Where did we come from, where are we going?

Cosmology to Astrobiology to Space Travel and Space Colonization

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

Jefferson's Implied Question

- How is it, that "the Laws of Nature, and of Nature's God", as he put it, can lead to this: "We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness."

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 (homeostasis, create recognizable identity), destabilize too (balance of nature is temporary)

Lucretius said it…

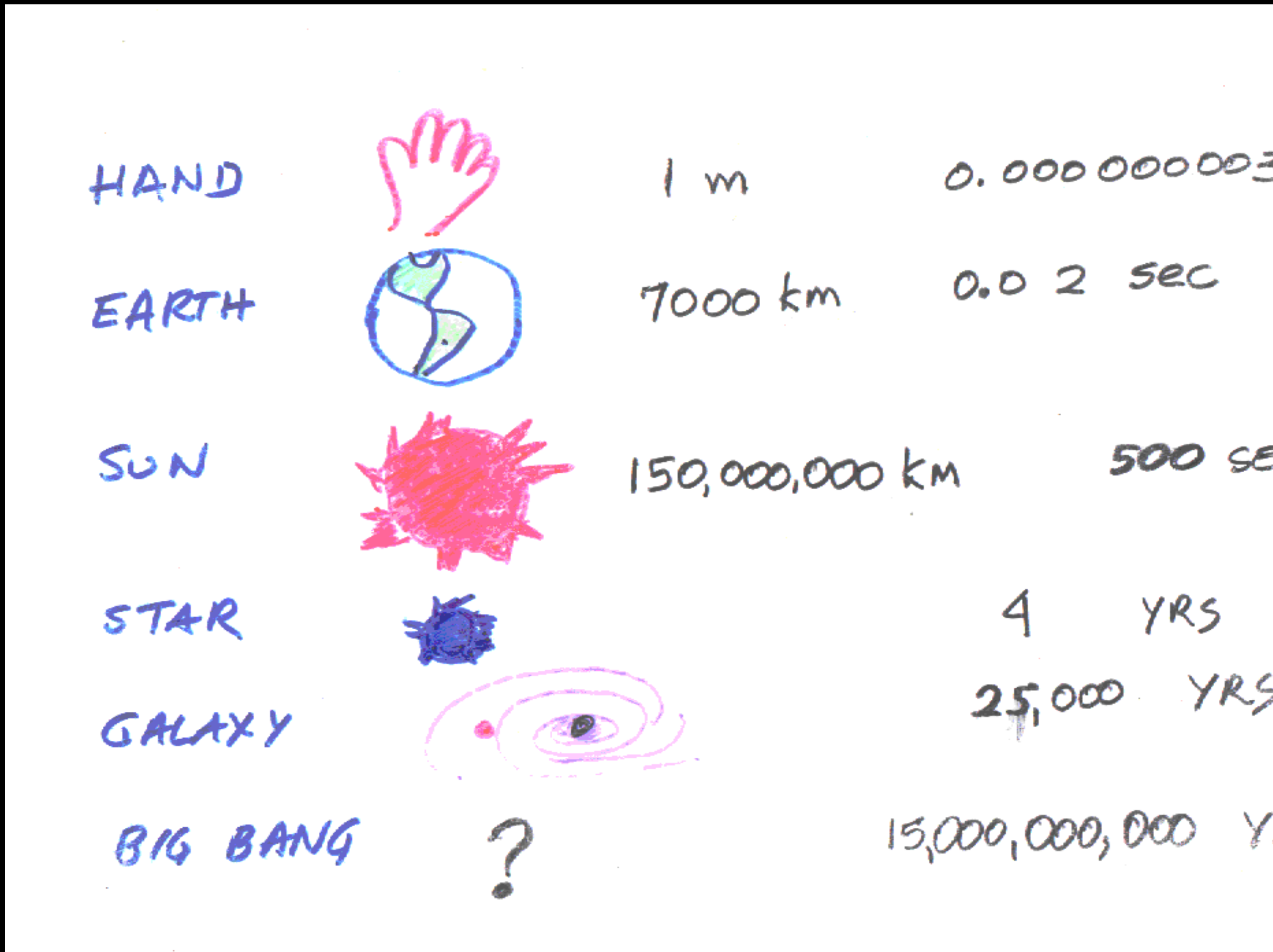
Lucretius (c. 99-55 B.C.)

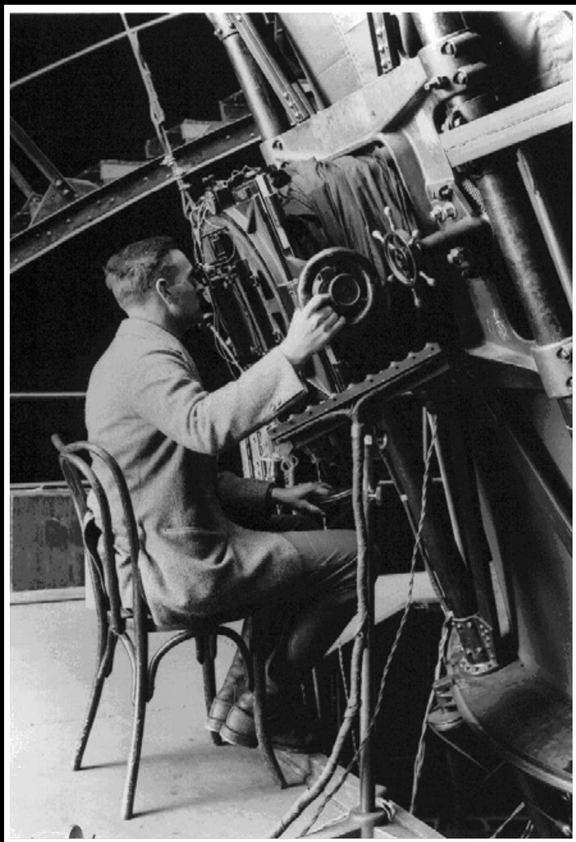
translated by W. H. Mallock

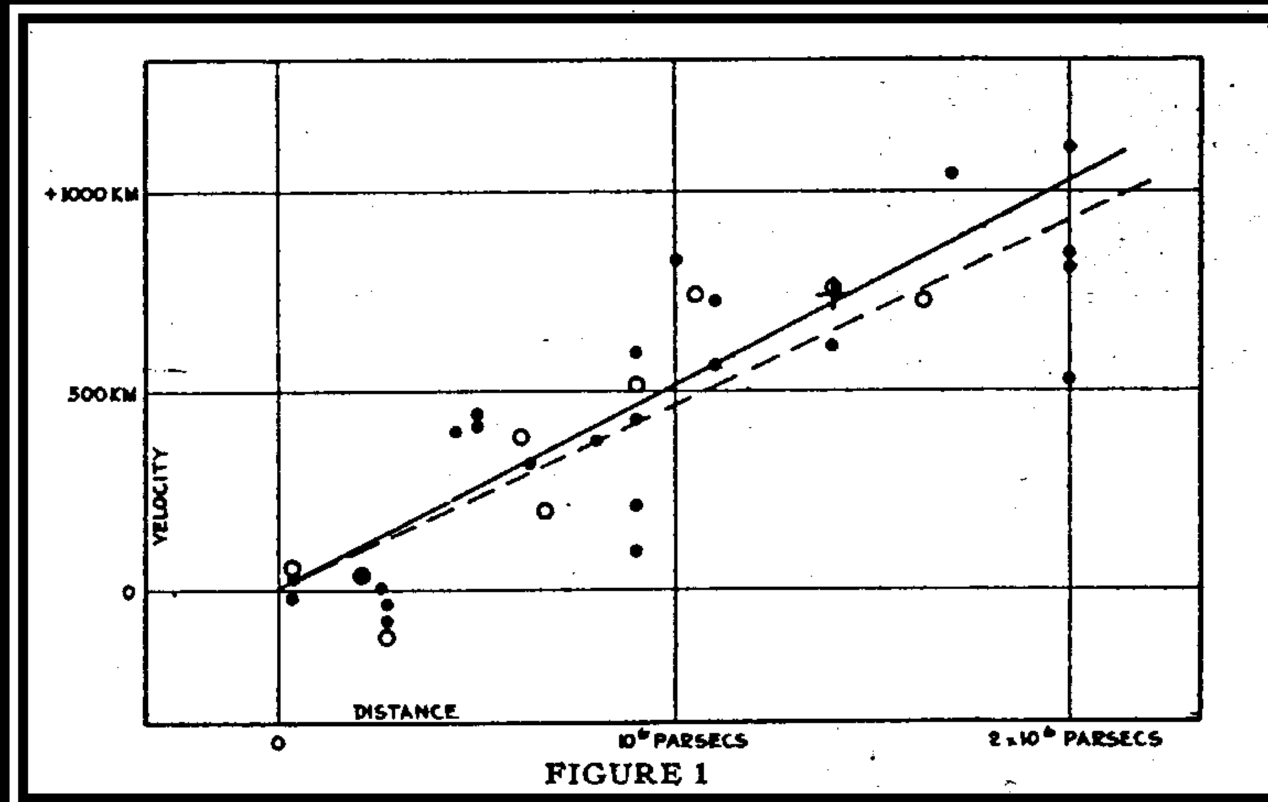
I

No single thing abides; but all things flow.
Fragment to fragment clings--the things thus grow
Until we know and name them. By degrees
They melt, and are no more the things we know.

