From the Big Bang to the Nobel Prize and the End of the Universe

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Senior Project Scientist, James Webb Space Telescope,

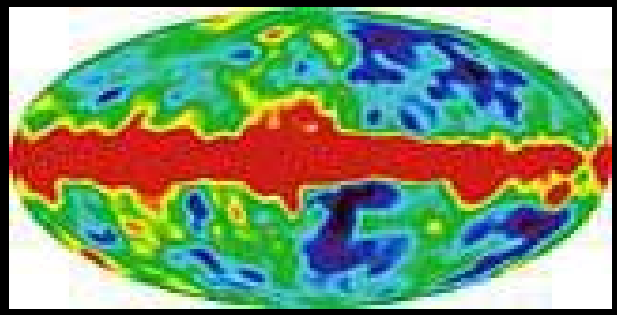
NASA's Goddard Space Flight Center

Sept. 28, 2009

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

Astronomical Search For Origins

First Galaxies



Big Bang

Galaxies Evolve

Life

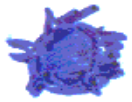
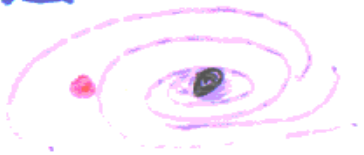
Planets

Stars

Can you imagine?

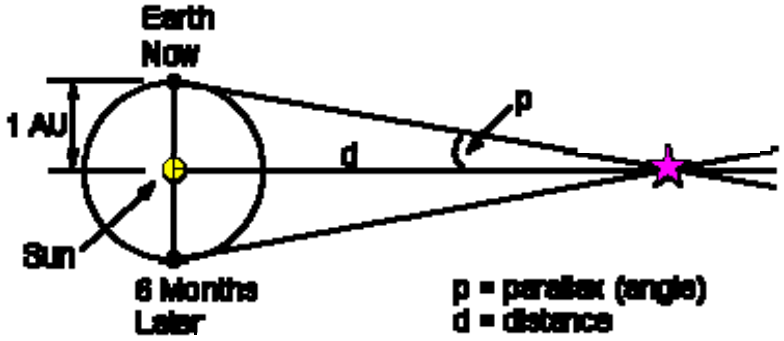
Your chin is made of exploded stars!

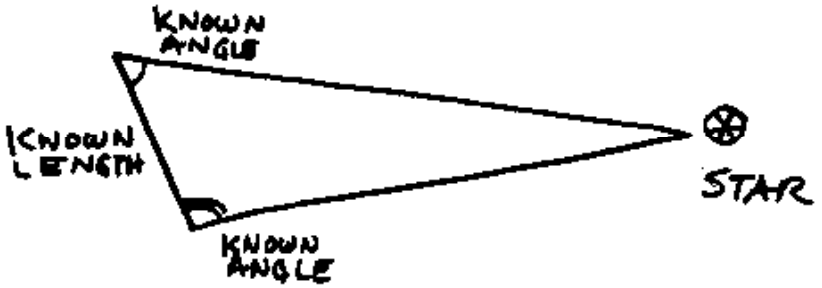
Looking Back in Time

HAND		1 m	0.000000003
EARTH		7000 km	0.0 2 sec
SUN		150,000,000 km	500 se
STAR			4 YRS
GALAXY			25,000 YRS
BIG BANG	?		15,000,000,000 Y

