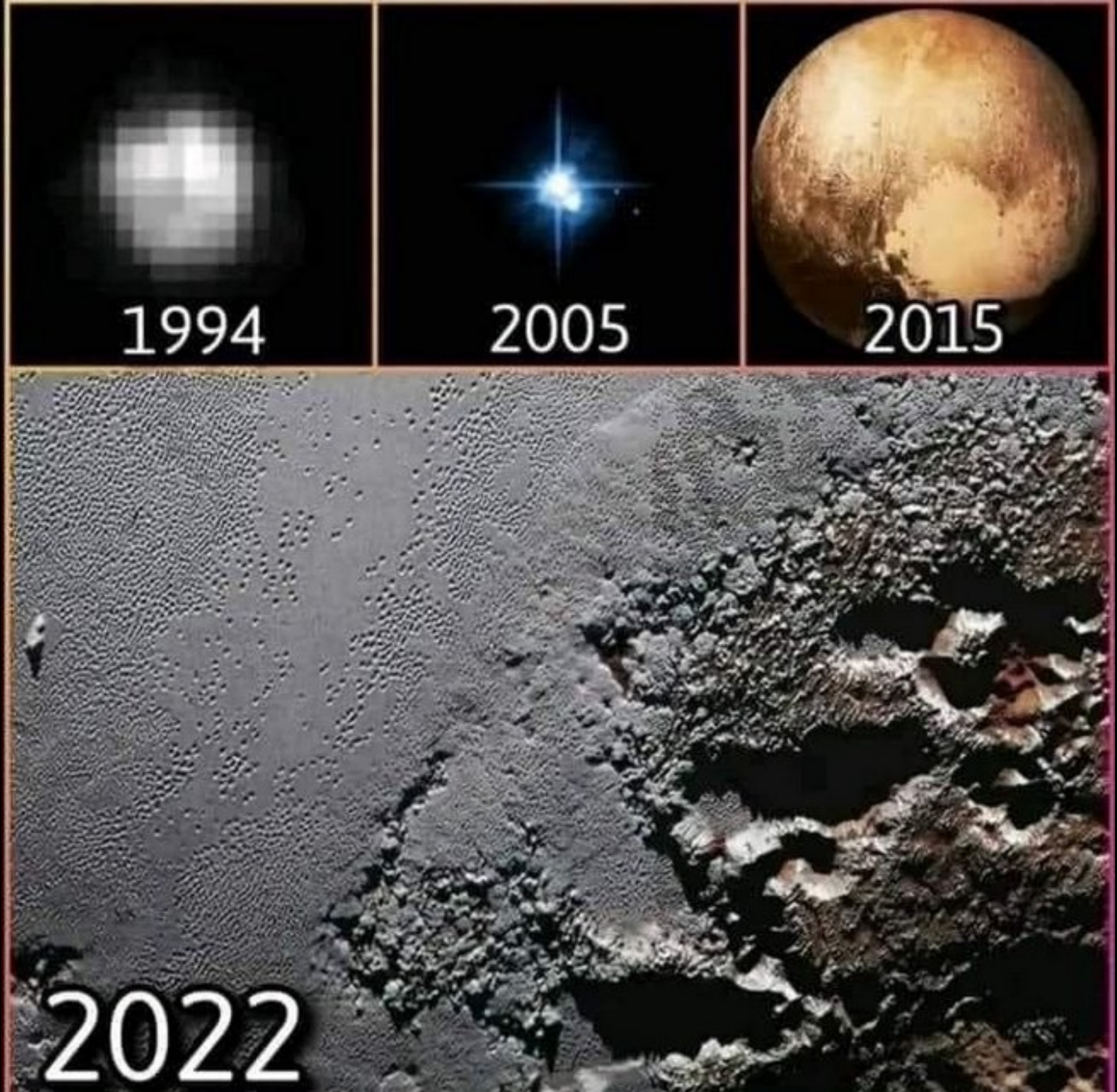
JWST

Carina Nebula

JWST

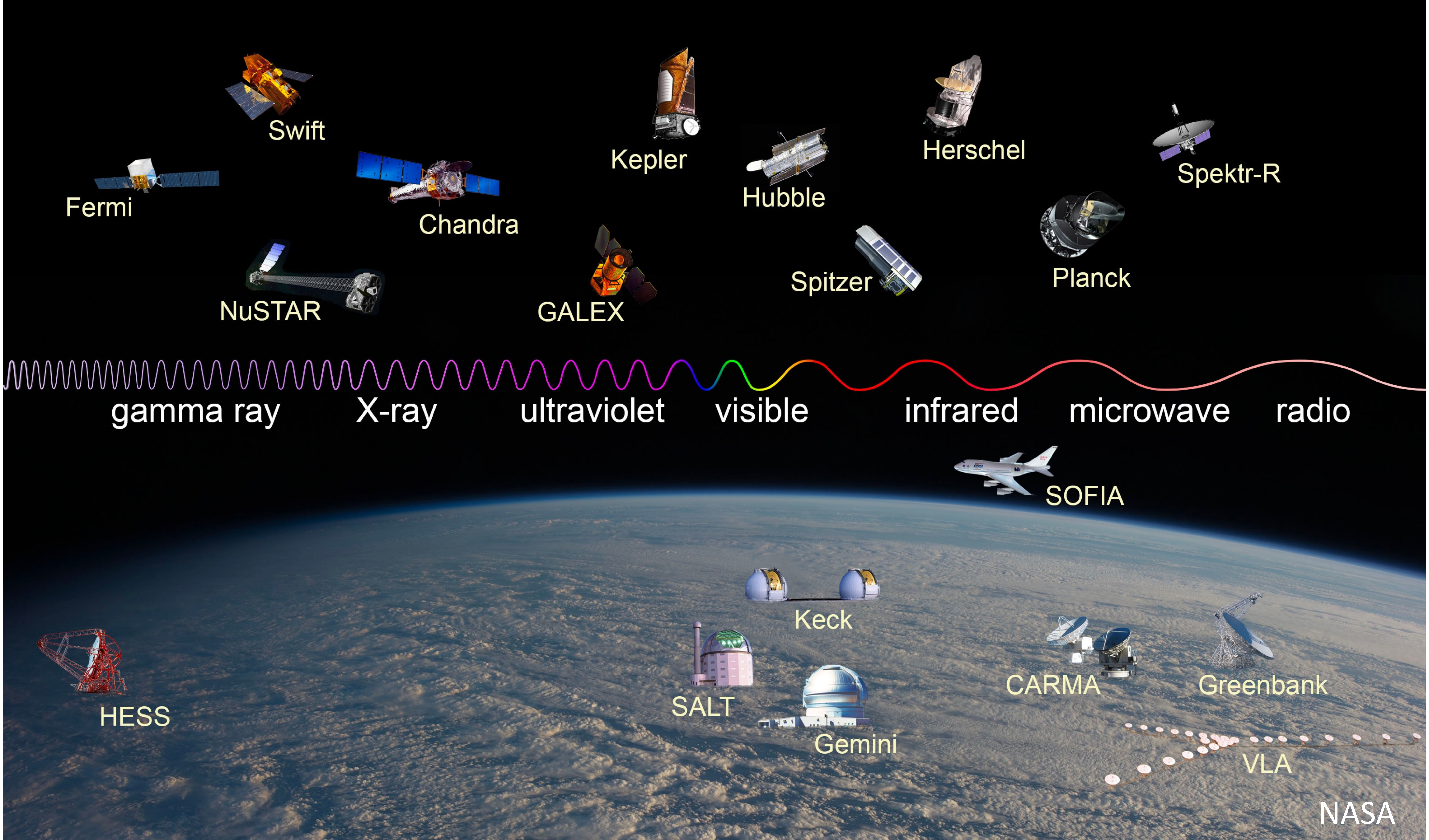


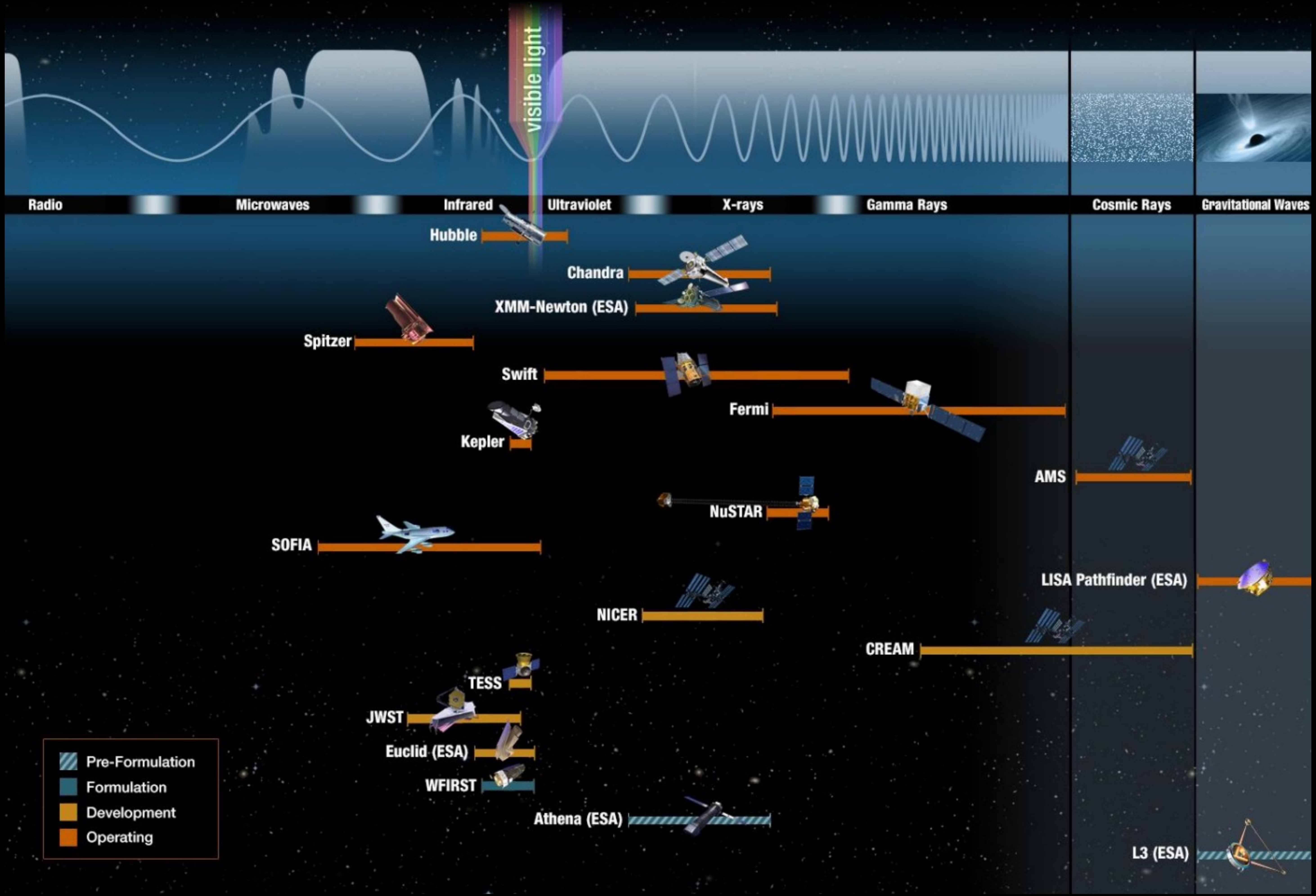
JWST



JWST

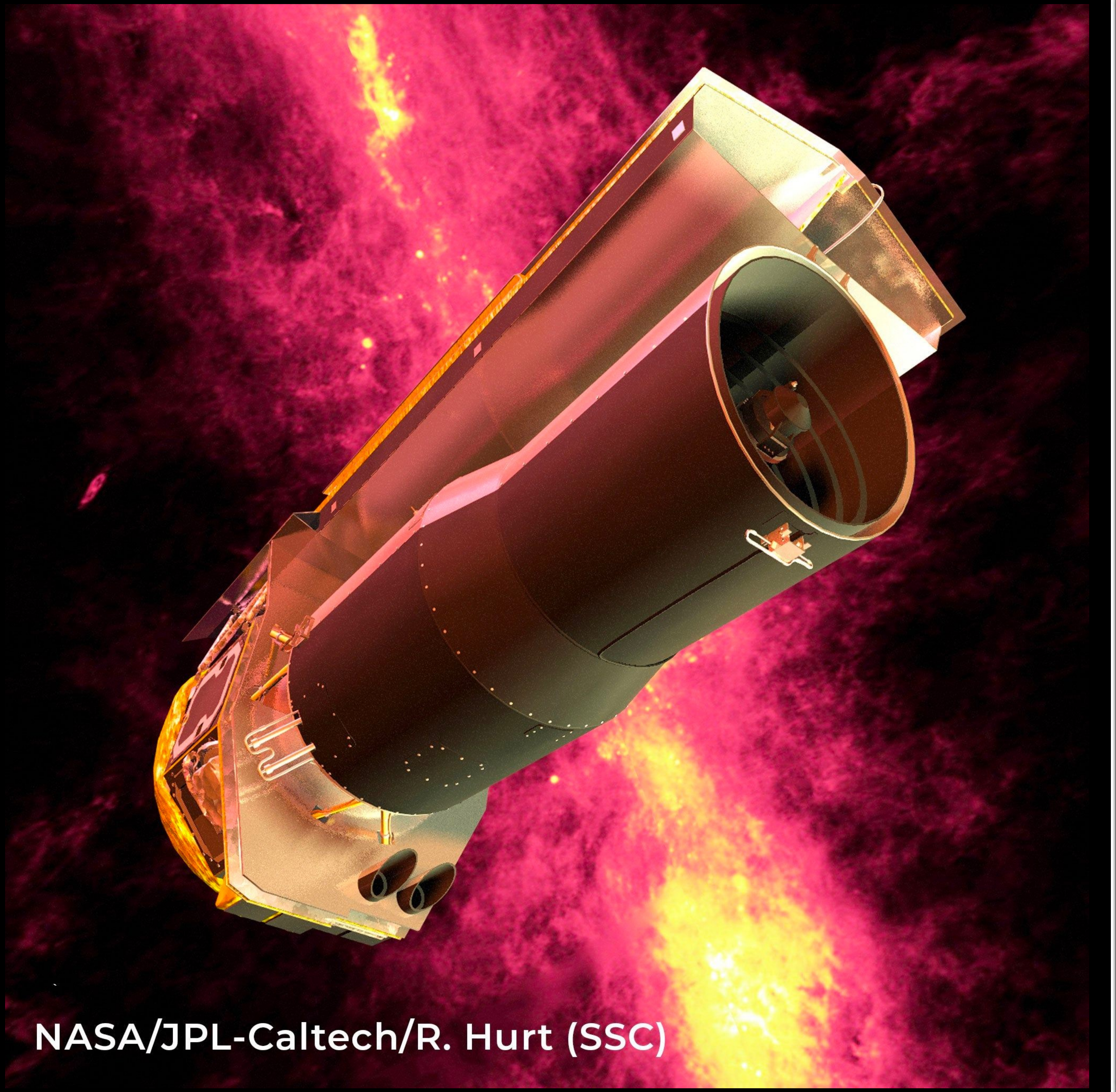
다파장 천문학 연구

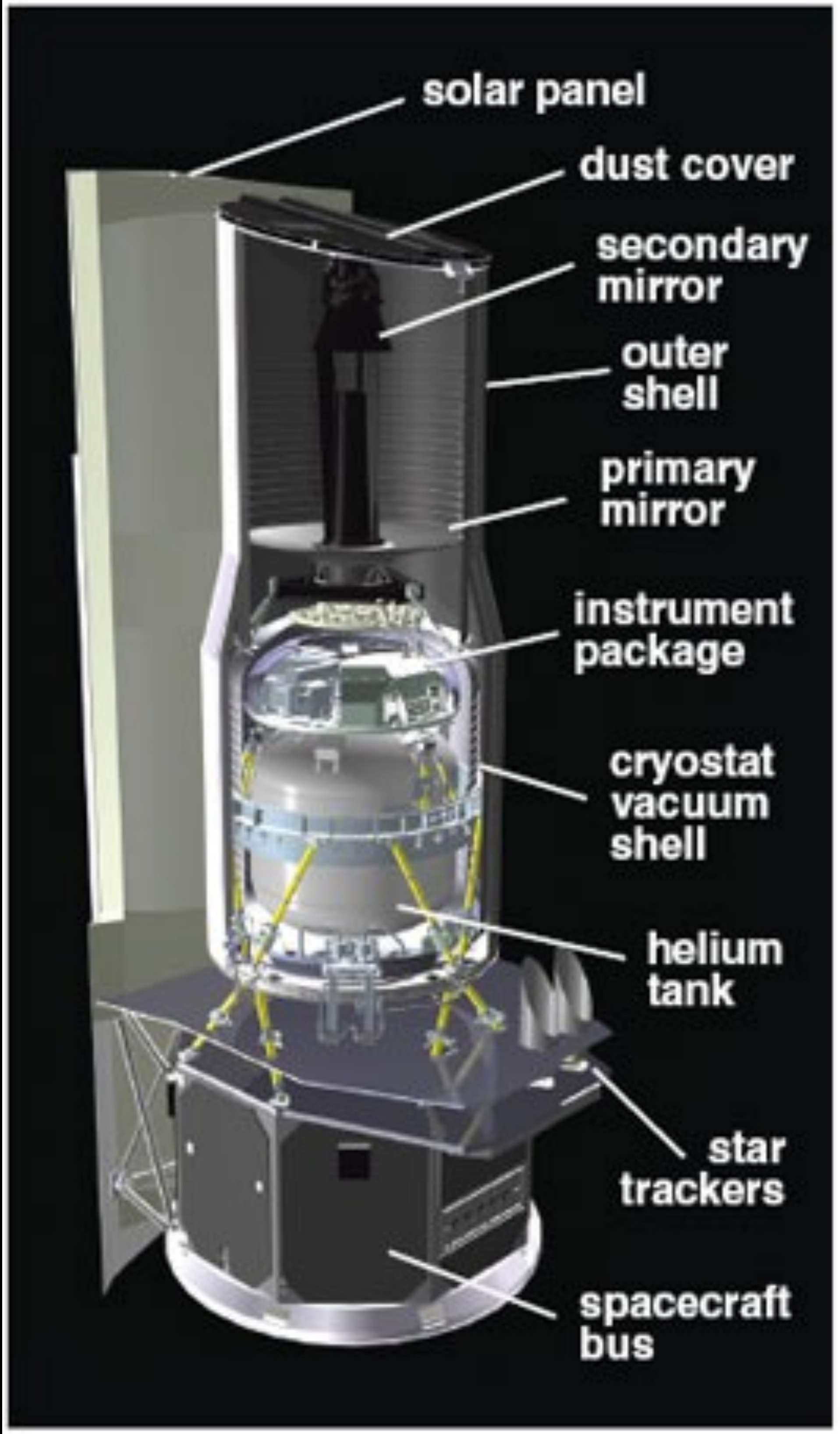

Swift
Fermi
Chandra
NuSTAR
Kepler
GALEX
Hubble
Spitzer
Herschel
Planck
Spektr-R
gamma ray
X-ray
ultraviolet
visible
infrared
microwave
radio
SOFIA
Keck
SALT
Gemini
HESS
CARMA
Greenbank
VLA
NASA



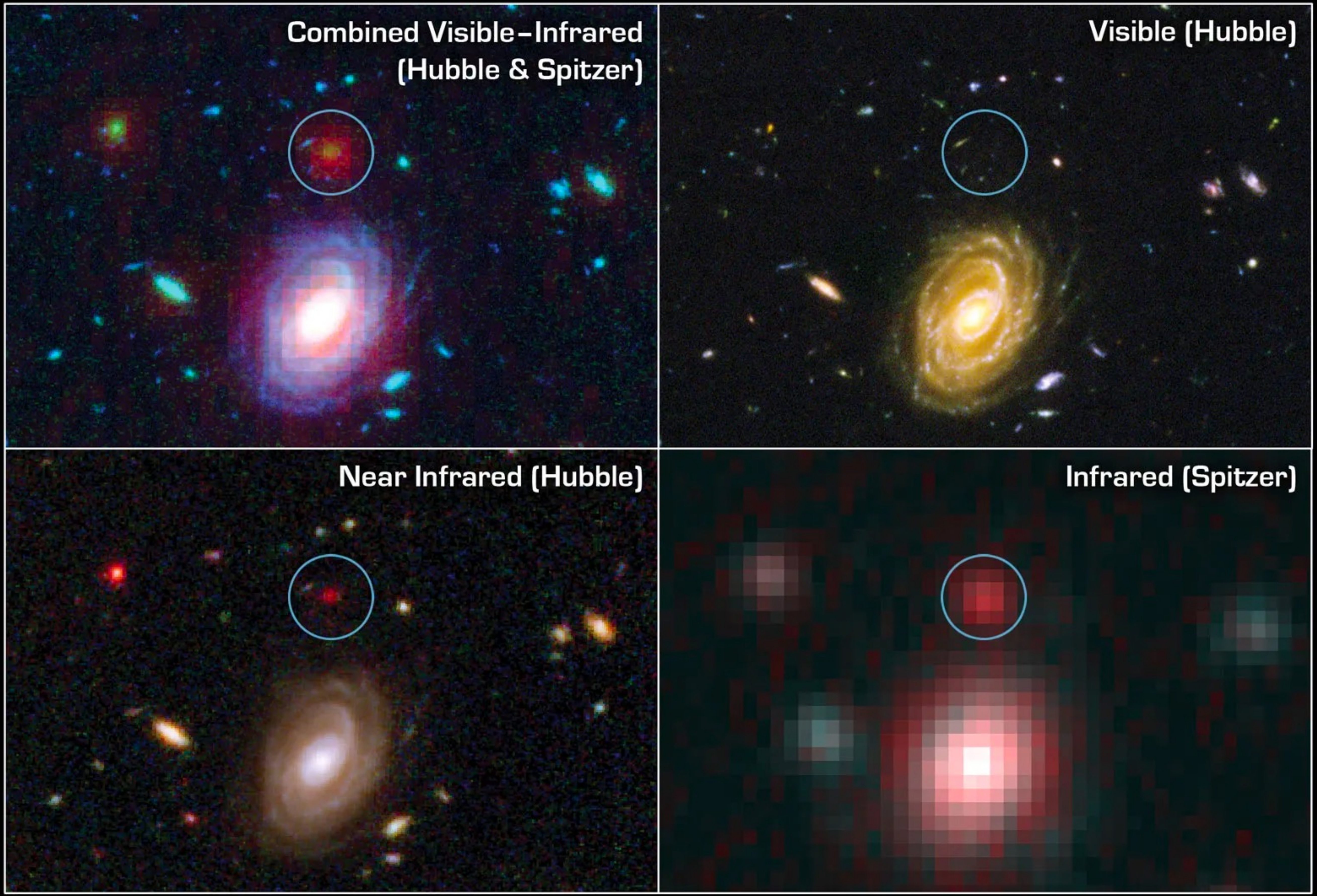