Looking Back in Time



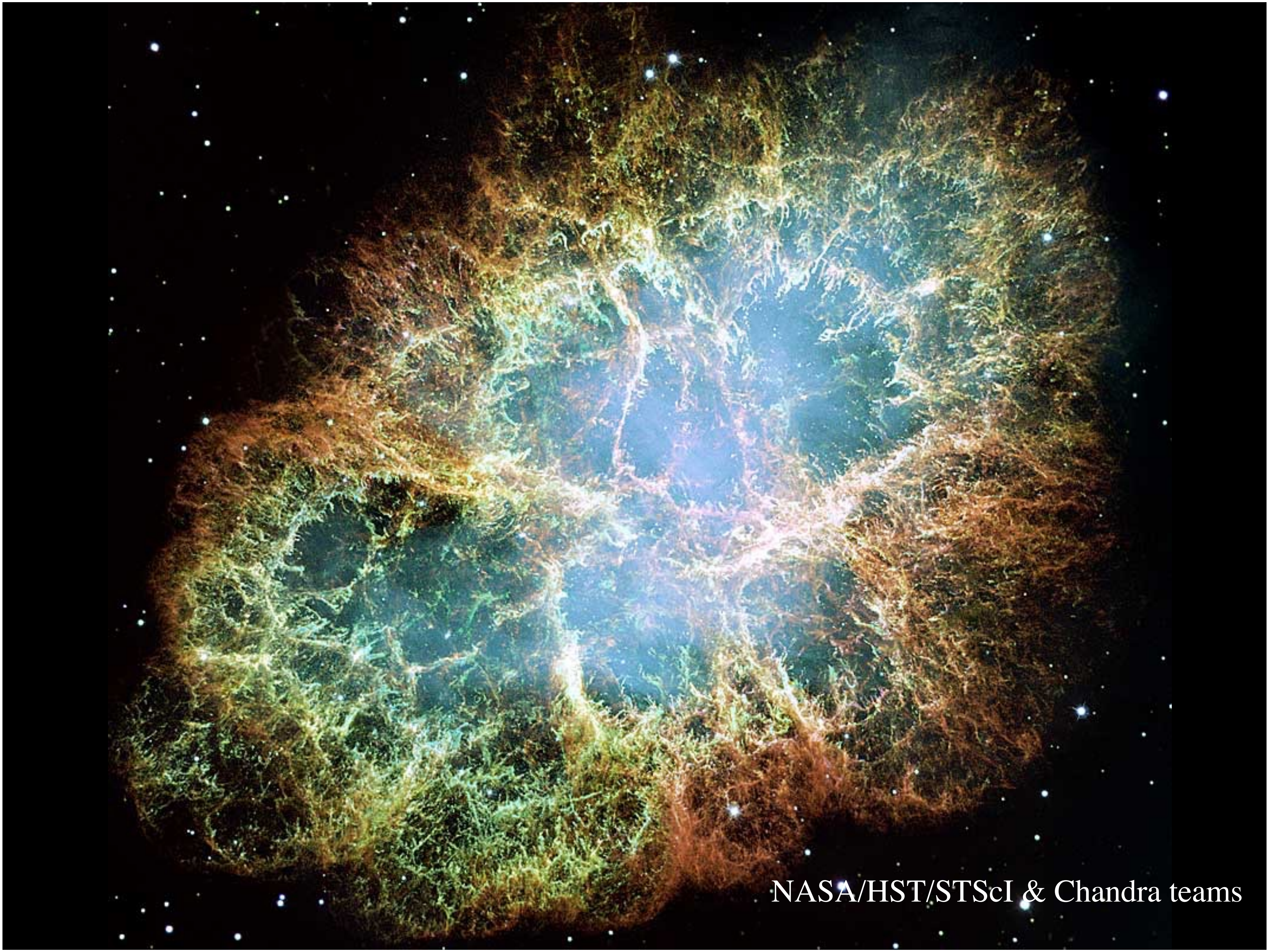



+1000 KM
500 KM
0
VELOCITY
DISTANCE
0
10⁶ PARSECS
2 x 10⁶ PARSECS
FIGURE 1

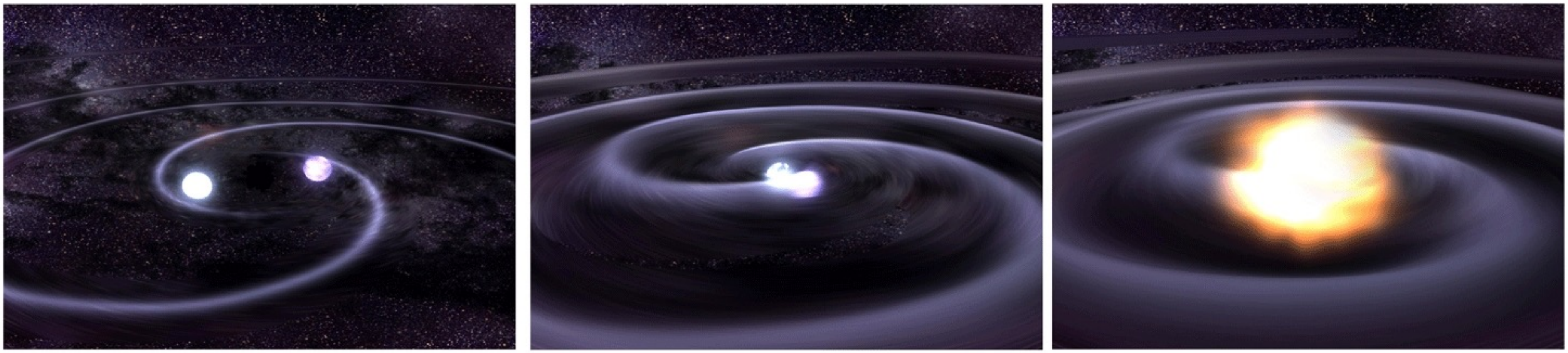
1929

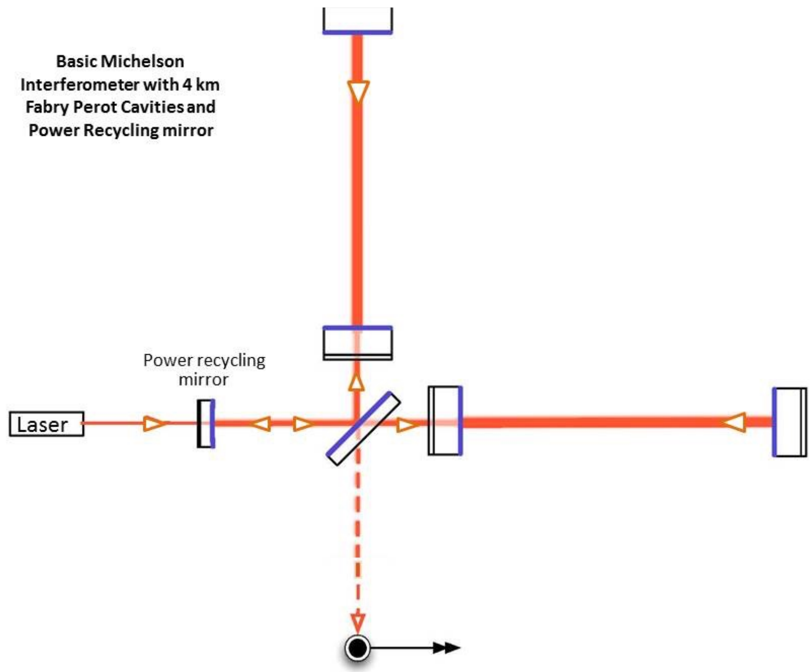
The early universe

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…

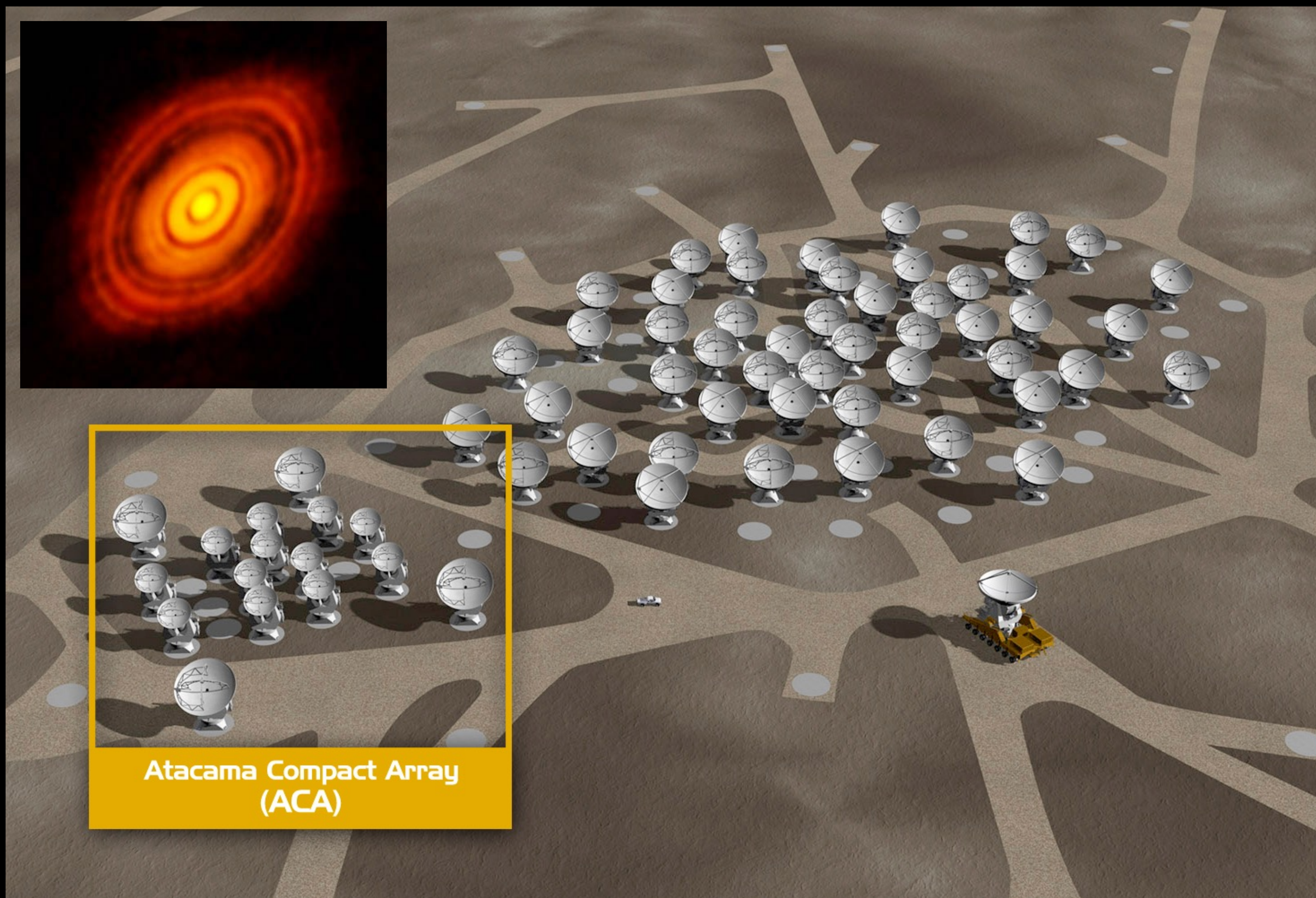

NASA/HST/STScI & Chandra teams

