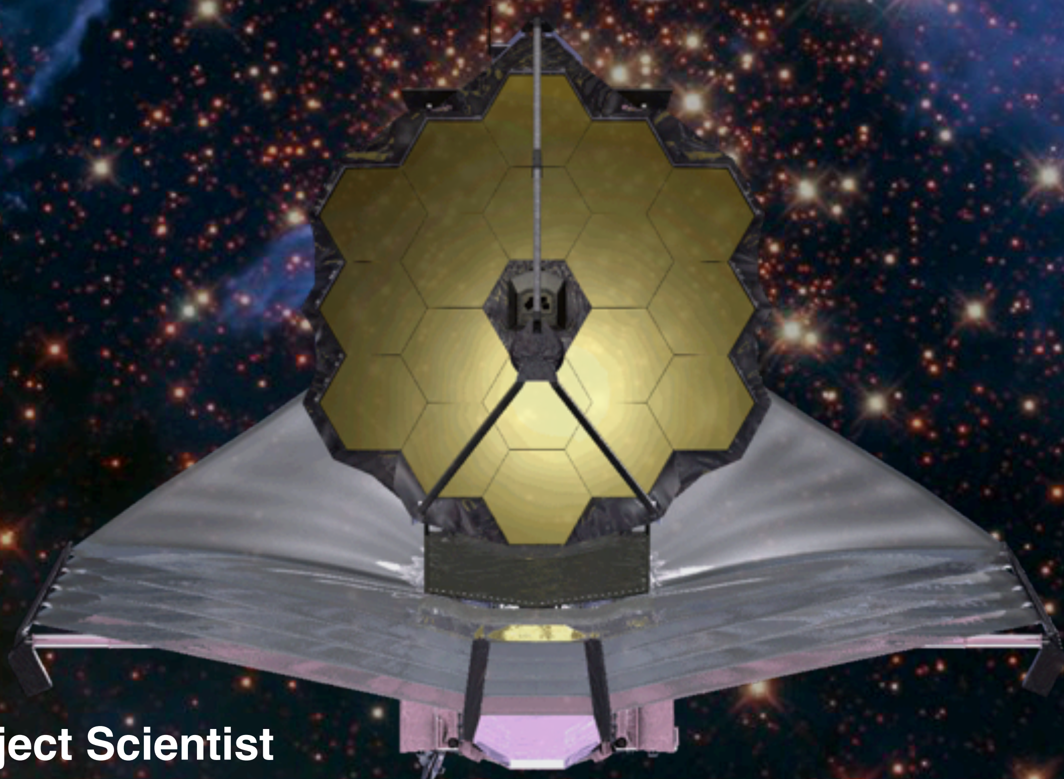
Where did we come from, where are we going?



John Mather
JWST Senior Project Scientist
NASA's Goddard Space Flight Center

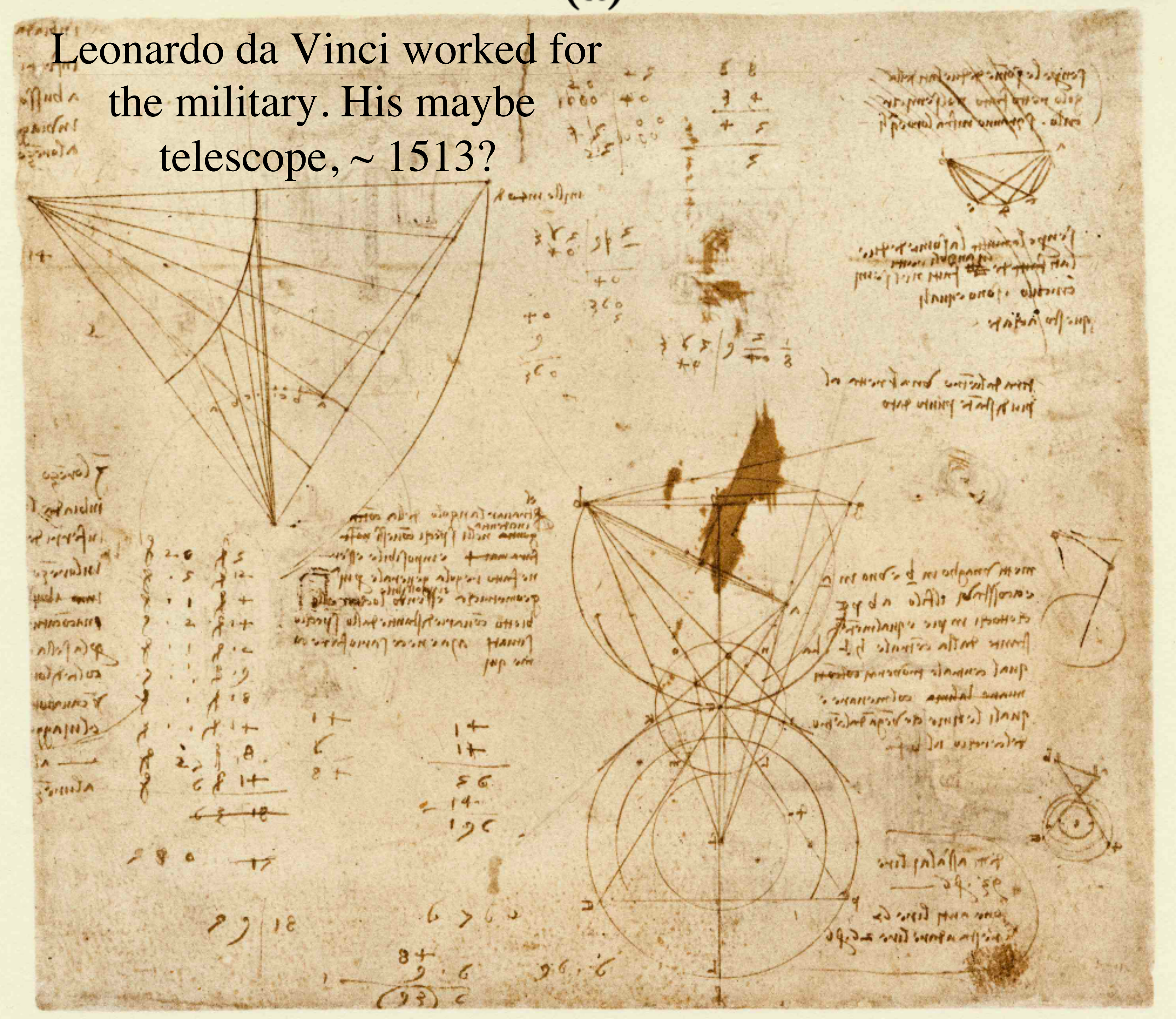
on behalf of 7 billion current Earthlings, ~10,000 future observers, ~ 3000 engineers and technicians, ~ 100 scientists worldwide, 3 space agencies

Rutgers University Lusscroft Farm - Site of Early Nerds in Sussex County, NJ

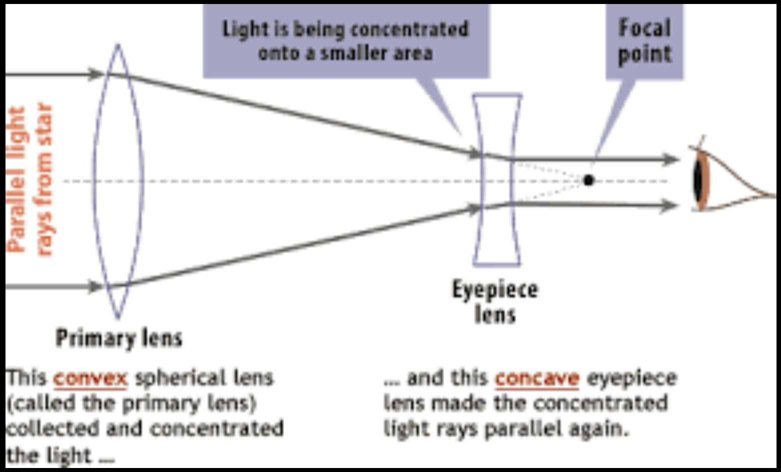
How did we get here?

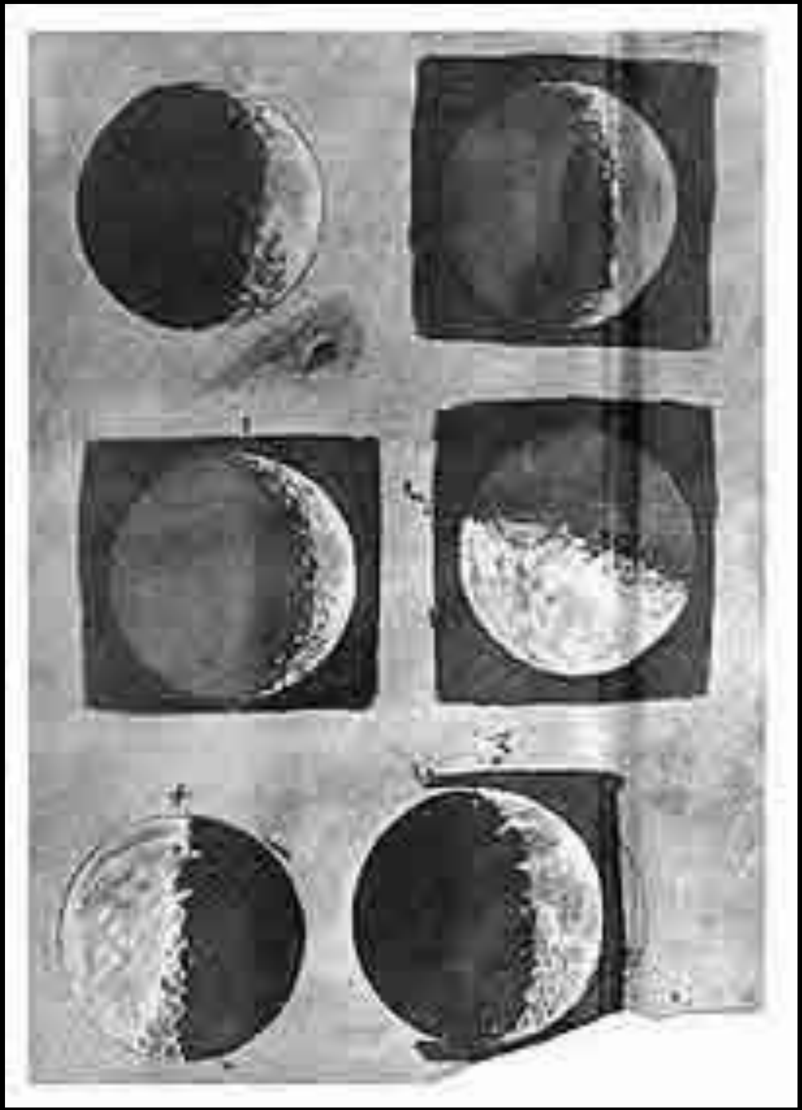
- Quantum mechanics determines properties of all matter from subatomic to DNA, iPhones, & concrete
- Expanding universe starts smooth and hot
- Instability everywhere: energy release from reorganization into complex systems
- Infinite (?) and ancient universe explores every possibility, time enough for possibility → reality
- Stored information (DNA & decoders, language, etc.) enables life, evolution (survival of the lucky), individuality, civilization
- Nested feedback loops stabilize systems (create recognizable identity), destabilize too (balance of nature is temporary)

Leonardo da Vinci worked for the military. His maybe telescope, ~ 1513?