Measuring Distance

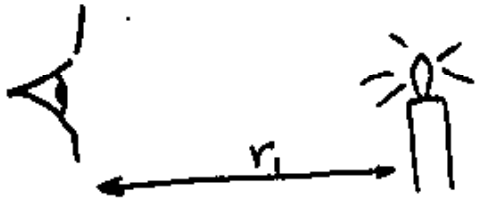
1. TRIANGLES





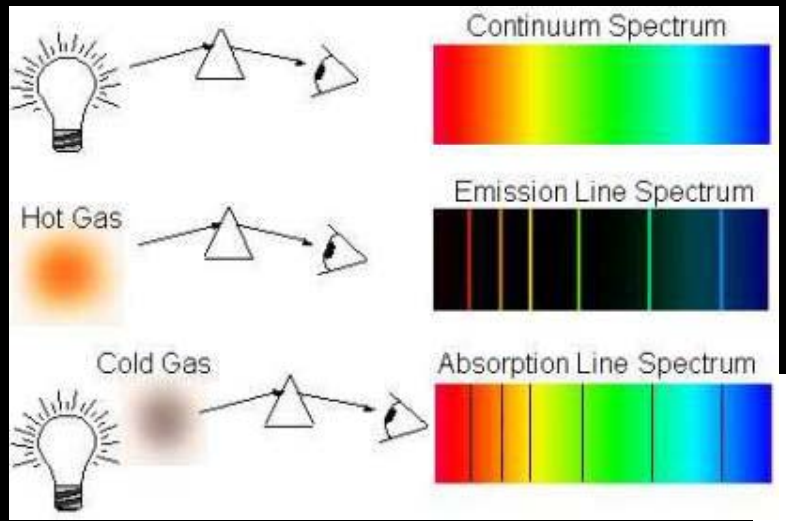
2. STANDARD CANDLES

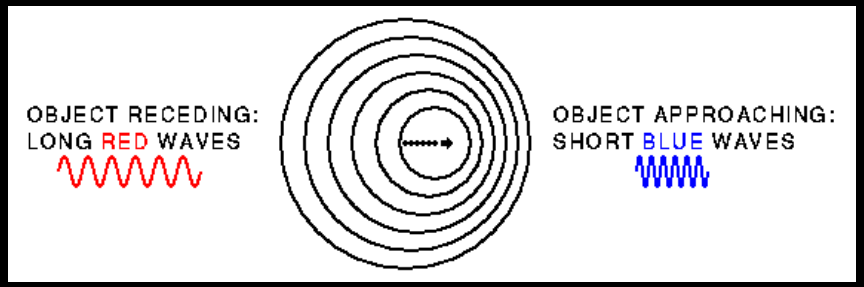
This technique enables measurement of enormous distances