Advanced LIGO (Laser Interferometer Gravitational wave Observatory) observed neutron star mergers, source of heavy elements

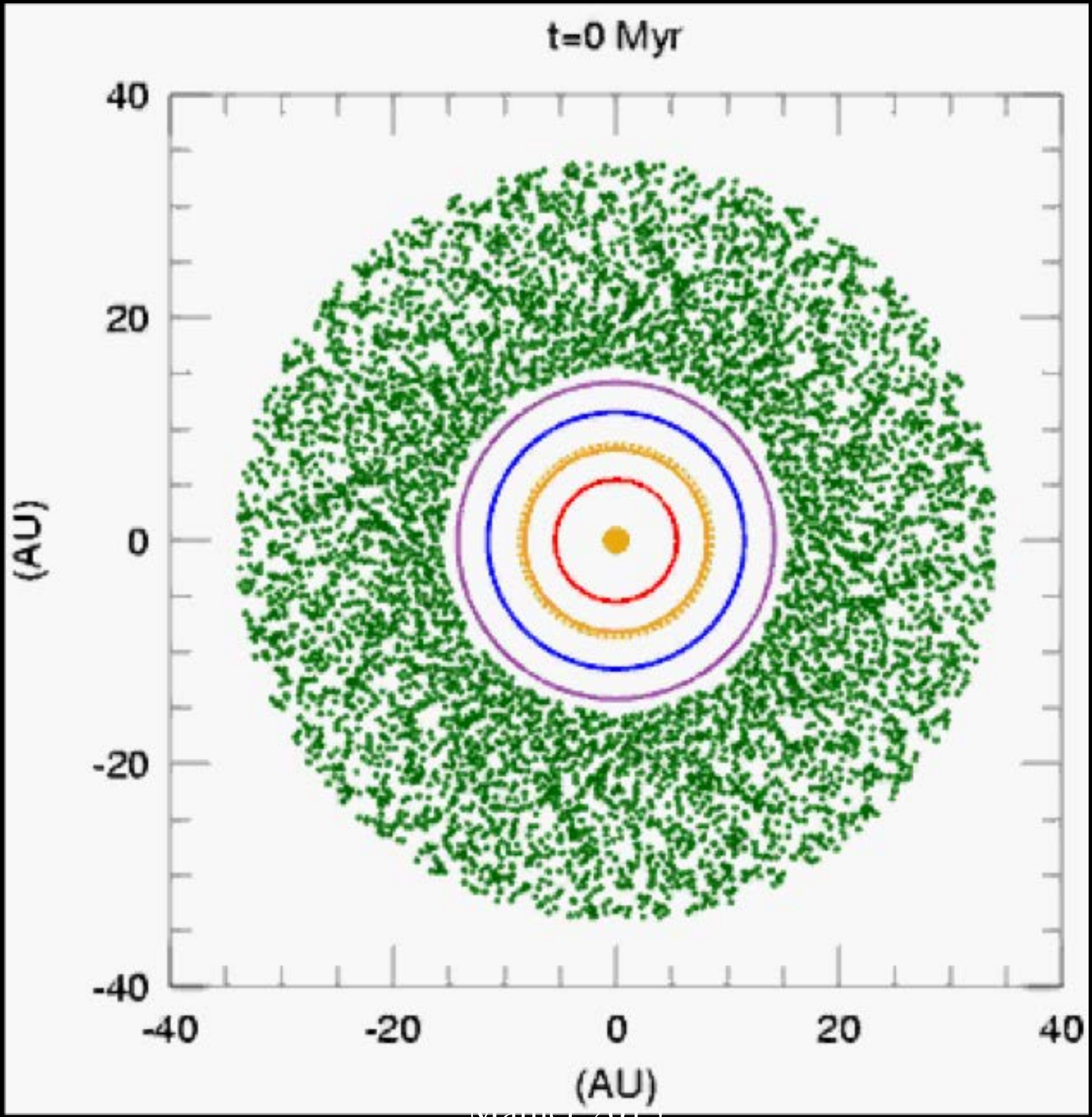




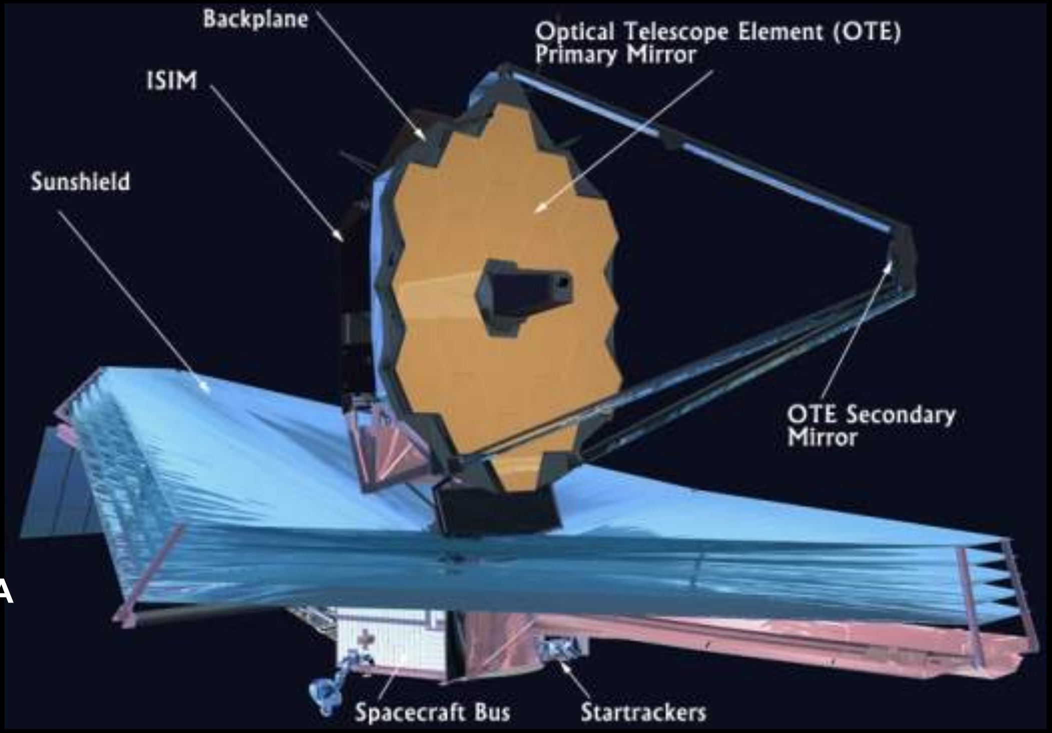
ALMA (Atacama Large Millimeter Array) sees proto-planetary disk



Possible Early Solar System



James Webb Space Telescope (JWST)



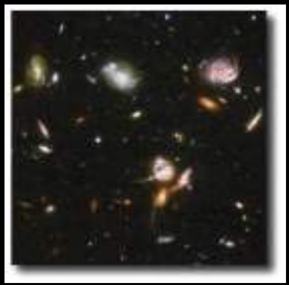
Organization

- 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)

