From the Big Bang to the Nobel Prize and on to James Webb Space Telescope and the Discovery of Alien Life

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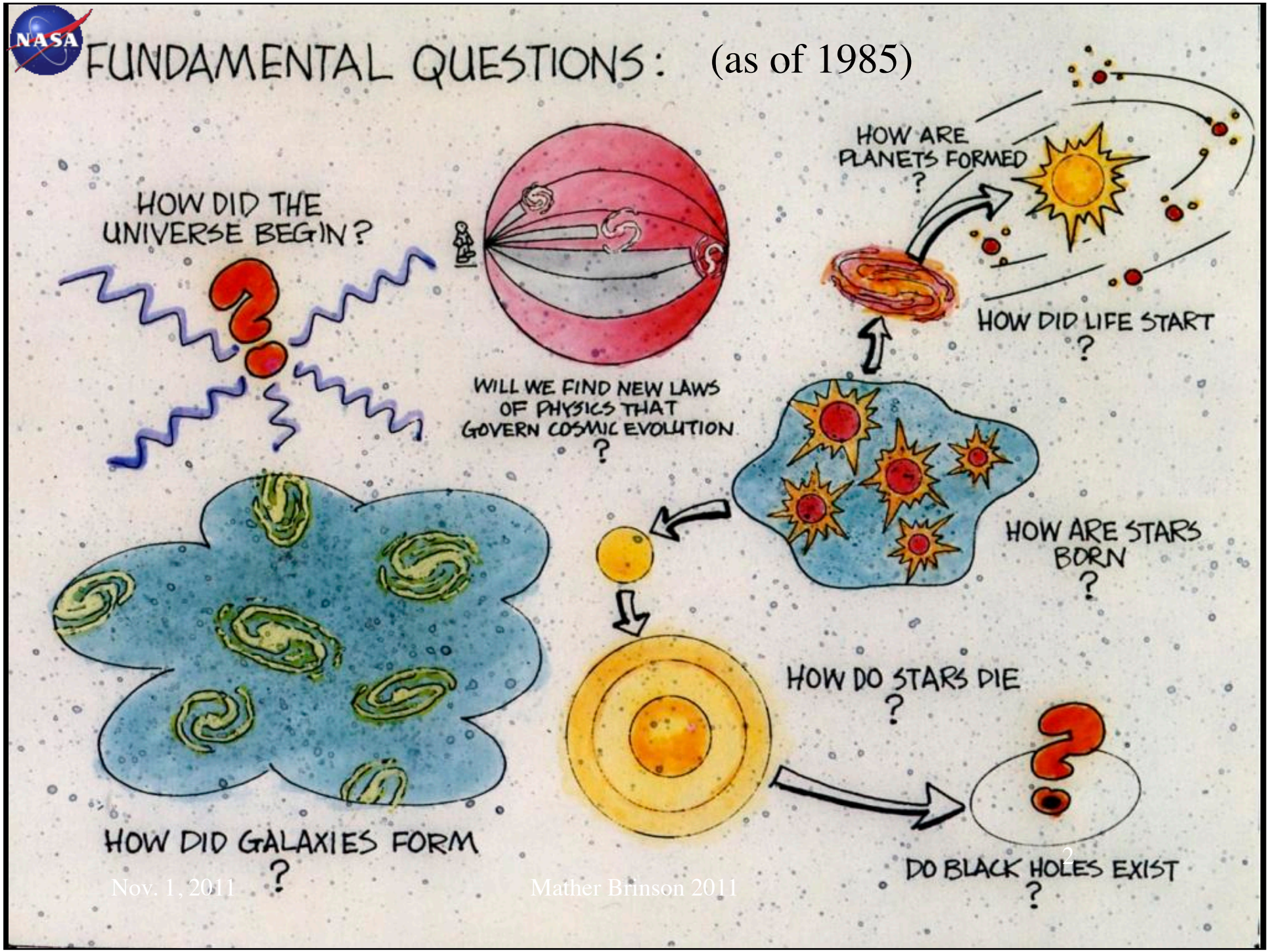
NASA's Goddard Space Flight Center

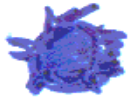
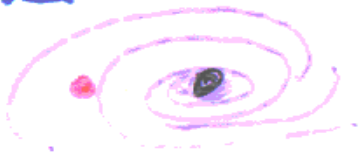
Nov. 1, 2011


FUNDAMENTAL QUESTIONS: (as of 1985)
HOW DID THE UNIVERSE BEGIN?
WILL WE FIND NEW LAWS OF PHYSICS THAT GOVERN COSMIC EVOLUTION ?
HOW ARE PLANETS FORMED ?
HOW DID LIFE START ?
HOW ARE STARS BORN ?
HOW DO STARS DIE ?
DO BLACK HOLES EXIST ?
HOW DID GALAXIES FORM ?

Can you imagine?

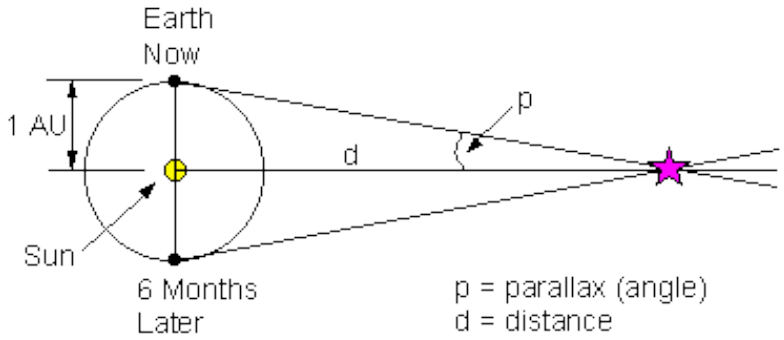
Your chin is made of exploded stars!

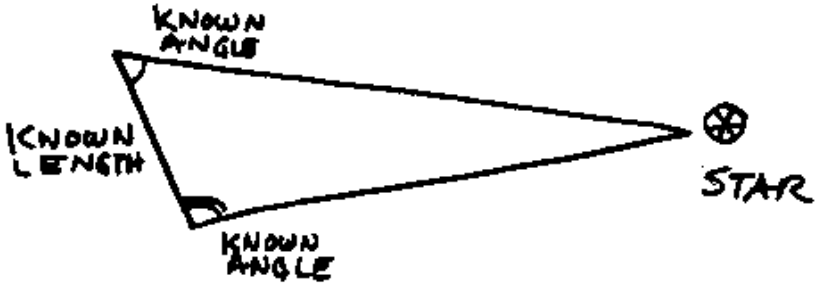
Looking Back in Time

HAND		1 m	0.000000003
EARTH		7000 km	0.02 sec
SUN		150,000,000 km	500 se
STAR			4 YRS
GALAXY			25,000 YRS
BIG BANG	?		15,000,000,000 Y

Measuring Distance

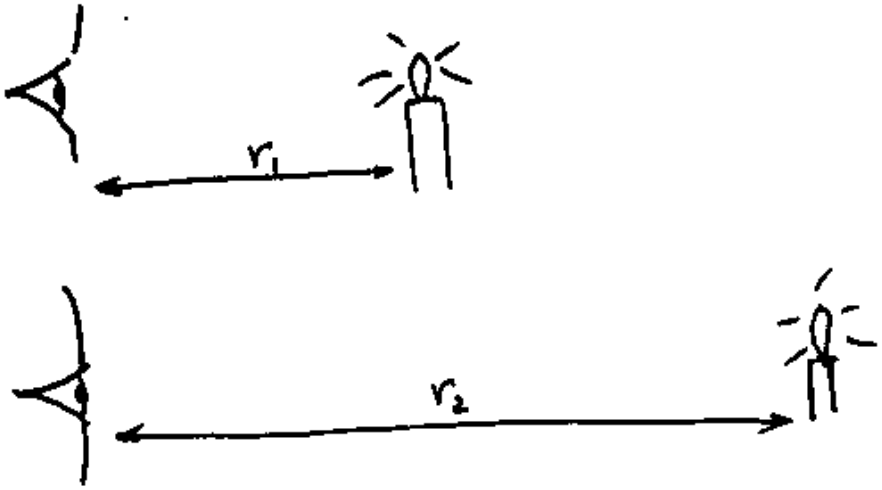
1. TRIANGLES





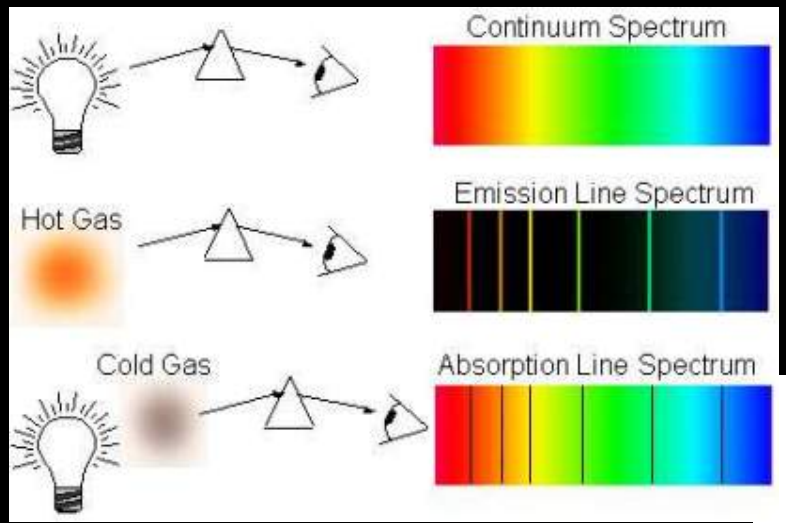
2. STANDARD CANDLES

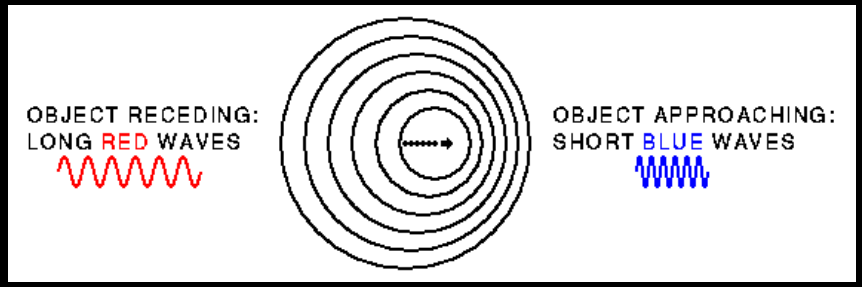
This technique enables measurement of enormous distances