visible light
Radio
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Rays
Cosmic Rays
Gravitational Waves
Hubble
Chandra
XMM-Newton (ESA)
Spitzer
Swift
Fermi
Kepler
AMS
NuSTAR
SOFIA
LISA Pathfinder (ESA)
NICER
CREAM
TESS
JWST
Euclid (ESA)
WFIRST
Athena (ESA)
L3 (ESA)
Pre-Formulation
Formulation
Development
Operating

NASA





NASA/SPITZER

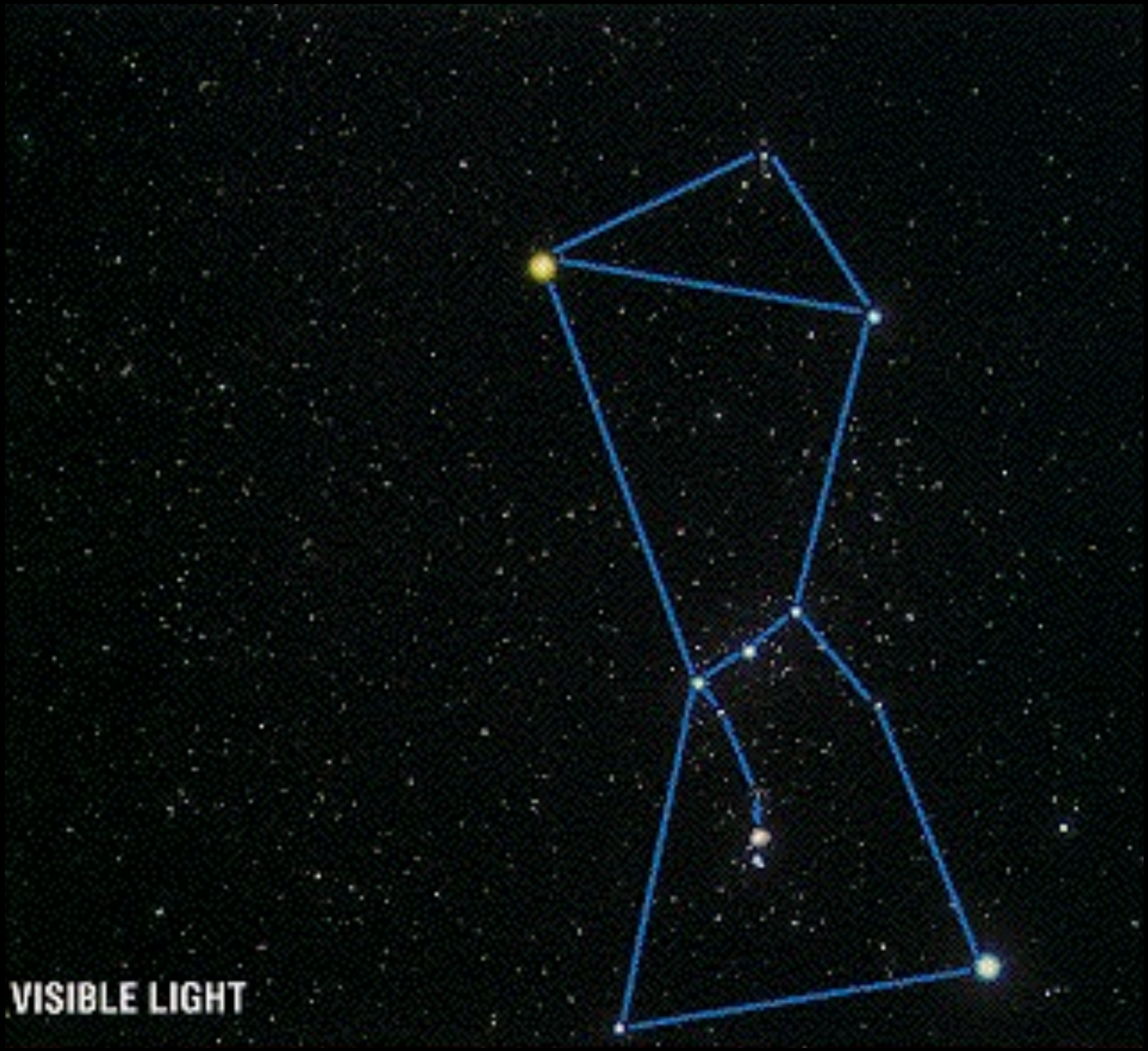


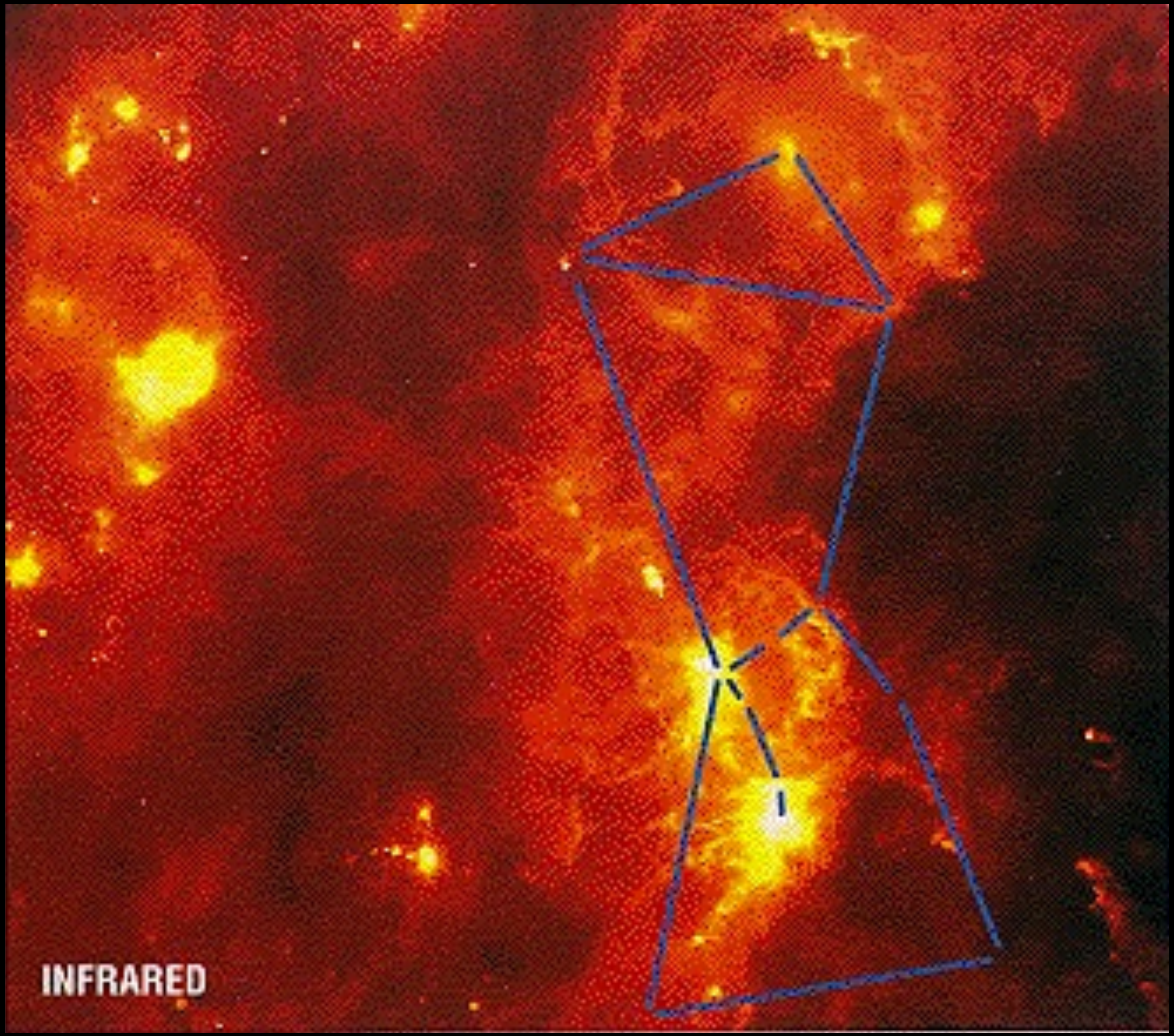
Distant Galaxy in the Hubble Ultra Deep Field