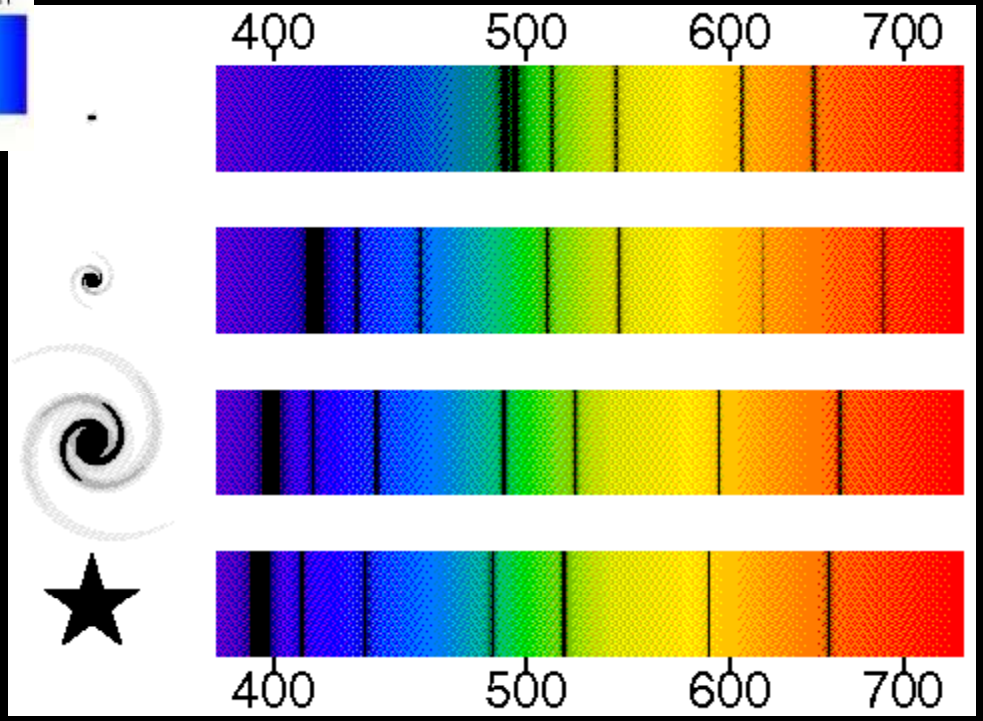


$$\frac{\text{BRIGHTNESS}_1}{\text{BRIGHTNESS}_2} = \frac{r_2^2}{r_1^2}$$

Astronomer's Toolbox #2:
Doppler Shift - Light



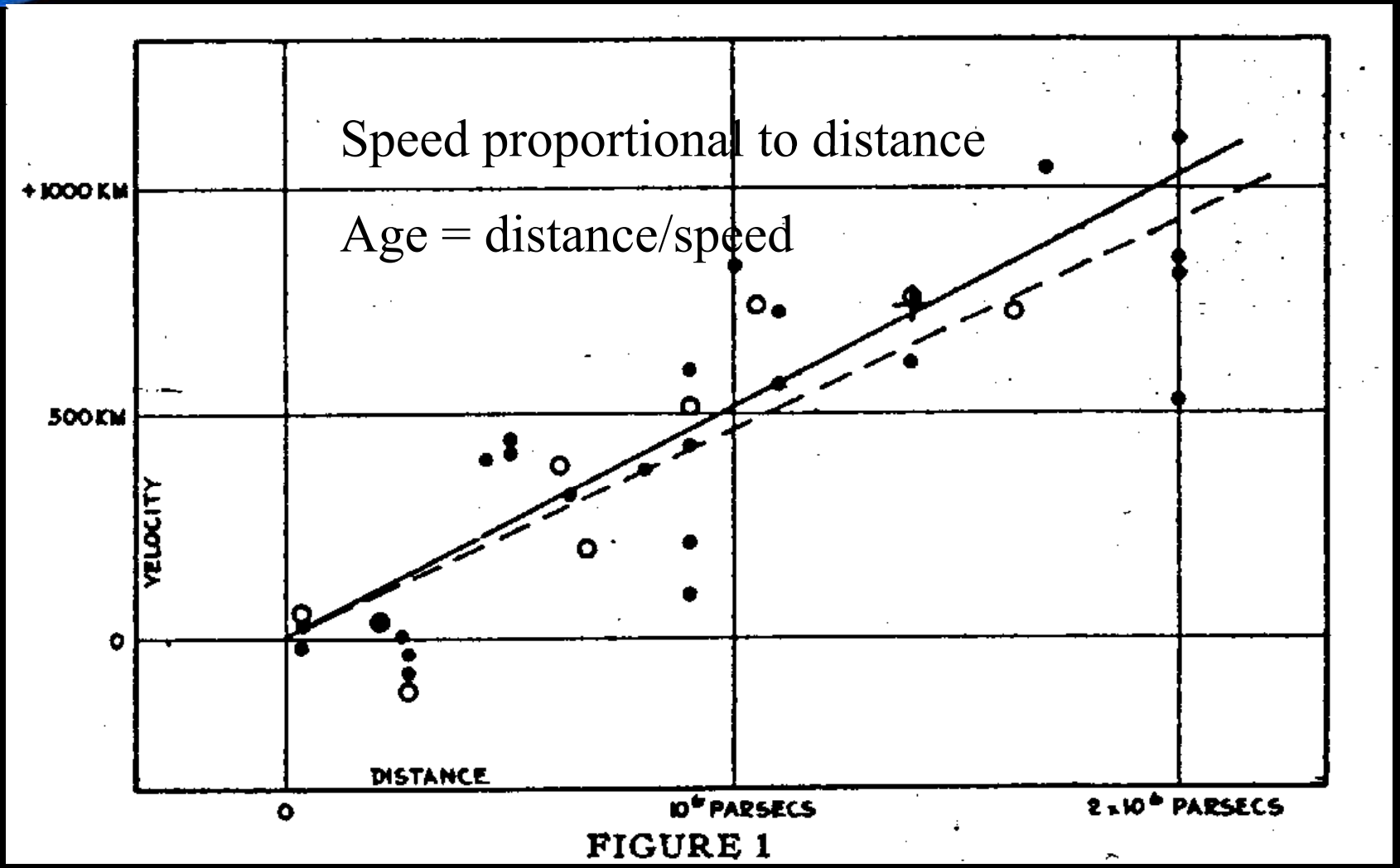




Atoms emit light at discrete wavelengths that can be seen with a spectroscope

This "line spectrum" identifies the atom and its velocity

Hubble's Law - 1929 Discovery