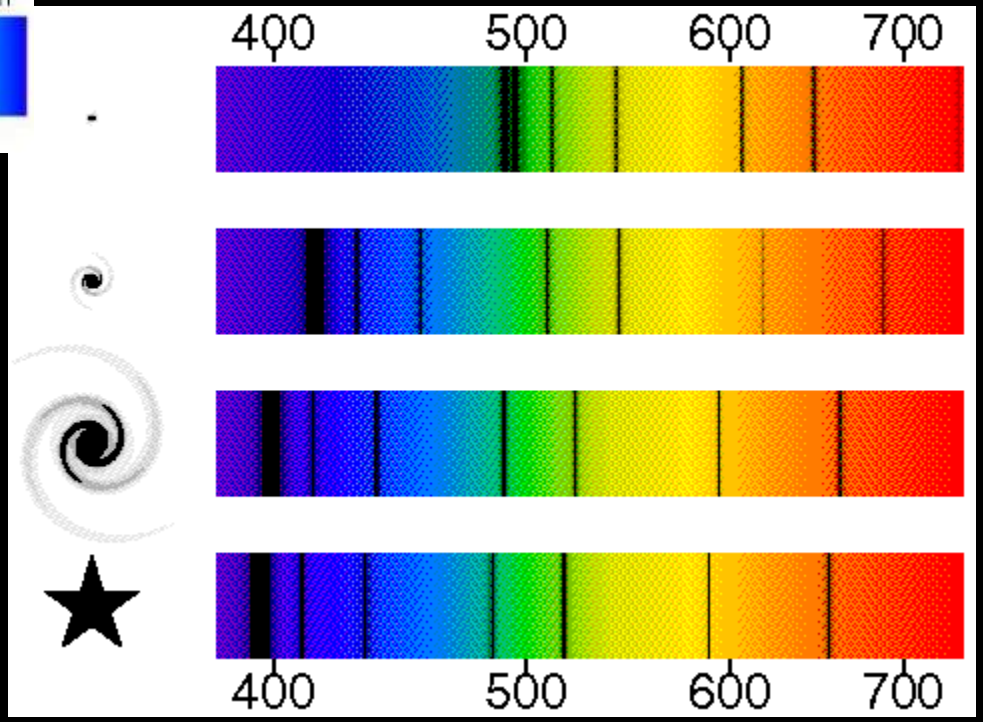


$$\frac{\text{BRIGHTNESS}_1}{\text{BRIGHTNESS}_2} = \frac{r_2^2}{r_1^2}$$

Astronomer's Toolbox #2:
Doppler Shift - Light



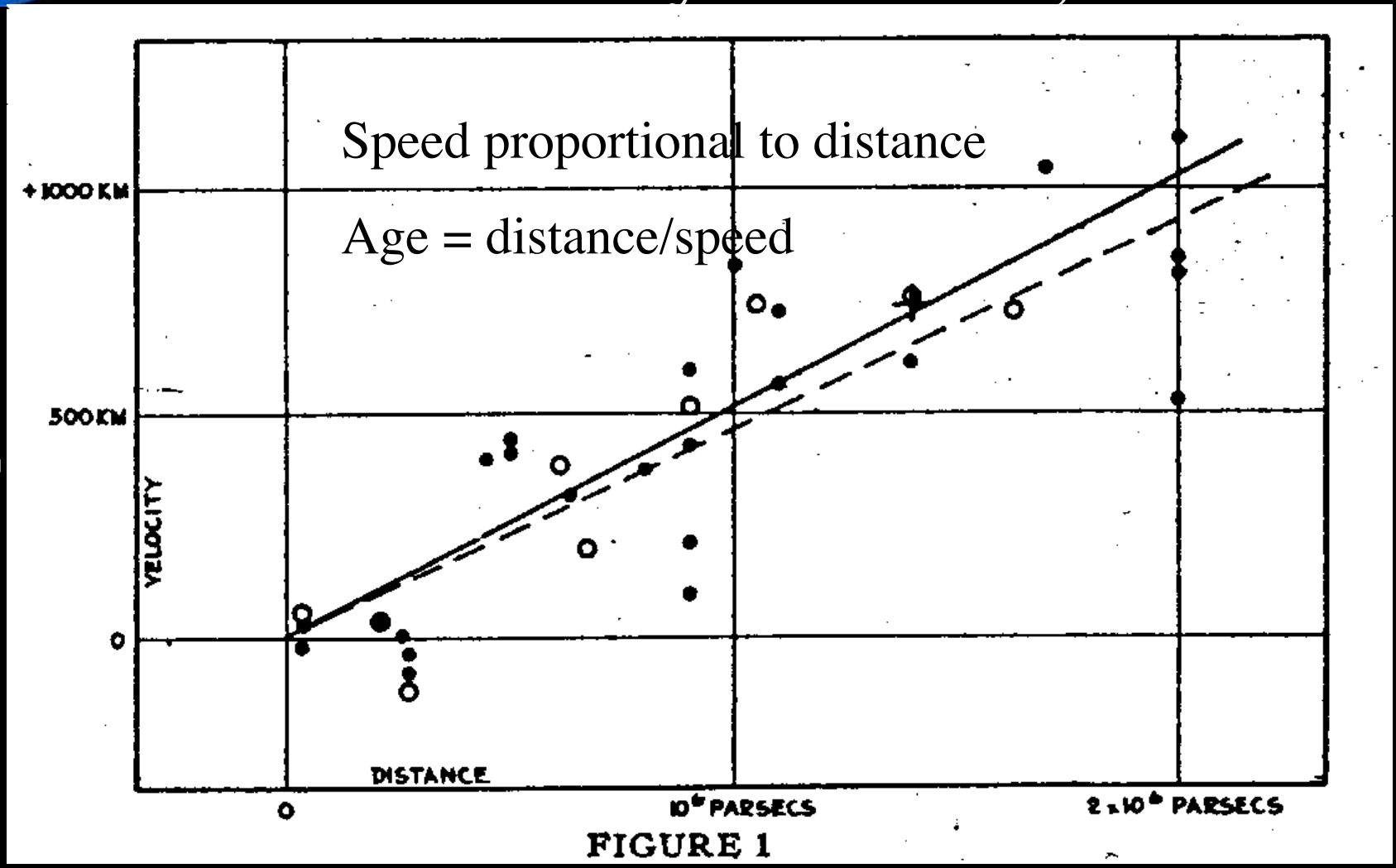




Atoms emit light at discrete wavelengths that can be seen with a spectroscope

This "line spectrum" identifies the atom and its velocity

Hubble's Law – 1929 Data Discovered by Lemaître, 1927!



Speed -->

Distance -->

The Power of Thought

Alexander Friedman

Georges Lemaître & Albert Einstein

George Gamow

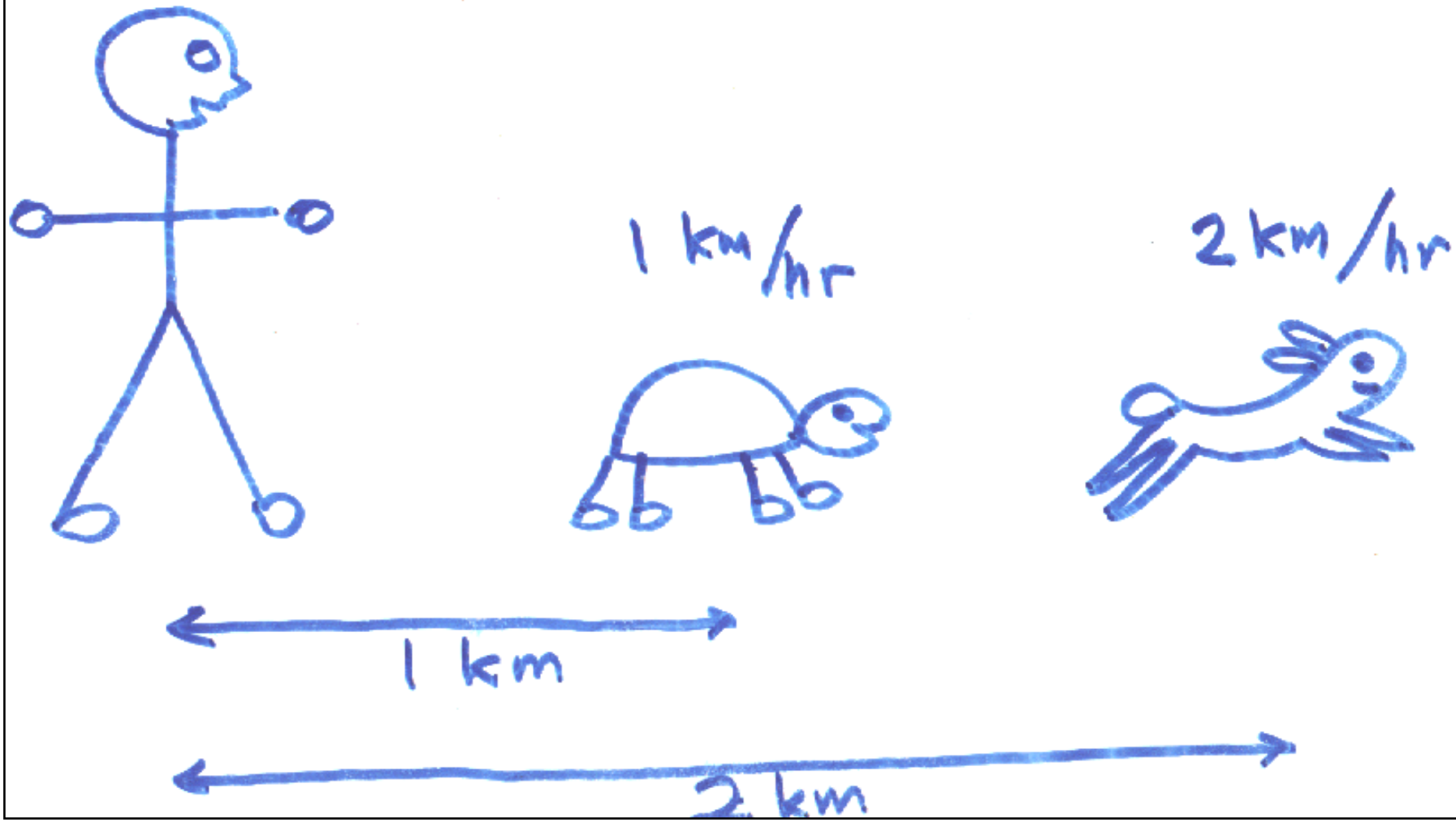
Robert Herman & Ralph Alpher

Rashid Sunyaev

Jim Peebles

HUBBLE'S LAW

NO NECESSARY CENTER!



Big Bang - Cosmic Explosion 13.7 billion years ago

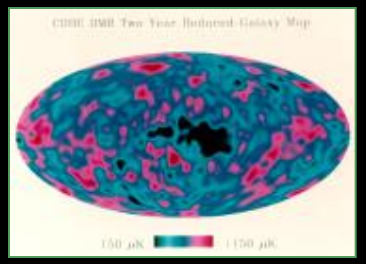
IMPOSSIBLE TO DRAW A PICTURE!

How did a smooth Big Bang make complicated things like us?

- Gravity is long range attractive force
  - Matter distribution is unstable
    - Remove heat, and system heats up more
    - Makes condensed objects (stars, galaxies, etc.)
    - Gravitational energy flows support complexity
- Stars release heat from nuclear reactions
  - Heat & light received by Earth support complexity, from weather to photosynthesis

Early History of the Universe

Big Bang seen by COBE & WMAP



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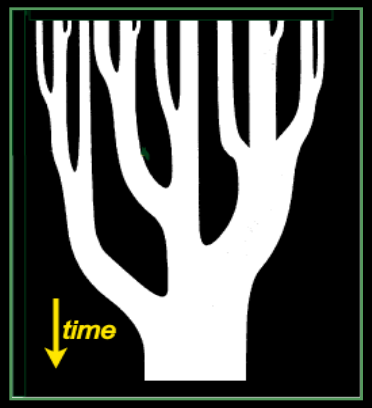
Galaxy assembly