Spitzer Space Telescope • IRAC
Hubble Space Telescope • ACS • NICMOS

NASA, ESA / JPL-Caltech / B. Mobasher (STScI/ESA)

ssc2005-19a





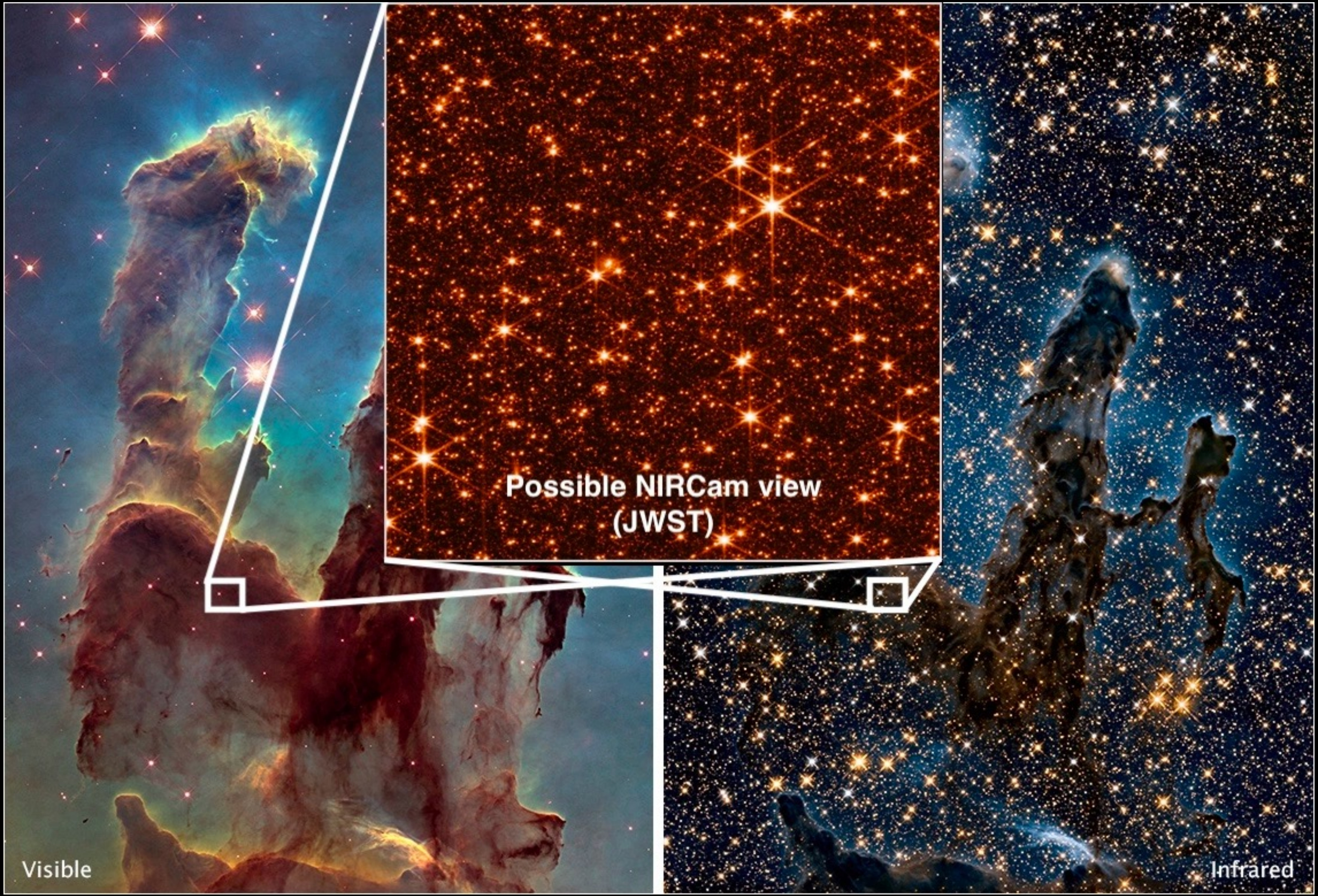
SPITZER

JWST

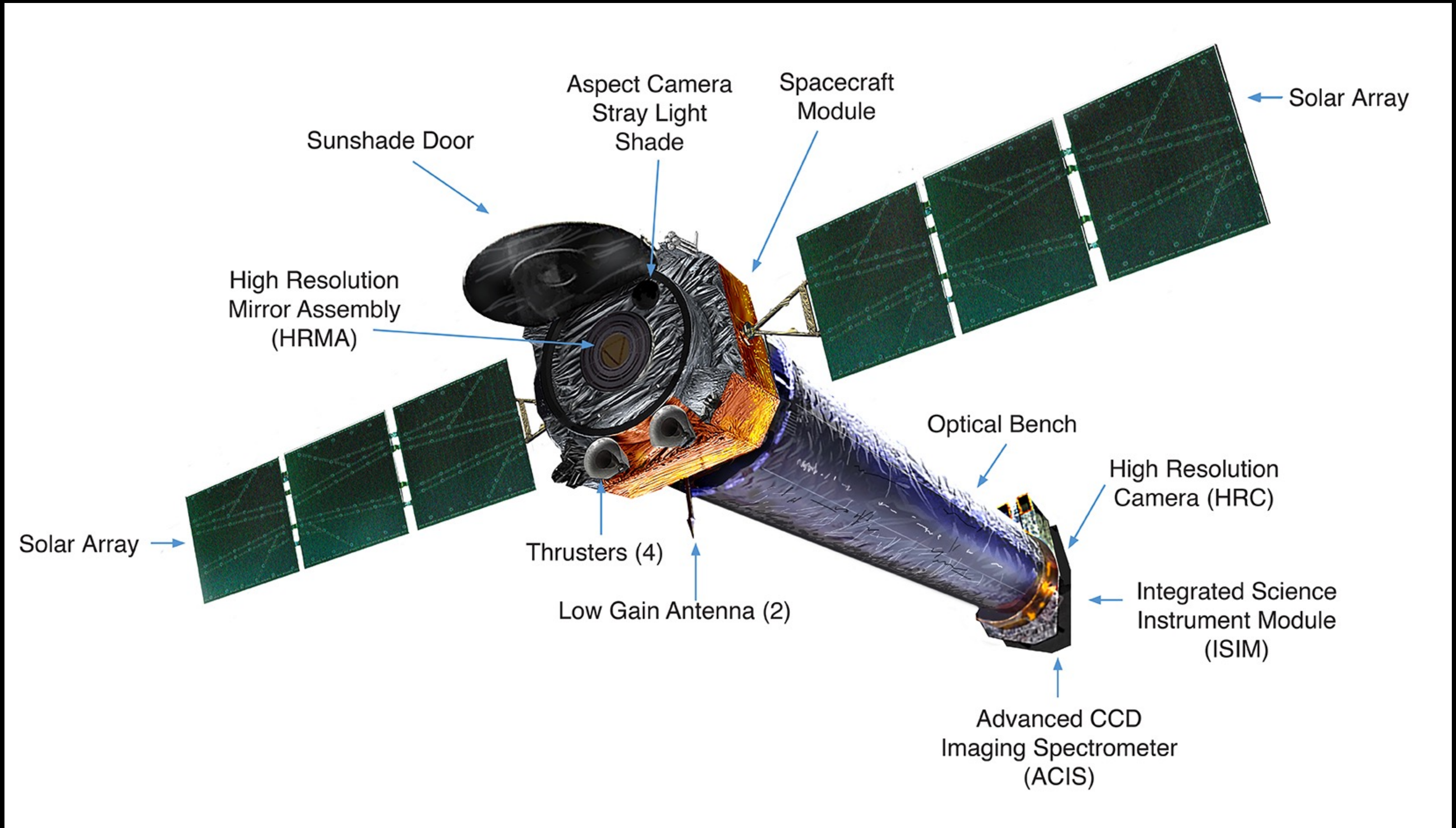
Visible · WFC3 · 2015

Infrared · WFC3 · 2015

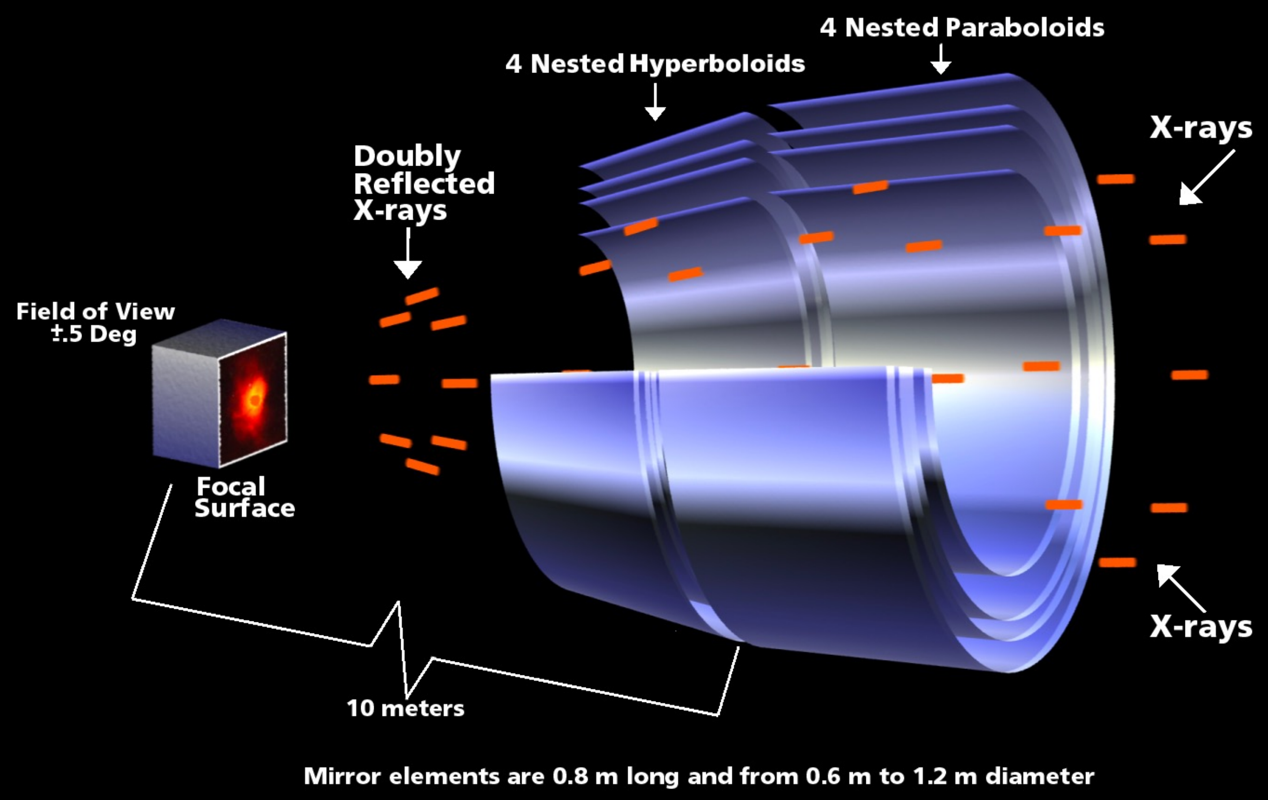
JWST



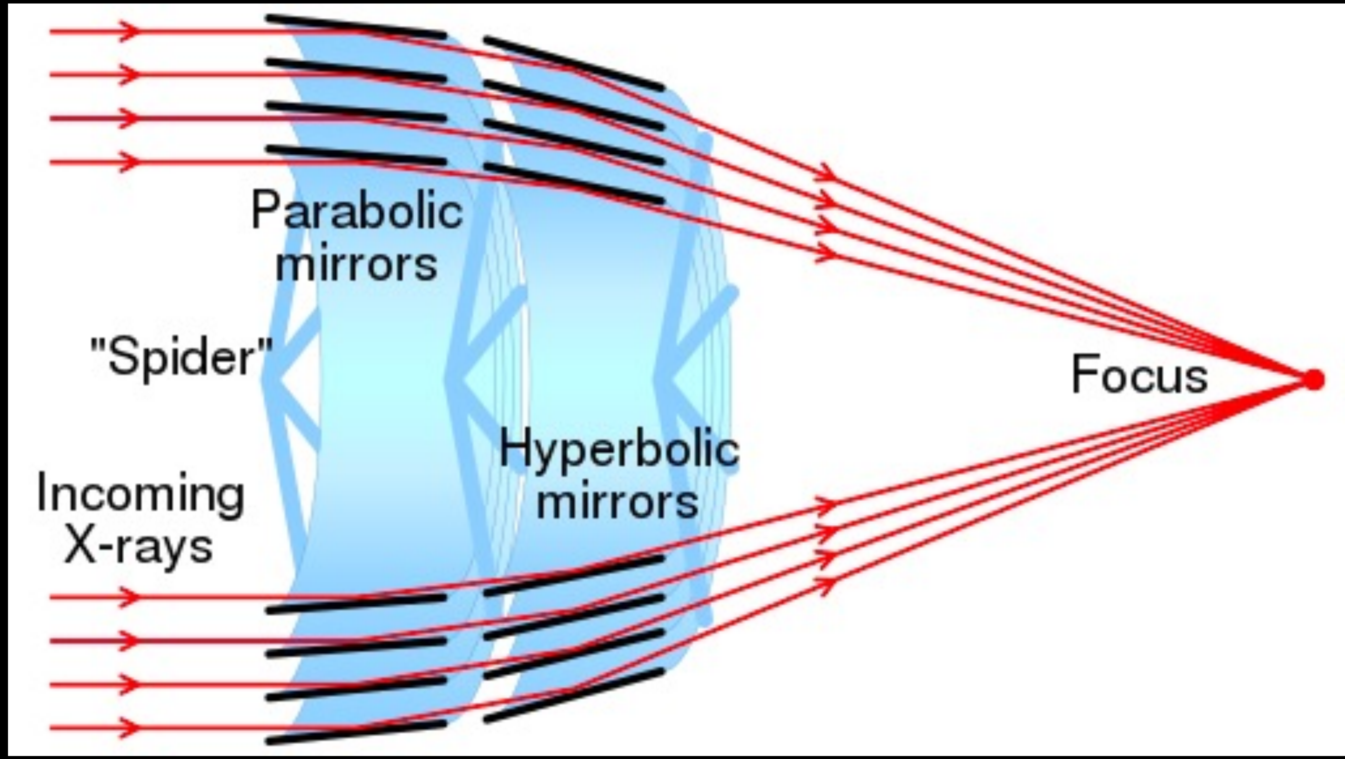
JWST



Sunshade Door
Aspect Camera
Stray Light
Shade
Spacecraft
Module
Solar Array
High Resolution
Mirror Assembly
(HRMA)
Optical Bench
High Resolution
Camera (HRC)
Solar Array
Thrusters (4)
Low Gain Antenna (2)
Integrated Science
Instrument Module
(ISIM)
Advanced CCD
Imaging Spectrometer
(ACIS)



4 Nested Paraboloids
4 Nested Hyperboloids
Doubly
Reflected
X-rays
X-rays
Field of View
±.5 Deg
Focal
Surface
X-rays
10 meters
Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter



Parabolic
mirrors
"Spider"
Focus
Hyperbolic
mirrors
Incoming
X-rays

Chandra

Home | About Chandra | Education | Field Guide | Photo Album | Press Room | Resources & Multimedia | Video Series | Blog | Research

10 Chandra flies 200 times higher than Hubble - more than 1/3 of the way to the moon! MORE

9 Chandra can observe X-rays from clouds of gas so vast that it takes light five million years to go from one side to the other! MORE

8 During maneuvers from one target to the next, Chandra slews more slowly than the minute hand on a clock. MORE

7 At 45 feet long, Chandra is the largest satellite the shuttle has ever launched. See also: Top 10 Facts Infographic MORE

6 If Colorado were as smooth as Chandra's mirrors, Pikes Peak would be less than one inch tall! MORE

5 Chandra's resolving power is equivalent to the ability to read a stop sign at a distance of twelve miles. MORE

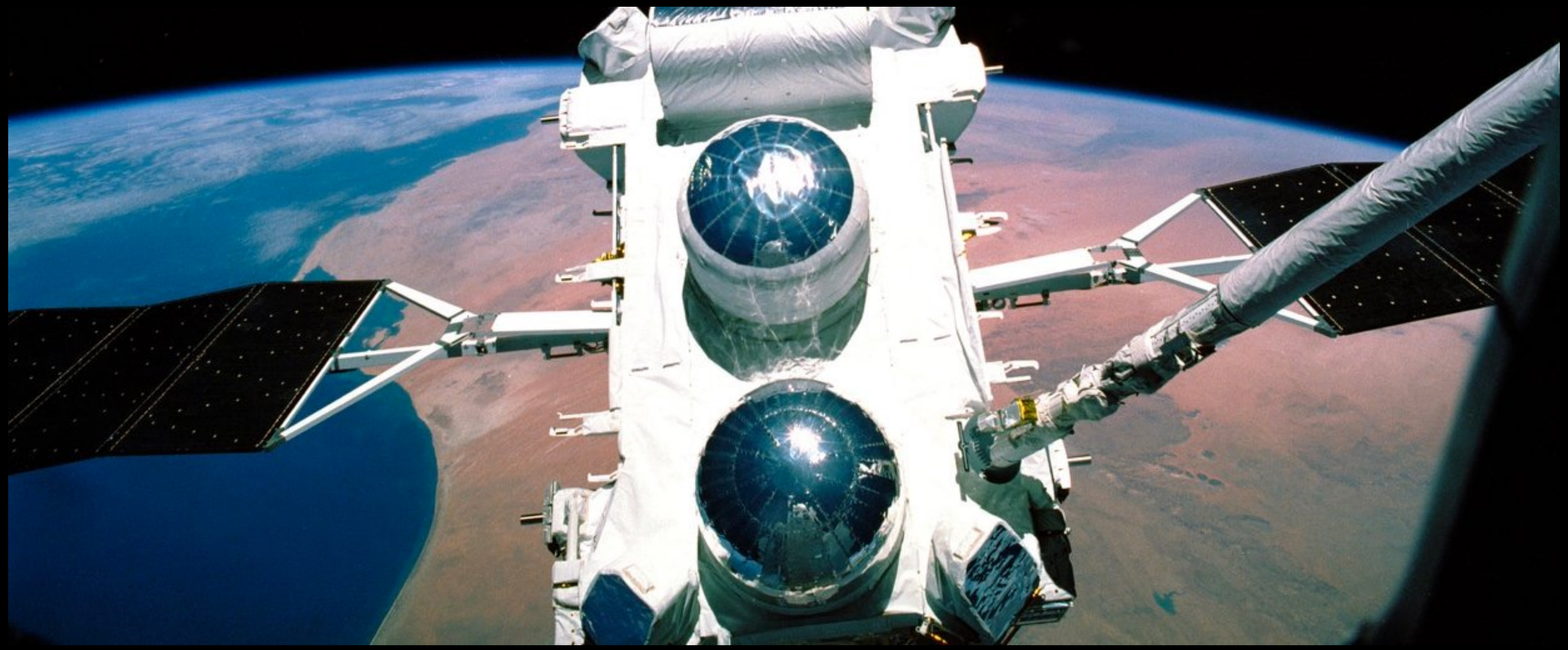
4 The electrical power required to operate the Chandra spacecraft and instruments is 2 kilowatts, about the same power as a hair dryer. MORE