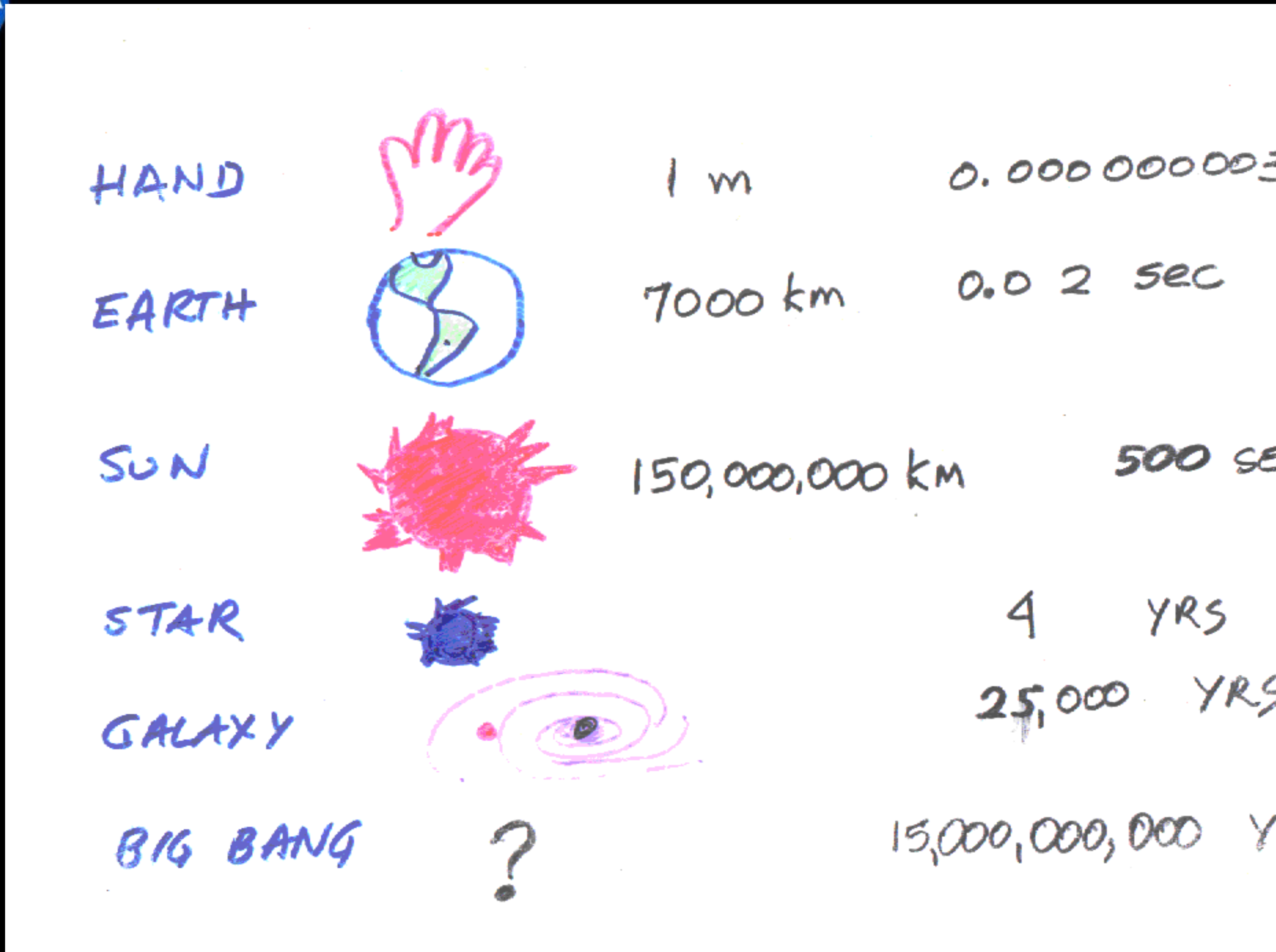


Galileo 1609



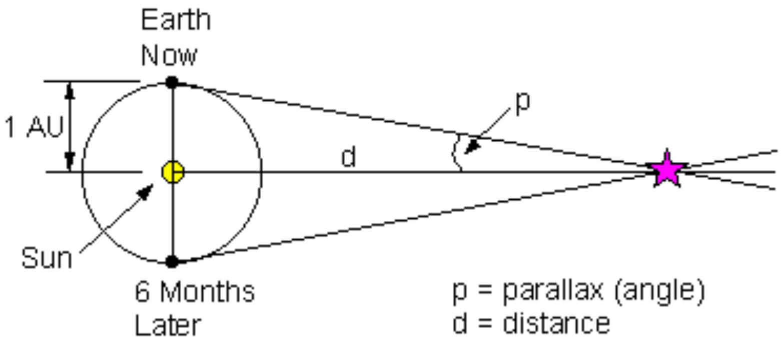


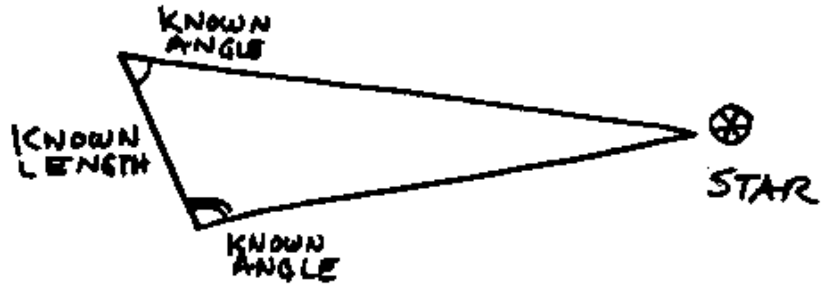
Looking Back in Time



Measuring Distance

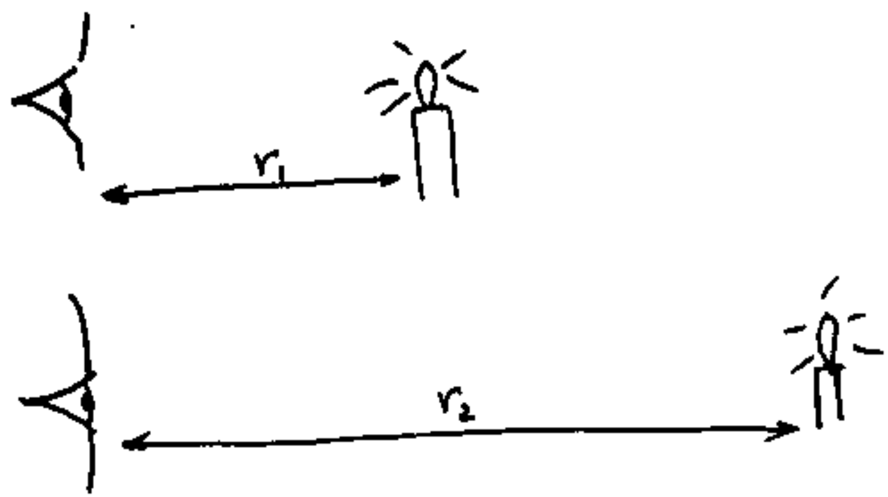
1. TRIANGLES





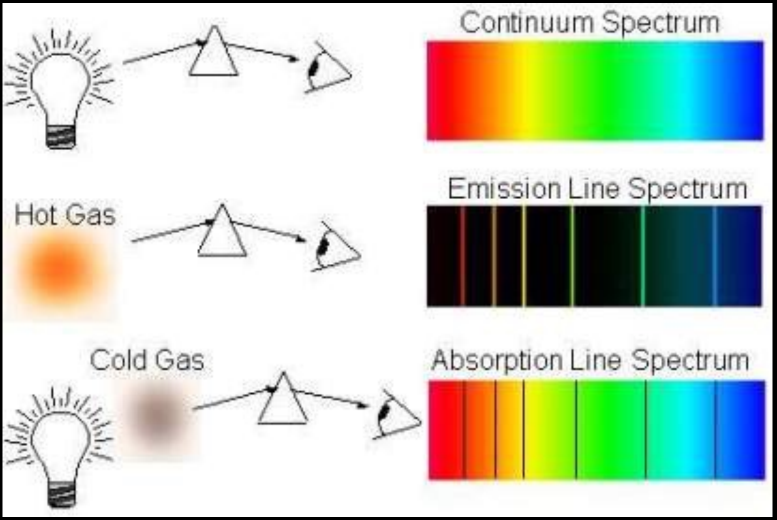
2. STANDARD CANDLES

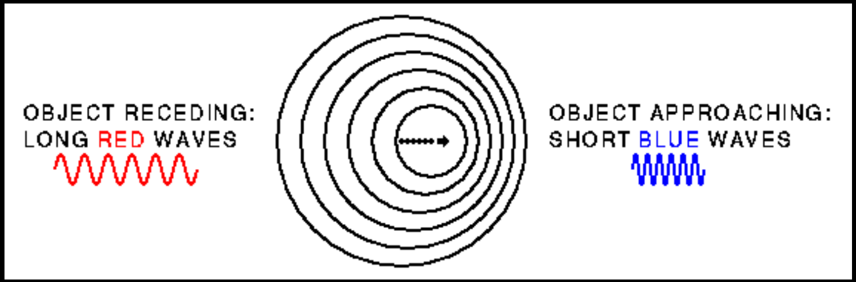
This technique enables measurement of enormous distances

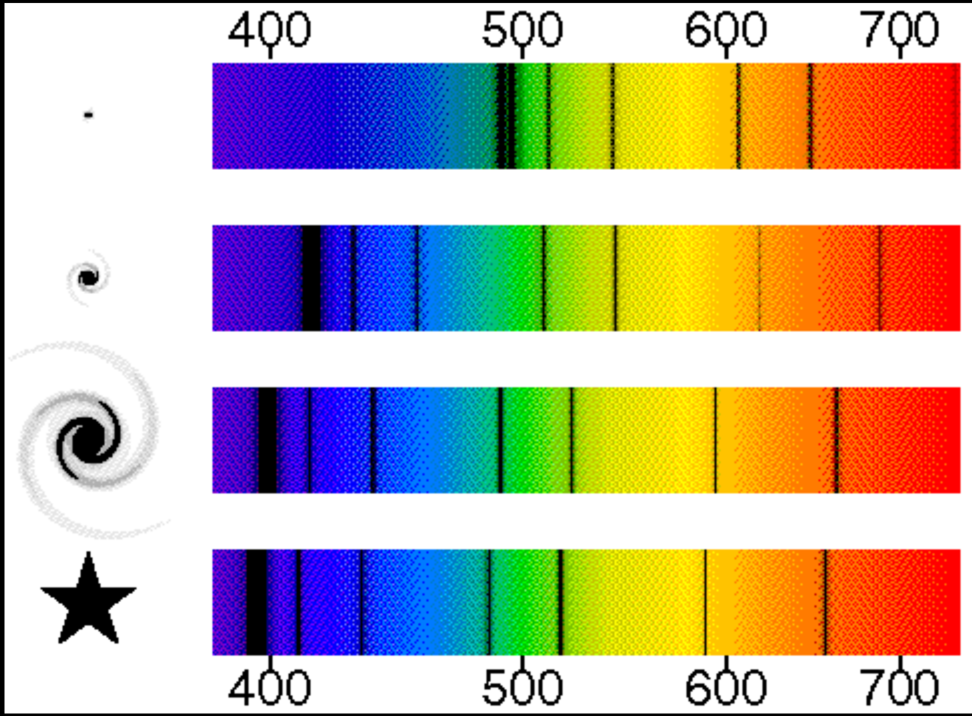


$$\frac{BRIGHTNESS_1}{BRIGHTNESS_2} = \frac{r_2^2}{r_1^2}$$

Astronomer's Toolbox #2: Doppler Shift - Light





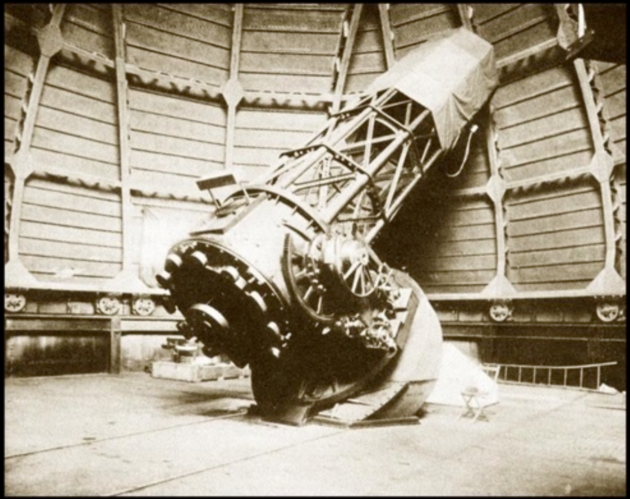


Atoms emit light at discrete wavelengths that can be seen with a spectroscope

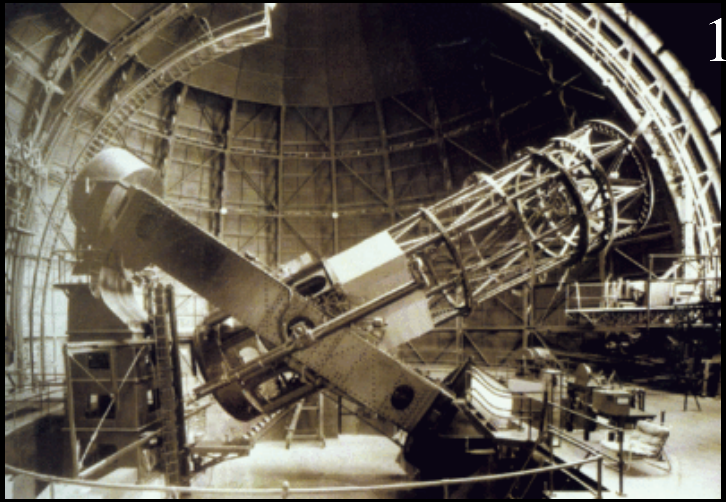
This "line spectrum" identifies the atom and its velocity

George Ellery Hale’s 4 telescopes

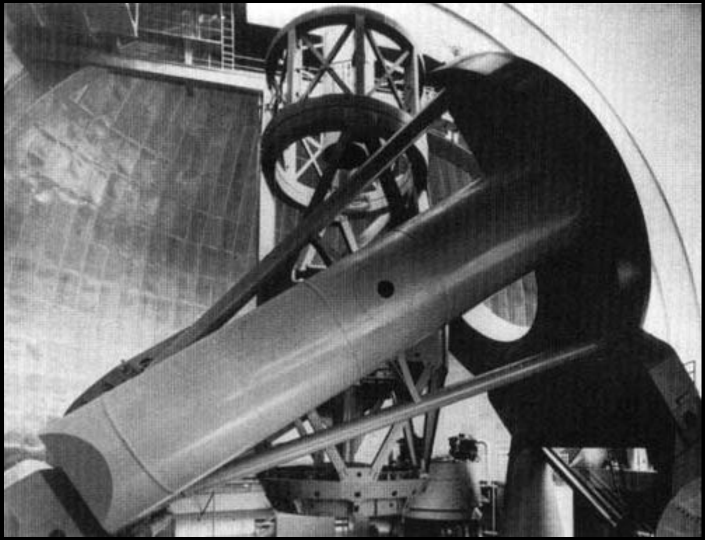
40”



60”



100”



200”

The Power of Thought

Alexander Friedman

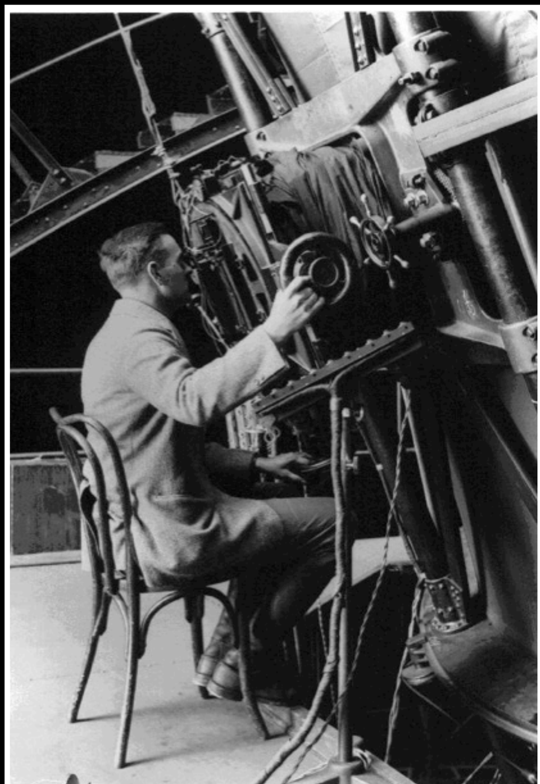
Georges Lemaître & Albert Einstein

George Gamow

Robert Herman & Ralph Alpher

Rashid Sunyaev

Jim Peebles



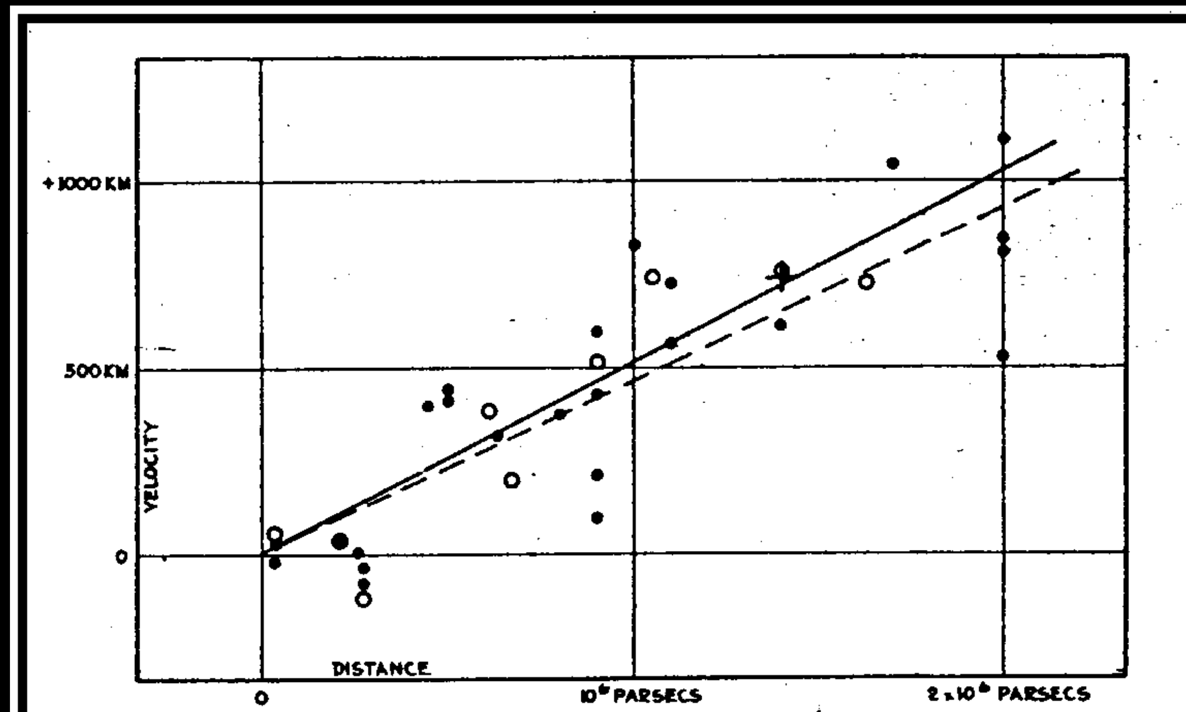
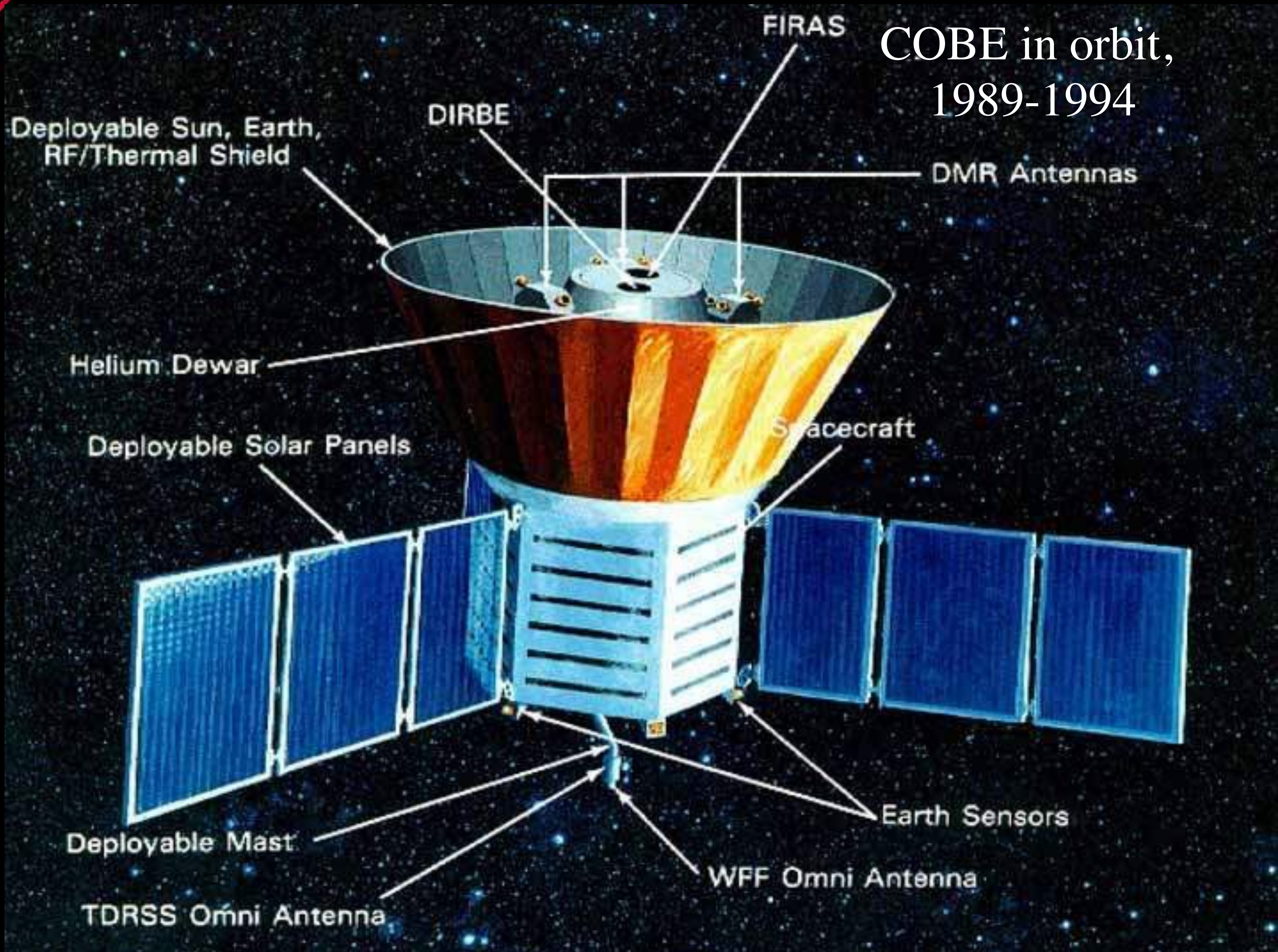
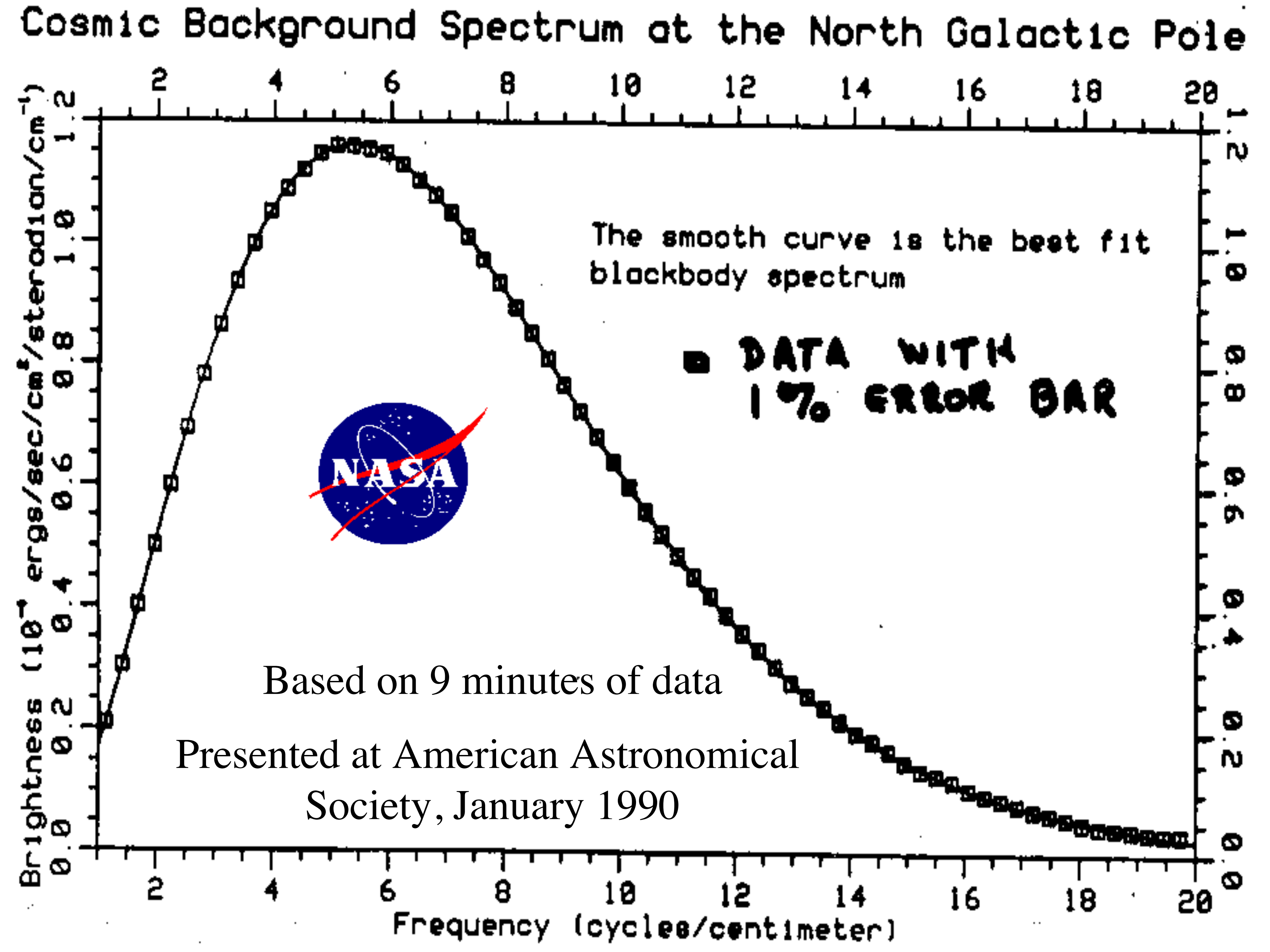