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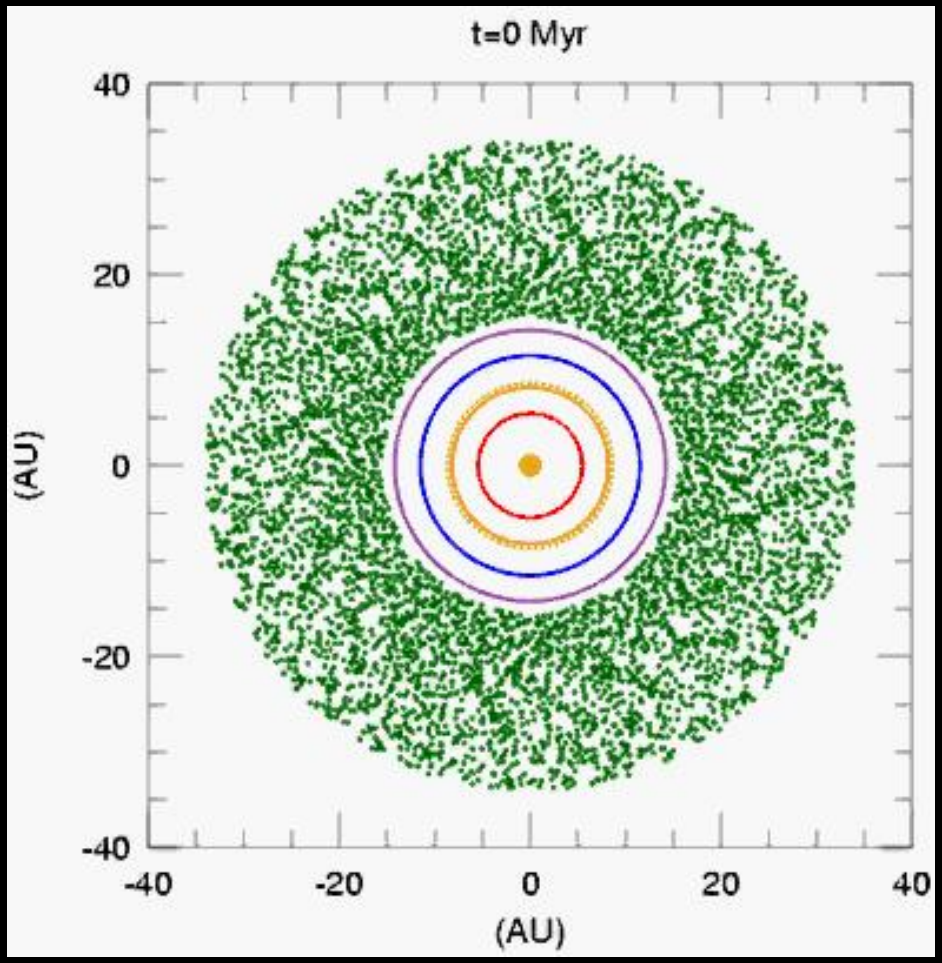
Galaxies, stars, planets, life

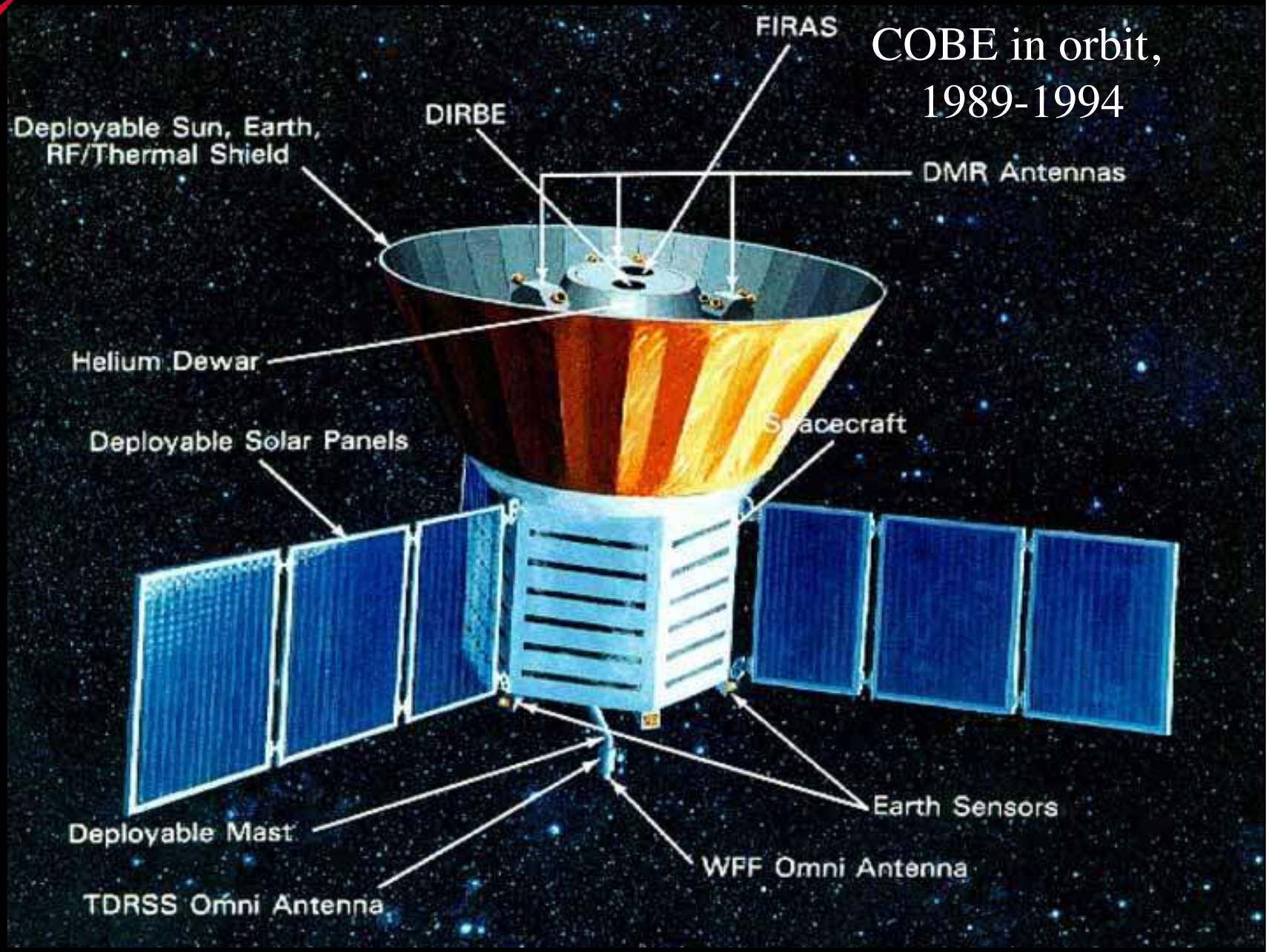
- Horrendous Space Kablooey - exponential expansion, primordial fluctuations, matter/antimatter, dark matter, dark energy, 13.75 ± 0.11 billion years ago (WMAP7)
- Annihilation of antiparticles, 1 part per billion matter remaining
- Formation of Helium nuclei, 3 minutes, redshift z = 10^9
  - [1+z = size of universe now / size then]
- Formation of neutral gas "recombination", 389,000 yrs, z=1089
- Population III supermassive stars, super-supernovae, and black holes, z=17 (age ~ 200 Myr)
- Galaxy formation in small parts, star formation, merging and clustering of galaxy parts, until z~1
- Expanding universe begins to accelerate, 5 billion years ago