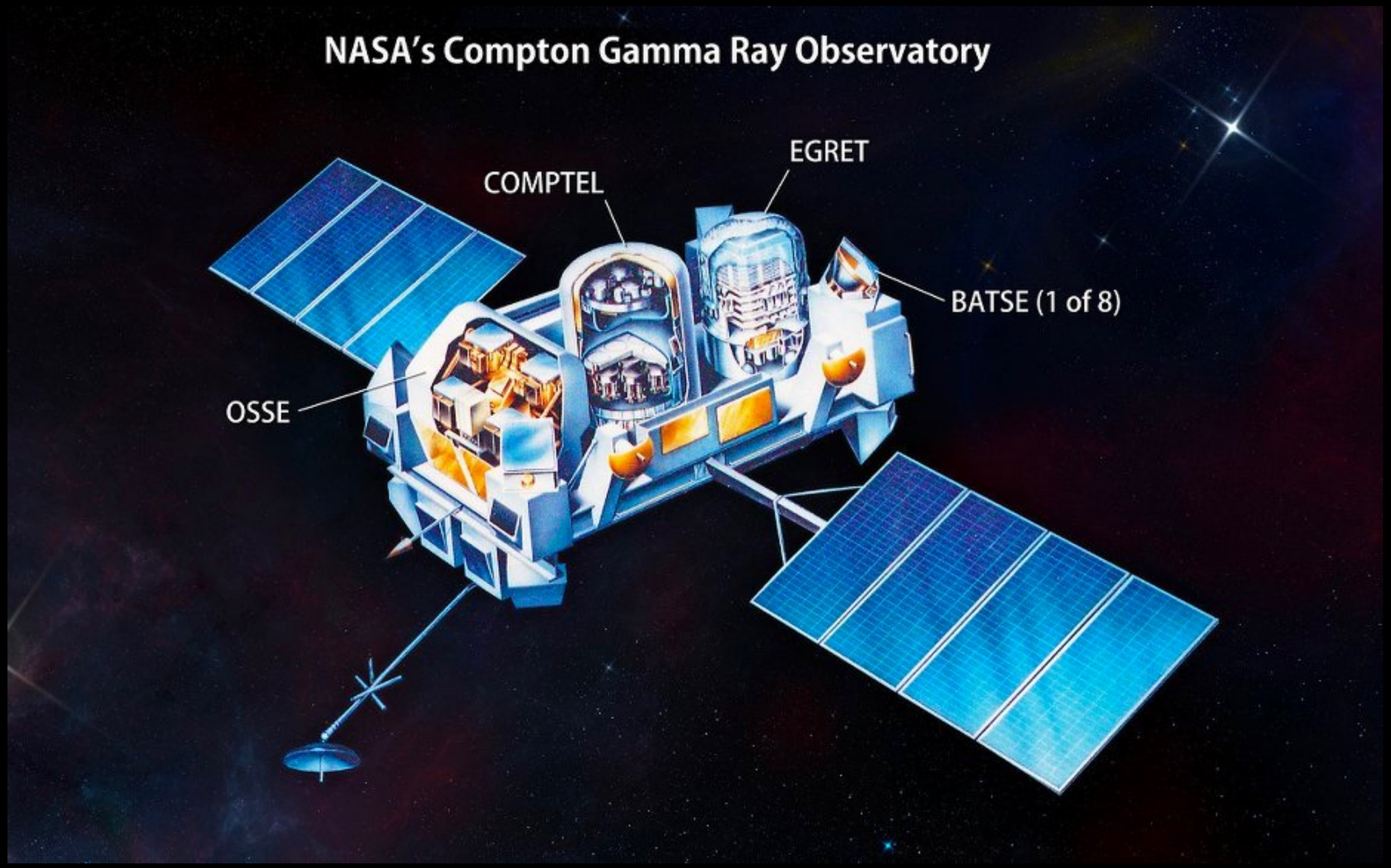
3 The light from some of the quasars observed by Chandra will have been traveling through space for ten billion years. MORE

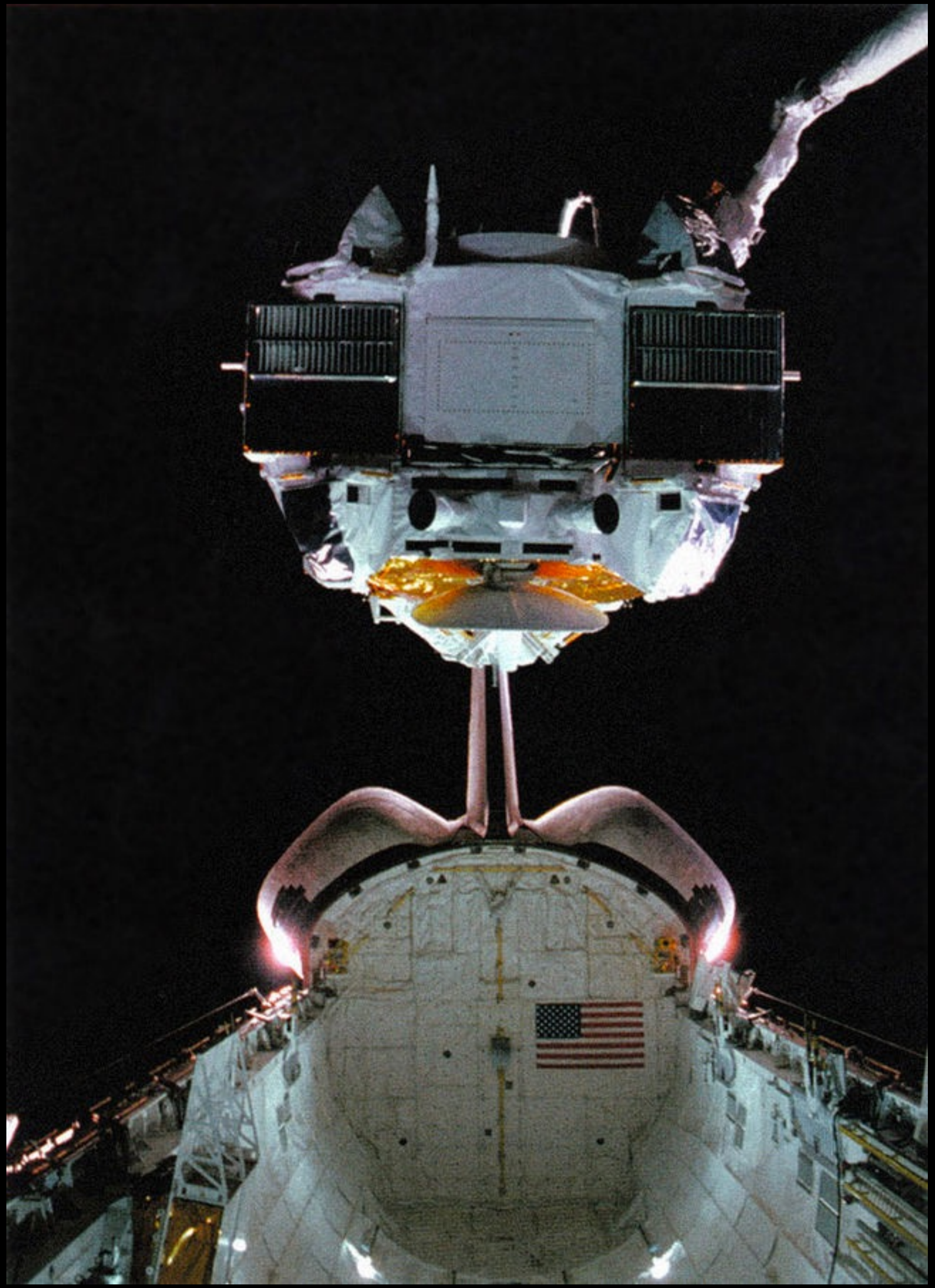
2 STS-93, the space mission that deployed Chandra, was the first NASA shuttle mission commanded by a woman. MORE

1 Chandra can observe X-rays from particles up to the last second before they fall into a black hole!!! MORE

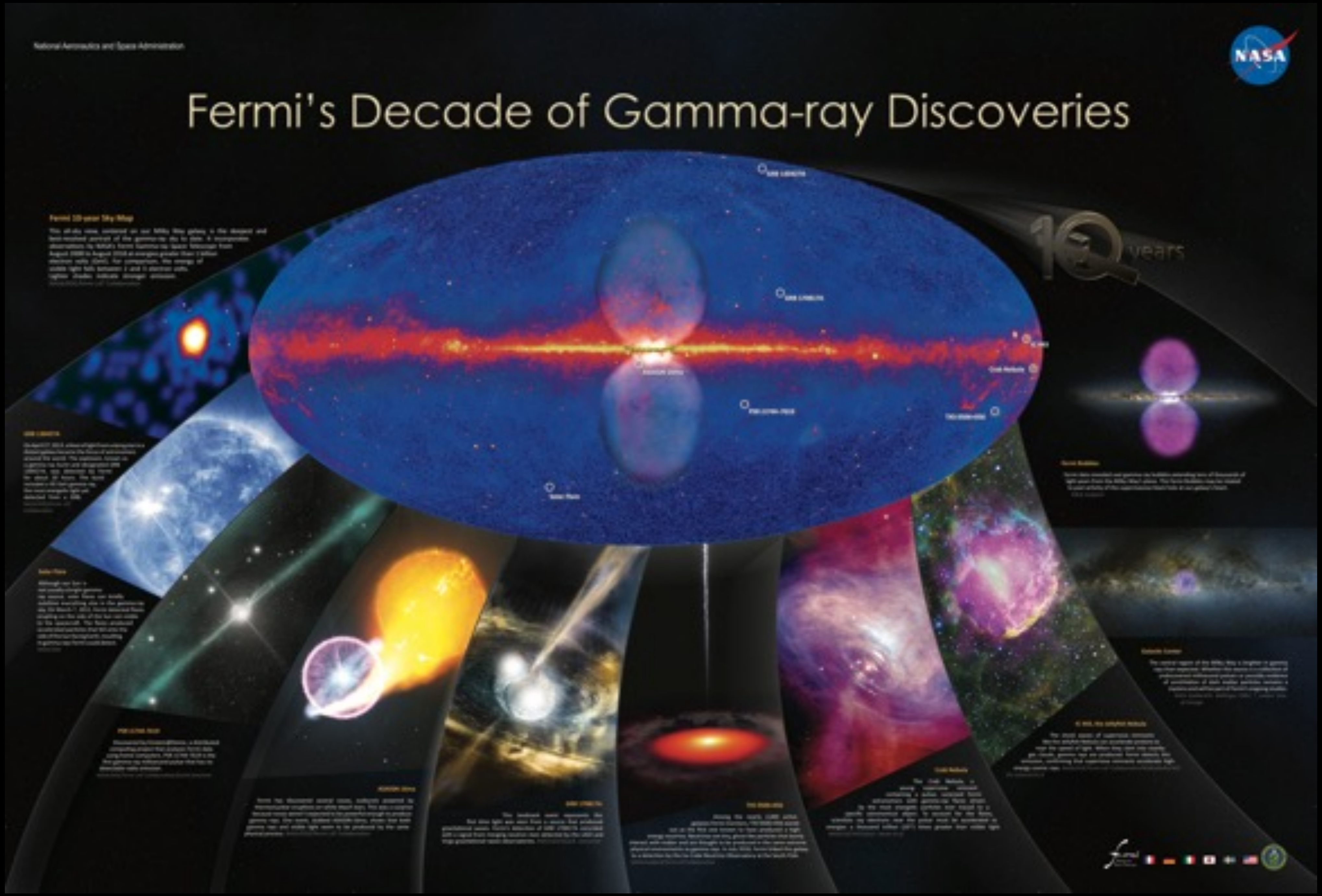
Chandra



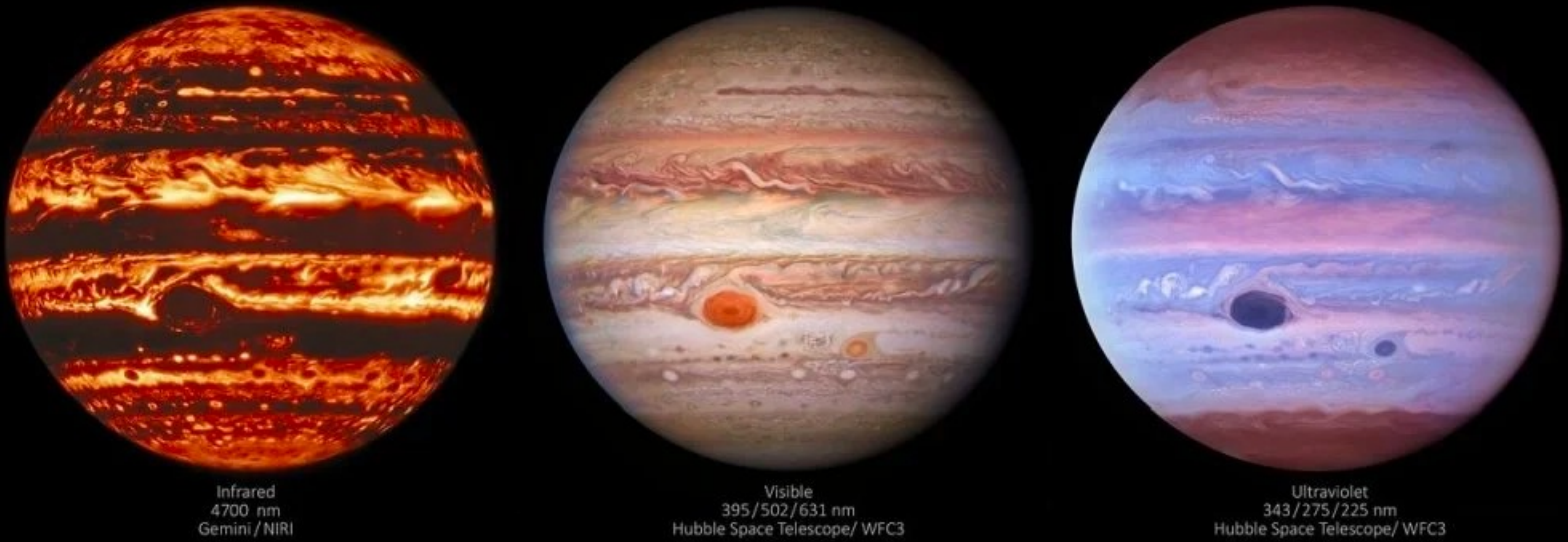

NASA's Compton Gamma Ray Observatory
COMPTEL
EGRET
BATSE (1 of 8)
OSSE



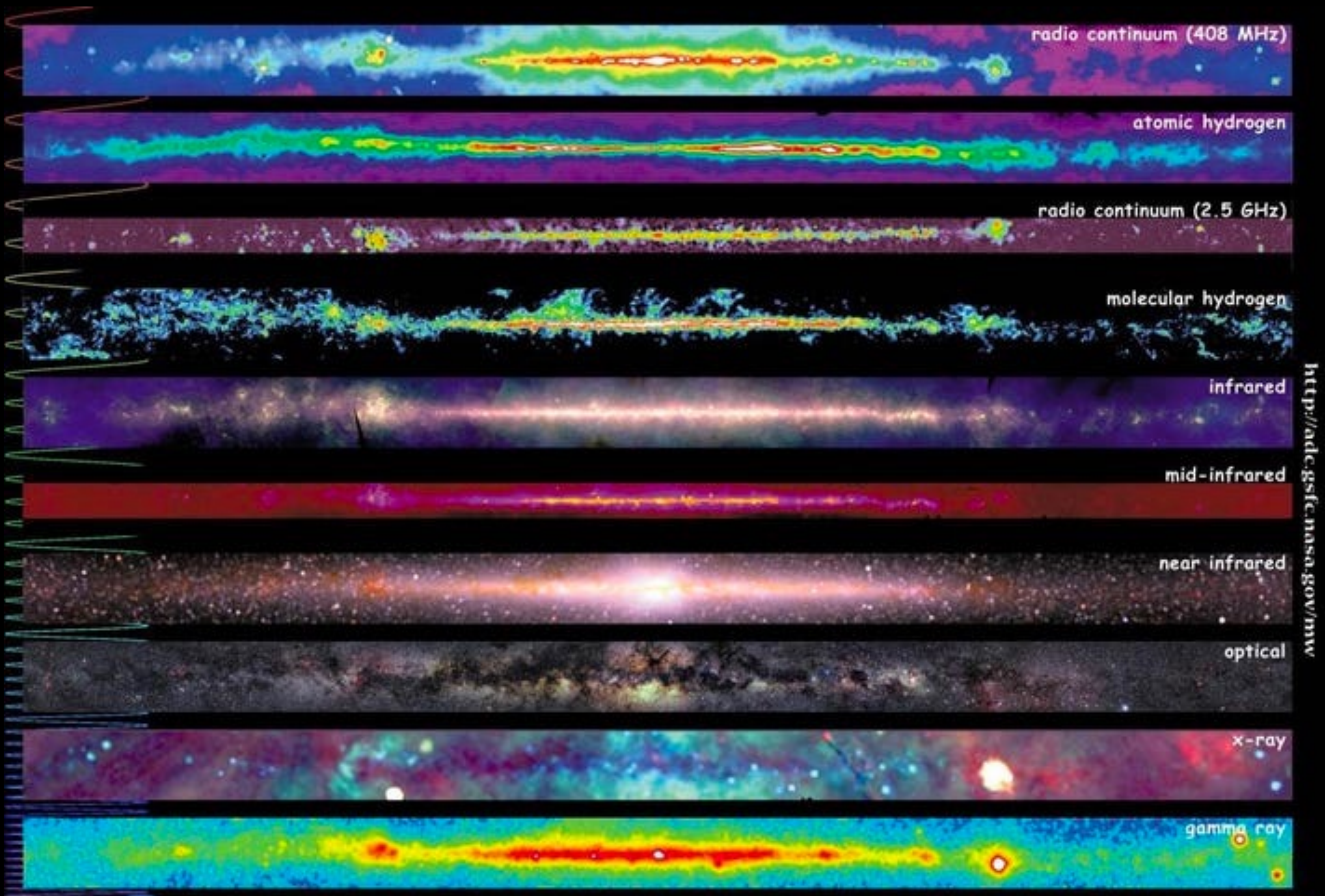
CGRO


National Aeronautics and Space Administration
NASA
Fermi's Decade of Gamma-ray Discoveries
10 years