JWST Science Themes



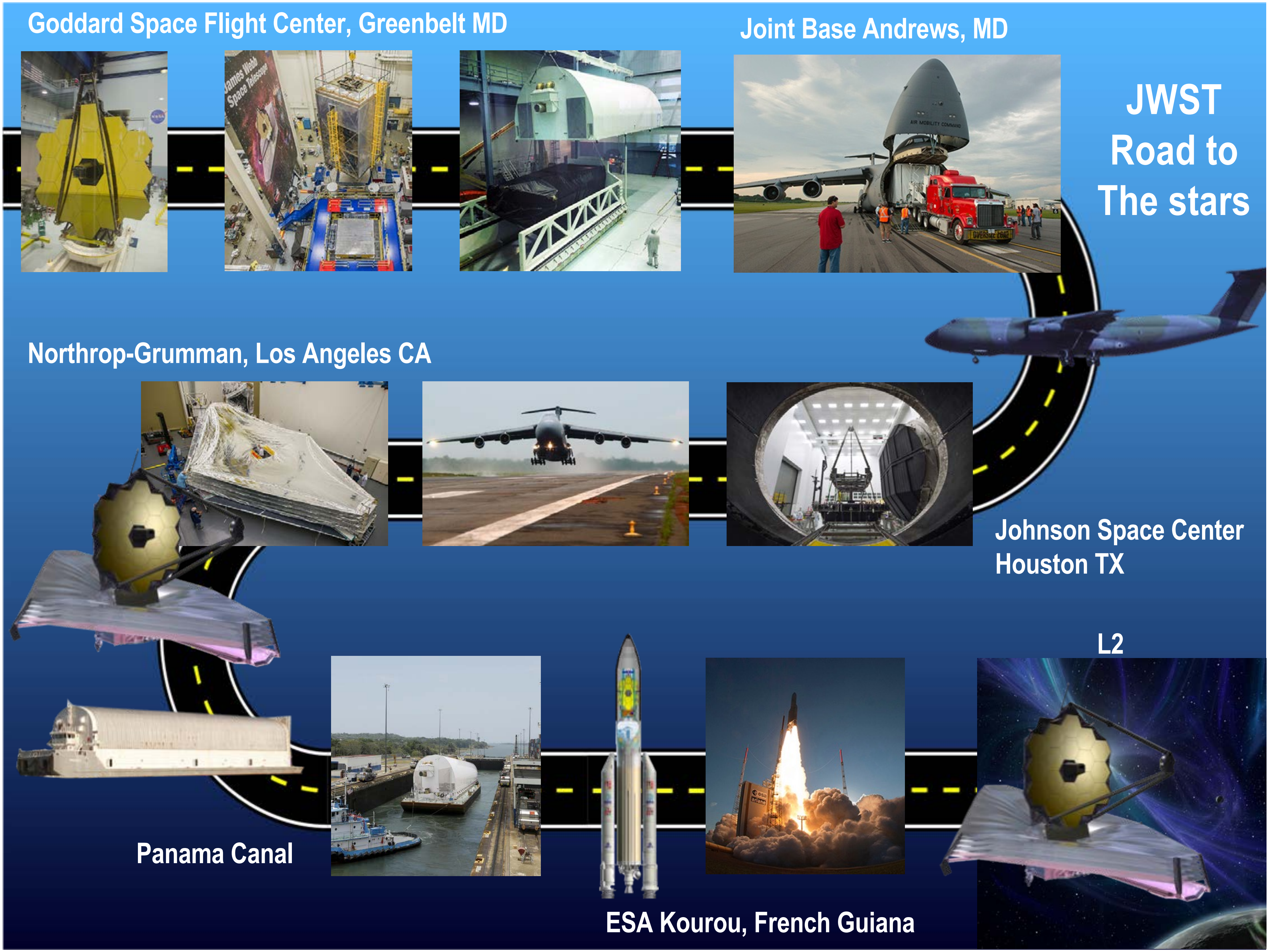
End of the dark ages: First light and reionization

The assembly of galaxies

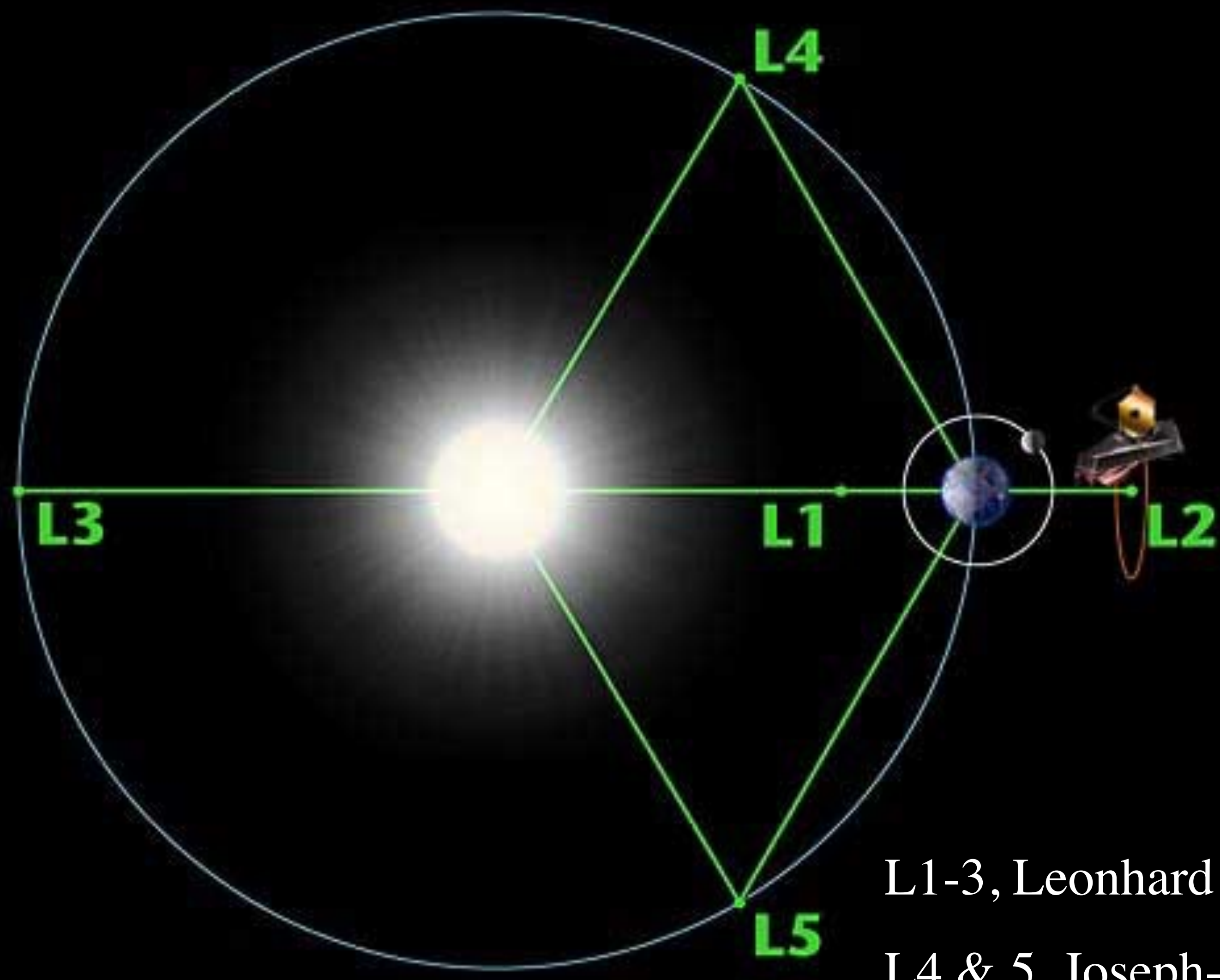
Birth of stars and proto-planetary systems

Planetary systems and the origin of life

www.JWST.nasa.gov


Goddard Space Flight Center, Greenbelt MD
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

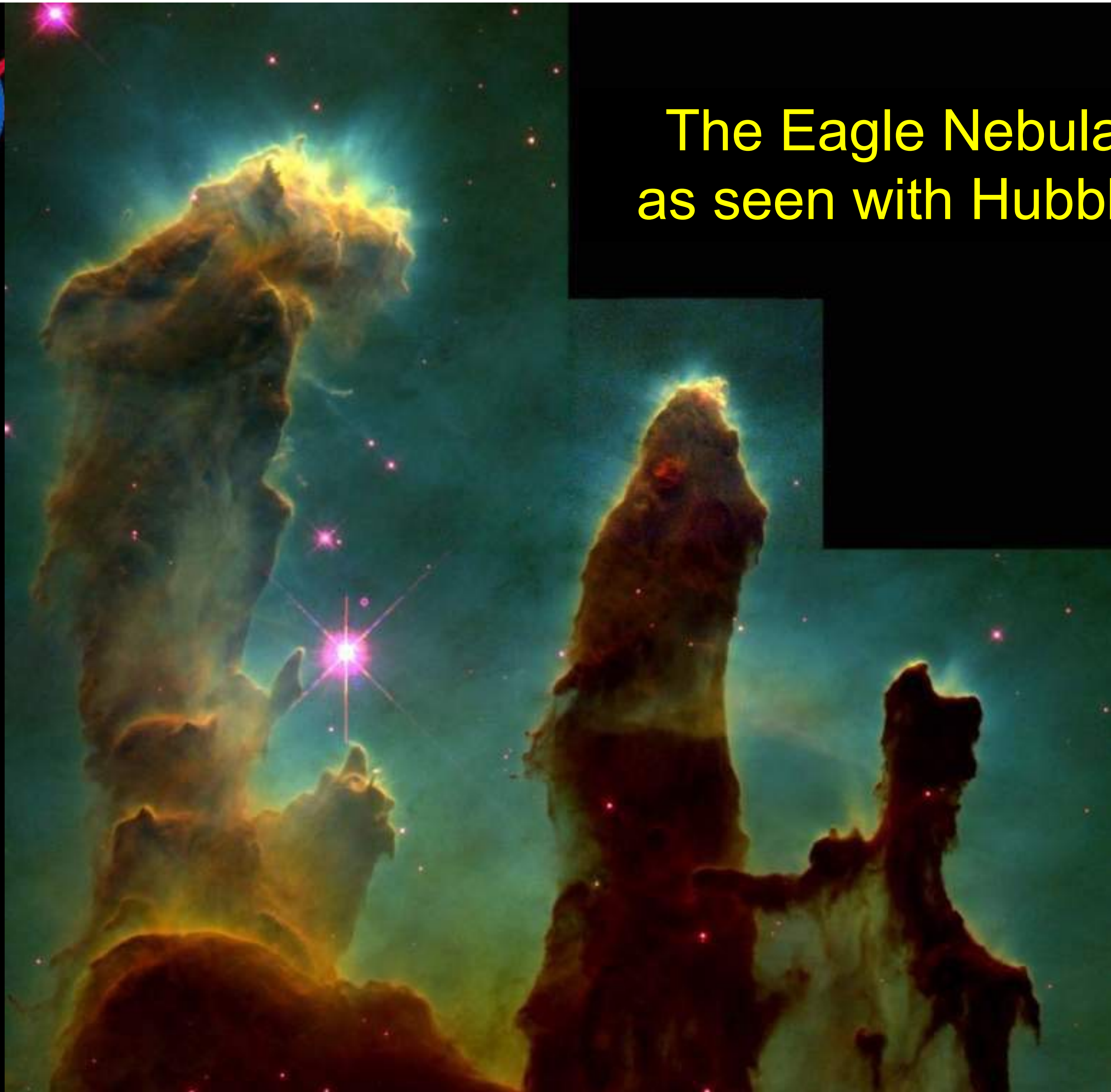
JWST Orbits the Sun-Earth Lagrange Point L2