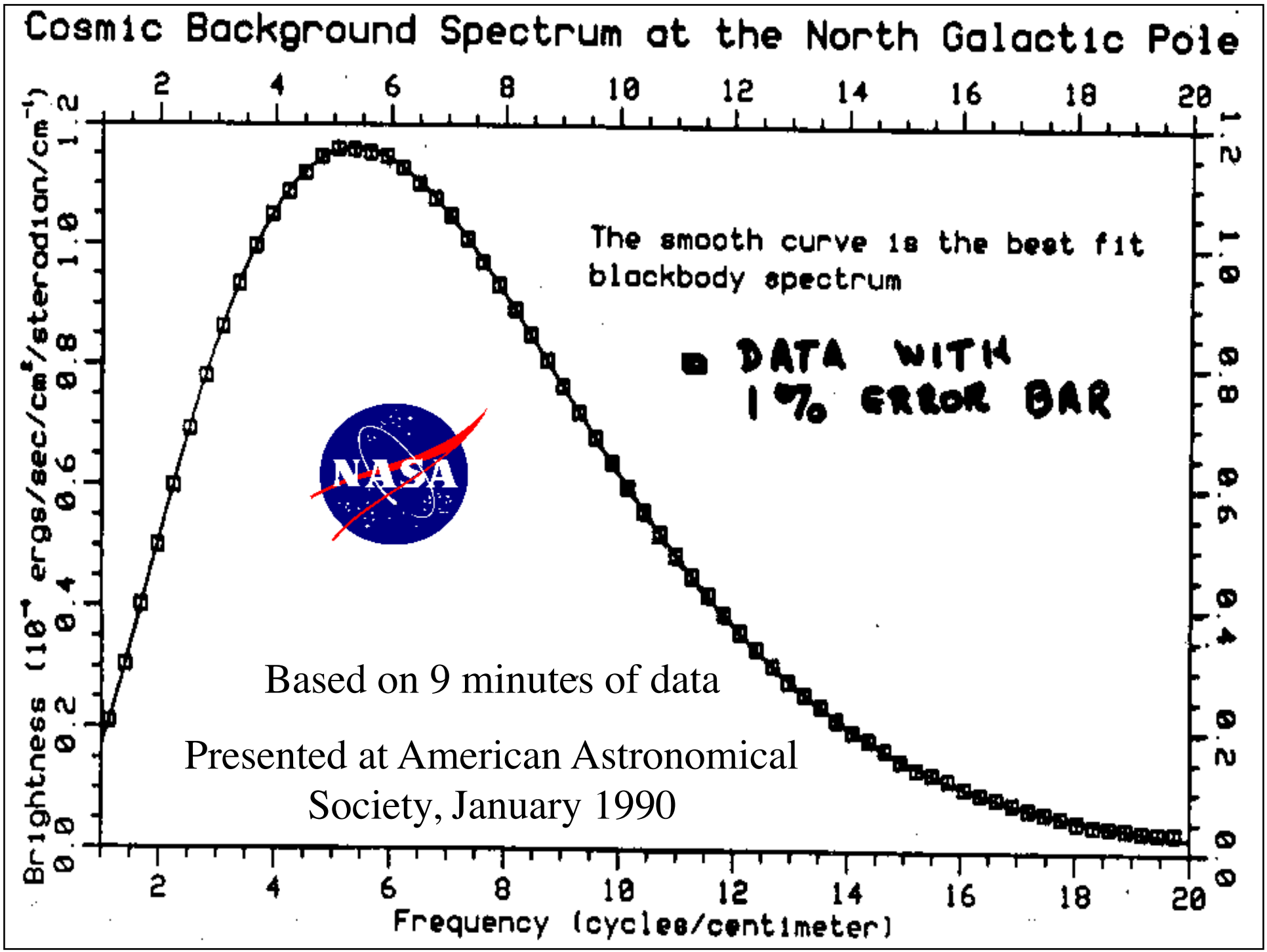
Possible Early Solar System

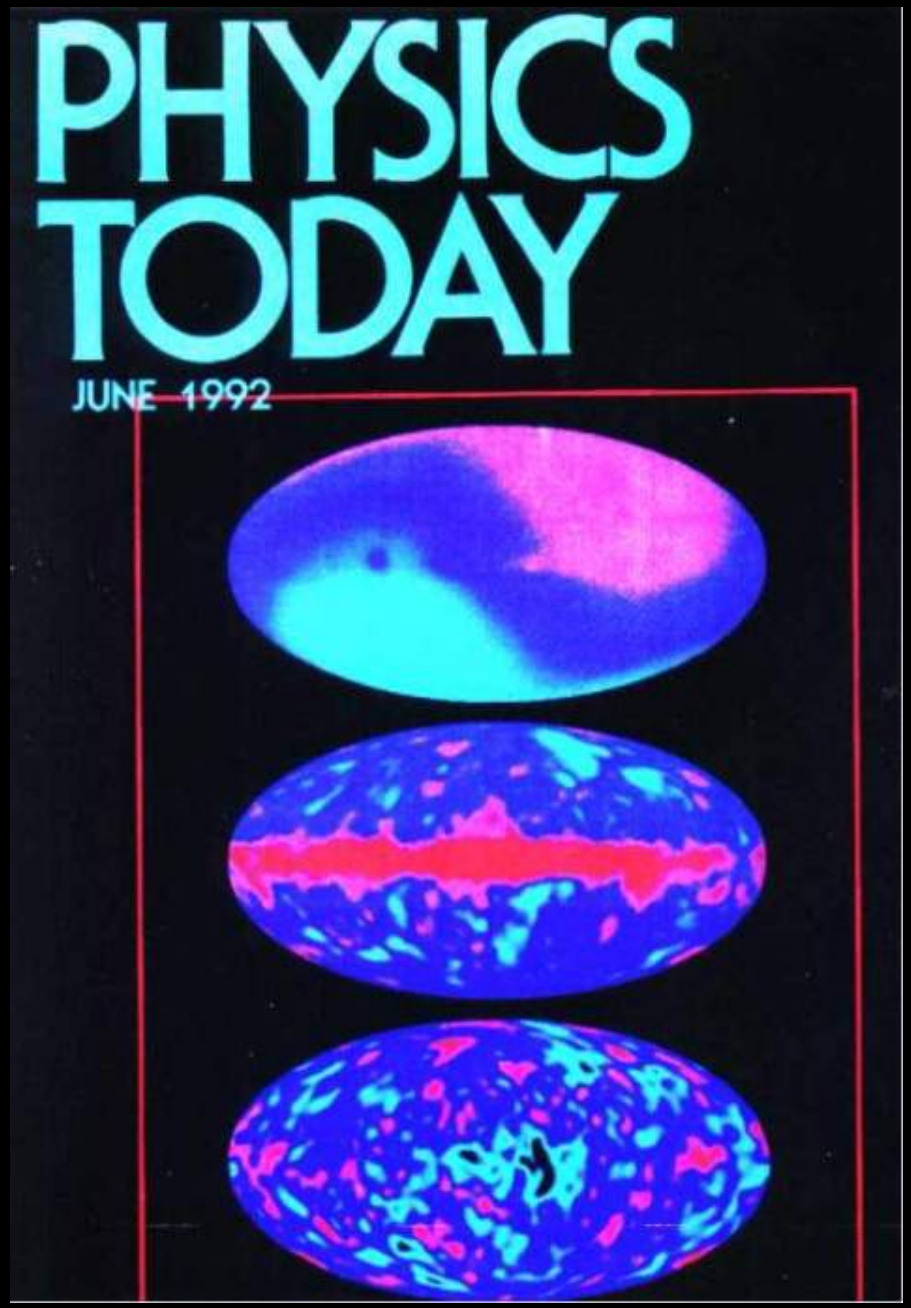


Civilization and the Future

- Galileo's telescope 1609 (2009 International Year of Astronomy)
- 2012, nothing happens!
- AD 2200? We run out of coal and oil, it's very warm, ocean is acidic, sea level is much higher… (your guess here, Cassandra problem)
- Possible far future: all the CO_2 goes into rocks, BIG FREEZE
- 1 BY in future, sun is brighter, Earth gets too hot for us
- 5 BY, sun becomes red giant, and Andromeda Nebula collides with Milky Way
- 7.6 BY, sun goes out
- Accelerating universe continues, galaxies recede, stars go out: dark!


COBE in orbit,
1989-1994
FIRAS
DIRBE
Deployable Sun, Earth,
RF/Thermal Shield
DMR Antennas
Helium Dewar
Deployable Solar Panels
Spacecraft
Earth Sensors
Deployable Mast
WFF Omni Antenna
TDRSS Omni Antenna


Cosmic Background Spectrum at the North Galactic Pole
The smooth curve is the best fit blackbody spectrum
DATA WITH 1% ERROR BAR
Based on 9 minutes of data
Presented at American Astronomical Society, January 1990
Brightness (10^{-4} ergs/sec/cm^2/steradian/cm^{-1})
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

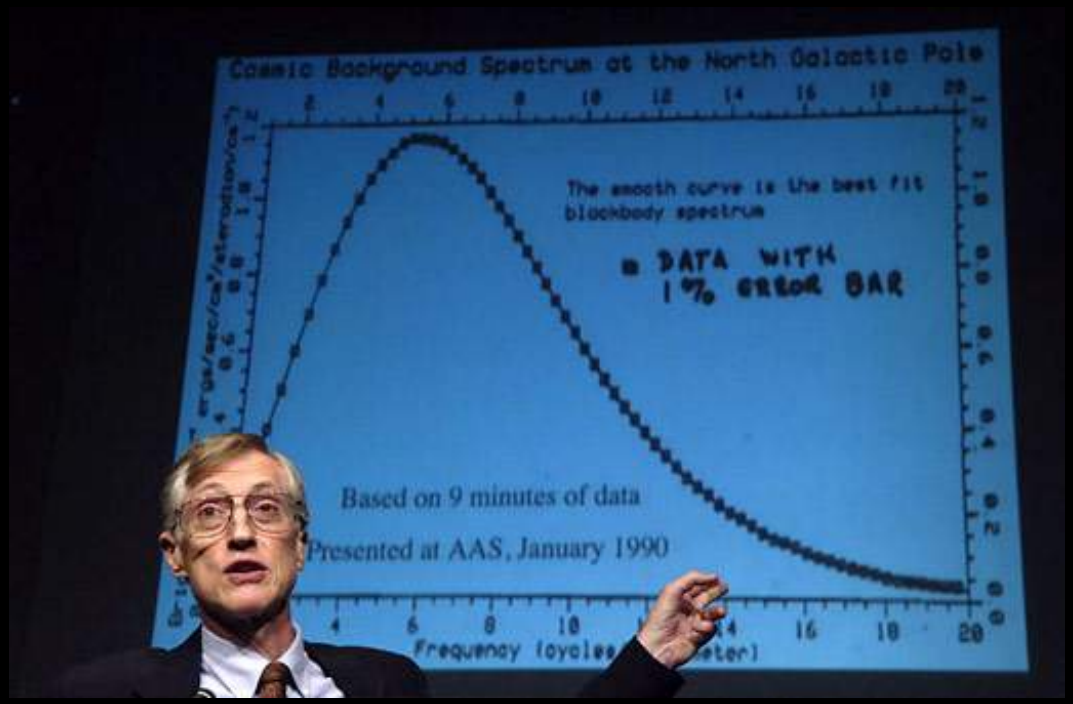


Sky map from DMR,
2.7 K +/- 0.003 K

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)

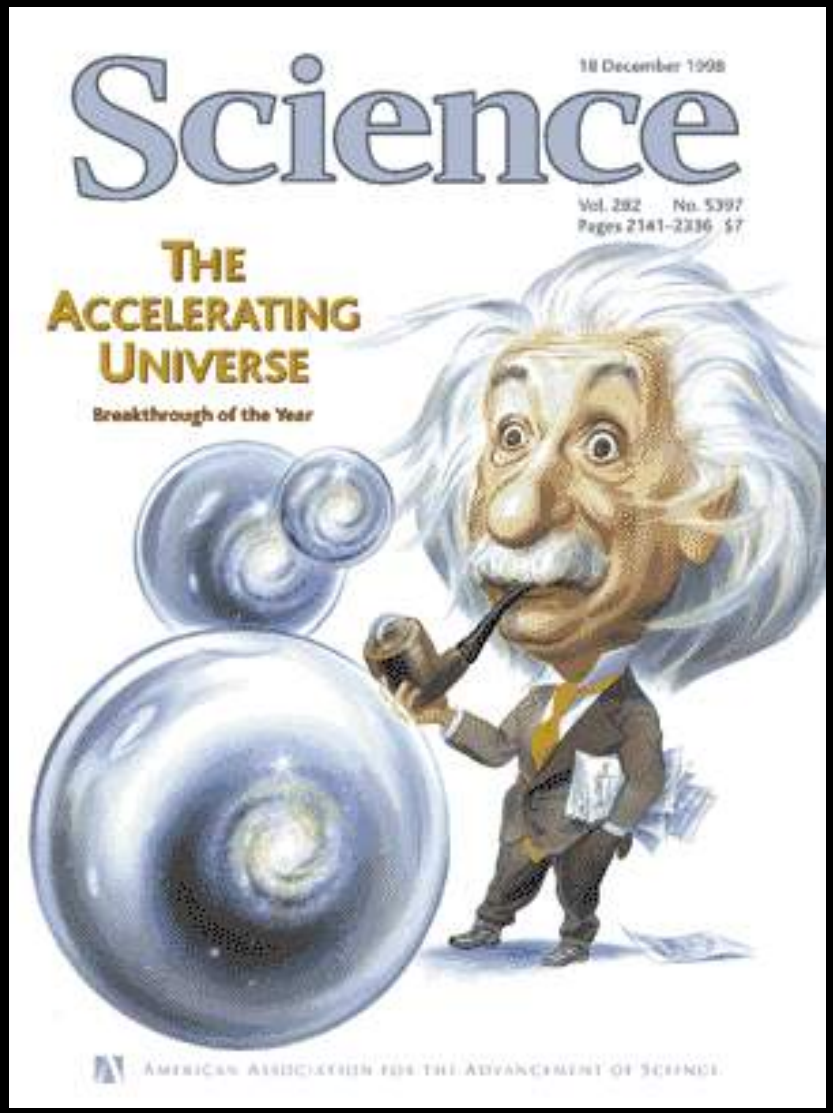
From Press Conference to Stockholm



© Nobel Foundation
Photo by Hans Mehlin

Nobel 2011 for Dark Energy!

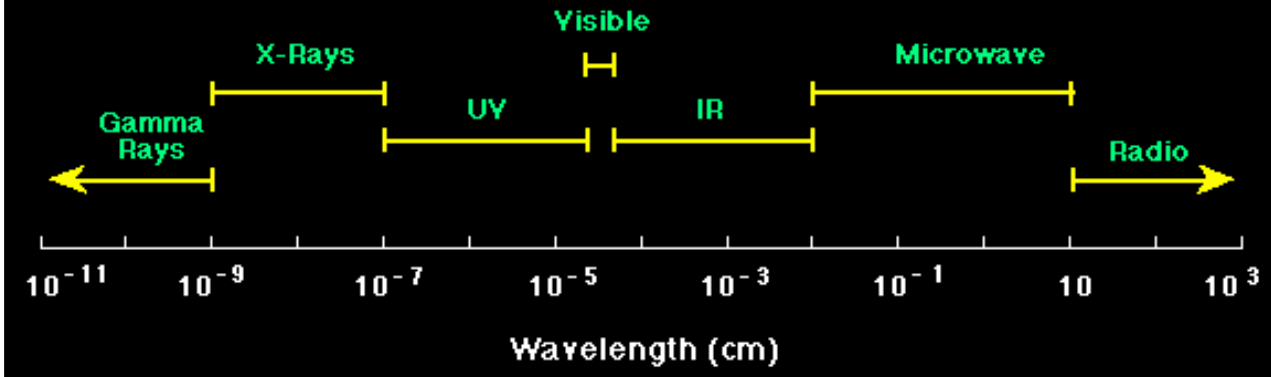
MacArthur Fellow
2008 - Adam Riess

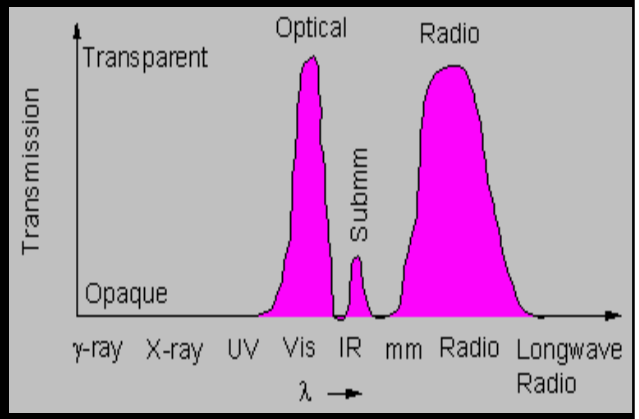


S. Perlmutter, A. Riess, B. Schmidt

Light comes in more colors than our eyes can see

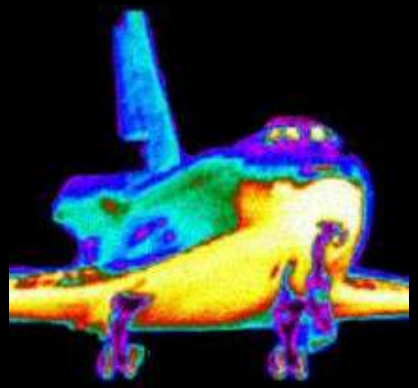
Light from the first galaxies is redshifted from the visible into the infrared.