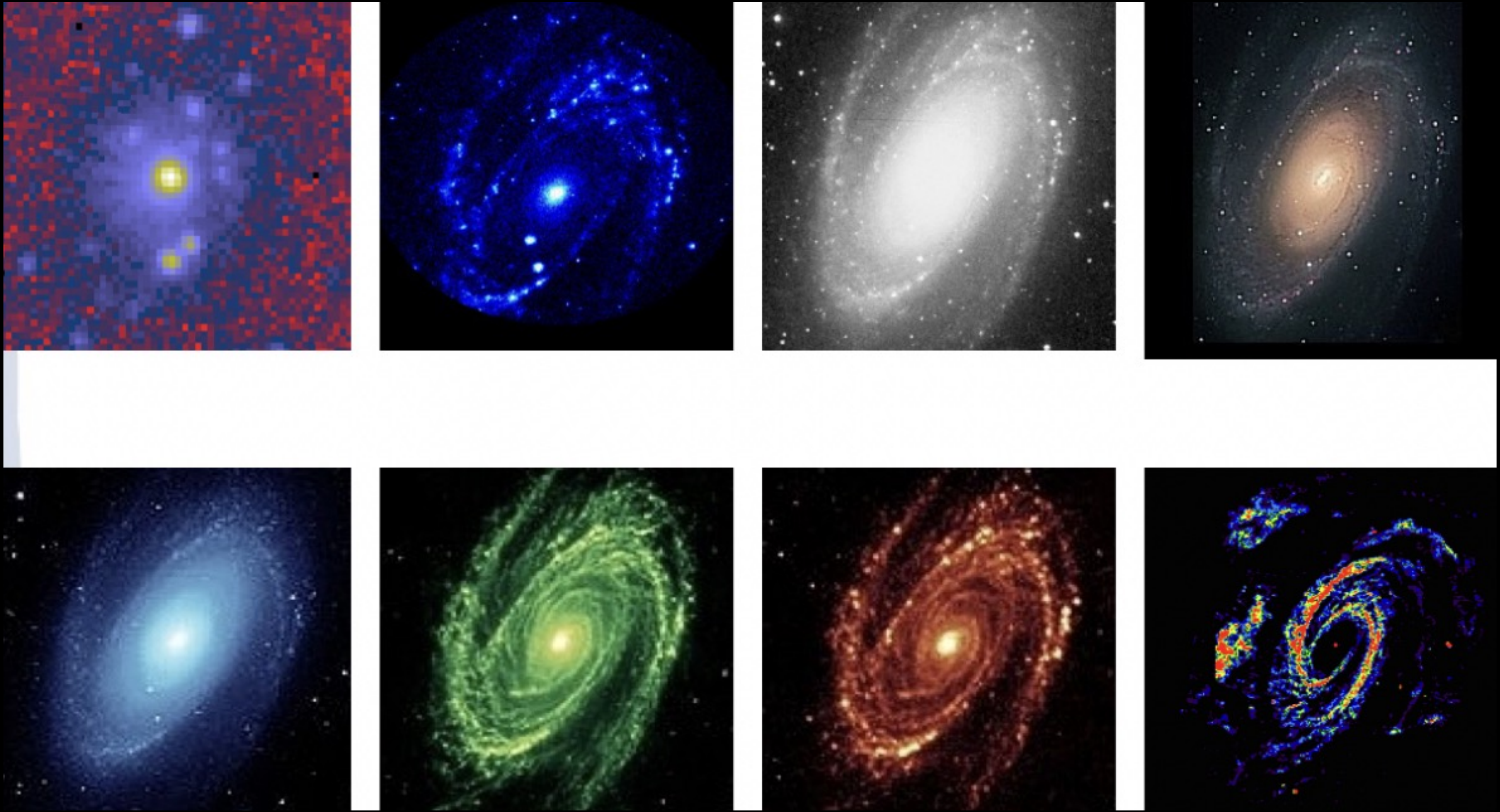
Fermi


Infrared
4700 nm
Gemini / NIRI
Visible
395 / 502 / 631 nm
Hubble Space Telescope/ WFC3
Ultraviolet
343 / 275 / 225 nm
Hubble Space Telescope/ WFC3

JWST



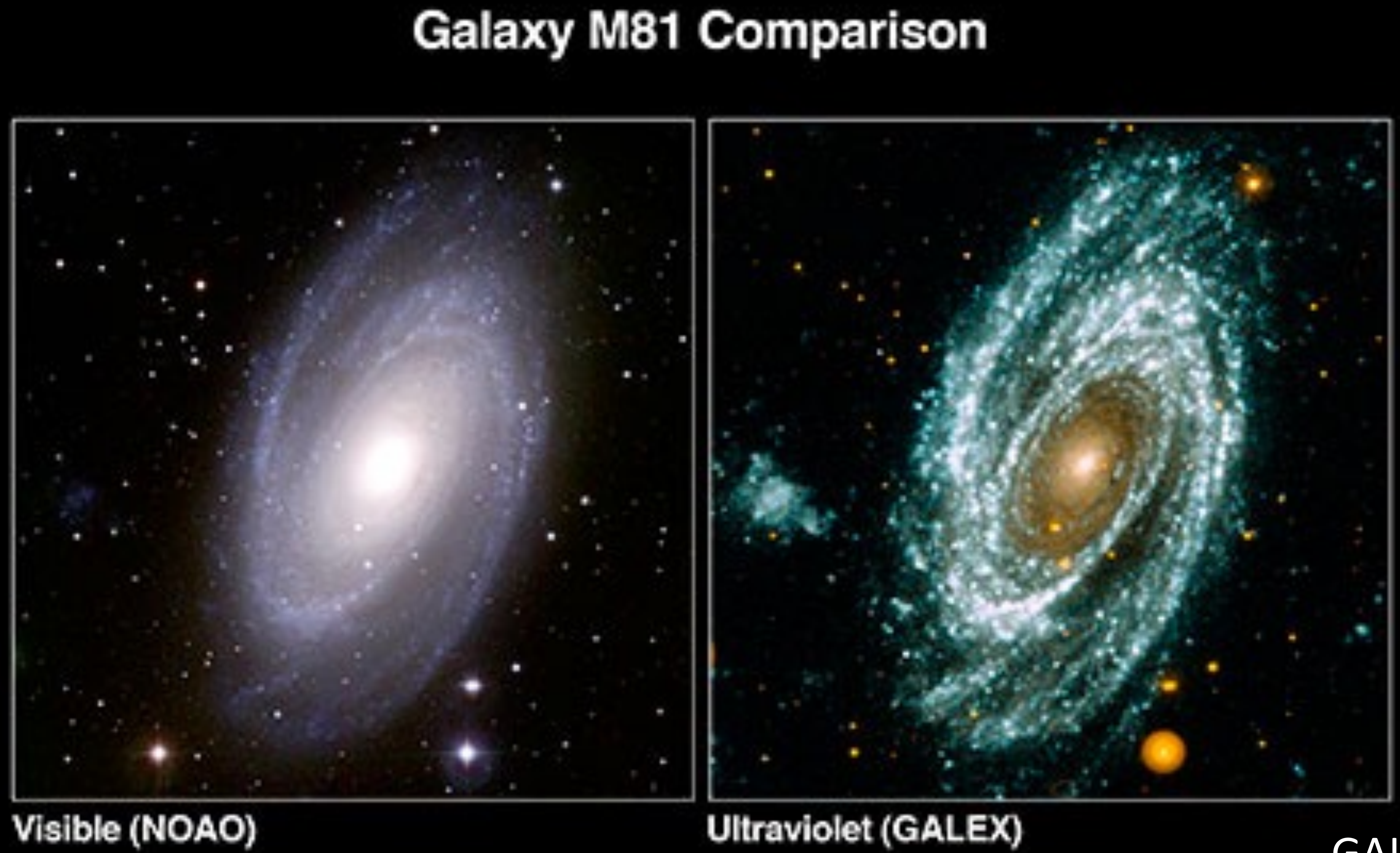
Multiwavelength Milky Way



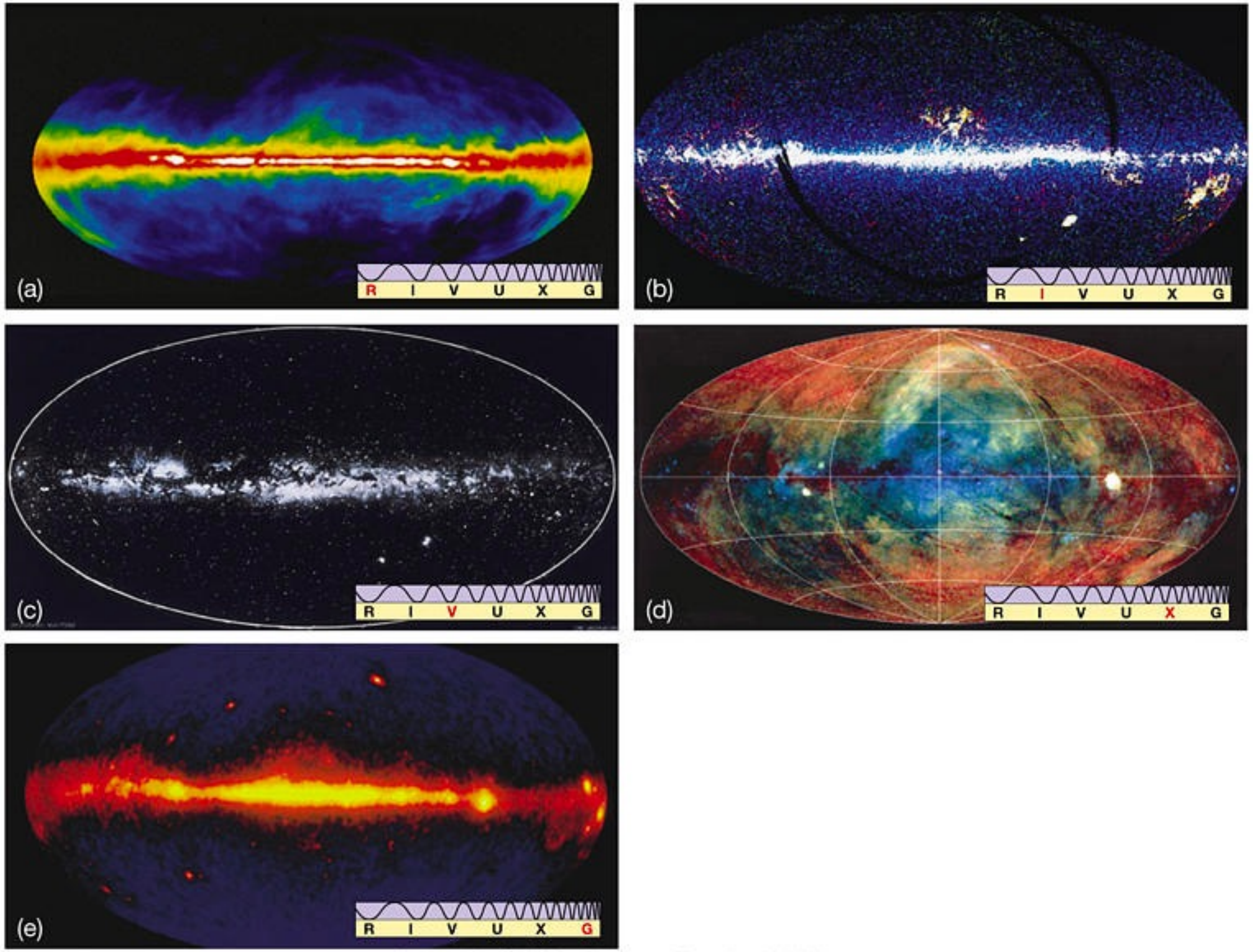
NASA


Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO₂ molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION

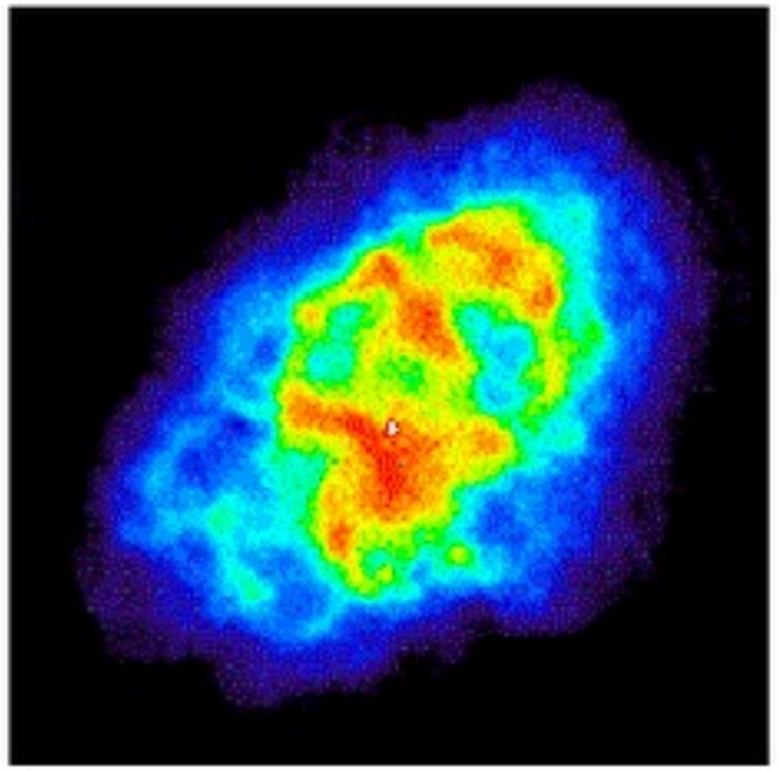
NASA



GALEX


(a)
R I V U X G
(b)
R I V U X G
(c)
R I V U X G
(d)
R I V U X G
(e)
R I V U X G

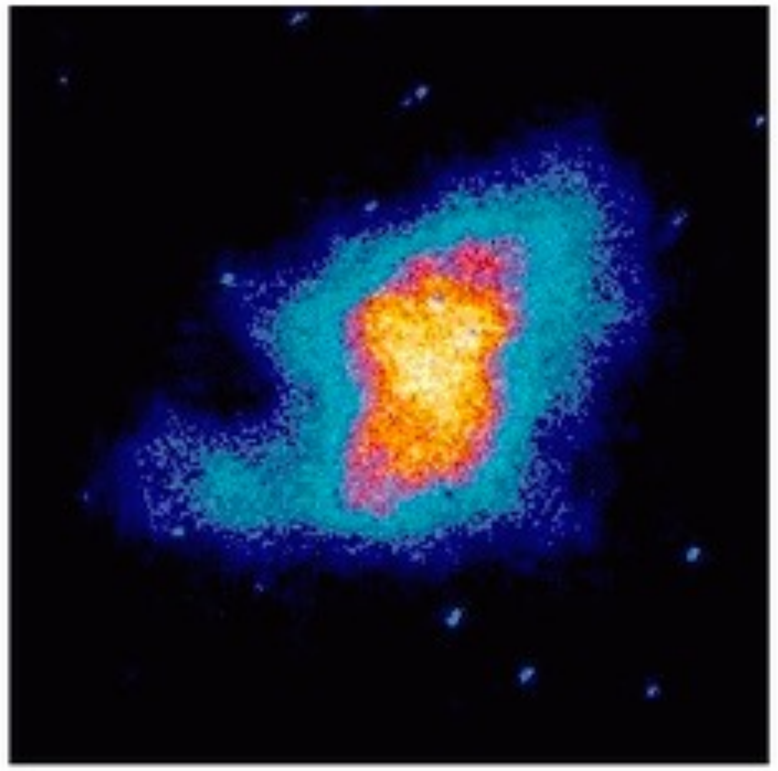
Crab Nebula: Remnant of an Exploded Star (Supernova)