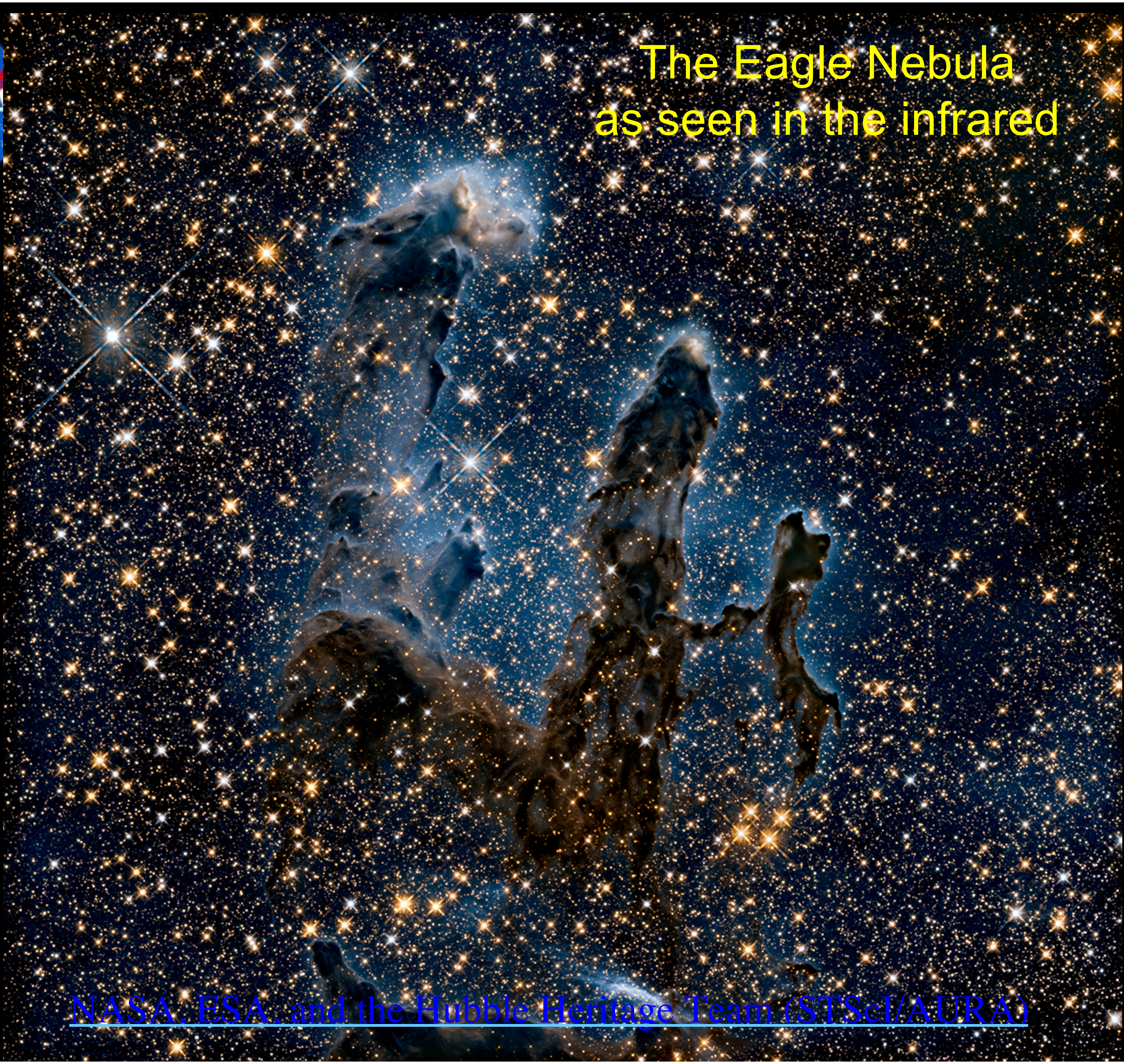


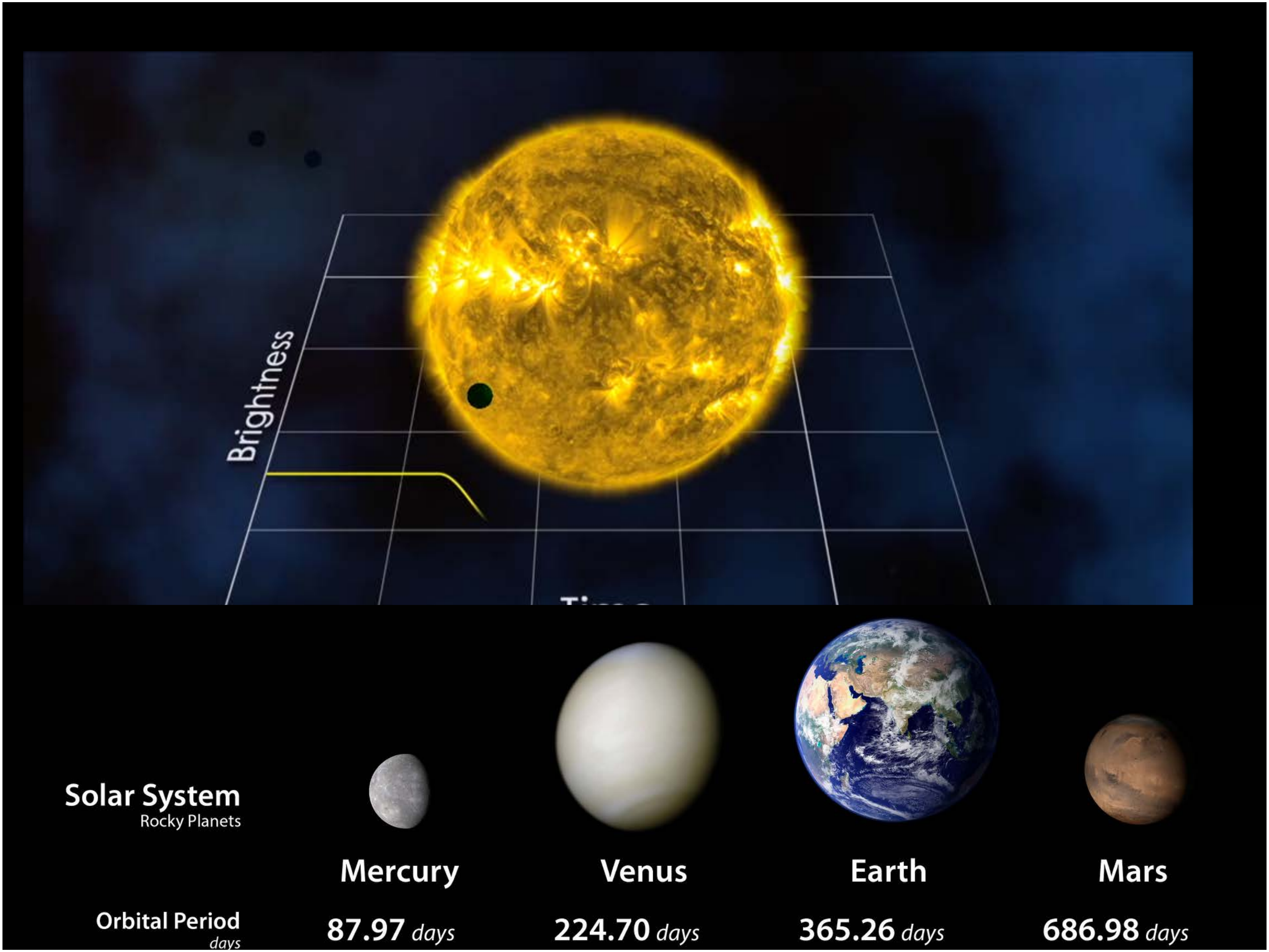
L1-3, Leonhard Euler, 1750.