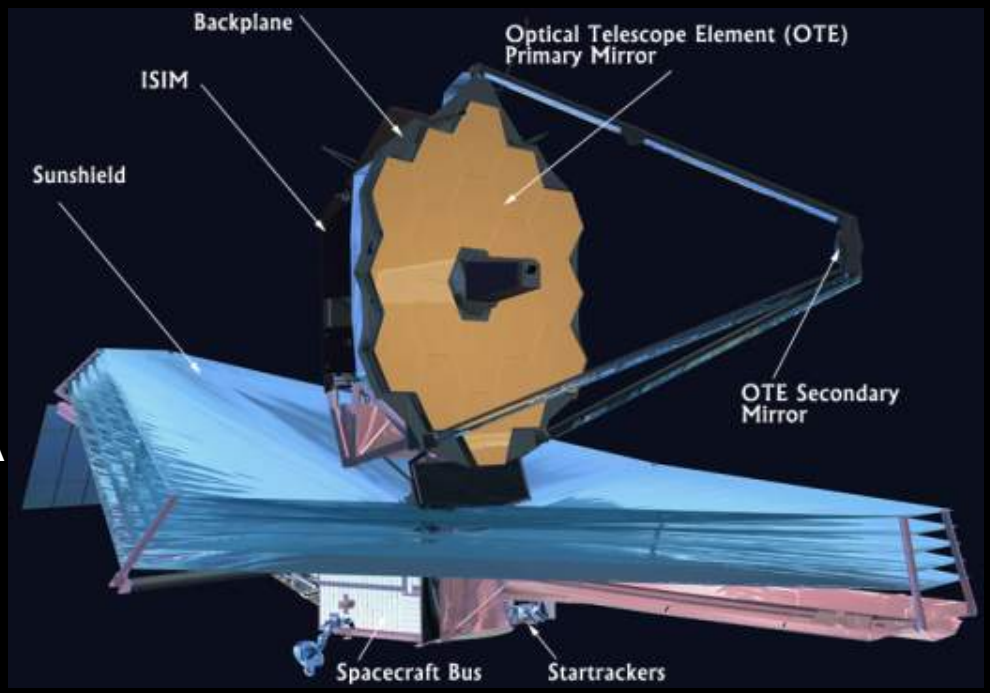


Infrared is heat radiation

Our eyes can't see it, but our skin can feel it



James Webb Space Telescope (JWST)



Organization

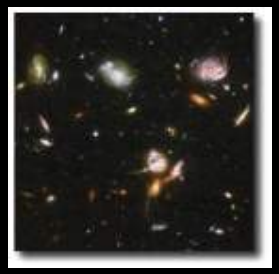
- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA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

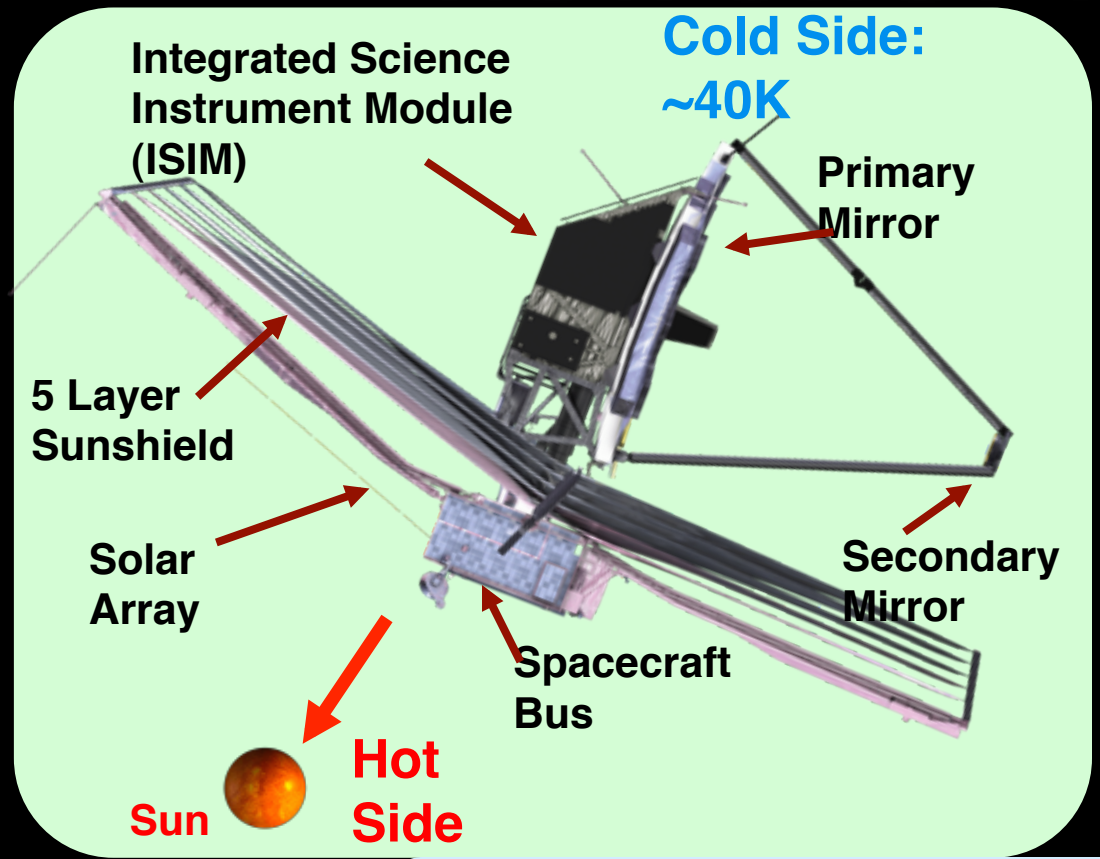
Planetary systems and the origin of life