FIGURE 1

1929

COBE in orbit, 1989-1994



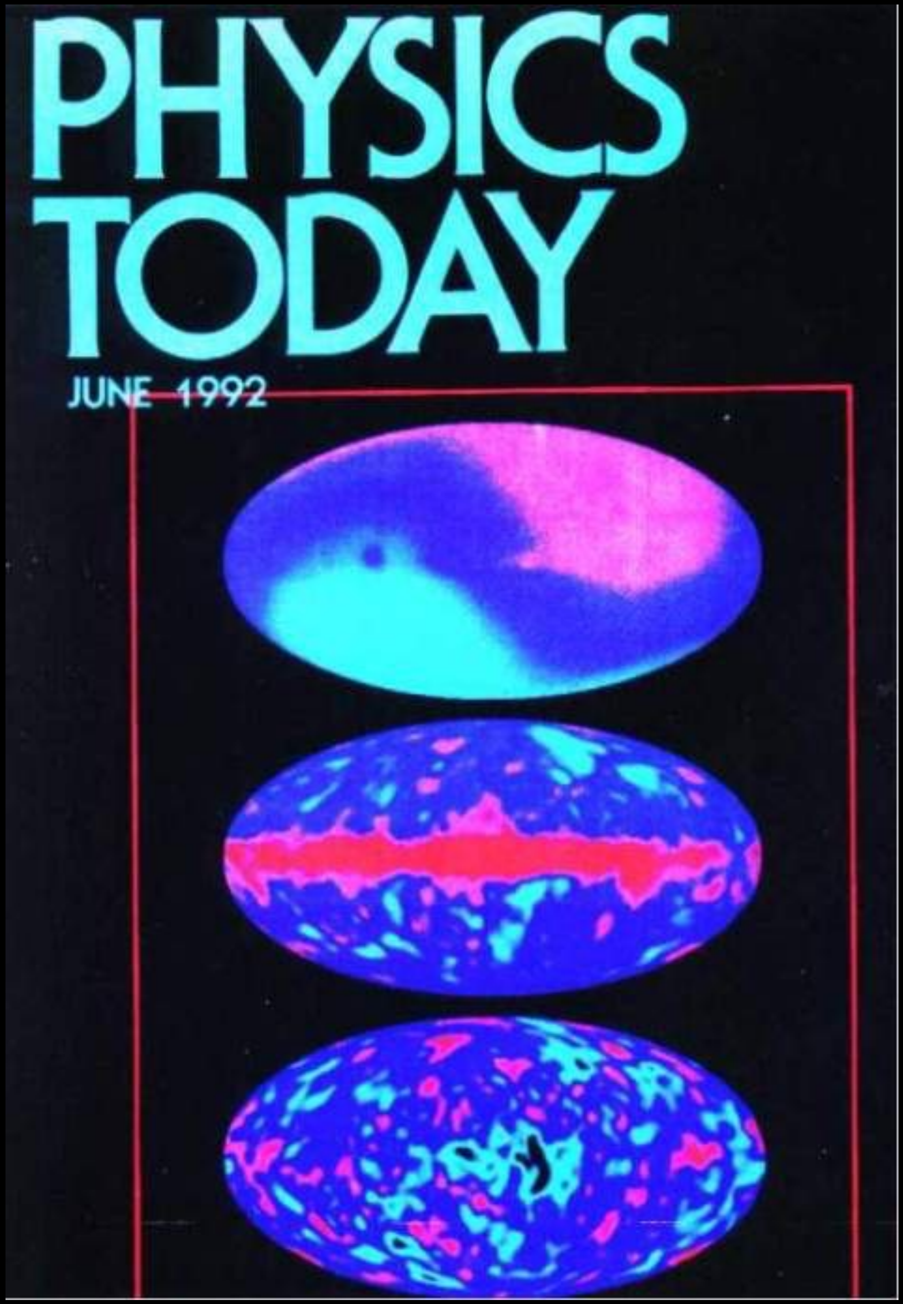


Cosmic Background Spectrum at the North Galactic Pole
The smooth curve is the best fit blackbody spectrum
DATA WITH 1% ERROR BAR
NASA
Based on 9 minutes of data
Presented at American Astronomical Society, January 1990
Brightness
Frequency (cycles/centimeter)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2
4
6
8
10
12
14
16
18
20

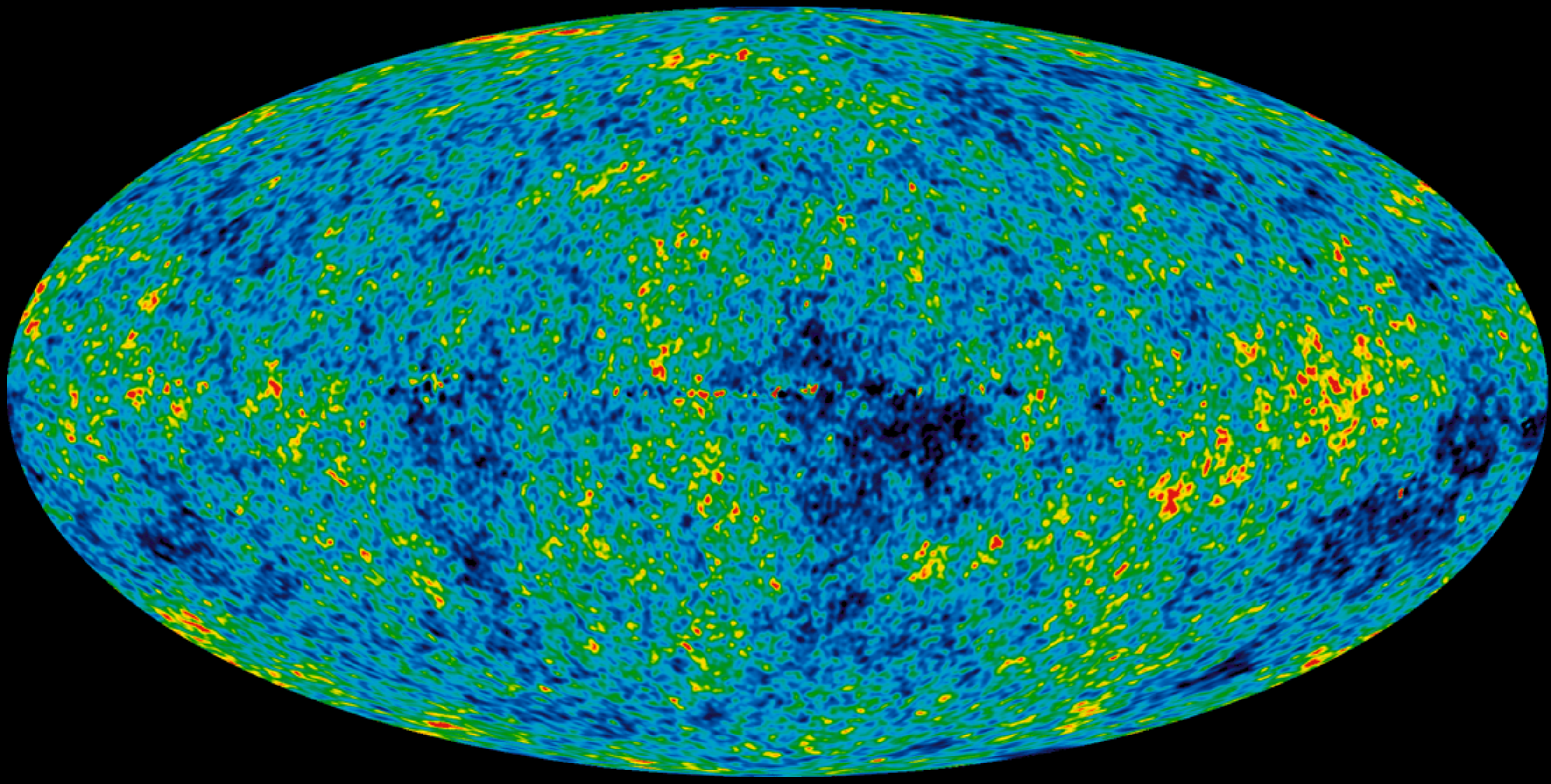
Sky map from DMR,
2.7 K +/- 0.003 K

Doppler Effect of Sun's motion removed (v/c = 0.001)

Cosmic temperature/density variations at 389,000 years, +/- 0.00003 K (part in 100,000)



WMAP all-sky map of CMB fluctuations, leading to existence of galaxies, stars, etc.
WMAP team won Breakthrough Prize, 2017



The early universe

very hot, very compressed
no center, no edge (infinite)
infinite universe expanding into itself
no first moment
no instant of creation
not a “big firecracker”
probably no end…

First Realistic Virtual Universe

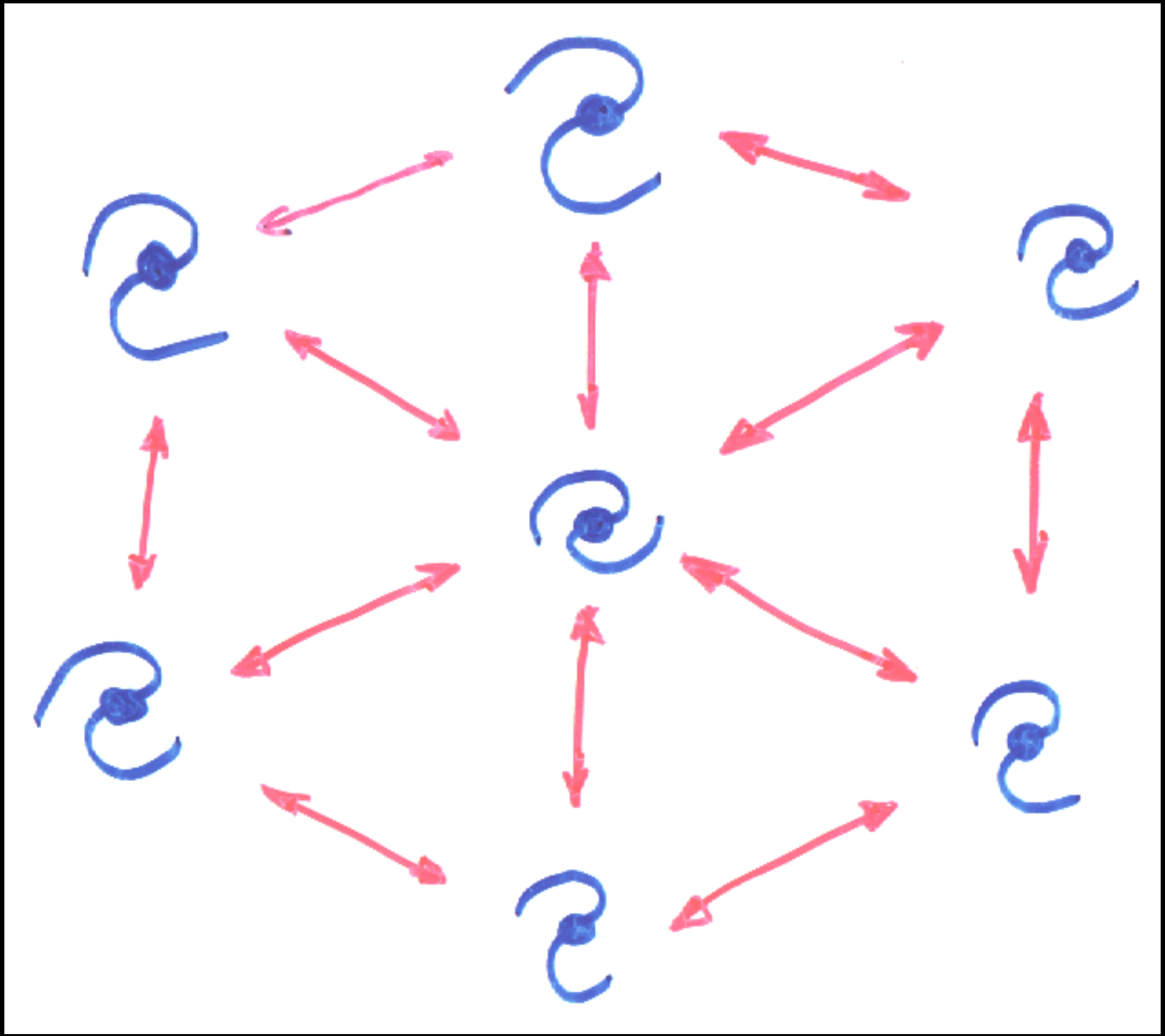
Mark Vogelsberger (MIT/Harvard-Smithsonian Center for Astrophysics)

Hubble is 27! And working well!