L4 & 5, Joseph-Louis Lagrange, 1772

The Eagle Nebula as seen with Hubble

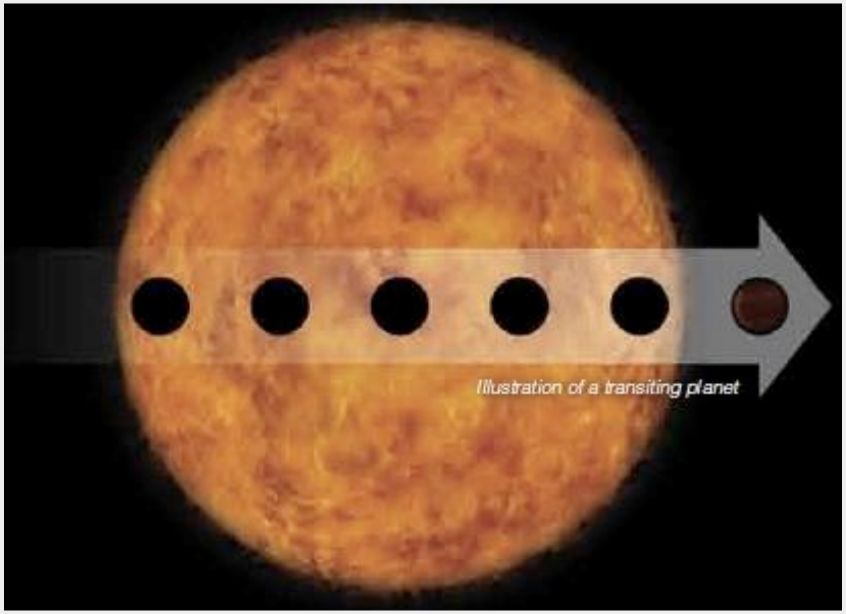


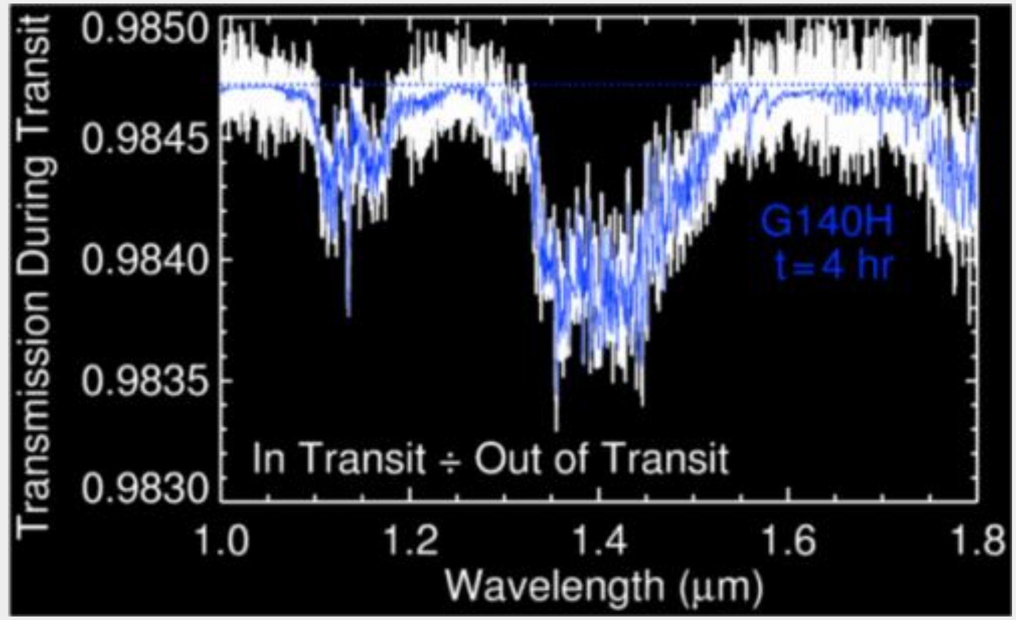

The Eagle Nebula
as seen in the infrared
NASA, ESA, and the Hubble Heritage Team (STScI/AURA)


Brightness
Solar System
Rocky Planets
Mercury
Venus
Earth
Mars
Orbital Period
days
87.97 days
224.70 days
365.26 days
686.98 days

The James Webb Space Telescope

JWST Science Themes – The Origins of Life





Atmospheric transmission spectrum (4 hours) for HD209458-like Kepler source using NIRSpec (R=3000).
Simulation from J. Valenti

JWST Questions

1.) How do planets Form?

2.) What are the properties of circumstellar disks like our solar system?

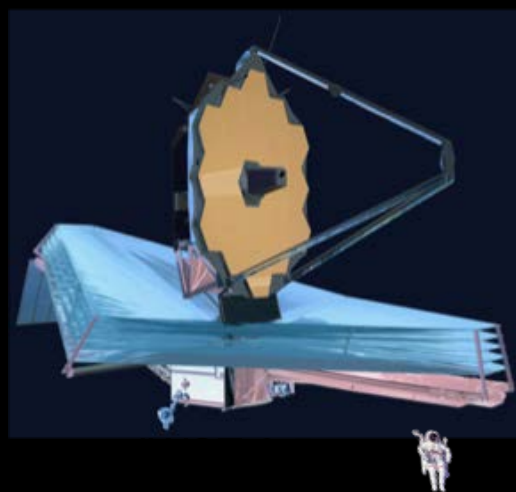
3.) What criteria should be used to establish habitable zones?

4.) Is there evidence for liquid water on exoplanets?

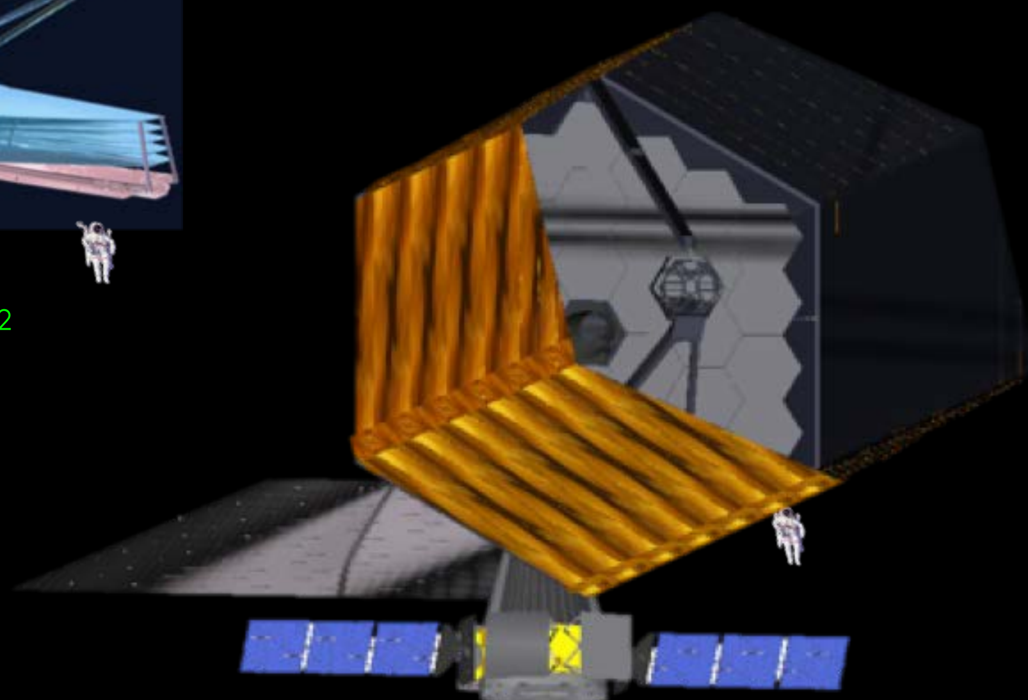
→ JWST will detect water in habitable zone super Earths

The Search for Life requires larger, lighter space telescopes

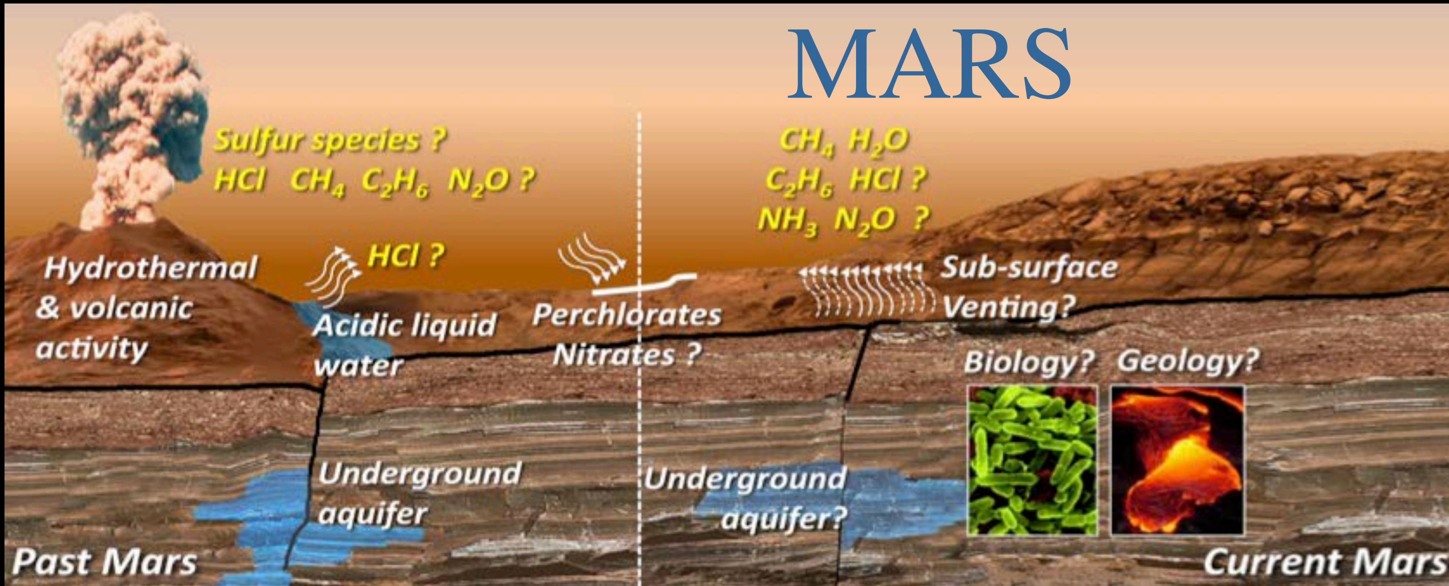
2540 kg/m^2



240 kg/m^2



<80 kg/m^2



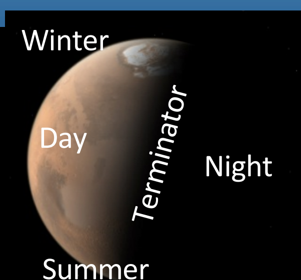
Past/current habitability?