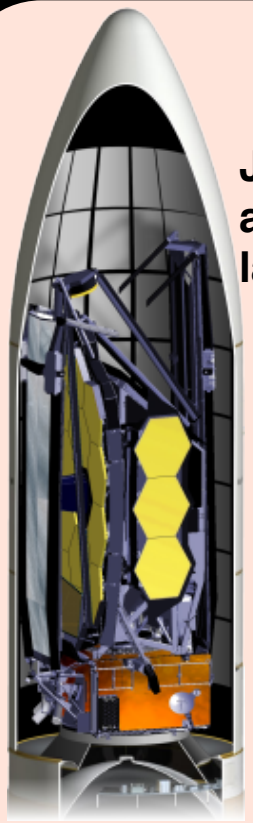
Northrop Grumman's JWST model

Washington, DC 2007

Munich, Germany 2008

HOW JWST WORKS

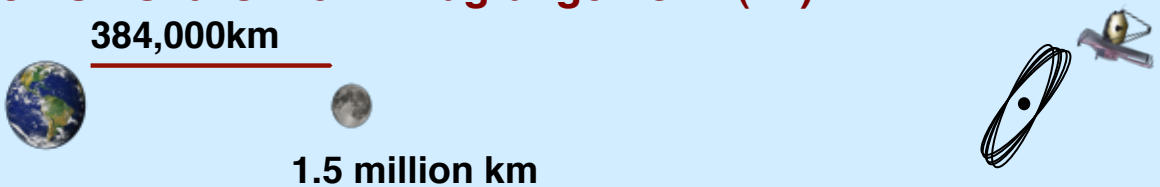




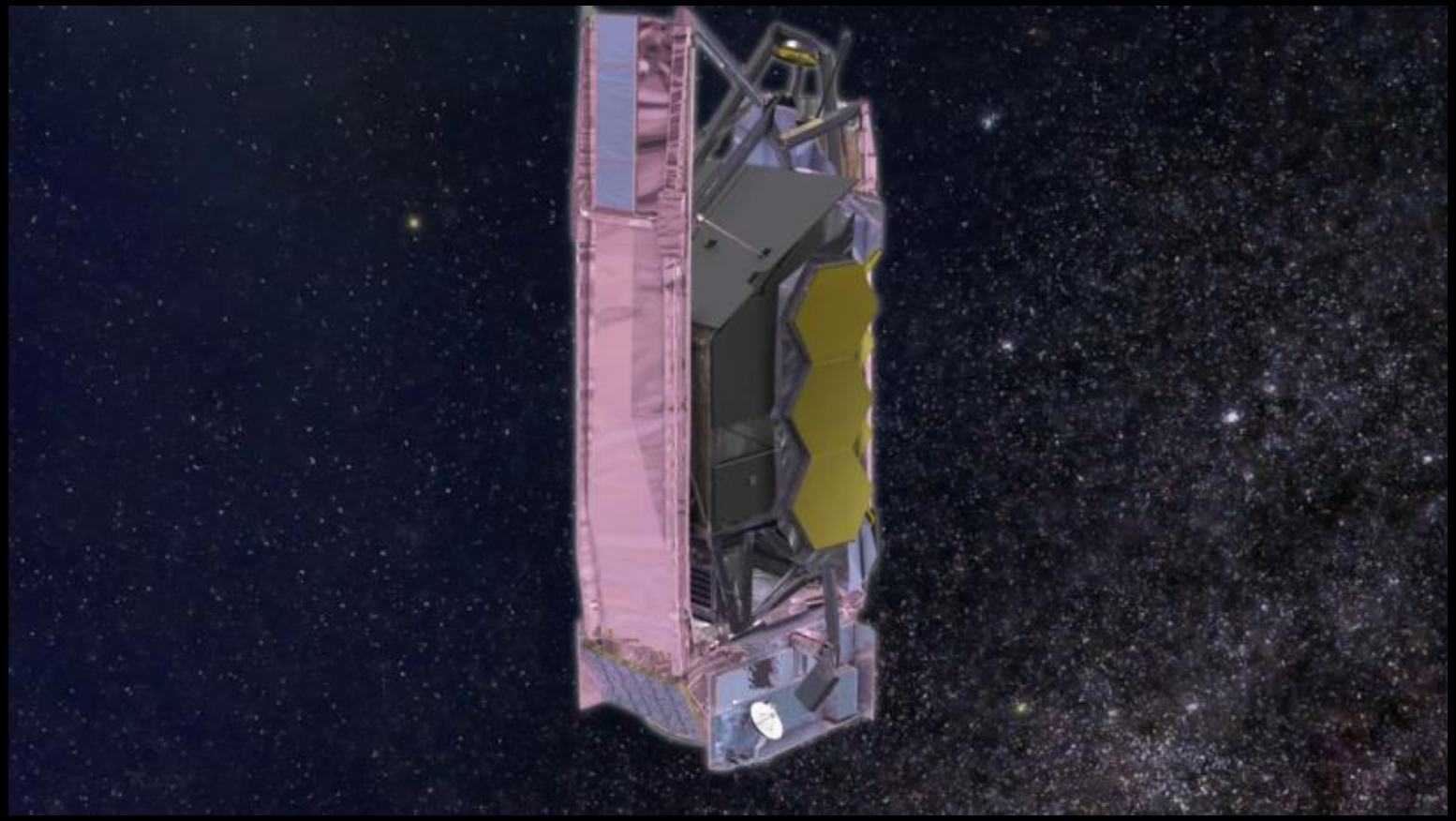
JWST is folded and stowed for launch

Observatory is deployed after launch

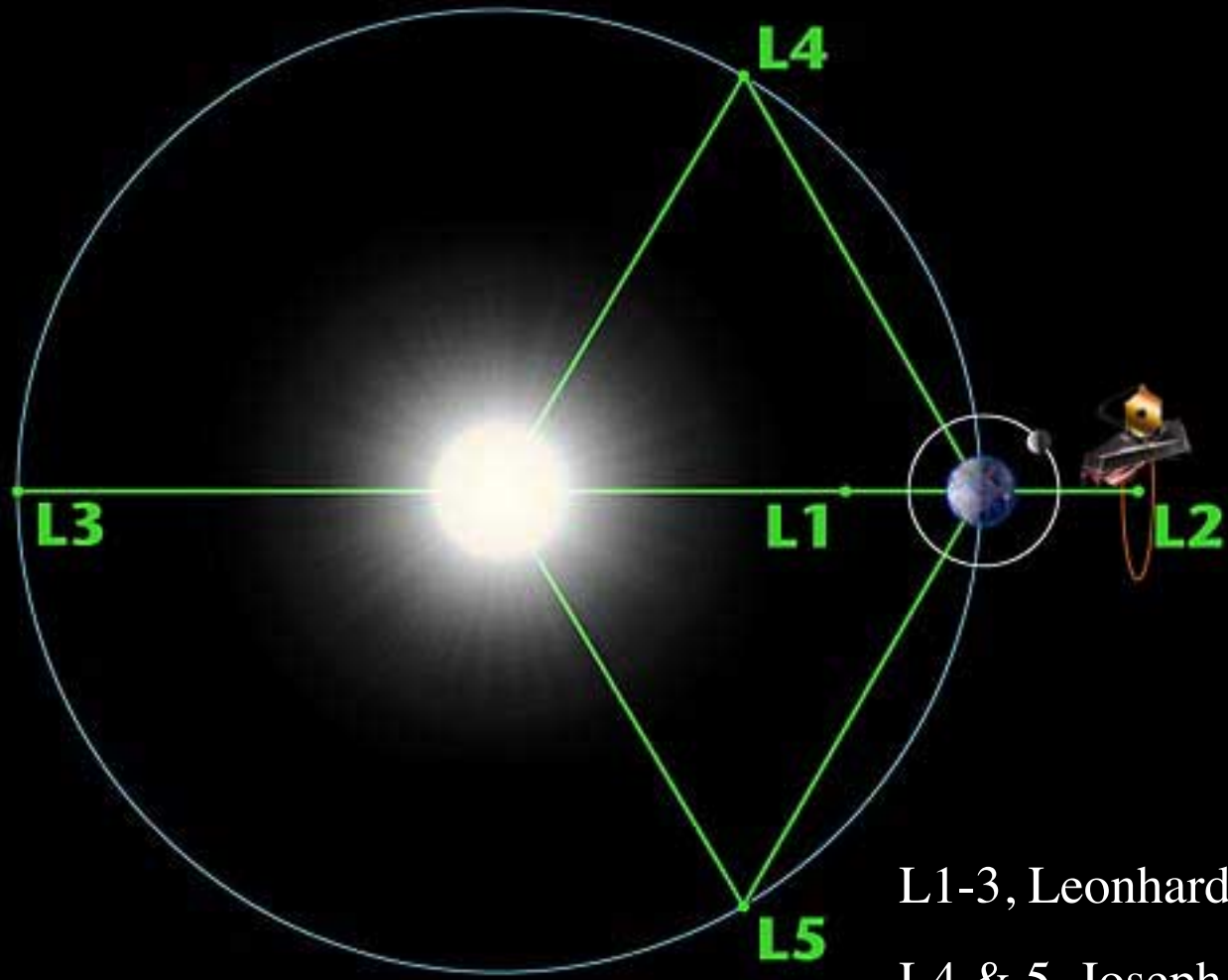
JWST Orbits the 2nd Lagrange Point (L2)



JWST Deployment



JWST Orbits the Sun-Earth Lagrange Point L2



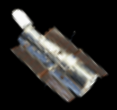
L1-3, Leonhard Euler, 1750.

L4 & 5, Joseph-Louis Lagrange, 1772

JWST and its Precursors

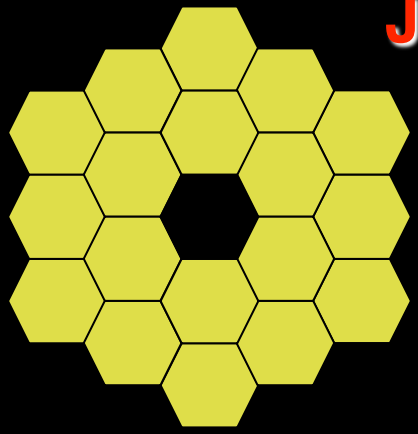
HUBBLE

2.4-meter
T ~ 270 K

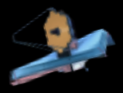


123” x 136”
$\lambda/D_{1.6\mu m}$~ 0.14”

JWST



6.5-meter
T ~ 40 K

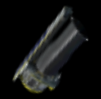


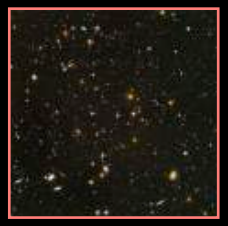
132” x 264”
$\lambda/D_{2\mu m}$~ 0.06”

114” x 84”
$\lambda/D_{20\mu m}$~ 0.64”

SPITZER

0.8-meter
T ~ 5.5 K

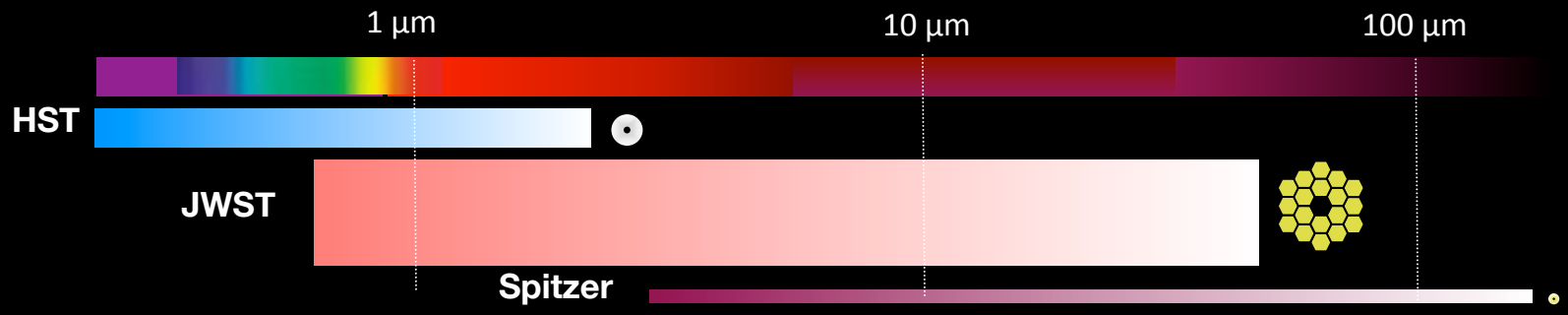




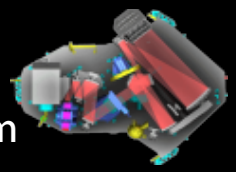
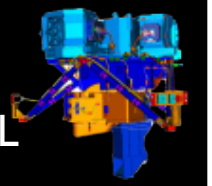
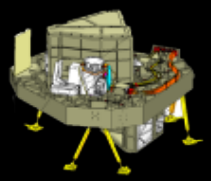
312” x 312”
$\lambda/D_{5.6\mu m}$~ 2.22”

324” x 324”
$\lambda/D_{24\mu m}$~ 6.2”

Wavelength Coverage



JWST Instrumentation

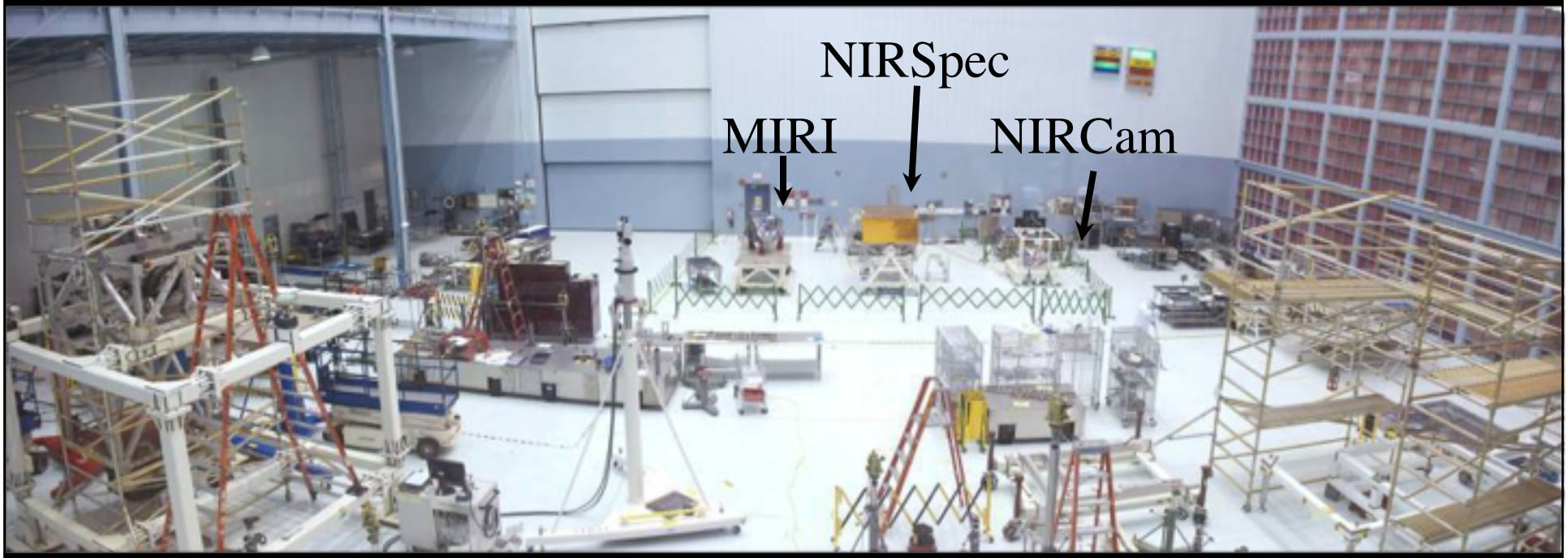
Instrument	Science Requirement	Capability
NIRCam Univ. Az/LMATC	Wide field, deep imaging ›0.6 µm - 2.3 µm (SW) ›2.4 µm - 5.0 µm (LW)	Two 2.2' x 2.2' SW Two 2.2' x 2.2' LW Coronagraph
NIRSpec ESA/Astrium 	Multi-object spectroscopy ›0.6 µm - 5.0 µm	9.7 Sq arcmin Ω + IFU + slits 100 selectable targets: MSA R=100, 1000, 3000
MIRI ESA/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"x3.7" – 7.1"x7.7" IFU R=3000 - 2250
FGS/TFI CSA 	Fine Guidance Sensor 0.8 µm - 5.0 µm Tunable Filter Imager ›1.6 µm - 4.9 µm	Two 2.3' x 2.3' 2.2' x 2.2' R=100 with coronagraph

Flight Mirror Cryo Testing at MSFC

Testbed Telescope

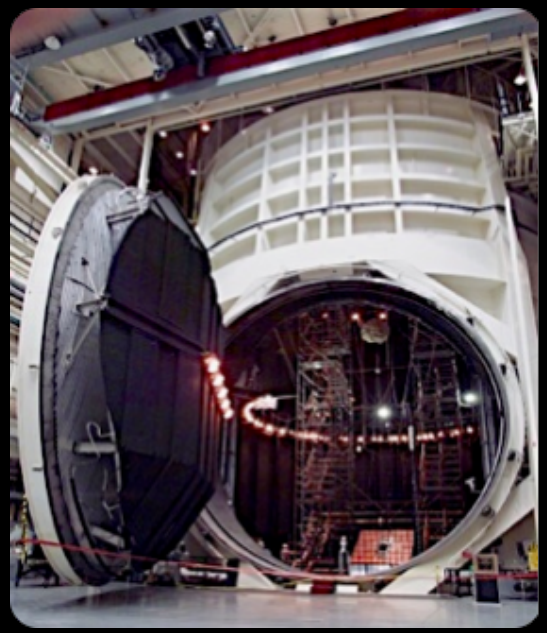
- 1/6 scale model with all the same adjustments
- Proves that all the adjustment procedures work as expected