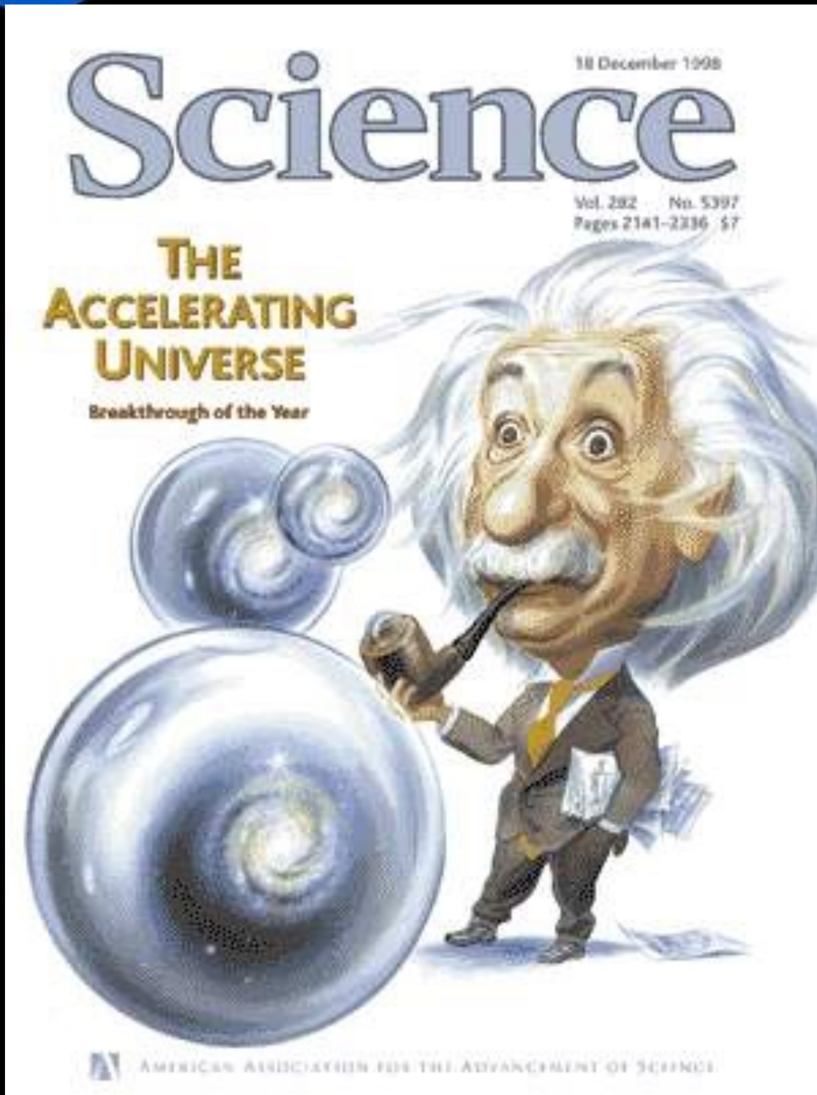
Galaxies attract each other, so the expansion should be slowing down -- Right??

To tell, we need to compare the velocity we measure on nearby galaxies to ones at very high redshift.

In other words, we need to extend Hubble's velocity vs distance plot to much greater distances.



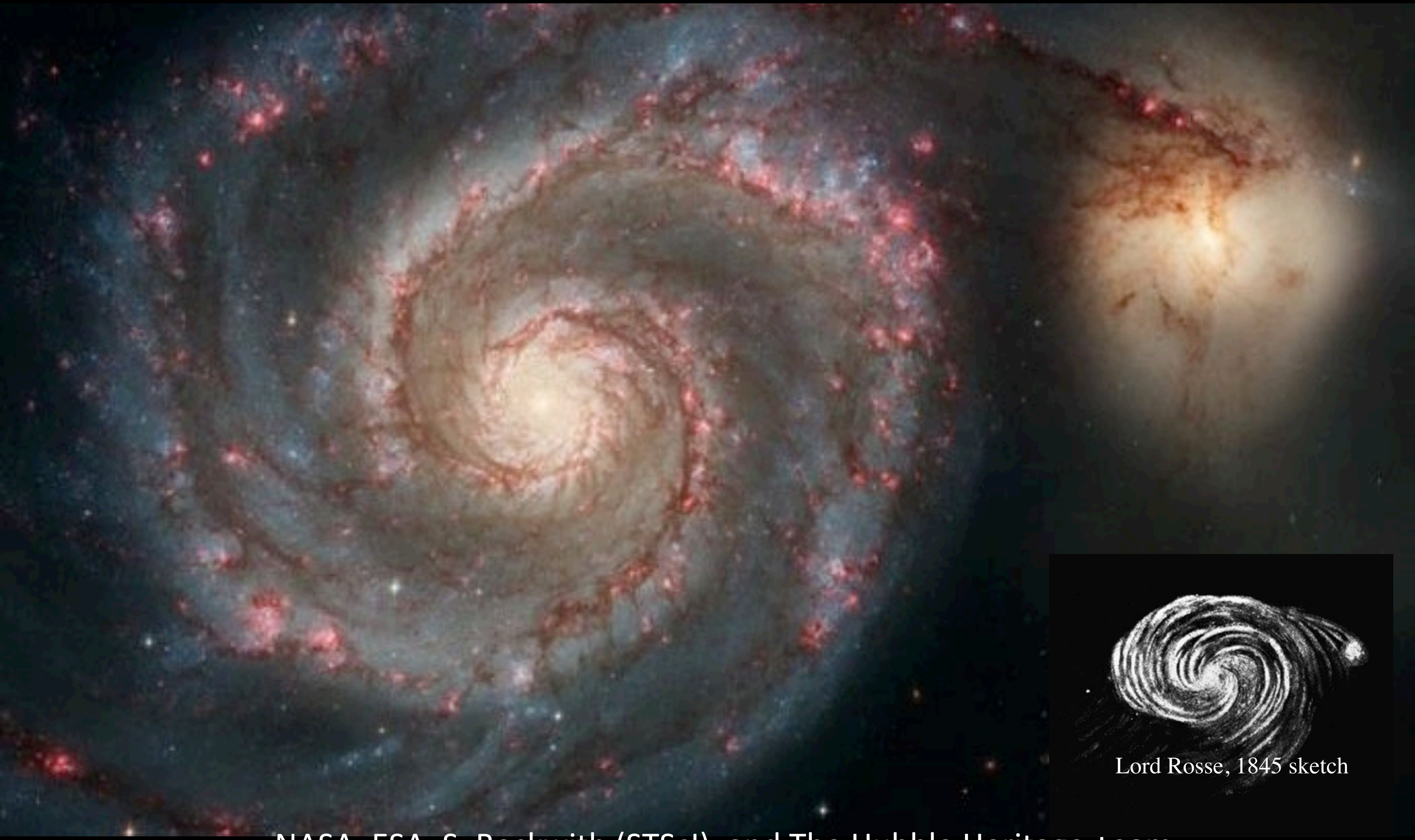
Nobel Prize, 2011 Dark Energy



MacArthur Fellow
2008 - Adam Riess

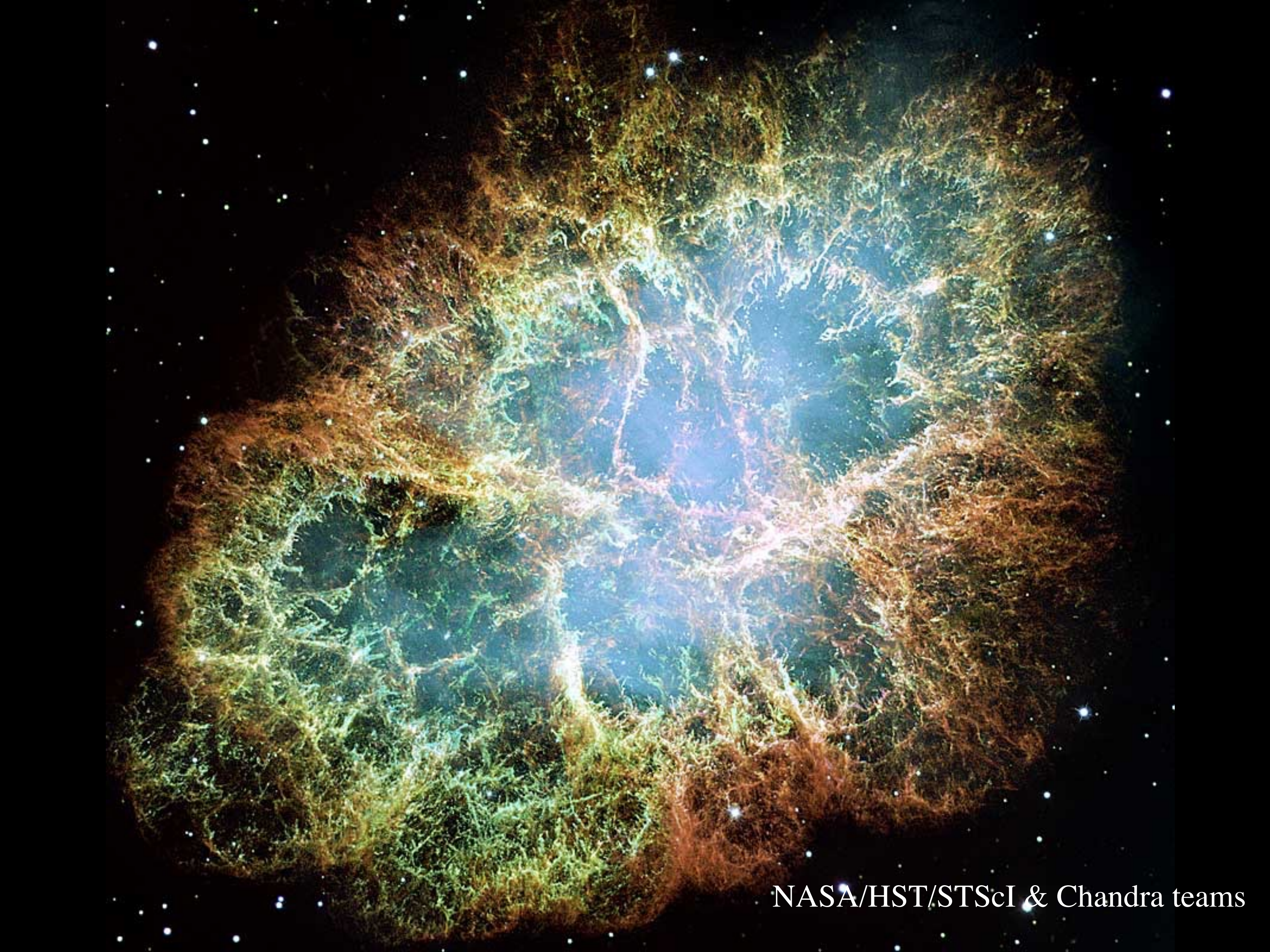
S. Perlmutter, A. Riess, B. Schmidt
Shaw Prize, Hong Kong, 2006

M51 Whirlpool Nebula



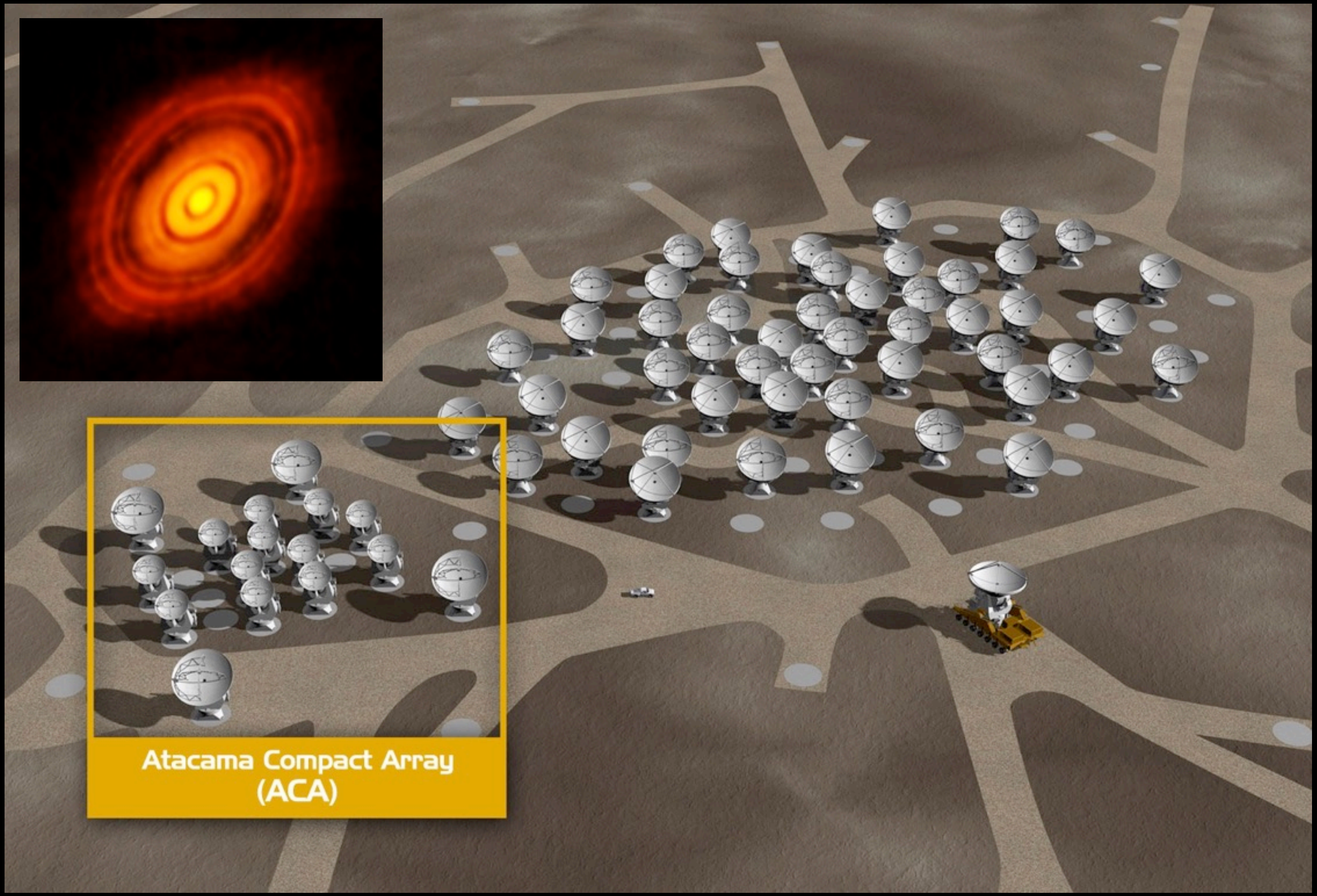
Lord Rosse, 1845 sketch

NASA, ESA, S. Beckwith (STScI), and The Hubble Heritage Team

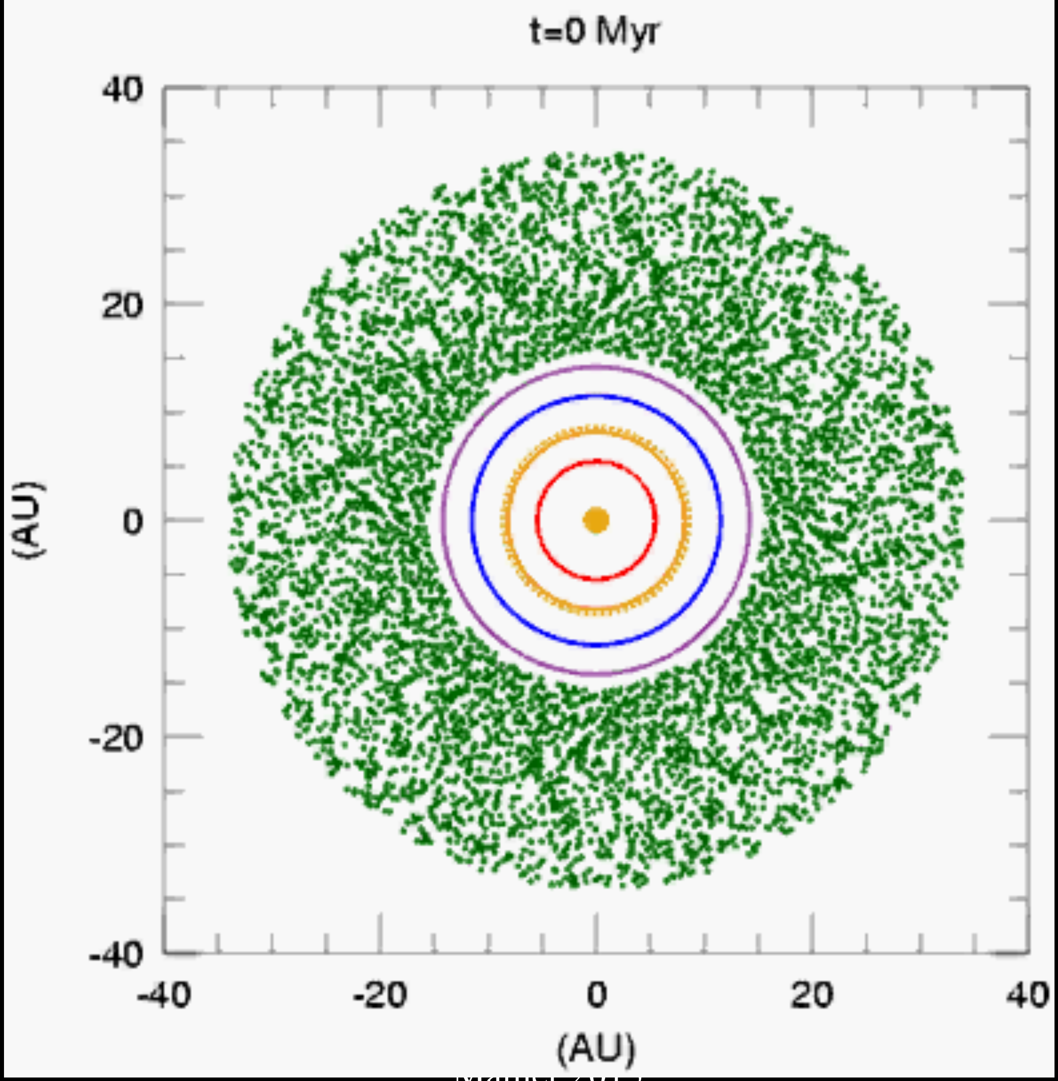


NASA/HST/STScI & Chandra teams

ALMA (Atacama Large Millimeter Array) sees proto-planetary disk

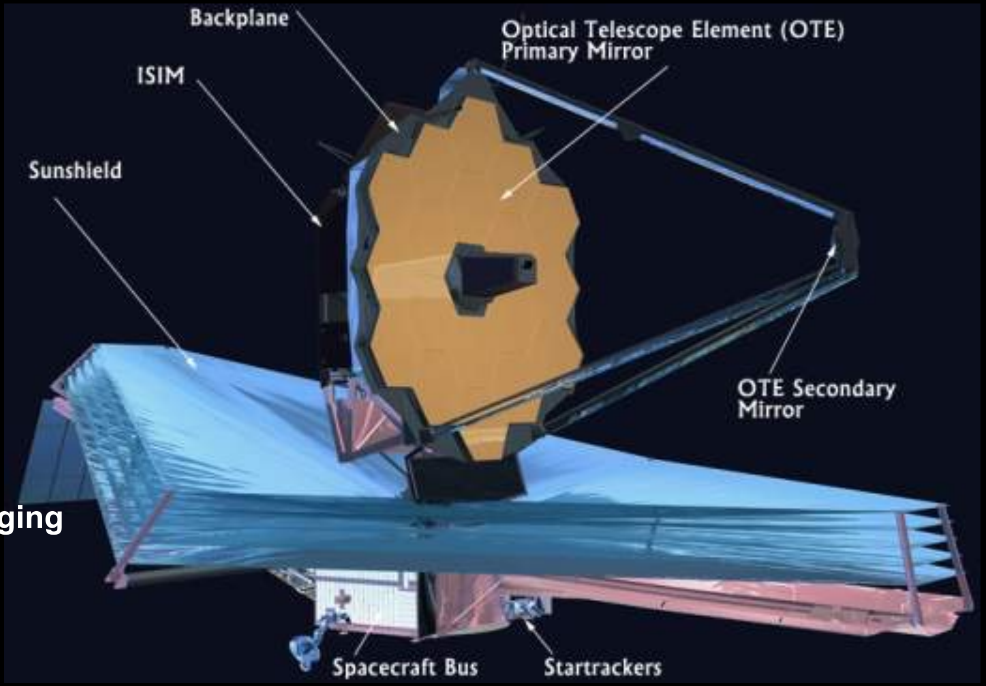


Possible Early Solar System



Square Kilometer Array (SKA)