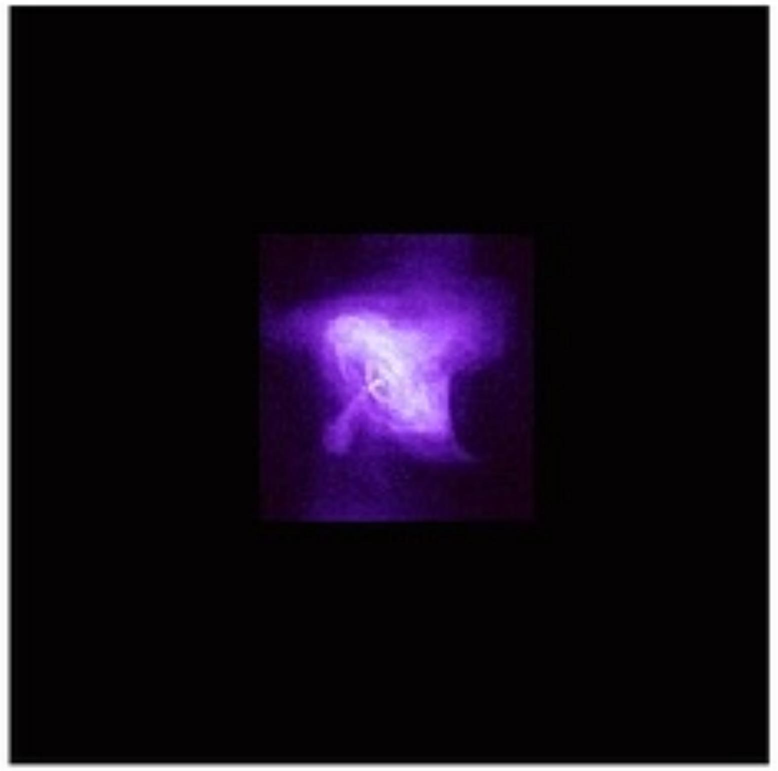
Radio wave (VLA)

Infrared radiation (Spitzer)

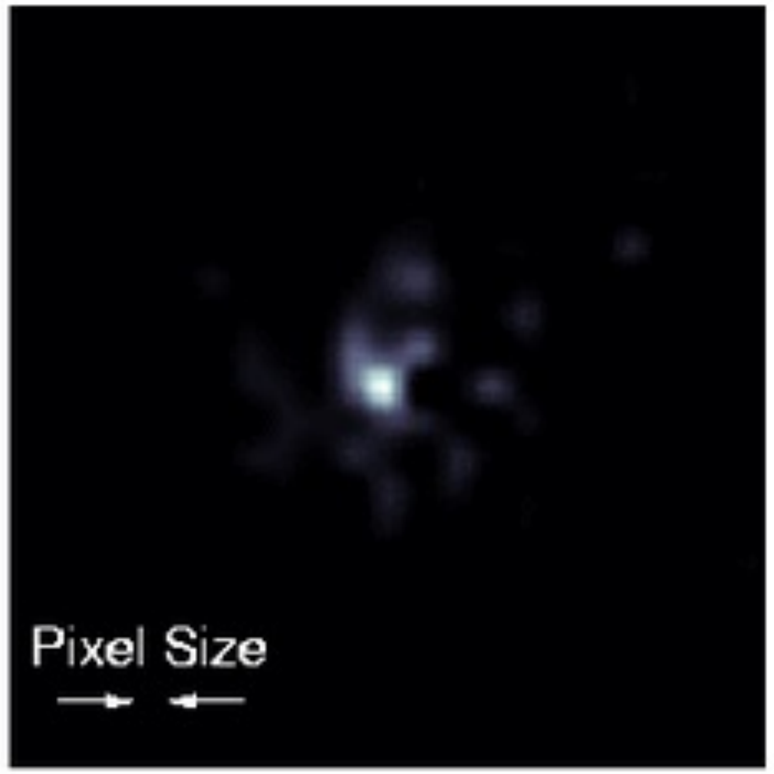
Visible light (Hubble)



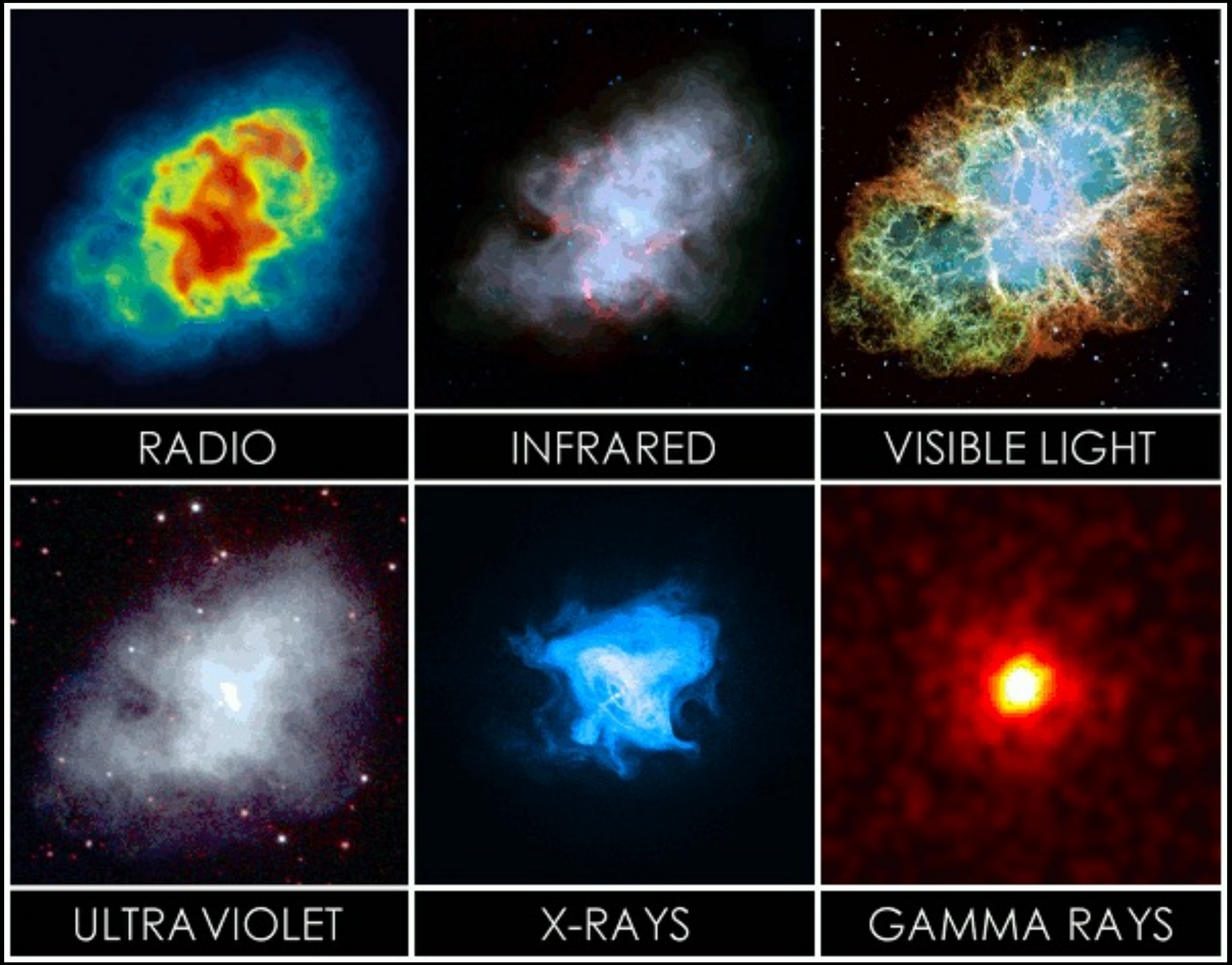
Ultraviolet radiation (Astro-1)



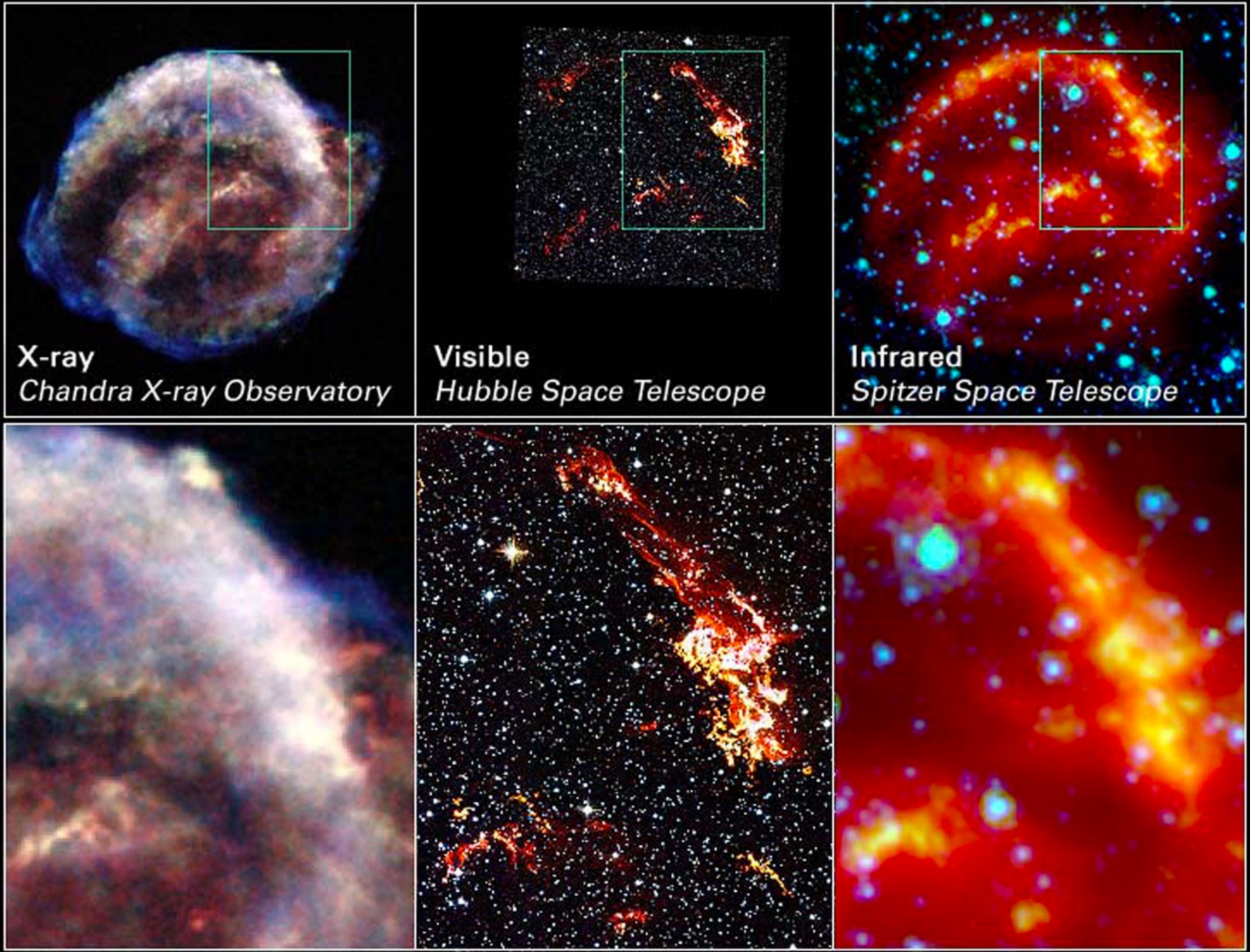
Low-energy X-ray (Chandra)