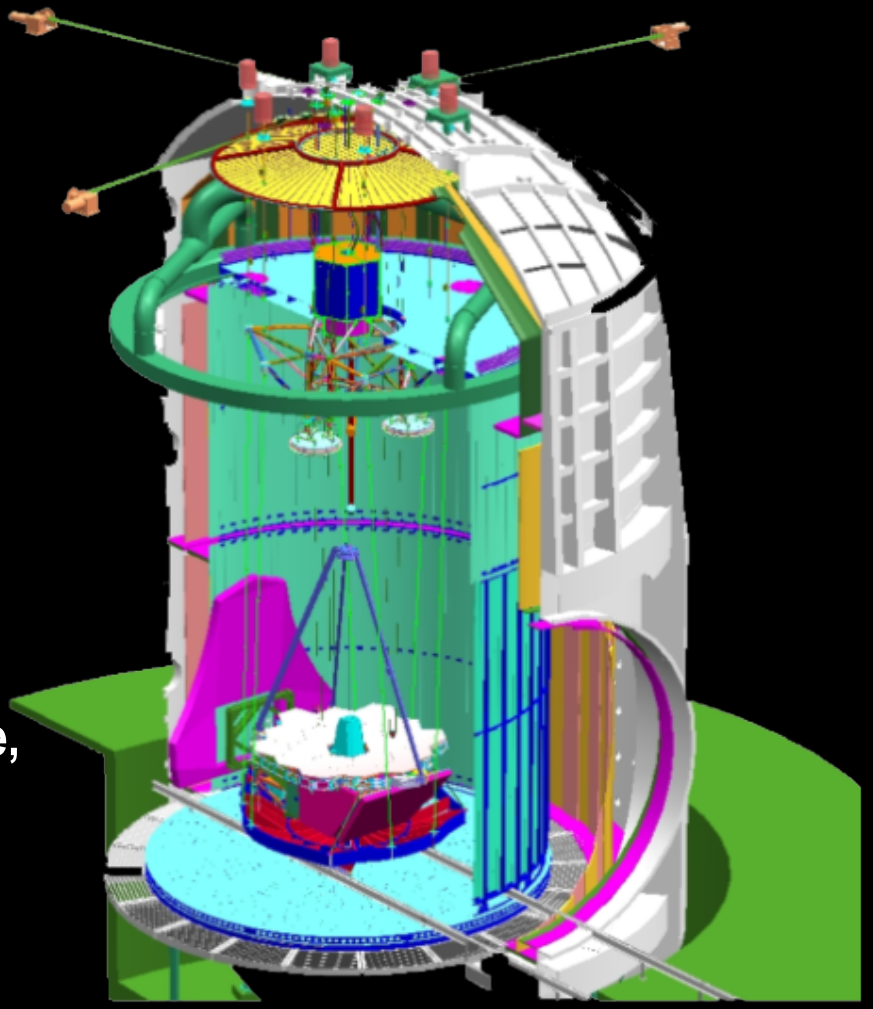
Engineering Test Units Instruments at GSFC



http://www.jwst.nasa.gov/webcam.html

Optical End-to-End Test @ JSC

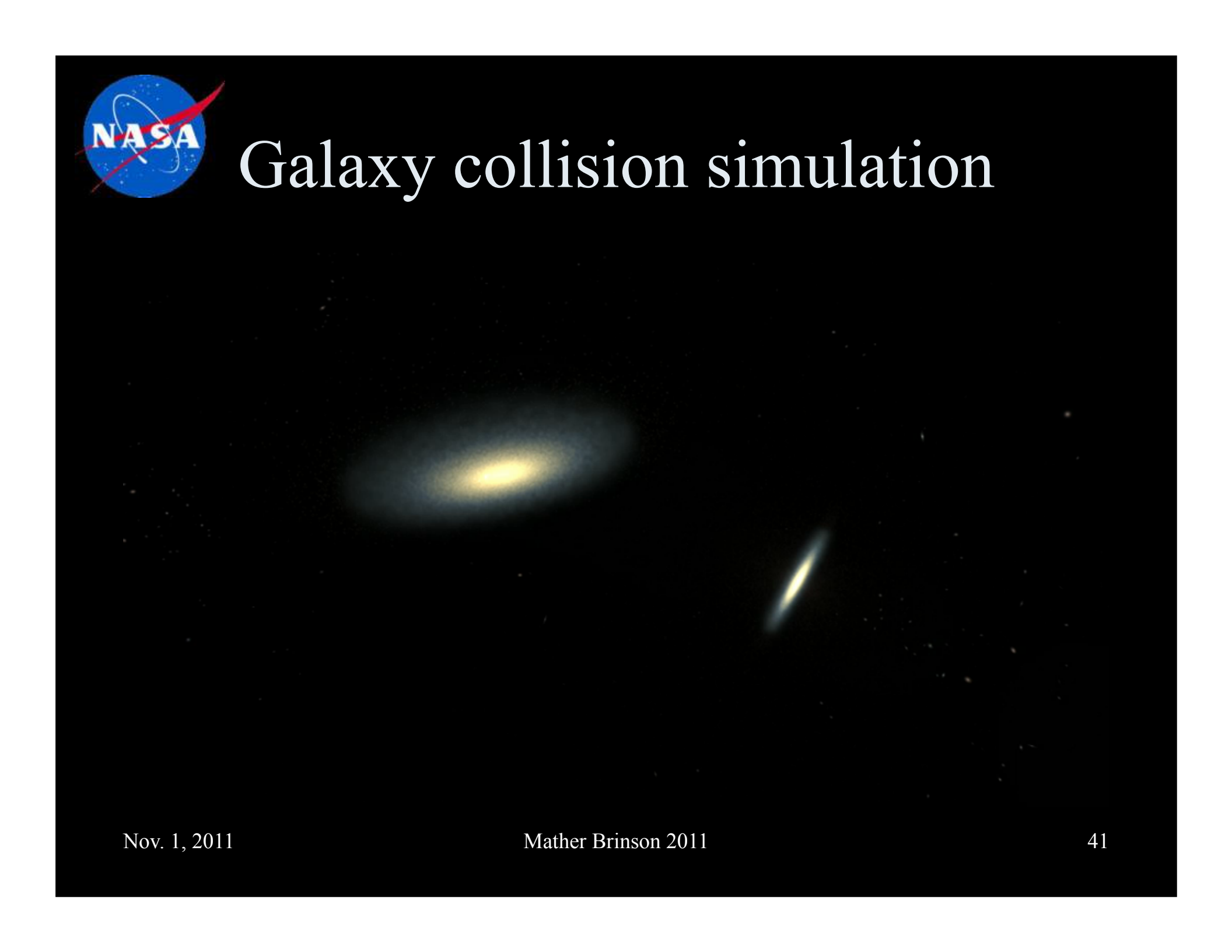




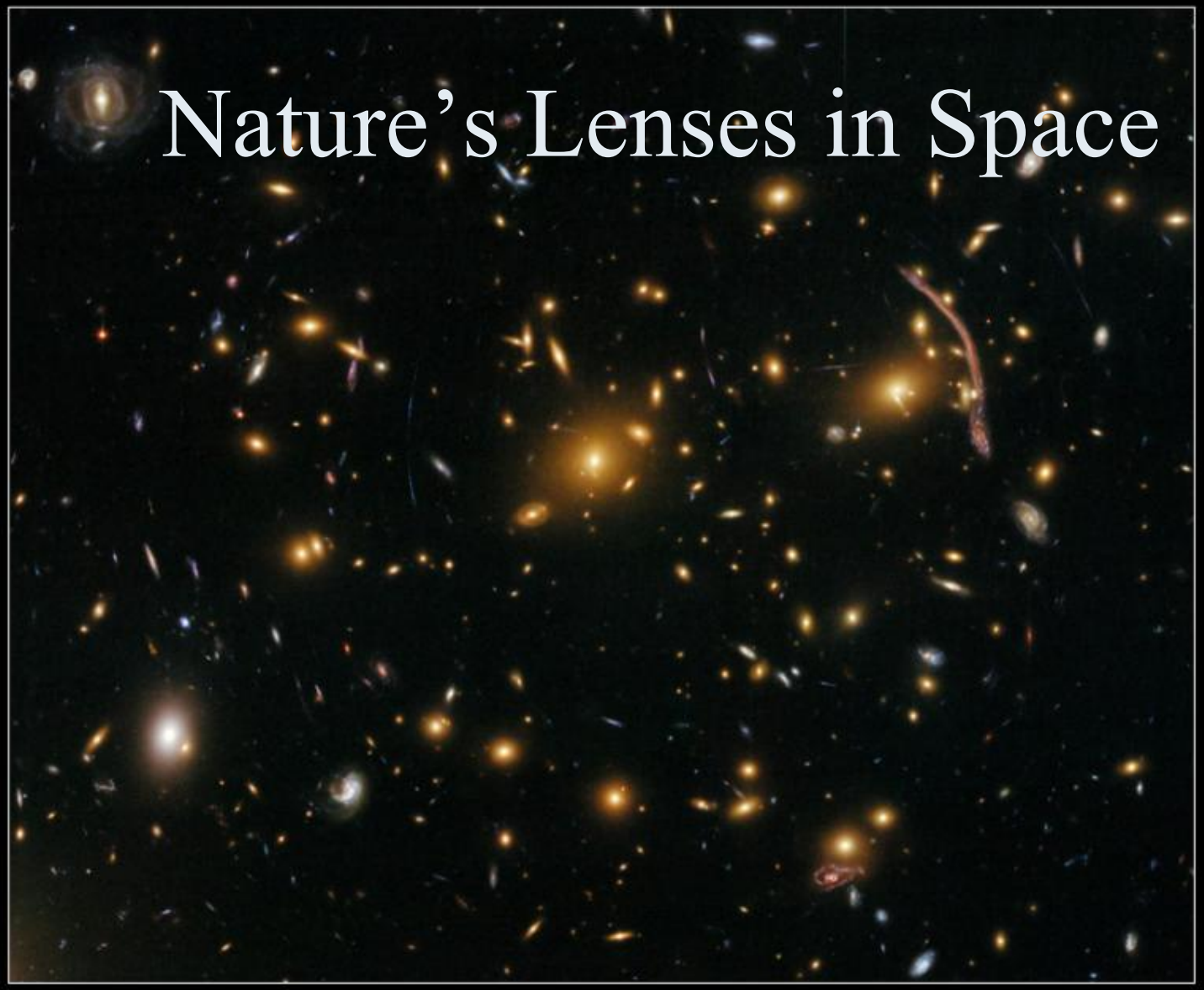
- Verify Optical alignment; center of curvature, autocollimator flats
- ➡ Verify workmanship
- ➡ Thermal balance
- Chamber outside dimensions 65’ x 120’