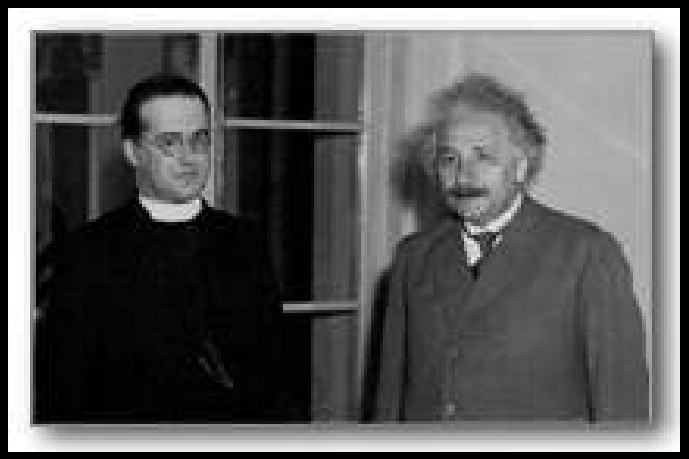


Speed -->

Distance -->

The Power of Thought

Alexander Friedman



Georges Lemaître & Albert Einstein

George Gamow

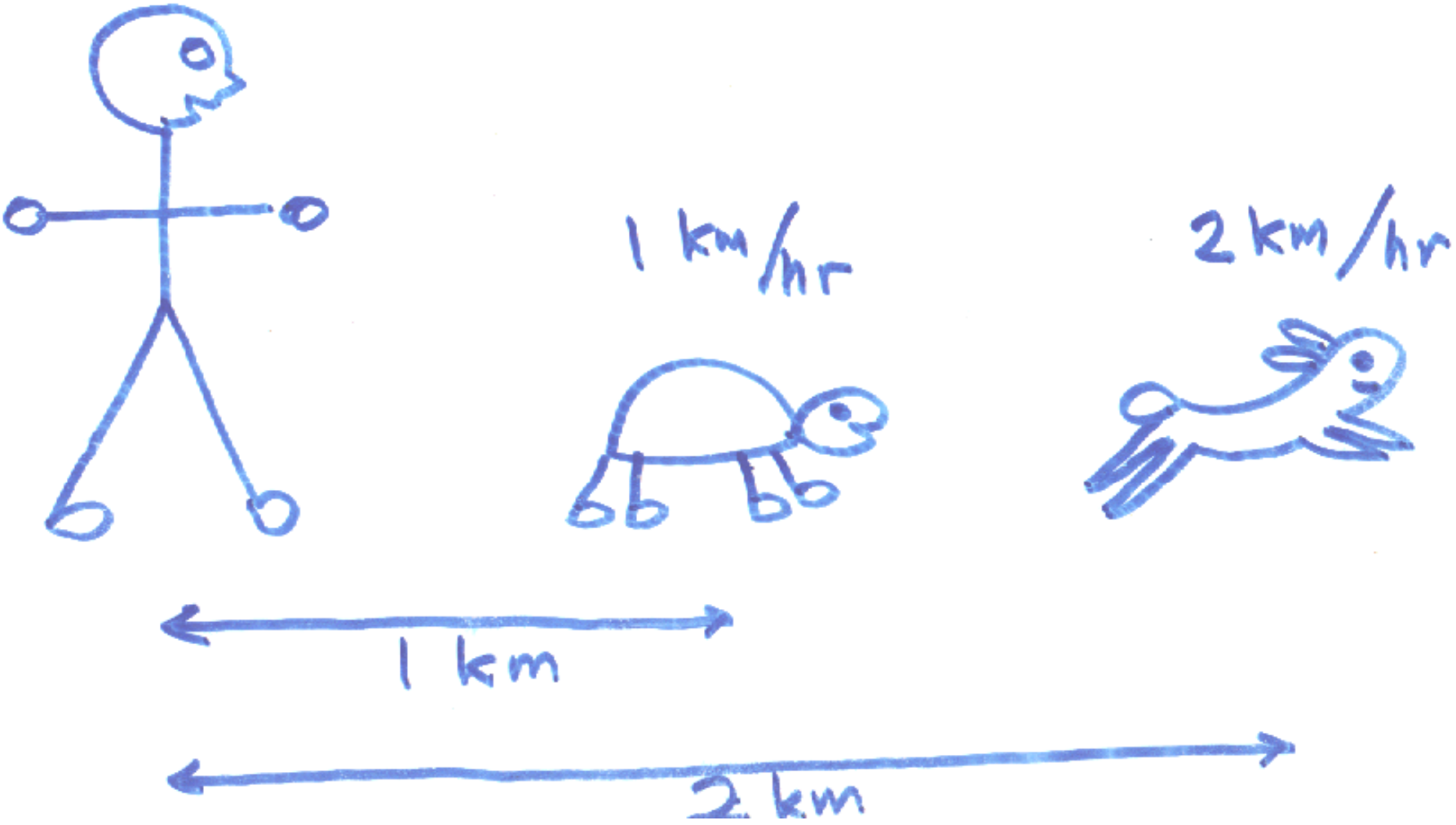
Robert Herman & Ralph Alpher

Rashid Sunyaev

Jim Peebles

HUBBLE'S LAW

NO NECESSARY CENTER!



Big Bang - Cosmic Explosion 13.7 billion years ago

IMPOSSIBLE TO DRAW A PICTURE!