High-energy X-ray (HEFT)
*** 15 min exposure ***


RADIO
INFRARED
VISIBLE LIGHT
ULTRAVIOLET
X-RAYS
GAMMA RAYS

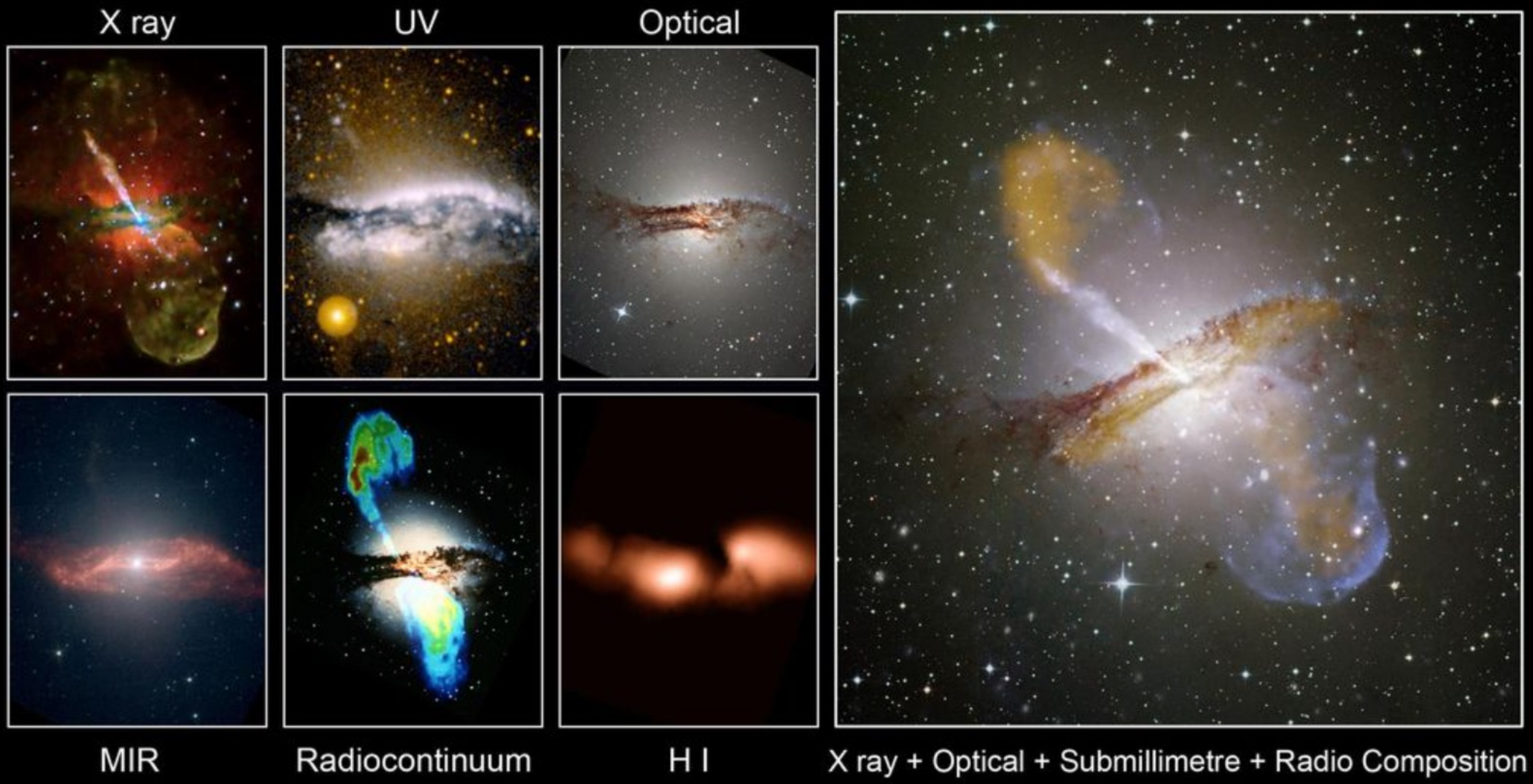
Kepler's Supernova Remnant ▪ SN 1604



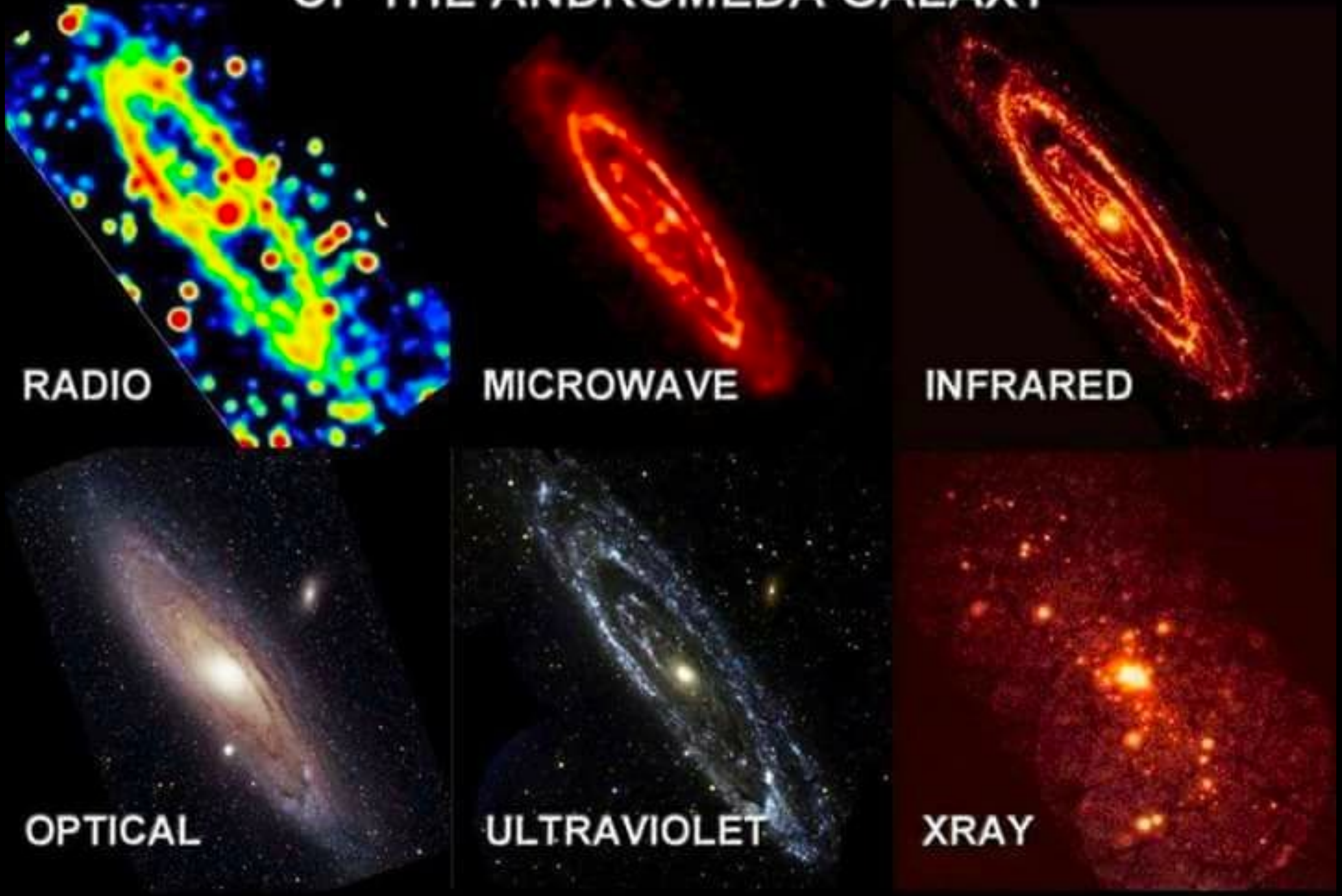
NASA, ESA, R. Sankrit and W. Blair (Johns Hopkins University)

STScI-PRC04-29b

Multiwavelength Views of Cen A



THE MULTIPLE WAVELENGTHS OF THE ANDROMEDA GALAXY



ORIGINAL BY ROB SIMPSON.
ANNOTATED BY CALLUM C. J. SUTHERLAND FOR MILKYWAYMUSINGS.COM

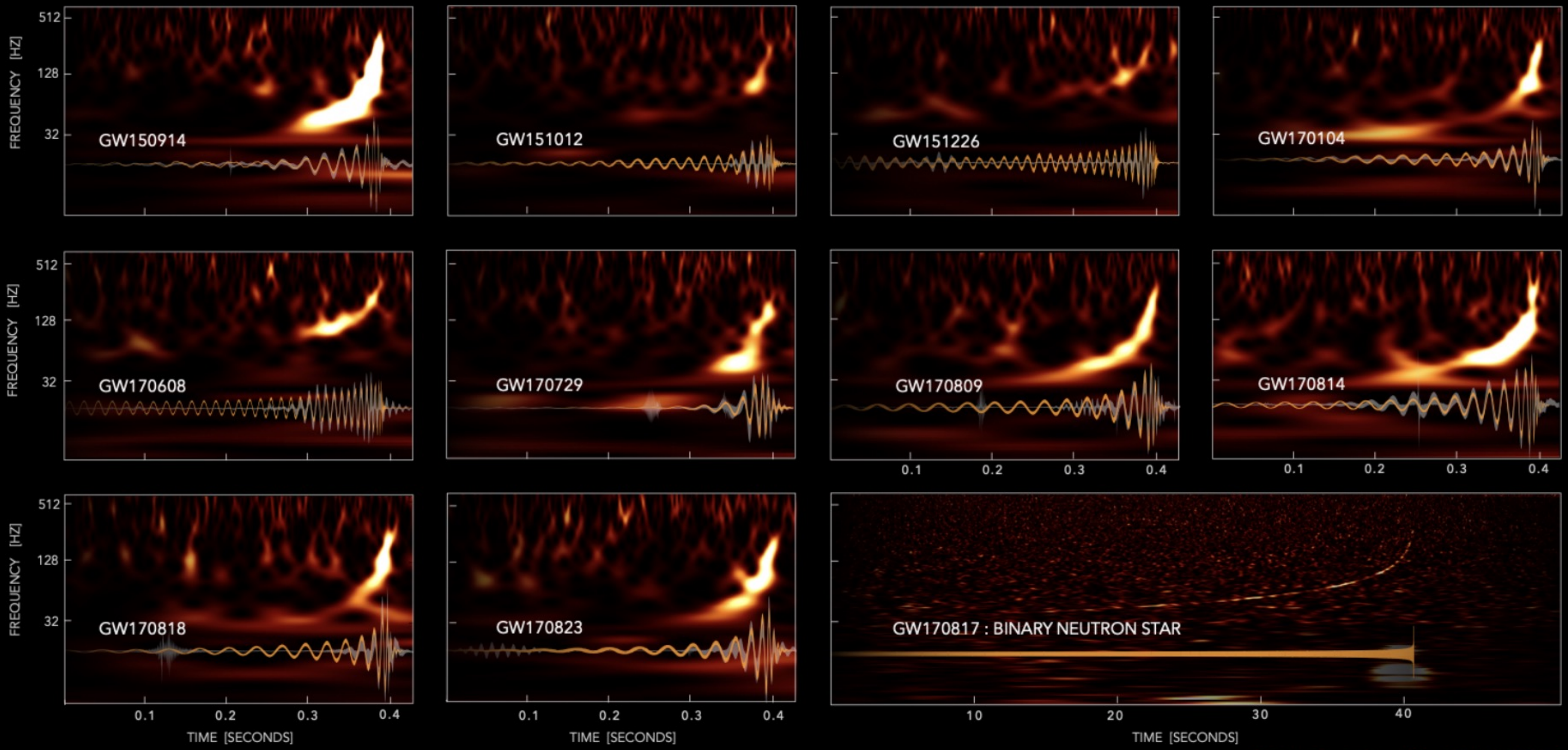
APOD: Stephan's Quintet from Webb, Hubble, Subaru (2022 Jul 18)
Image Credit: Webb, Hubble, Subaru; NASA, ESA, CSA, NOAJ, STScI; Processing & Copyright: Robert Gendler
https://apod.nasa.gov/apod/ap220718.html

다중신호 천문학

https://www.sedaily.com/NewsVIew/1OMC5SZMK4

HUBBLE

GRAVITATIONAL-WAVE TRANSIENT CATALOG-1



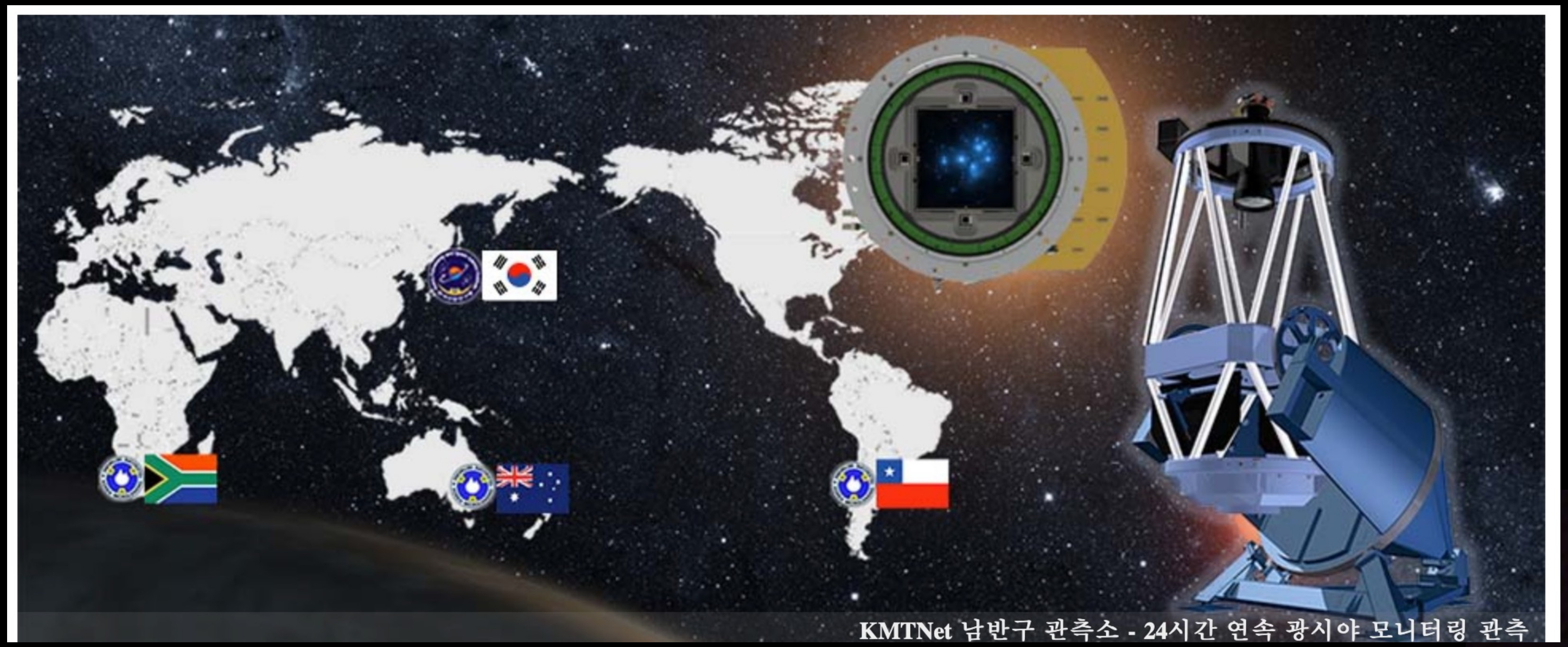
[Abbott et al, arXiv:1811.12907]

LIGO-VIRGO DATA: HTTPS://DOI.ORG/10.7935/82H3-HH23

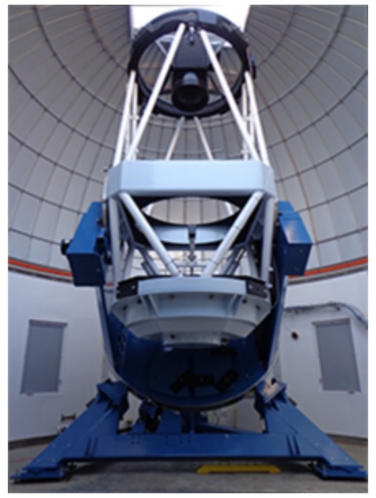
WAVELET (UNMODELED)

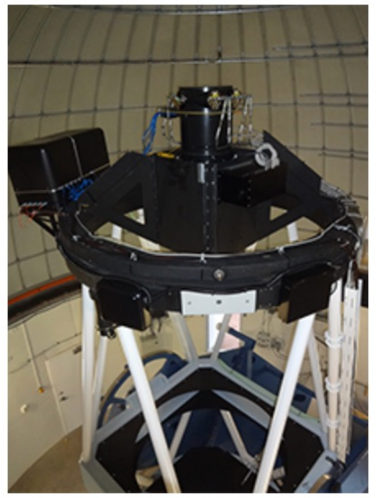
EINSTEIN'S THEORY

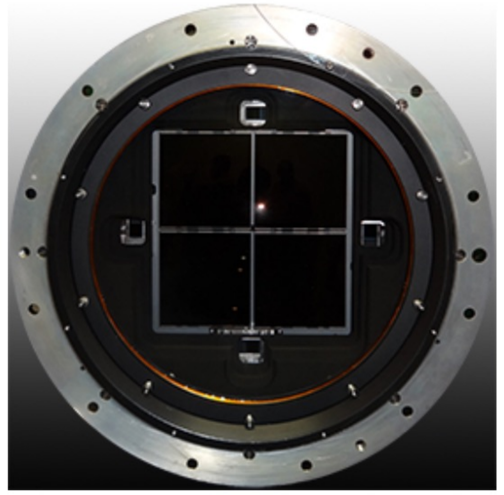
S. GHONGE, K. JANI | GEORGIA TECH

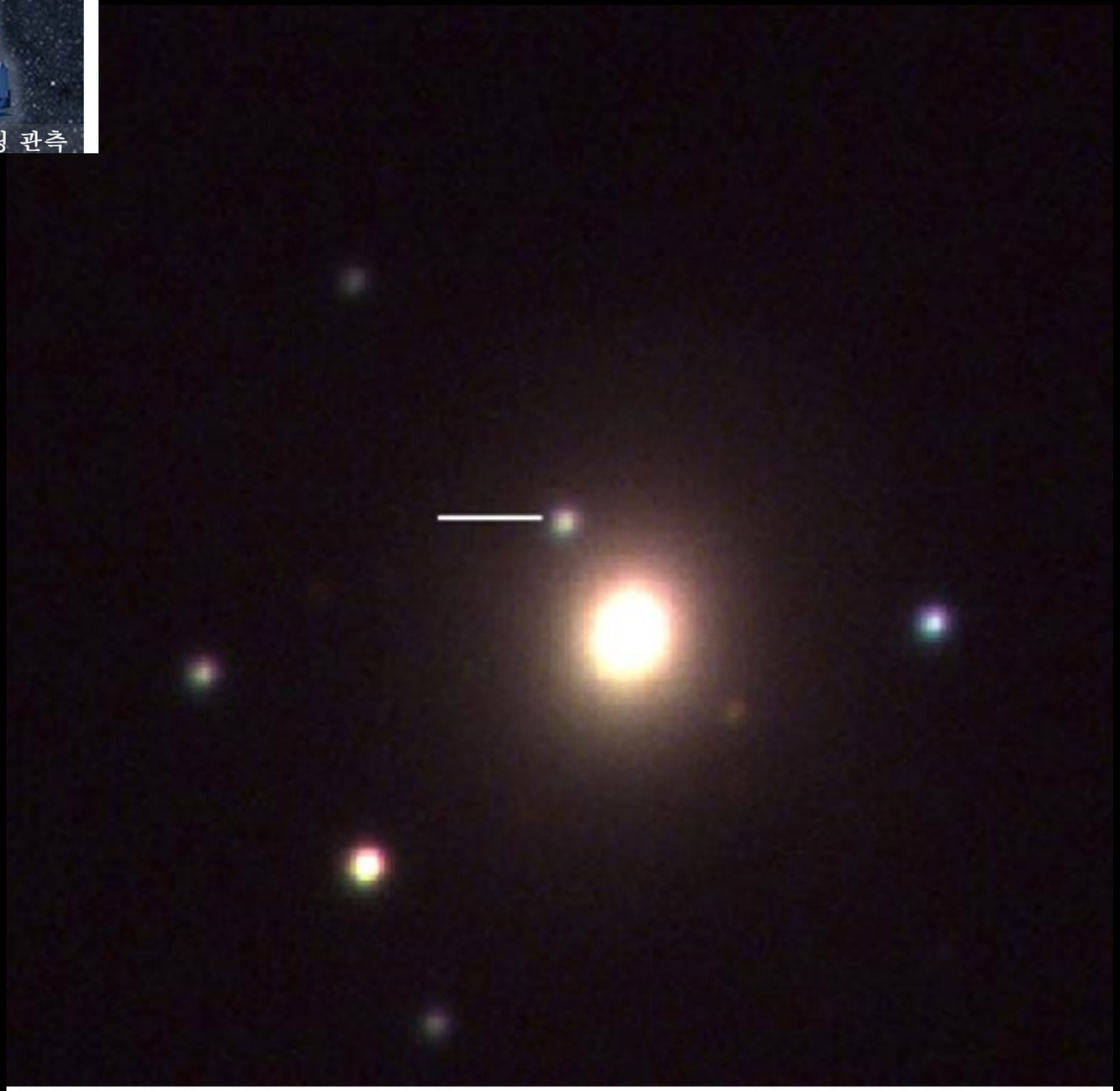


Telescope	Camera	FOV	Site	Target
PanSTARRS 1.8m × 4	1400M pixel CCD	7.0 deg^2	Haleakala, USA	All sky survey
MOA 1.8m	80M pixel CCD	2.4 deg^2	Mt. John, New Zealand	Galactic Bulge
KMTNet 1.6m × 3	340M pixel CCD	4.0 deg^2	CTIO - SAAO - SSO	Galactic Bulge
SkyMapper 1.35m	268M pixel CCD	5.7 deg^2	SSO, Australia	All sky survey
OGLE-IV 1.3m	268M pixel CCD	1.4 deg^2	LCO, Chile	Galactic Bulge