James Webb Space Telescope (JWST)



Organization

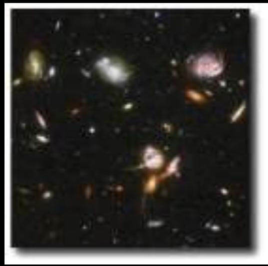
- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) and Near IR Imaging Slitless Spectrograph (NIRISS) – CSA
- Operations: Space Telescope Science Institute

Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov

JWST Science Themes



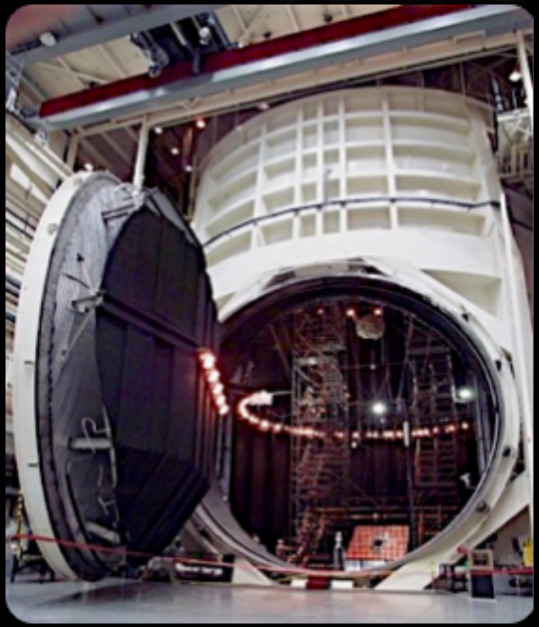
End of the dark ages: First light and reionization

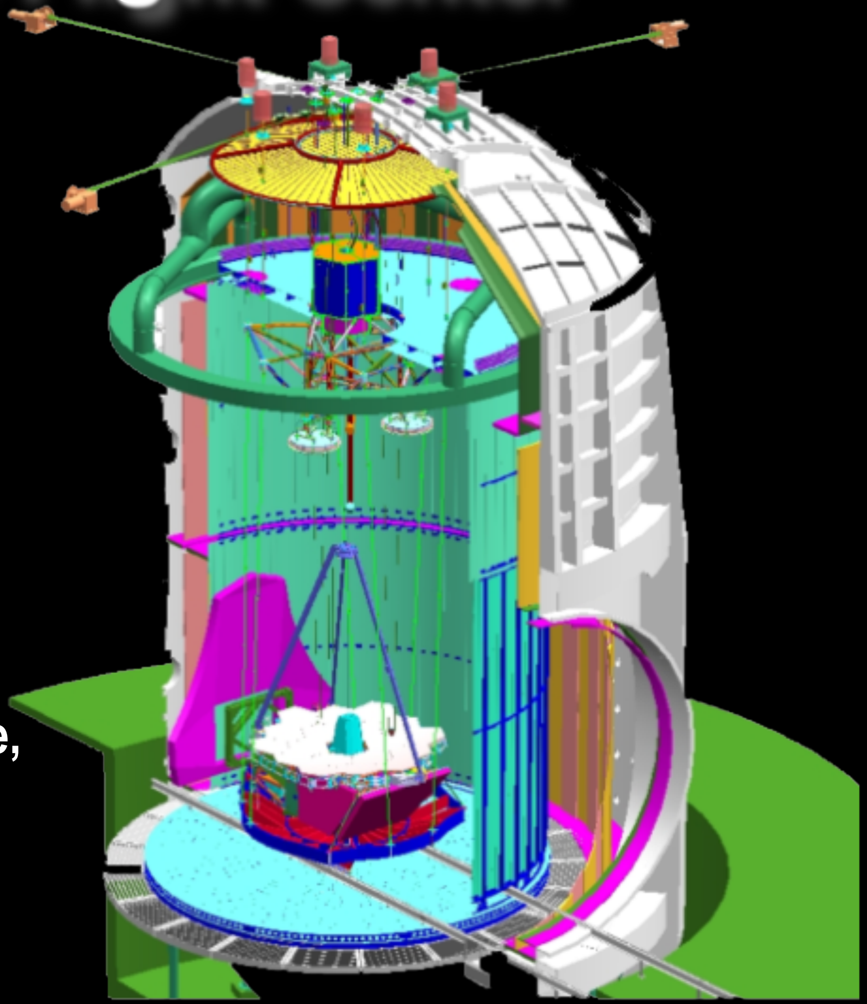
The assembly of galaxies

Birth of stars and proto-planetary systems

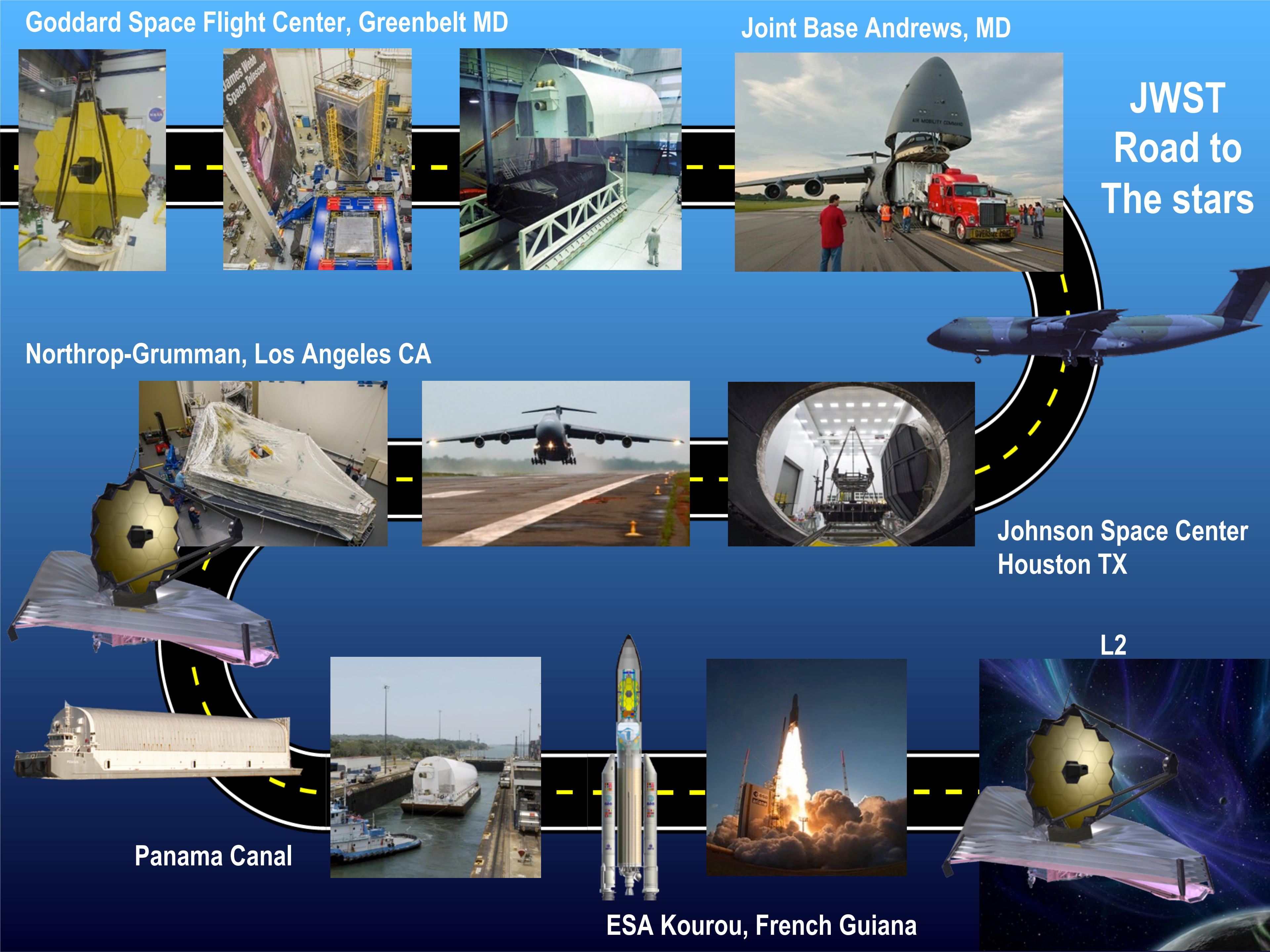
Planetary systems and the origin of life

Optical End-to-End Test @ Johnson Space Flight Center



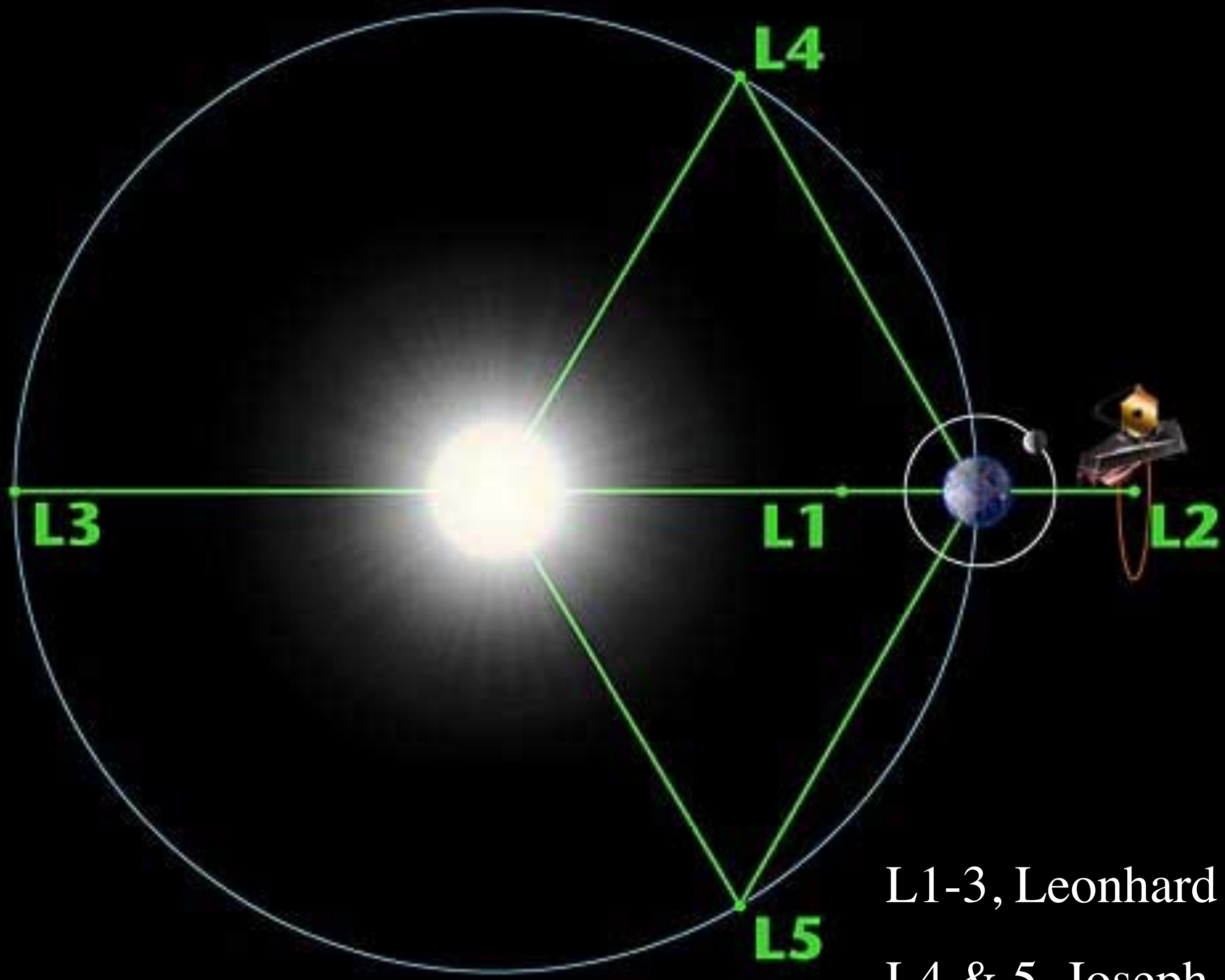


- Verify Optical alignment; center of curvature, autocollimator flats
- ➡ Verify workmanship
- ➡ Thermal balance
- ▪ Chamber outside dimensions 65’ x 120’



Goddard Space Flight Center, Greenbelt MD
James Webb Space Telescope
Joint Base Andrews, MD
JWST
Road to
The stars
Northrop-Grumman, Los Angeles CA
Johnson Space Center
Houston TX
L2
Panama Canal
ESA Kourou, French Guiana

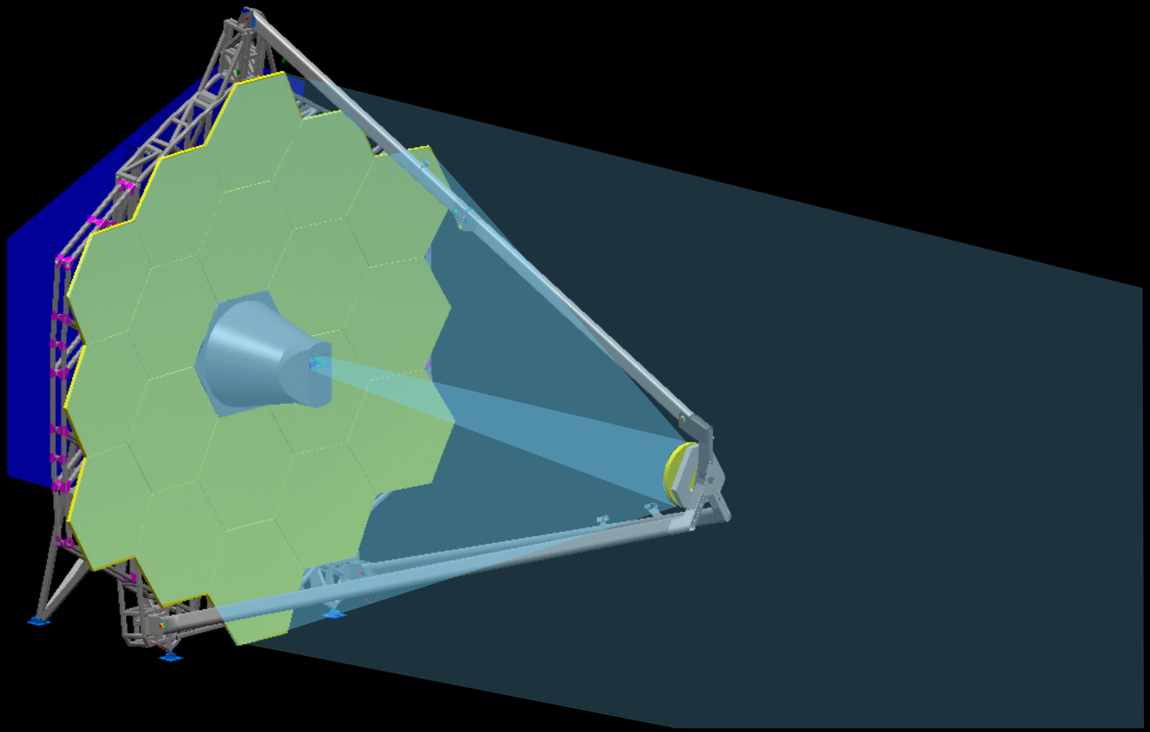
JWST Orbits the Sun-Earth Lagrange Point L2



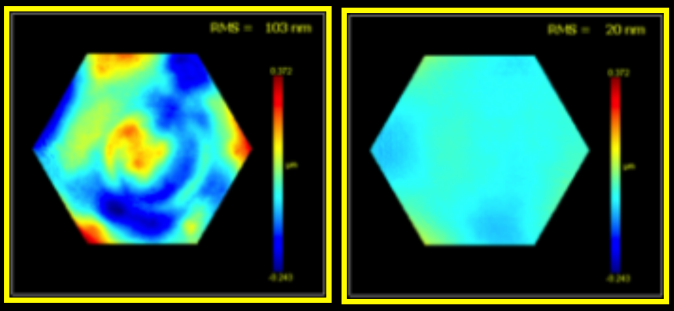
L1-3, Leonhard Euler, 1750.