Was Mars Wet? and how much water is currently available?

Stability of the polar caps, surface regolith and atmosphere.

The unique value of the JWST L2 orbit

- *Seasonal studies, including the stability of the polar caps.*
- *Diurnal studies and of processes near the day/night terminator.*
- *Transient events.*

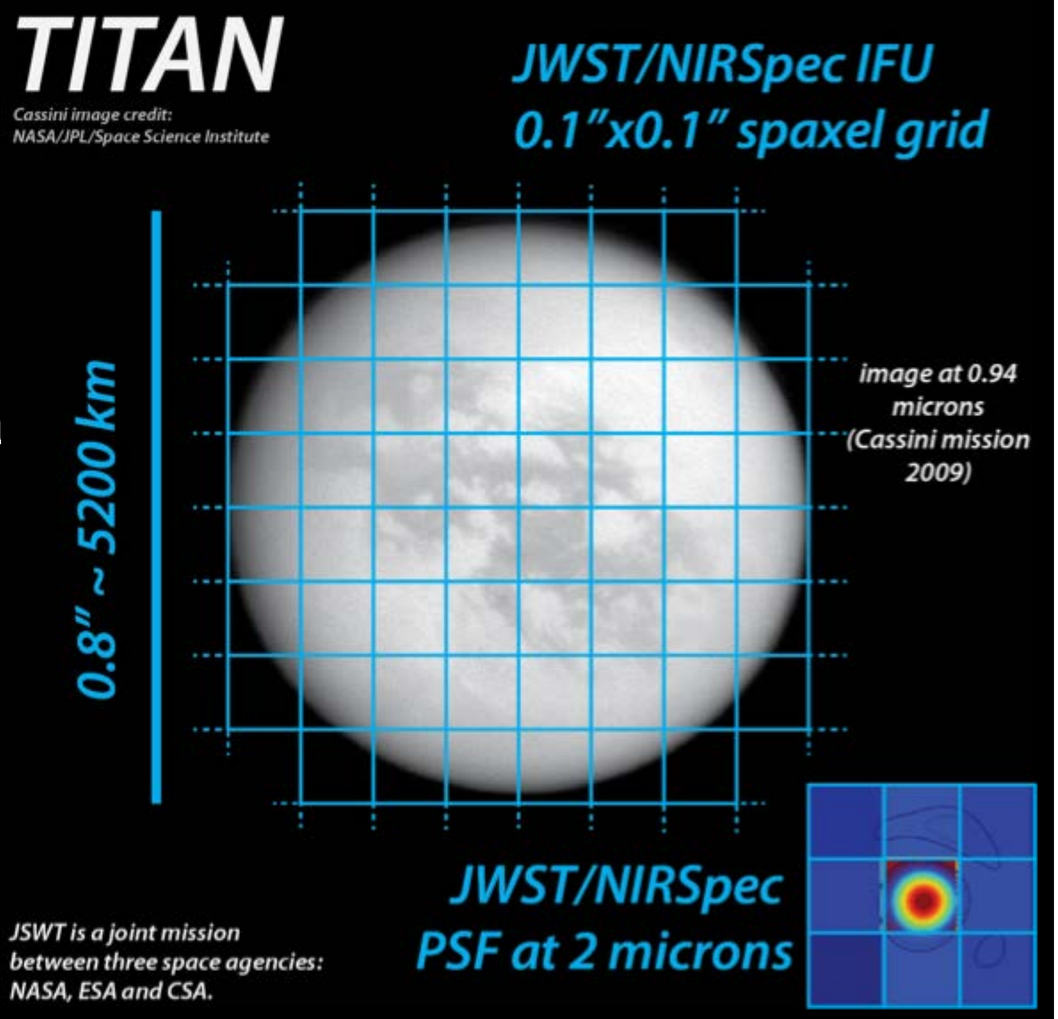


New Frontiers with JWST

- *Maps of water D/H: revealing possible exchange reservoirs on Mars*
- *Photochemical cycles of CO_2, CO, H_2O and other key trace species: characterizing the climate and the active chemistry.*
- *Formation and evolution of global dust storms and cloud systems over volcanoes.*

Icy Satellites

- Europa
  - Hydrated minerals
  - Chemistry
- Titan
  - IFU spectral imaging of Tita to build on the 2004-2017 Cassini mission survey
- Other Satellites
  - Characterize surface
  - Seasonal variations
  - Chemical composition



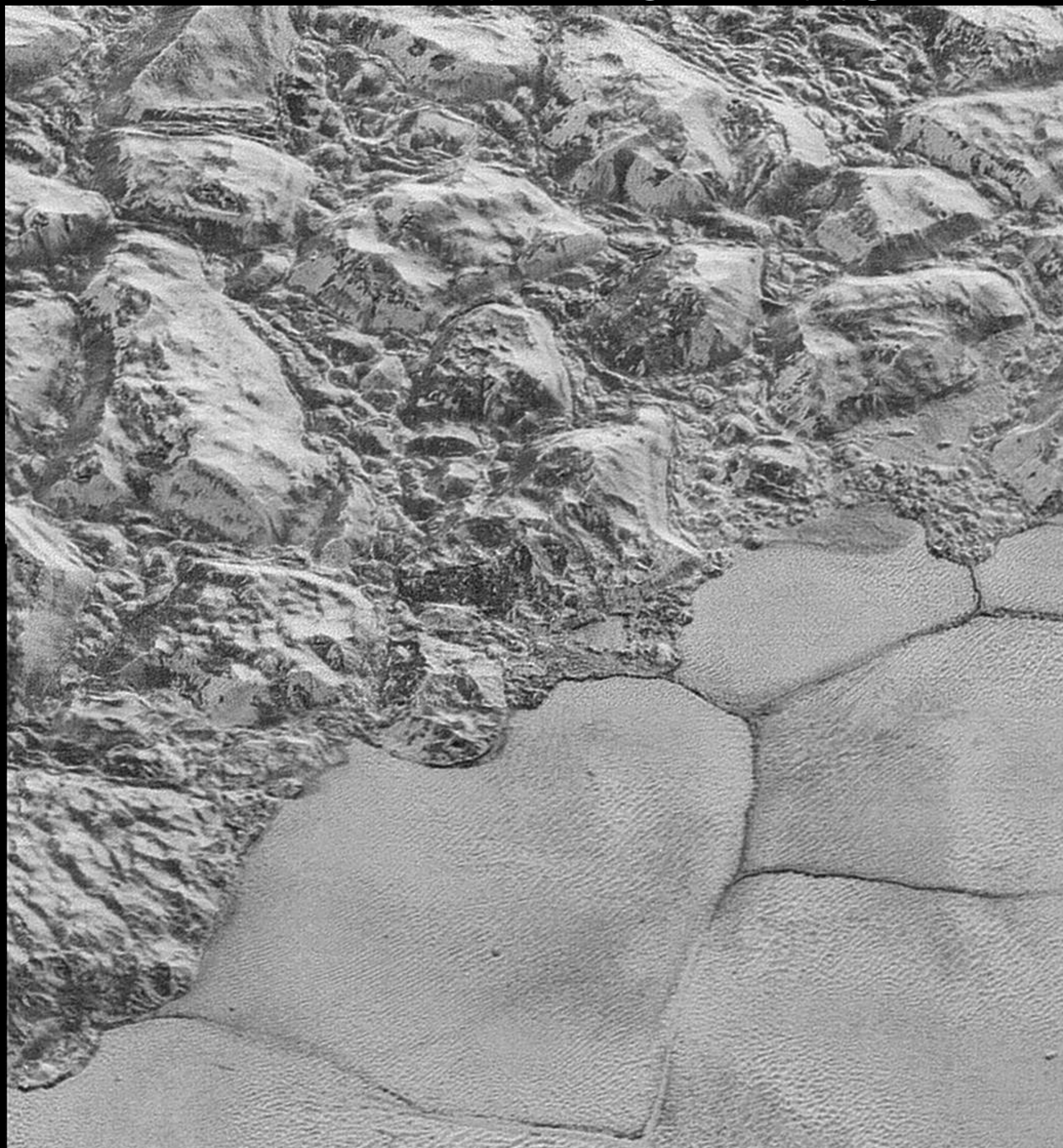

Europa
Europa has an ocean, ice sheets, and warm water spritzers
What’s a good landing spot?

Titan, cold version of Earth

- Satellite of Saturn
- Rain, rivers, lakes (methane, ethane, etc.)
- Mountains and valleys (water ice)
- Atmospheric chemistry (nitrogen and hydrocarbons), 1.45 x Earth pressure, hazy, T = 94 Kelvin
- Possibility of subsurface water ocean
- Possibility of cryo-volcanism (water/ammonia as lava)
- Internal heating from tides
- If life doesn't have to be like home, look here!