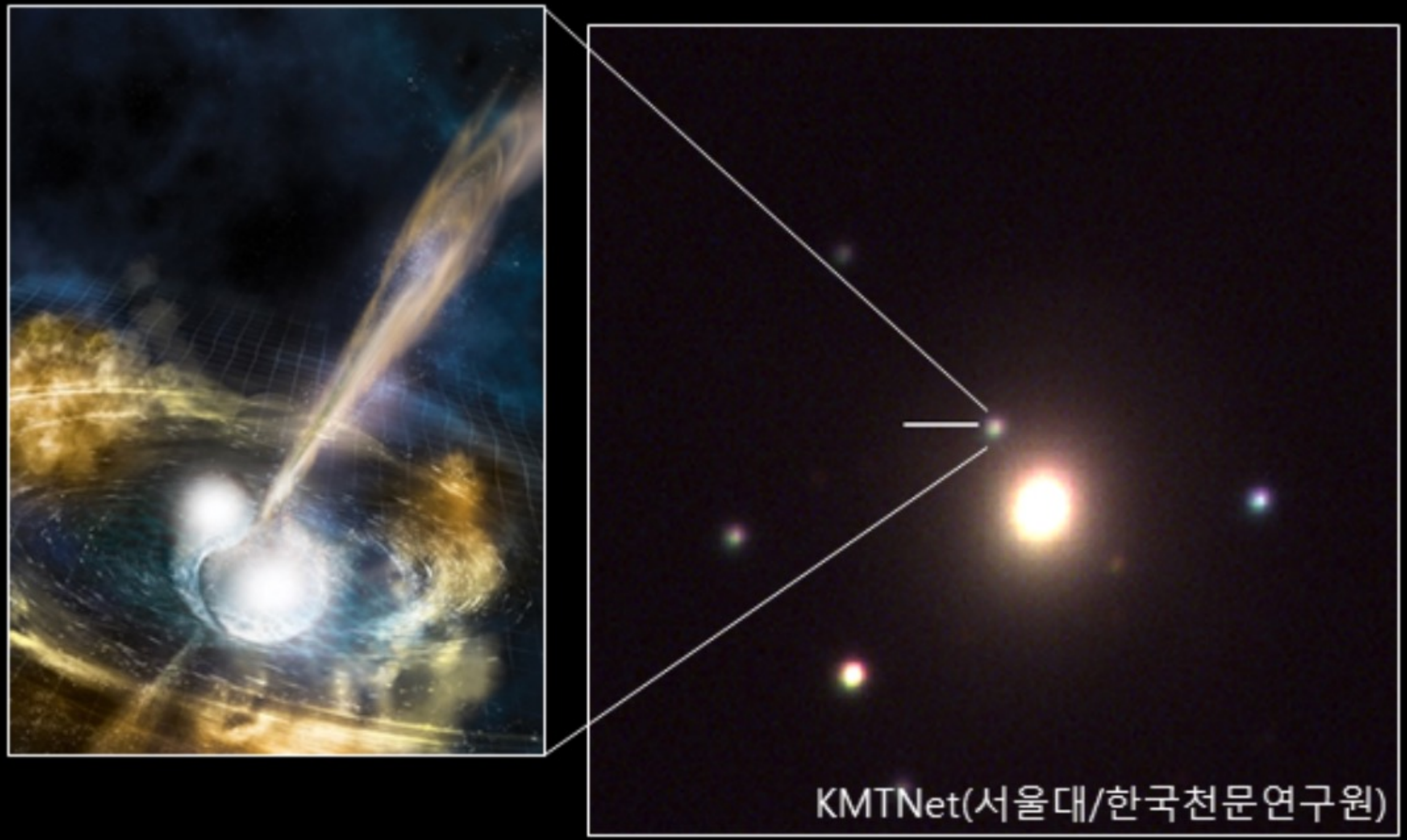


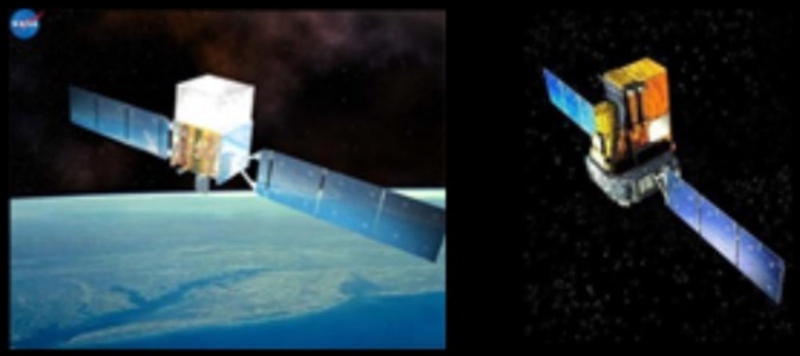


KMTNet 남아공 관측소가 포착한 GW170817의 모습

KASI/KMT-net

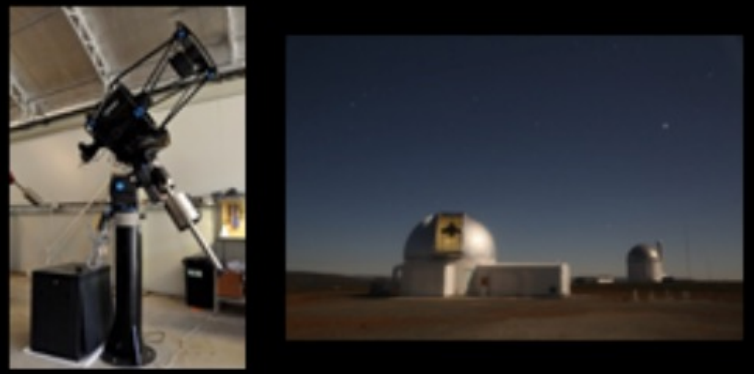
2017-08-17 12:41:04 UTC
라이고 및 비르고 중력파 신호 포착





+2초 후
페르미 및 인티그랄 감마선 신호 포착

+약 11시간 후
칠레 천문대 망원경들이
가시광선 신호 포착



+약 21시간 후
국내연구진 호주 이상각망원경으로
추적관측시작. 이후 약 4주간 추적관측
(KMTNet, BOOTES-5망원경 등)

+약 9일 후
찬드라 우주망원경
X-선 신호 포착

+약 16일 후
지상 전파망원경
전파 신호 포착

그림출처: LIGO, NASA, 1M2H/UC Santa Cruz and Carnegie Observatories/Ryan Foley,
서울대/한국천문연구원/임명신, NSF/Sonoma 주립대/A. Simonnet, NRAO

서울대학교 초기우주천체연구단
(임명신)

GRB 160821B occurred in the outskirts of a spiral galaxy about two billion light-years away, at a projected offset of 52,185 light-years from the galaxy’s center. Image credit: Troja *et al*, doi: 10.1093/mnras/stz2255

GRB 160812B, 2016 킬로노바로 확인됨.

관측천문학의 미래

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SCIENCE QUESTIONS

How does the universe work? | How did we get here? | Are we alone?

Big Questions

How does the universe work?

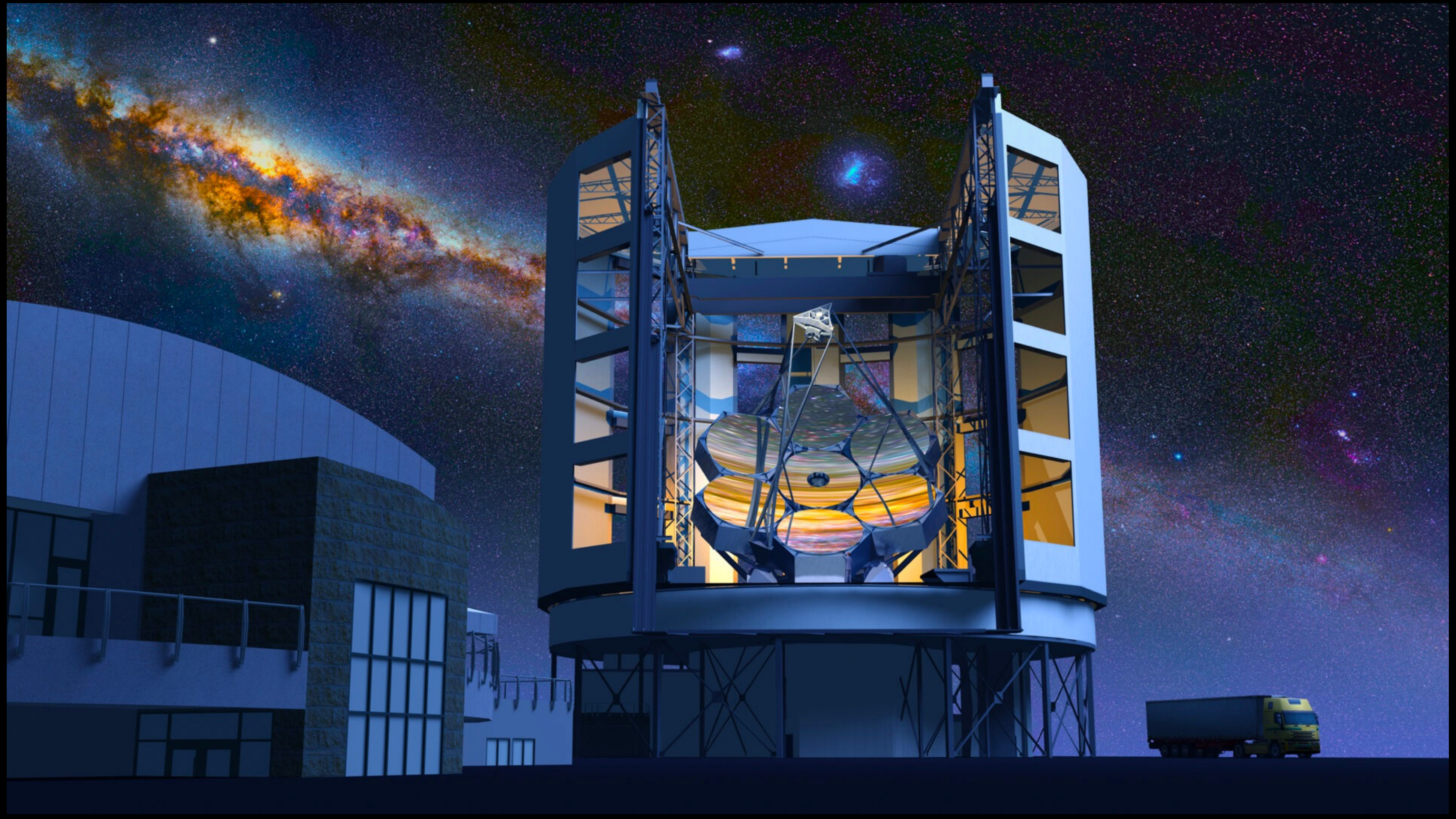
How does the universe work? Understanding the universe's birth and its ultimate fate are essential first steps to unveil the mechanisms of how it works. This, in turn, requires knowledge of its history, which started with the Big Bang.

How did we get here?

How did we get here? In order to understand how the universe has changed from its initial simple state following the Big Bang (only cooling elementary particles like protons and electrons) into the magnificent universe we see as we look at the night sky, we must understand how stars, galaxies and planets are formed.

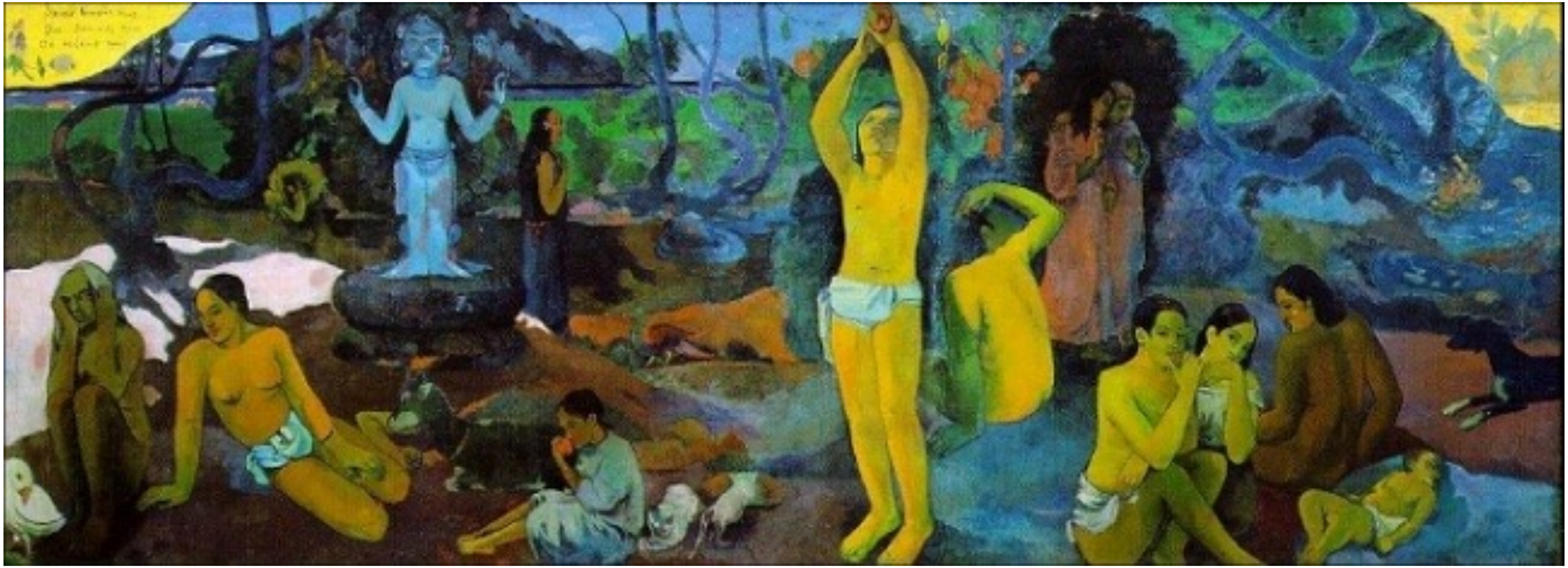
Are we alone?

Are we alone? For millennia, people have turned their eyes to the stars and wondered if there are others like themselves out there. Does life, be it similar to our own or not, exist elsewhere?



https://universemagazine.com/en/powerful-than-james-webb-top-4-telescopes-to-build-by-2030/

Origins, LUVOIR, HabEx, and, Lynx https://skyandtelescope.org/astronomy-news/2020-decadal-survey-future-astronomy/



폴 고갱 (Paul Gauguin ,1848-1903)
Whre Do We Come From? What Are We? Where Are We Going?
139cm × 374.7㎝

Kahoot! (카훗)

감사합니다.