L4 & 5, Joseph-Louis Lagrange, 1772

JWST's Telescope Design



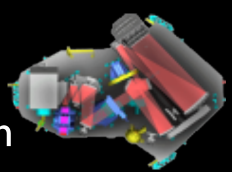
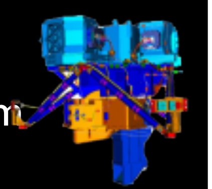
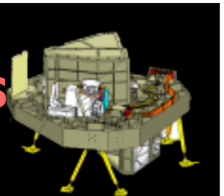
- ➡ 18 primary mirror segments
- ➡ 6 degrees of freedom + ROC
- ➡ Beryllium mirrors
- ➡ 40 K operation
- ➡ <u>Cryo-polishing required</u>
- ➡ Long lead time fabrication



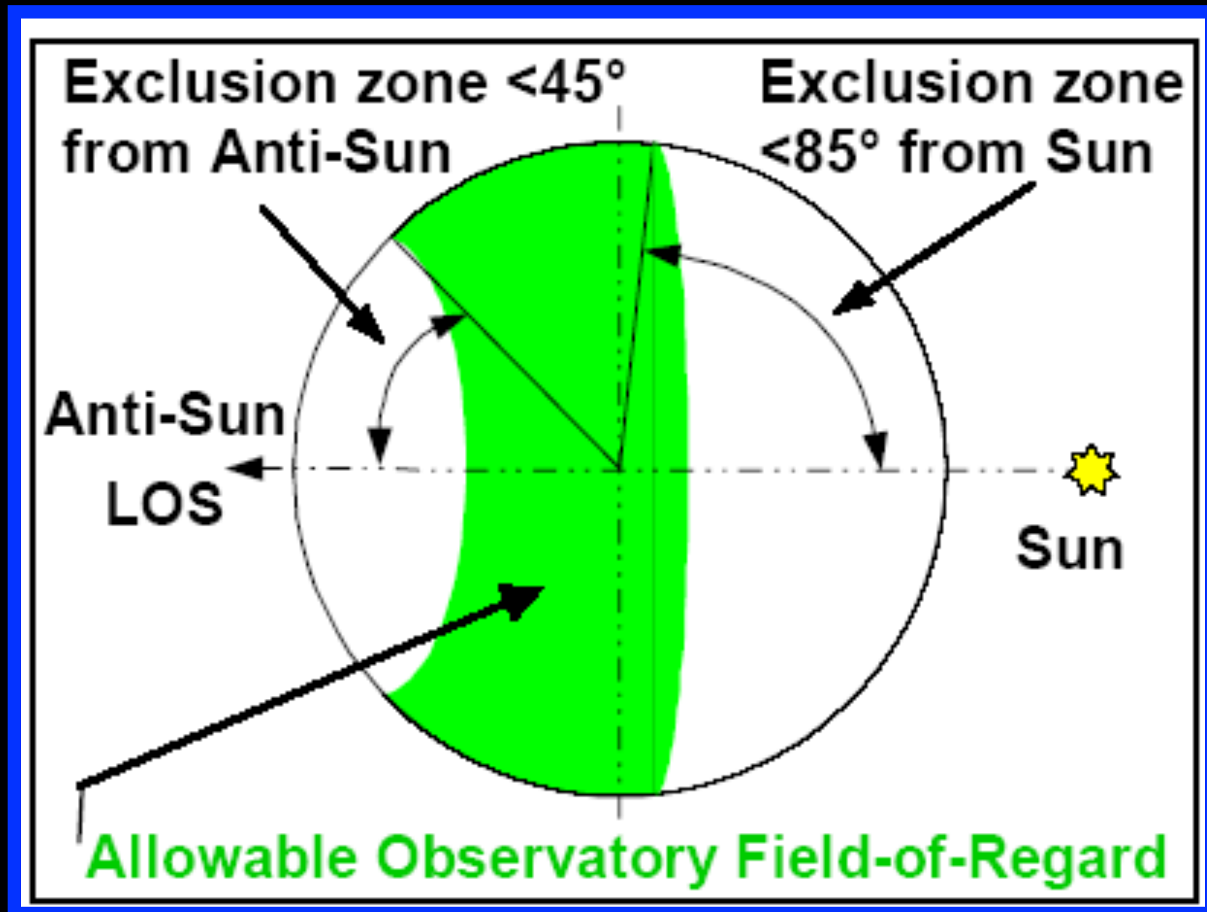
Ambient Surface   Cryo Surface

- ➡ *Elliptical* f/1.2 Primary Mirror (PM)
- ➡ *Hyperbolic* Secondary Mirror (SM)
- ➡ *Elliptical* Tertiary Mirror (TM) images pupil at *Flat* Fine Steering Mirror (FSM)
- ➡ Diffraction-limited imaging at ≥ 2 μm [150 nm WFE @ NIRCam focal plane]

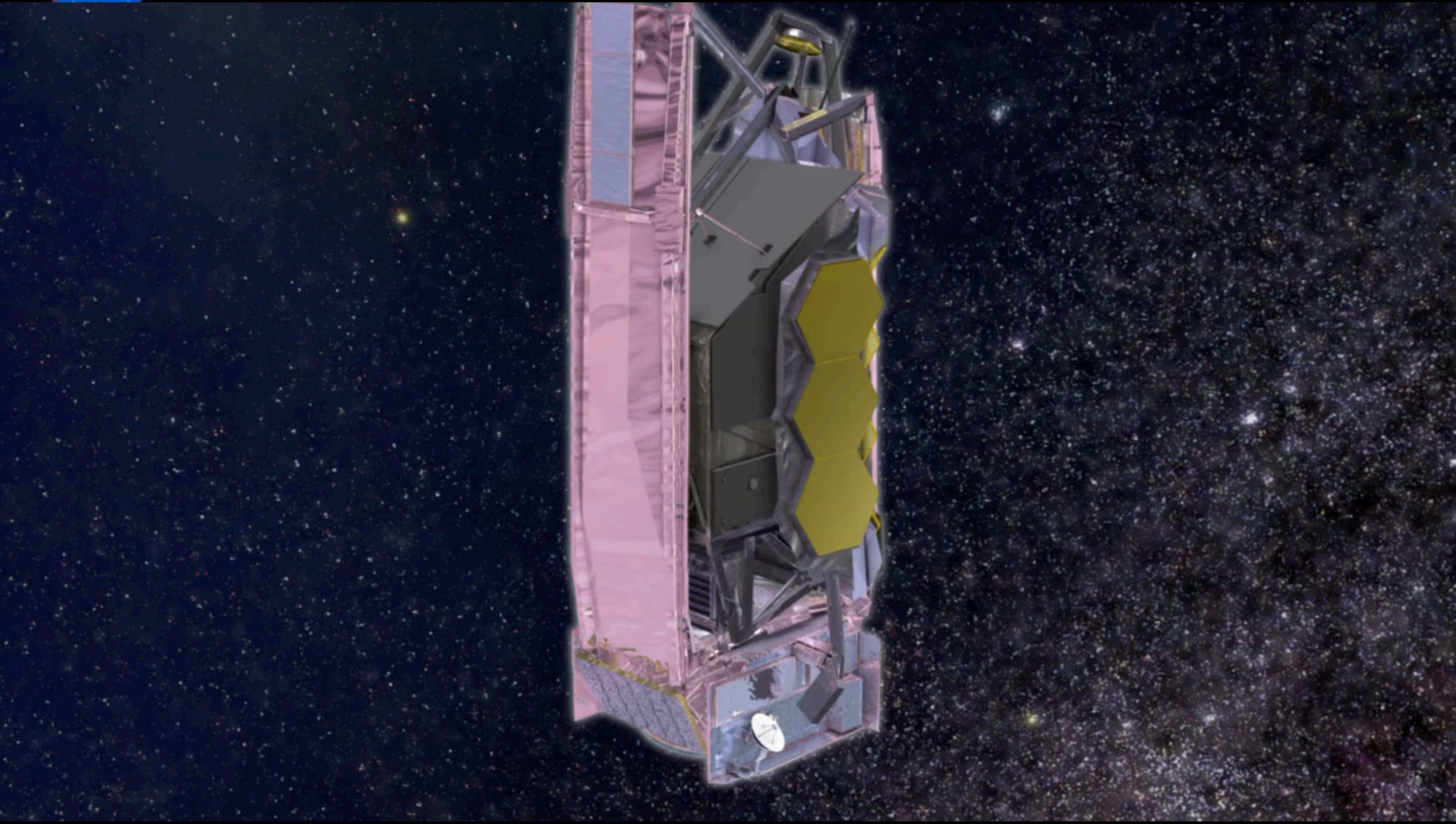
JWST Instrumentation

Instrument	Science Requirement	Capability
NIRCam Univ. Az/LMATC 	Wide field, deep imaging ‣0.6 μm - 2.3 μm (SW) ‣2.4 μm - 5.0 μm (LW)	2.2' x 4.4' SW at same time as 2.2' x 4.4' LW with dichroic Coronagraph
NIRSpec ESA/Astrium 	Multi-object spectroscopy ‣0.6 μm - 5.0 μm	9.7 Sq arcmin Ω + IFU + slits 100 selectable targets: MSA R=100, 1000, 3000
MIRI ESA/Consortium /UKATC/JPL 	Mid-infrared imaging ‣ 5 μm - 27 μm Mid-infrared spectroscopy ‣ 4.9 μm - 28.8 μm	1.9' x1.4' with coronagraph 3.7"x 3.7" – 7.1"x 7.7" IFU R=3000 - 2250
FGS/NIRISS CSA 	Fine Guidance Sensor 0.8 μm - 5.0 μm Near IR Imaging Slitless Spectrometer	Two 2.3' x 2.3' 2.2' x 2.2' R= 700 with coronagraph

JWST Field of Regard

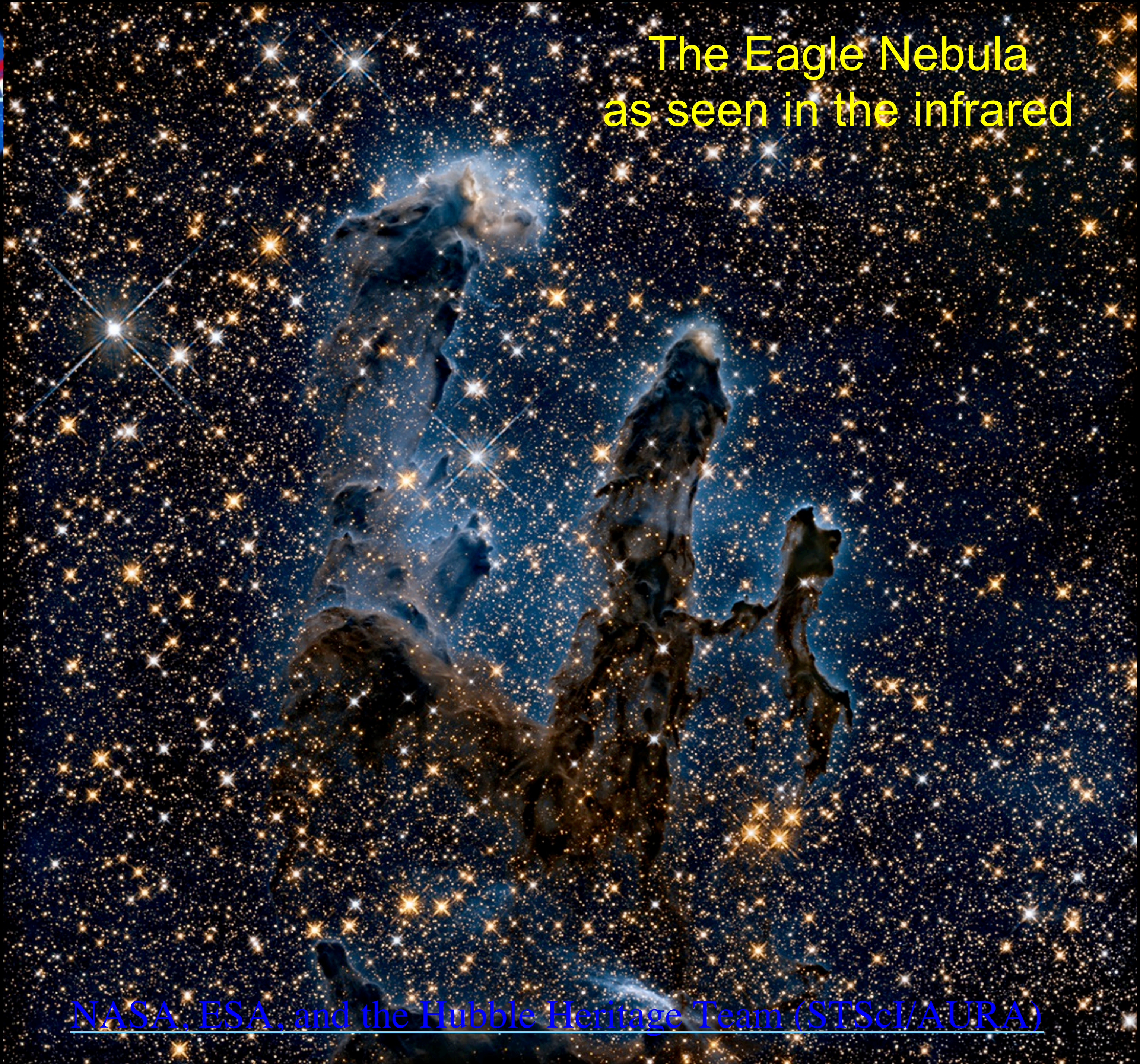


- JWST's optics must always be fully shaded
  - Solar-system observations will be made near quadrature
    - Similar to Spitzer and Herschel observatories



The Eagle Nebula as seen with Hubble

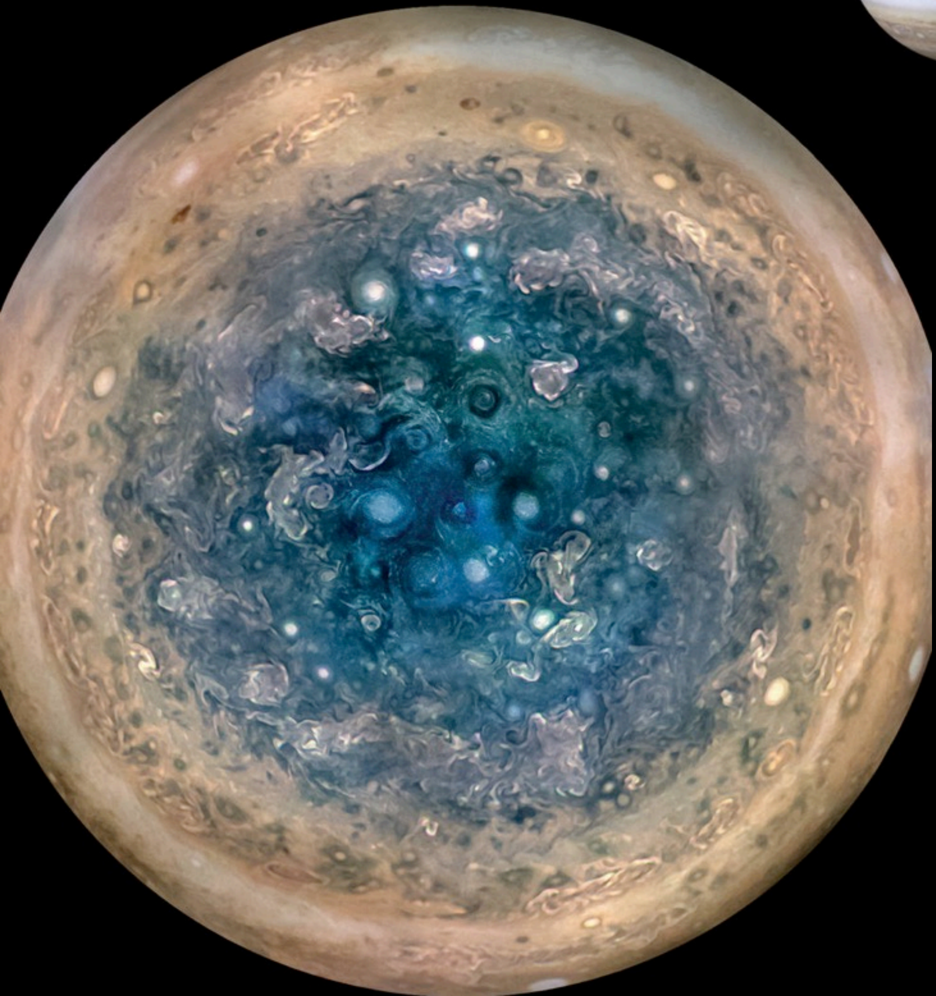
The Eagle Nebula as seen in the infrared



NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

Jupiter's North Pole and clouds seen by Hubble & Juno

NASA / ESA / Goddard / UC Berkeley / JPL-Caltech / STScI



Europa

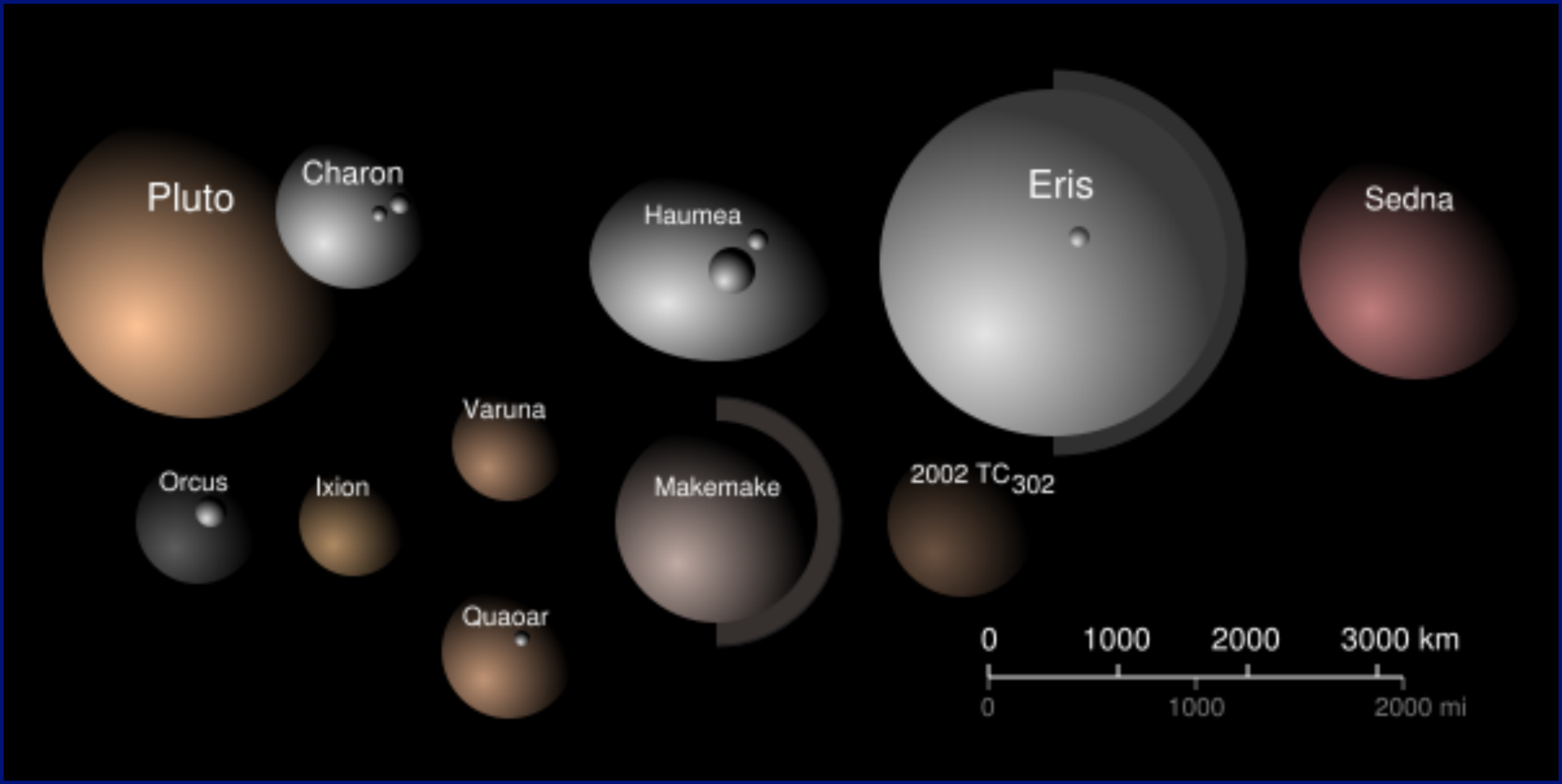
Europa has an ocean, ice sheets, and warm water spritzers

What’s a good landing spot?

Crushed Ice Mountain Shoreline "Sputnik Planum" on Pluto

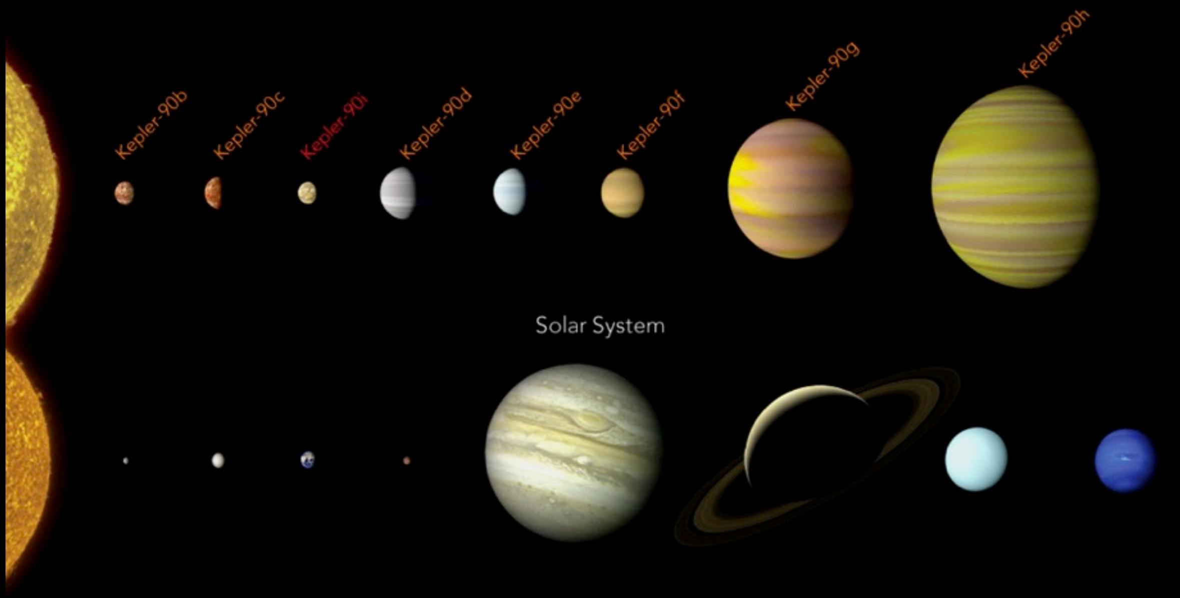
Credit: NASA/ JHUAPL/SwRI

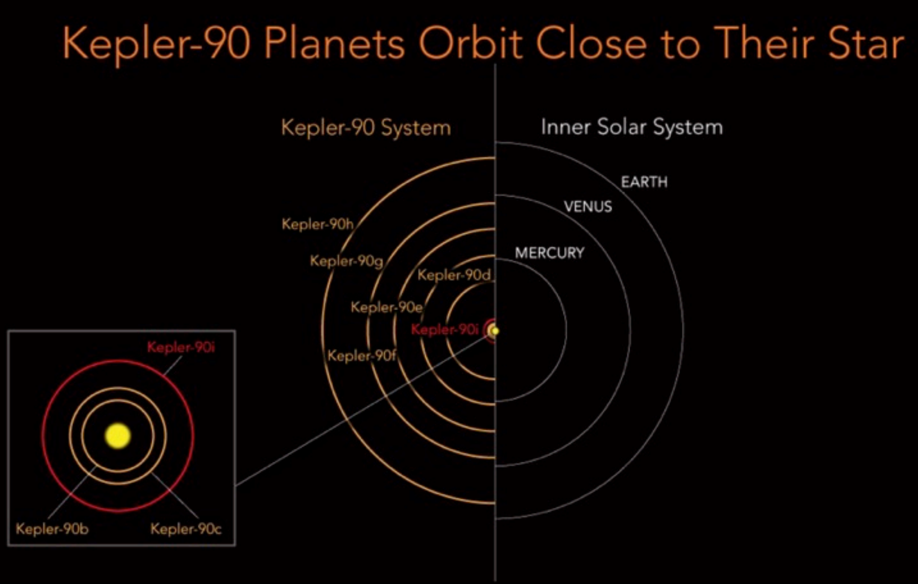
Dwarf Planets and Plutoids



May be 2000 more when whole sky is surveyed
With moving object tracking JWST is perfect tool

Kepler 90, G star with 8 planets





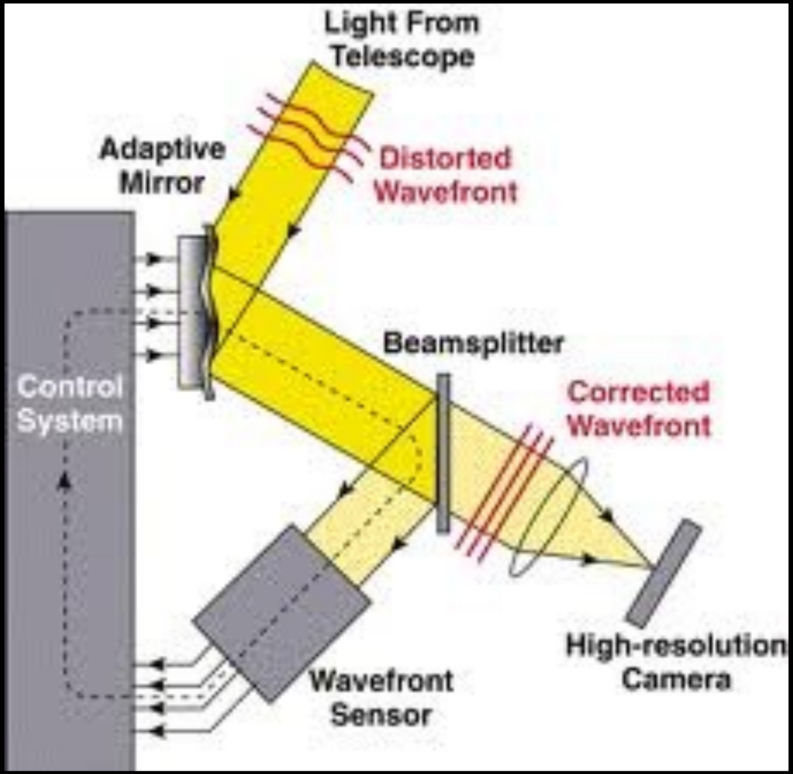
Where is everybody? (Fermi 1950)

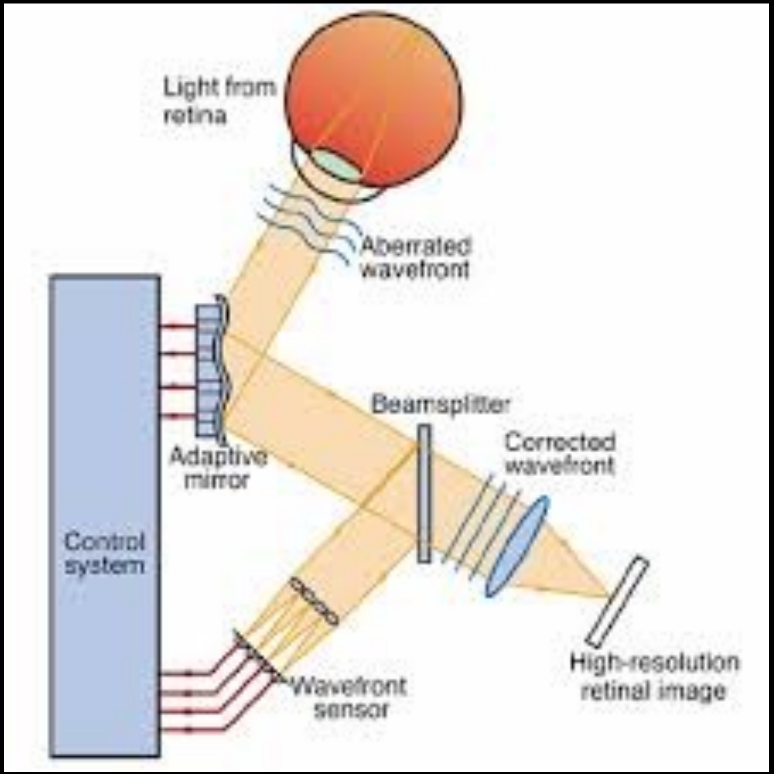
- Intelligence is here for 300 Myr: fish, reptiles, octopus, mammals, birds, insects – but we don’t speak their languages yet
- Interstellar travel barely conceivable, takes many lifetimes at best
- Interstellar conversation possible but slow, IF you know how to tune the receiver and point the antenna: SETI

Planets common, Earth special?

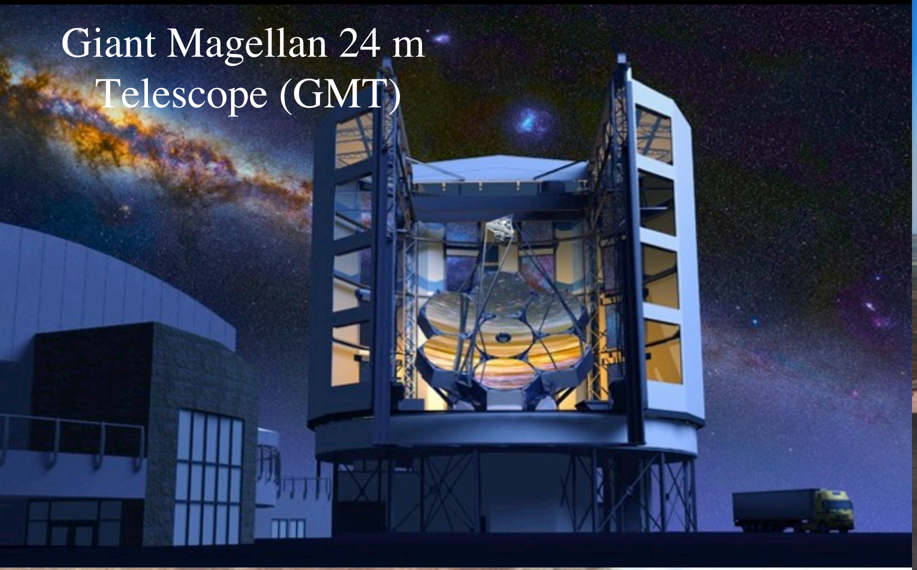
- Right temperature for liquid water
- Stable near-circular orbit
- Big moon, with tides, stabilizing spin axis
- Big magnetic field
- Oceans and continents: just enough water
- Right amount of carbon, nitrogen
- Good star – color right for life, not too dangerous
- Good place, far from black holes and other stars
- Plate tectonics recycles surface, ocean, atmosphere, & make undersea hydrothermal vents (possible proto-life reactor)

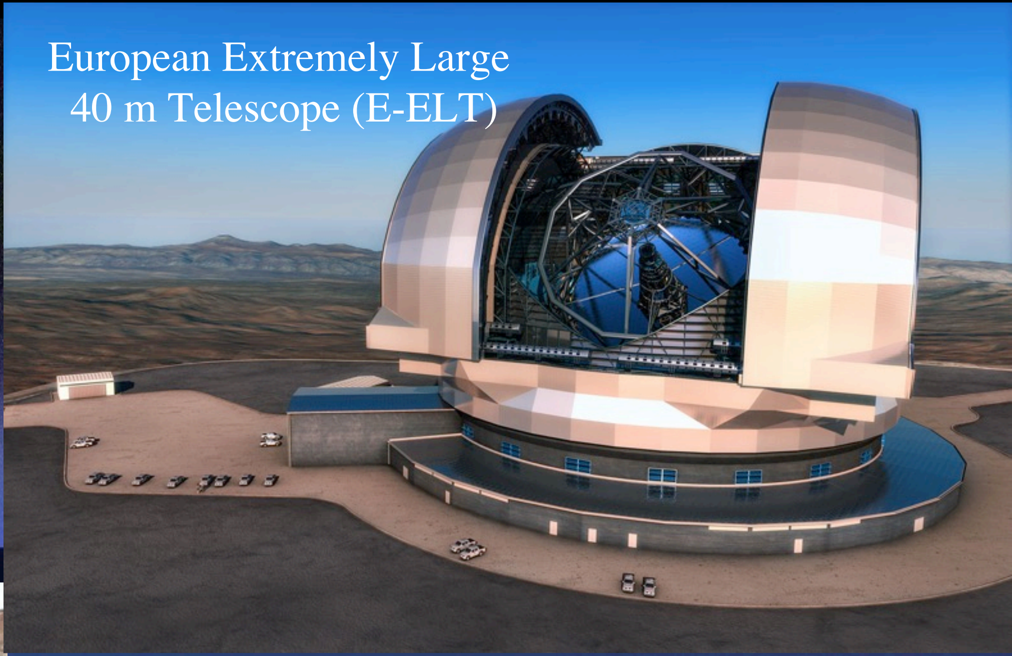
Adaptive Optics was for weapons, now astronomy & football

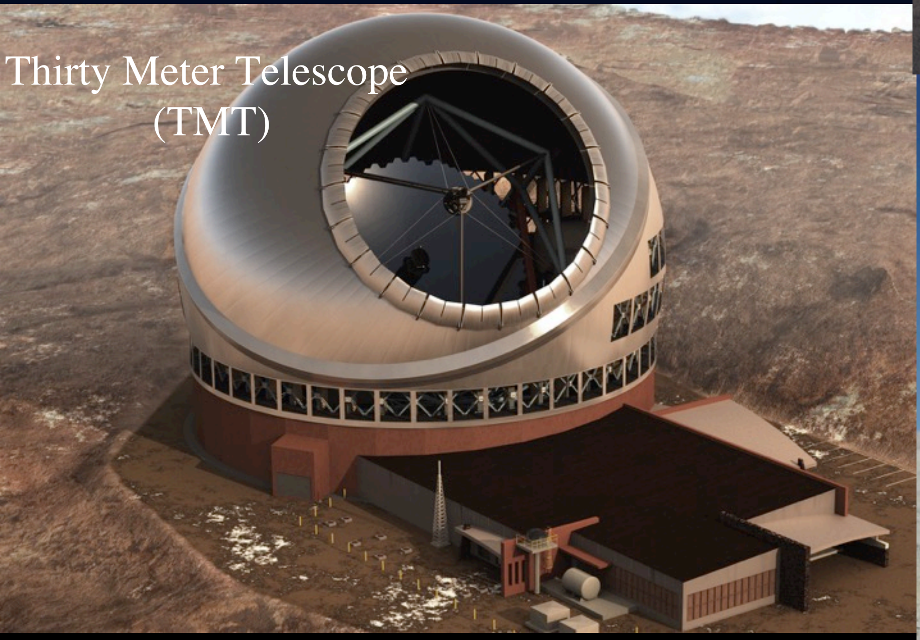




25 meters (1000 inches) and up!