Surface of Titan seen by Huygens lander from Cassini ESA/NASA/JPL/University of Arizona

Crushed Ice Mountain Shoreline "Sputnik Planum" on Pluto



Credit: NASA/JHUAPL/SwRI

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)

Astrobiology

- In 1990, little was known
- 1999, Dan Goldin appointed Barry Blumberg (NP 1976 for Hep B vaccine) to lead NASA's Astrobiology Institute
- Money, proposals, ideas, publications
- At least 2 peer-reviewed journals:
  - *International Journal of Astrobiology*
  - *Astrobiology* (journal)
- http://astrobiology.com , https://nai.nasa.gov

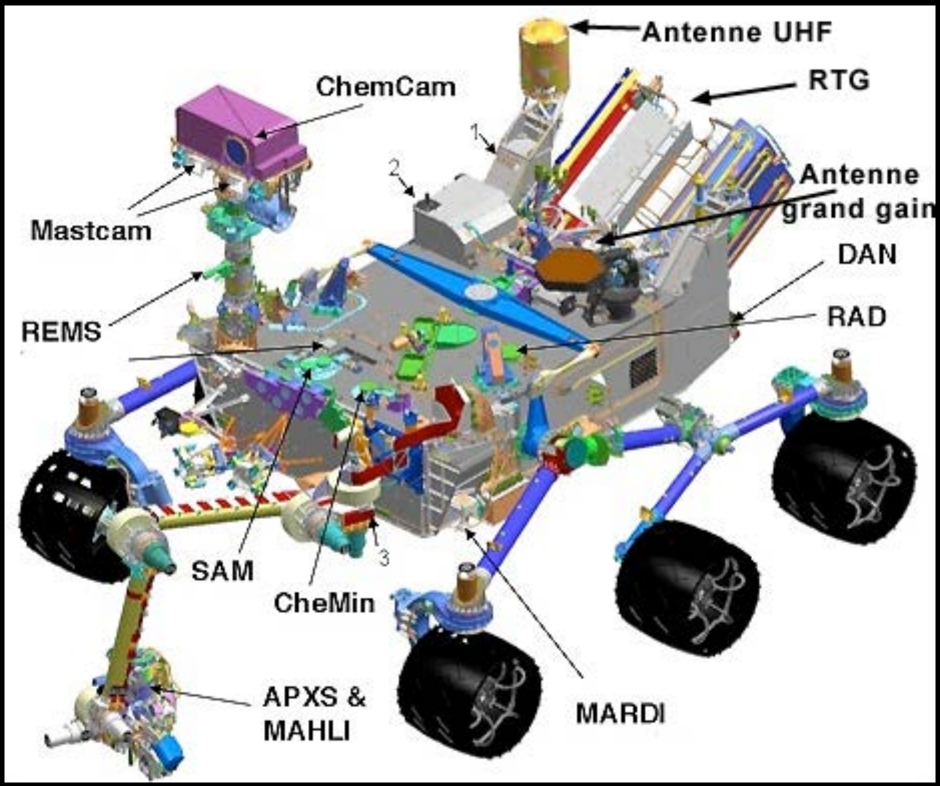
Big Questions

- Are carbon and water the only combination where life can originate? Survive?
- Are DNA and RNA the optimal or only information storage mechanism? Are ACTG the only useful letters?
- Is there a reason for right-handed molecules?
- Is the origin hard or easy? Thermodynamically favored? Fast or slow? Does it require special circumstances? Does evolution happen as a random walk, or is it forced by environmental changes?
- Could we create life ourselves?

What can we observe?

- Go visit: fly through water plumes and atmospheres of planets and satellites; look for neutrons from subsurface water
- Get pictures and physical structures: ice, oceans, lakes, rivers (hydrocarbons on Titan), snow, etc.
- Get samples: find meteorites (iron, stony, stony-iron, some with lots of carbon; also Martian, and Lunar)
- Bring home bits of asteroids, comets, the Moon (700 lb!), Mars (only meteorites so far)
- Remote atmospheric chemistry: spectroscopy compared with detailed models
- Remote chemistry: Mars labs

Wheels on Mars (MSL Curiosity launched 2011)



- 17 cameras including microscopes
- Laser to vaporize rocks for spectroscopy
- Drill to sample rocks
- X-ray diffraction and fluorescence
- Sample analyzer with quadrupole mass spectrometer, gas chromatograph, and tunable IR laser
- Pulsed neutrons to see subsurface water

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!

Going in person - hazards

- Motion (zero-g) sickness - most people
- Radiation sickness – very heavy physical shields; any help from biology?
- Bone & muscle loss – how to protect?
- Eye damage – loss of fluid circulation?
- Infection resistance changes
- Boredom, isolation, close confinement

Human Effects

Altered Gravity Field

1. Vision Impairments and Intracranial Pressure (VIIP)
2. Renal Stone Formation
3. Sensorimotor Alterations
4. Bone Fracture
5. Reduced Muscle Mass, Strength, and Endurance
6. Reduce Aerobic Capacity
7. Host-Microorganism Interactions
8. Cardiac Rhythm Problems
9. Orthostatic Intolerance
10. Intervertebral Disc Damage[a]
11. Space Adaptation Back Pain
12. Urinary Retention
13. Pharmacokinetics[a, b]

Radiation

14. Space Radiation Exposure

Distance from Earth

15. Adverse Outcomes due to Inflight Medical Conditions
16. Uneffective or Unpredictable Effects of Medication Due to Storage

Hostile/Closed Environment Space Craft Design

17. Inadequate Food and Nutrition
18. Inadequate Human-System Interaction Design
19. Injury from Dynamic Loads (Occupant Protection)
20. Injury and Compromised Performance Due to EVA Operations
21. Celestial Dust Exposure
22. Altered Immune Response
23. Exploration Atmospheres
24. Sleep Loss, Circadian Desynchronization, and Work Overload
25. Toxic Exposure
26. Decompression Sickness
27. Hearing Loss Related to Spaceflight
28. Acute and Chronic Carbon Dioxide Exposure
29. Injury from Sunlight Exposure
30. Electrical Shock[c]

Isolation

31. Adverse Cognitive or Behavioral Conditions
32. Inadequate Team Performance

Source: Human Research Program, 2015.
[a] Concern.
[b] Pharmacokinetics is the study of the movement of drugs in the body. [c] Risk has been retired.

Self-sufficiency?

- Construction materials? Rock + water + energy.
- Farming: not easy. Pressure low, but there is CO_2 on Mars. Closed ecosystem unstable. Effects of low gravity. What food is needed for long term health?
- Water recovery: not easy either. Calcium in urine can solidify in the pipes.
- Oxygen recovery: oxygen from CO_2 is possible with reverse fuel cell, will demo on Mars in 2020
- Heat and power: solar cells and batteries, or nuclear reactor (fission); fusion is in far future
- Return fuel: Oxygen from Martian CO_2, H_2 and O_2 from water (but we have to dig it up), Moon?

NASA Biology Programs

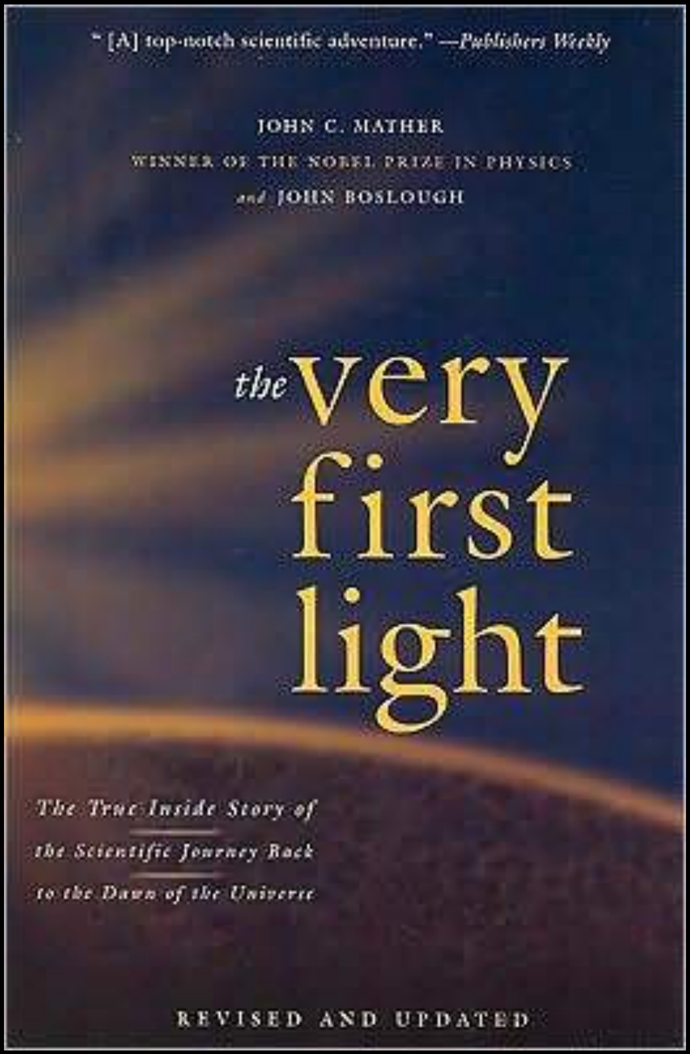
- Human Research Program (HRP)
- Human Health Countermeasures (HHC)
- ISS (International Space Station) research program – health and farming
- NASA Twins Study – (1 of 10 studies)
  - Metabolomic and Genomic Markers of Atherosclerosis as Related to Oxidative Stress, Inflammation, and Vascular Function in Twin Astronauts: Stuart M. C. Lee, Ph.D.

The Billion Year Challenge

- Food
- Water
- Energy
- Minerals
- Health
- Organization, government
- Culture

More Info:

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



The End

And the beginning!