Galaxy Evolution Simulation

Galaxy collision simulation



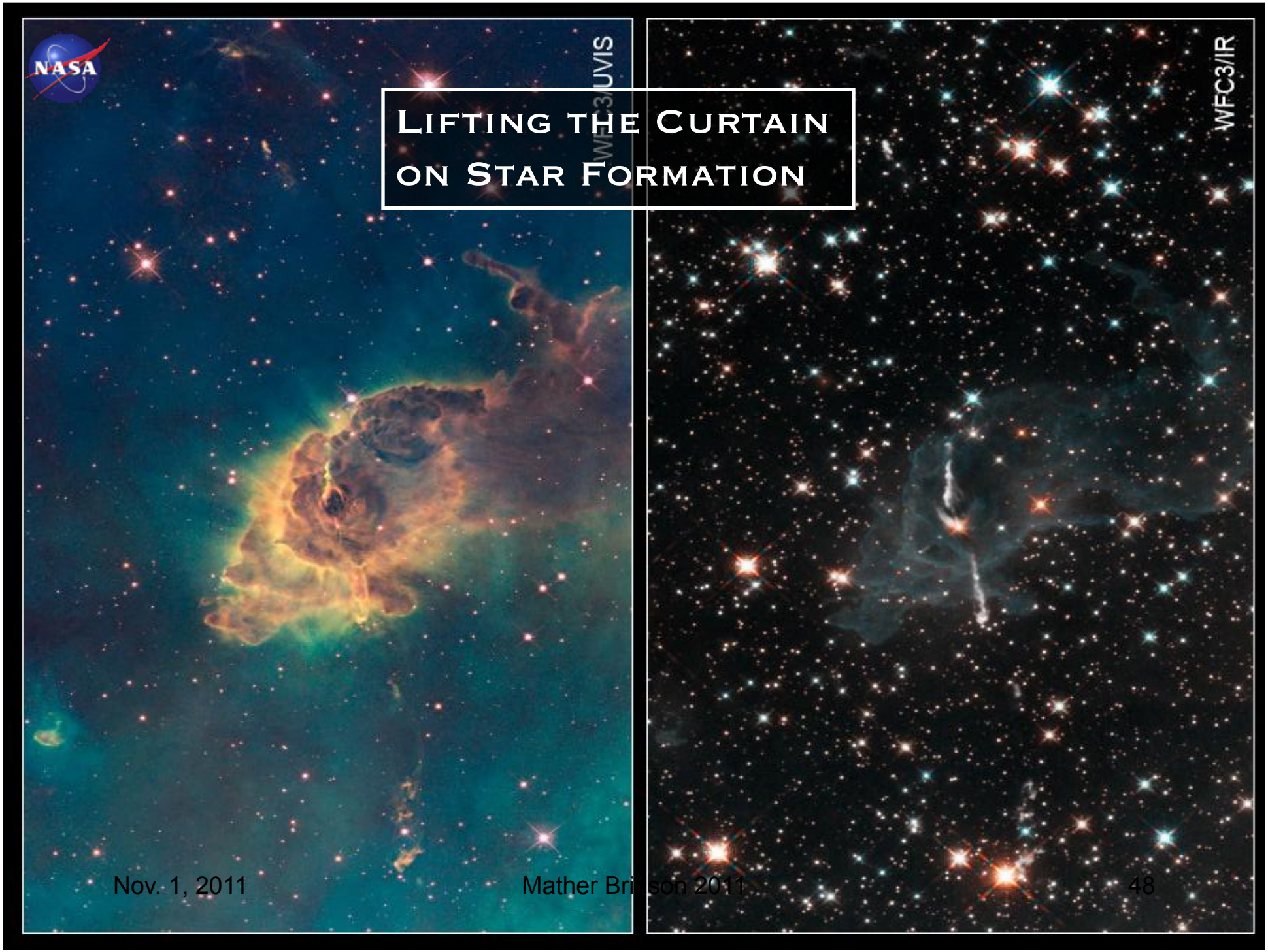
Nature's Lenses in Space



Galaxy Cluster Abell 370
Hubble Space Telescope ▪ ACS/WFC
NASA, ESA, the Hubble SM4 ERO Team, and ST-ECF
STScI-PRC09-25h

The Eagle Nebula as seen with Hubble

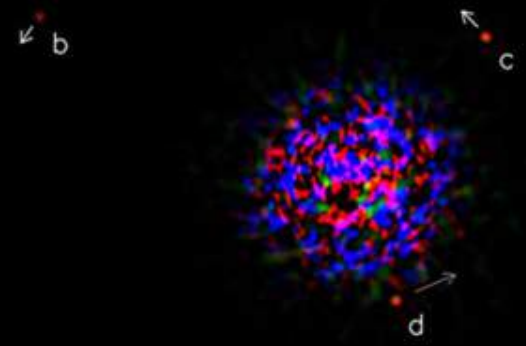
The Eagle Nebula
as seen in the infrared
M. J. McCaughrean
and M. Andersen, 1994

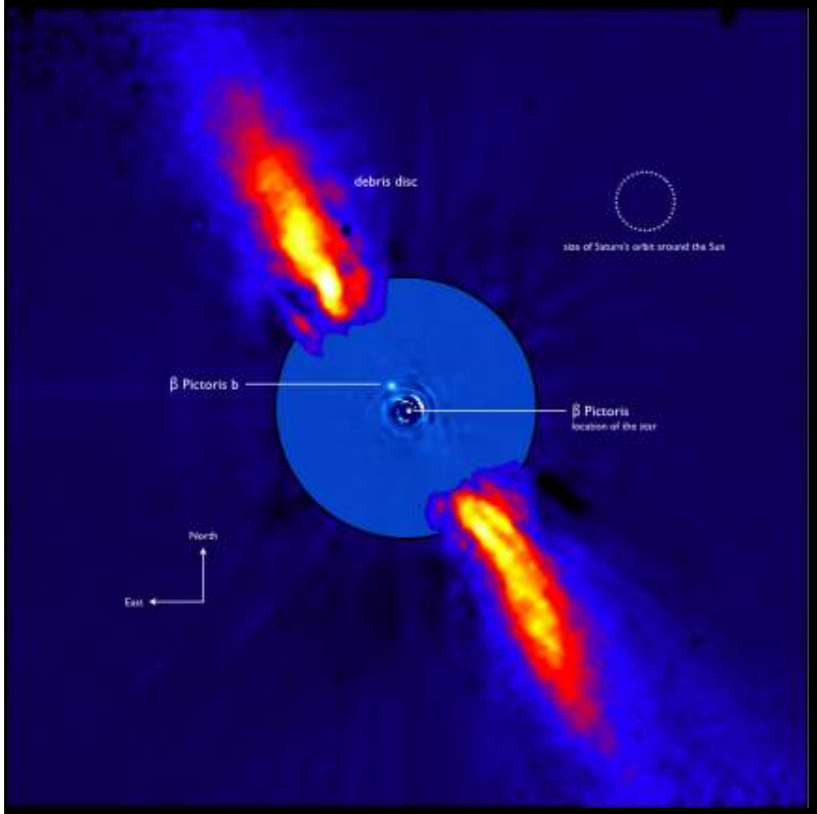


Lifting the Curtain on Star Formation

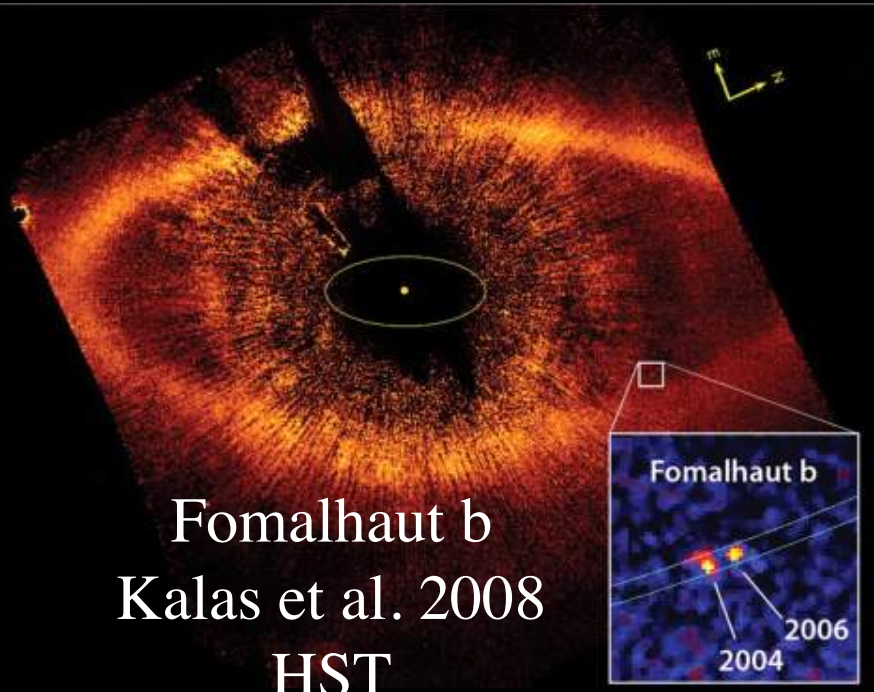
Planets Seen!

HR 8799 b,c,d
Marois et al. 2008
Gemini & Keck



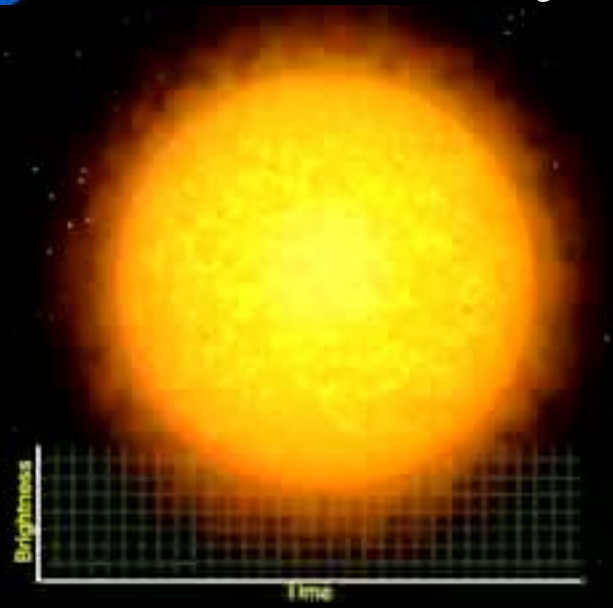


β Pictoris b
A.-M. Lagrange et al. 2008
VLT



Fomalhaut b
Kalas et al. 2008
HST

Primary



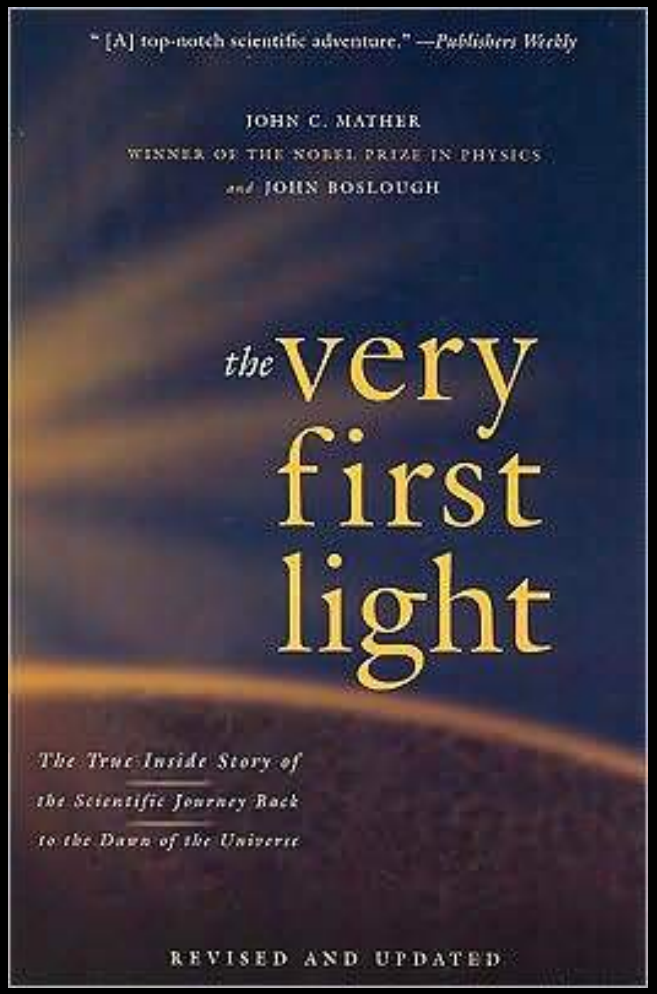
- Planet blocks light from star
- Visible/NIR light (Hubble/JWST/Kepler 1235 planets)
- Radius of planet/star
- Absorption spectroscopy of planet's atmosphere
- JWST: Look for moons, constituents of atmosphere, Earth-like planets with water

Secondary

- Star blocks light from planet
- Mid-Infrared light (Spitzer/JWST)
- Direct detection of photons from planet
- Temperature of planet
- Emission from surface
- JWST: Atmospheric characteristics, constituents of atmosphere, map planets

More Info:

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



The End

And the beginning!