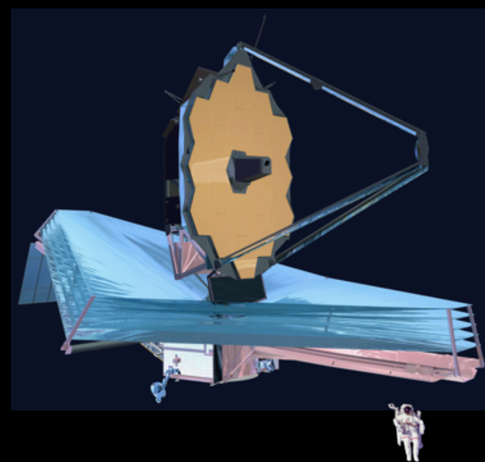




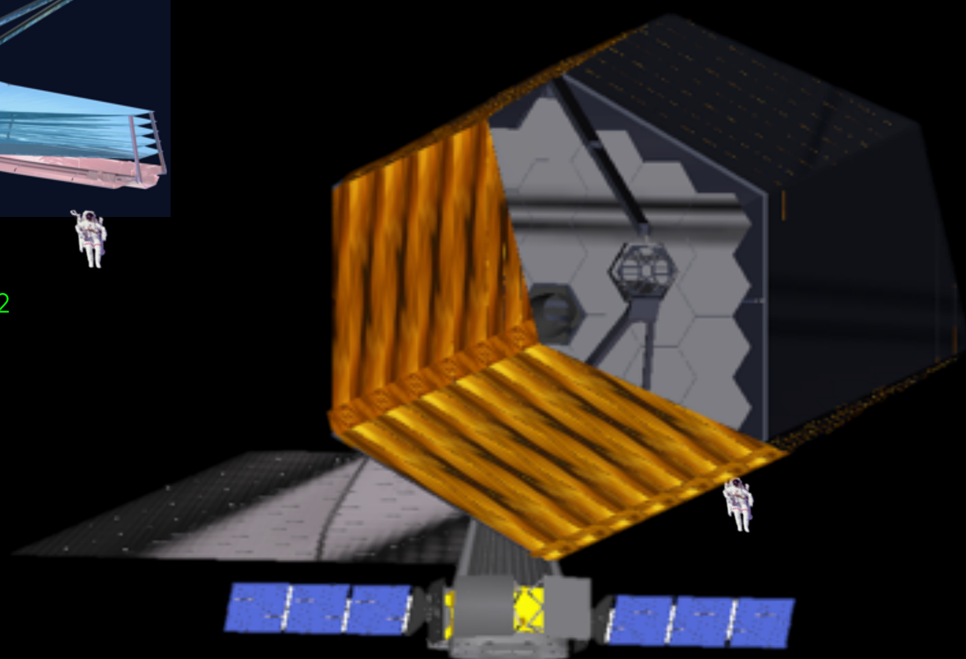


The Search for Life requires larger, lighter space telescopes

2540 kg/m^2

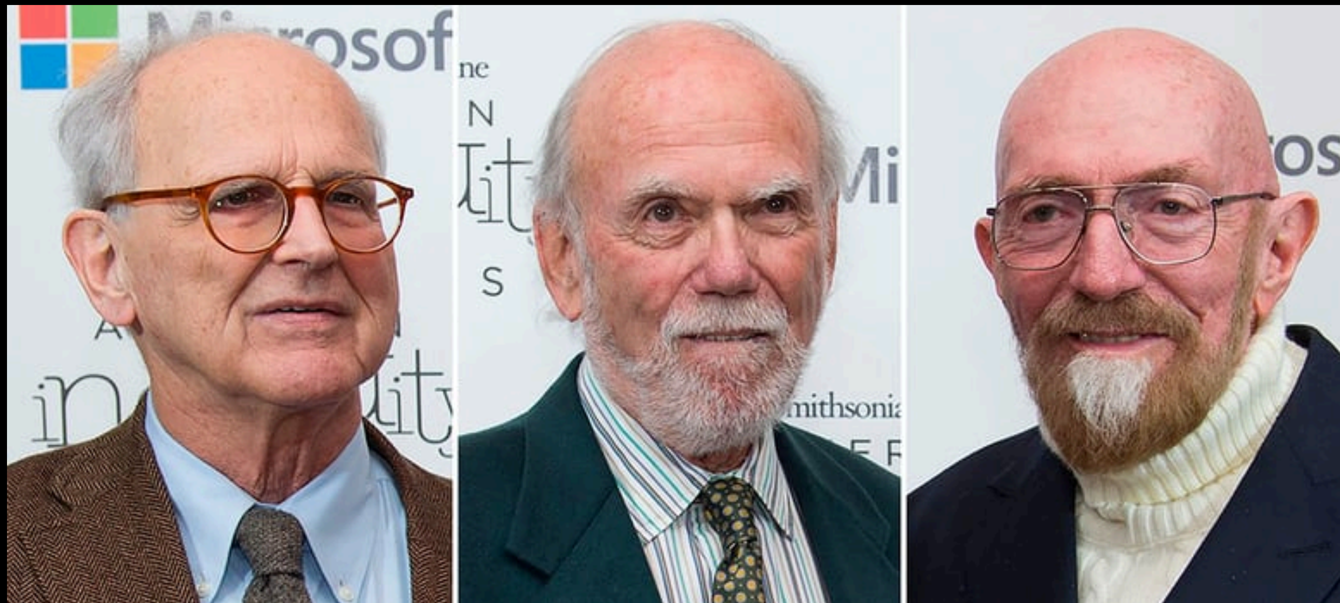


240 kg/m^2



<80 kg/m^2

2017 Nobel Prize in Physics

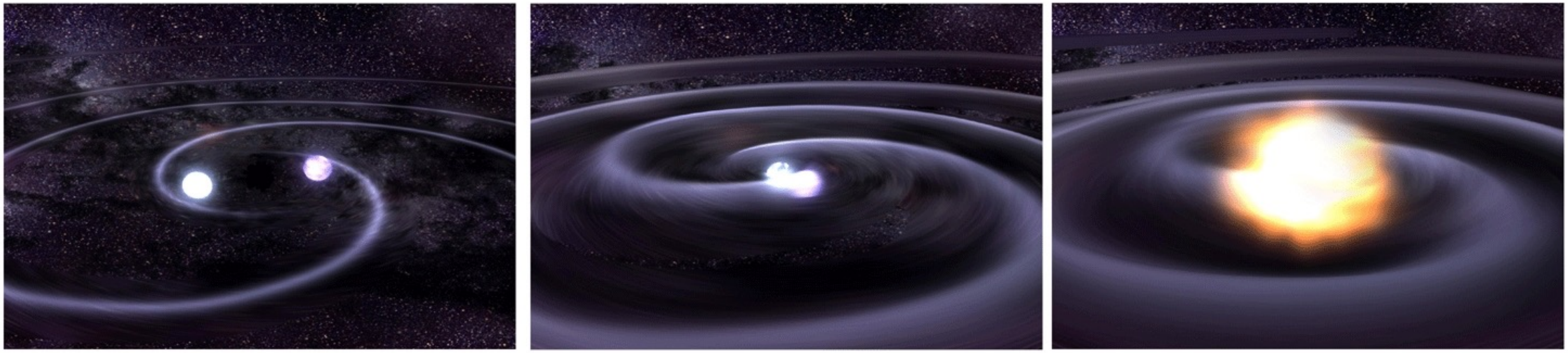


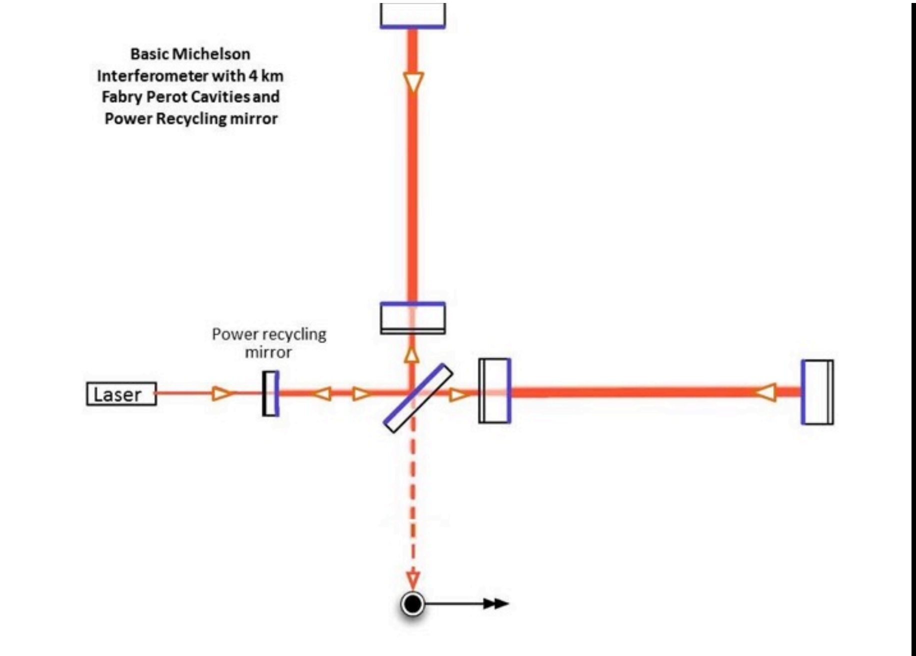
Left to right: Rainer Weiss, Barry Barish and Kip Thorne, who have ben awarded the 2017 Nobel prize in physics. Photograph: Molly Rile y/AFP/Getty Images. In The Guardian.

“The Nobel Prize in Physics 2017 was divided, one half awarded to Rainer Weiss, the other half jointly to Barry C. Barish and Kip S. Thorne *"for decisive contributions to the LIGO detector and the observation of gravitational waves"*.”

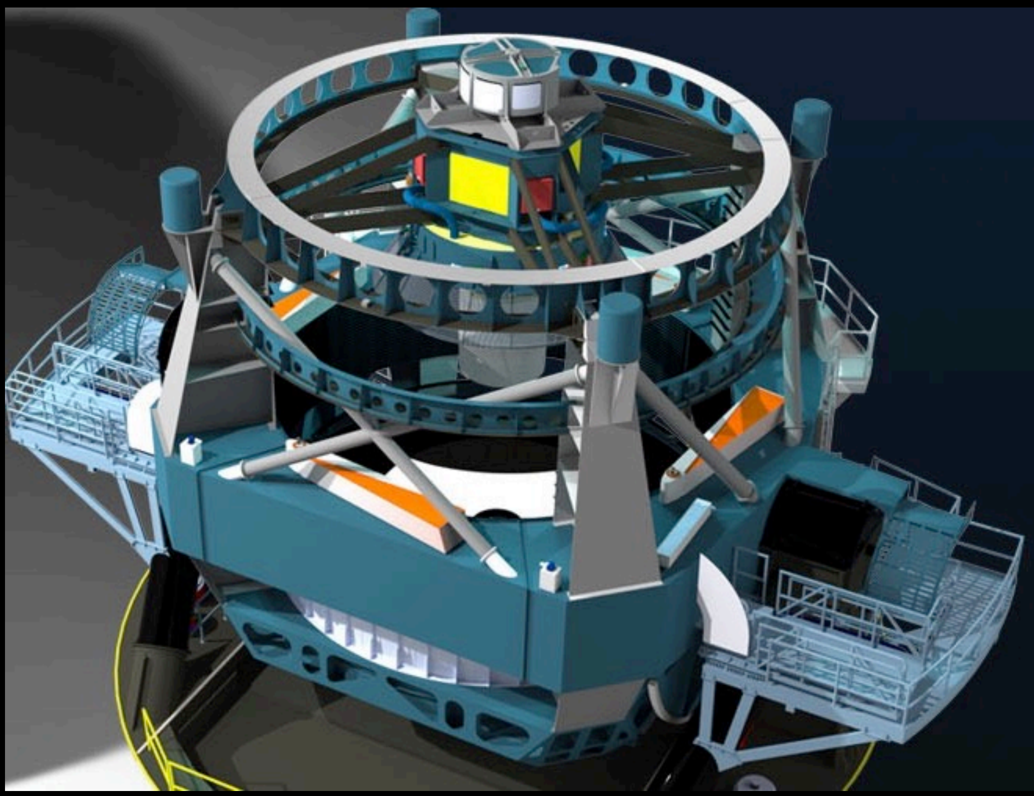
Nobelprize.org

Advanced LIGO (Laser Interferometer Gravitational wave Observatory)





Large Synoptic Survey Telescope
LSST.org



This telescope will produce the deepest, widest, image of the Universe:

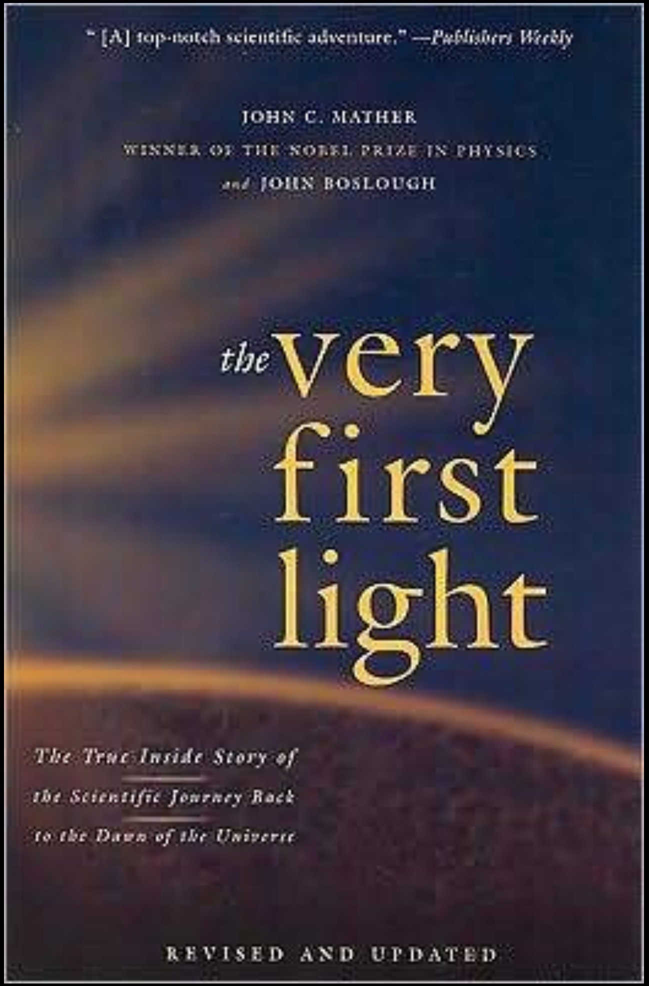
- **27-ft (8.4-m) mirror, the width of a singles tennis court**
- **3200 megapixel camera**
- **Each image the size of 40 full moons**
- **37 billion stars and galaxies**
- **10 year survey of the sky**
- **10 million alerts, 1000 pairs of exposures, 15 Terabytes of data .. every night!**

How far can we go?

- Robots everywhere on or near Earth or undersea (commercial, scientific, military reasons), all the planets, interesting asteroids, comets, moons, …
- Computers getting smarter every year: Chess, Jeopardy, Go,…
  - But who owns and controls them? (hint: not you!)
- People are fragile! chronic exposure to galactic cosmic rays → radiation sickness; unshielded solar flares → death
- Need 4H→ He (or D+T or H + B^{11} or $2xHe^3$ etc.) fusion drive for speed & distance
- Sensors to Alpha Centauri at c/4 by Breakthrough Starshot – laser propulsion and data relay
- Future robots: wherever *they or their owners* want them to go! But space is large, → Star Wars, 2001 Space Odyssey, etc. still fiction in AD 1,000,000,000. Even robots need patience!

More Info:

- http://www.jwst.nasa.gov
- http://lambda.gsfc.nasa.gov/
- http://nobelprize.org
- Book, 2nd Edition:



The End

And the beginning!