So what happened?

- Primordial material, possibly infinite in every dimension
- Small piece of it (10 cm in size?) does something quantum mechanical with unknown physics
- Rapid expansion, faster than light can keep up with, stretches this little bit into whole observable universe (cosmic inflation)

How did the whole observable universe fit into that little ball?

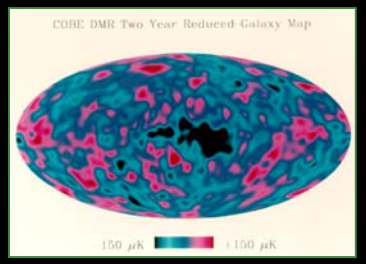
- Space is mostly empty - stars are very very far apart
- Atoms are mostly empty - atomic nuclei are very tiny compared to size of atoms
- Squeeze very hard, and compression can create antimatter and rip quarks apart inside protons and neutrons
- Higher temperatures fit more particles into given volume
- Inflation turns “false vacuum” energy into real particles
- Squeeze even harder, and the known laws of physics no longer apply - space and time may mix into higher dimensions?

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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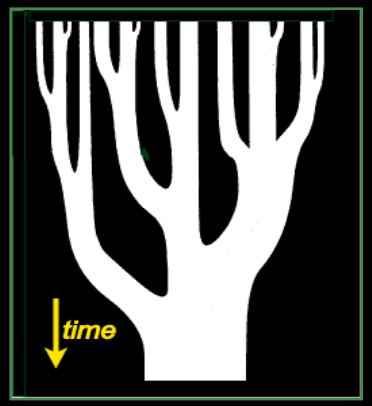
Galaxy assembly



?

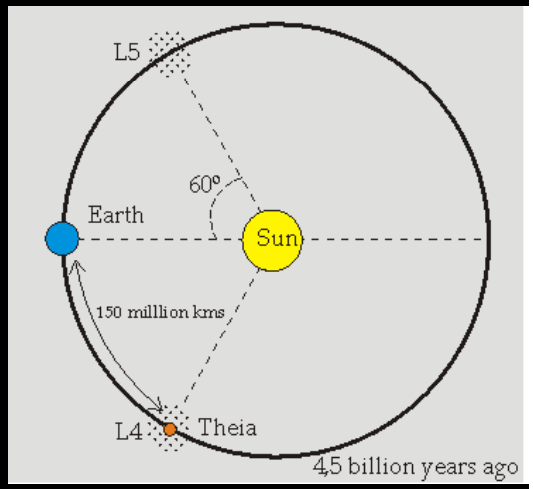
Galaxies, stars, planets, life

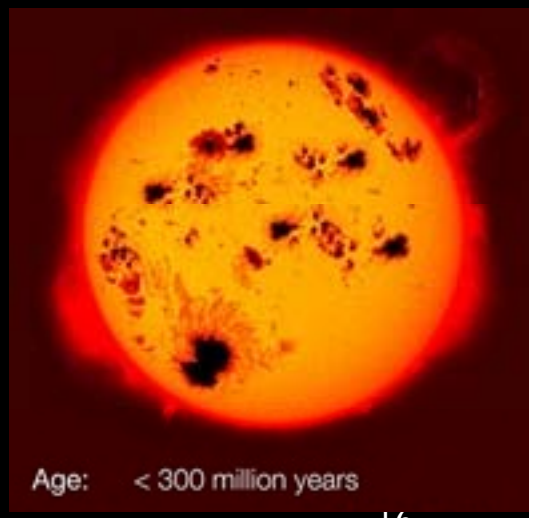
- Horrendous Space Kablooey - exponential expansion, primordial fluctuations, matter/antimatter, dark matter, dark energy, 13.7 ± 0.2 billion years ago
- Annihilation of antiparticles, 1 part per billion matter remaining
- Formation of Helium nuclei, 3 minutes, redshift z = 10^9
  - [1+z = size of universe 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 History of Earth

- Sun and first solid bodies in Solar System 4.567 billion years ago
- Mars-sized body "Theia" hits Earth, melting everything, dispersing volatiles like C and H; debris forms Moon, 90 MY AF (after formation)
- Cool early Earth, possibly with water
- Jupiter, Saturn orbits switch twice, clear debris from solar system, cause "late heavy bombardment", "Hadean" geologic period, many craters, new water and carbon delivery to Earth, 400 - 700 MY AF
- Life forms shortly after (~ 3.8 BY ago)
- Young Sun very active, gets steadily brighter with time, warming Earth

Hartman & Davis idea 1975





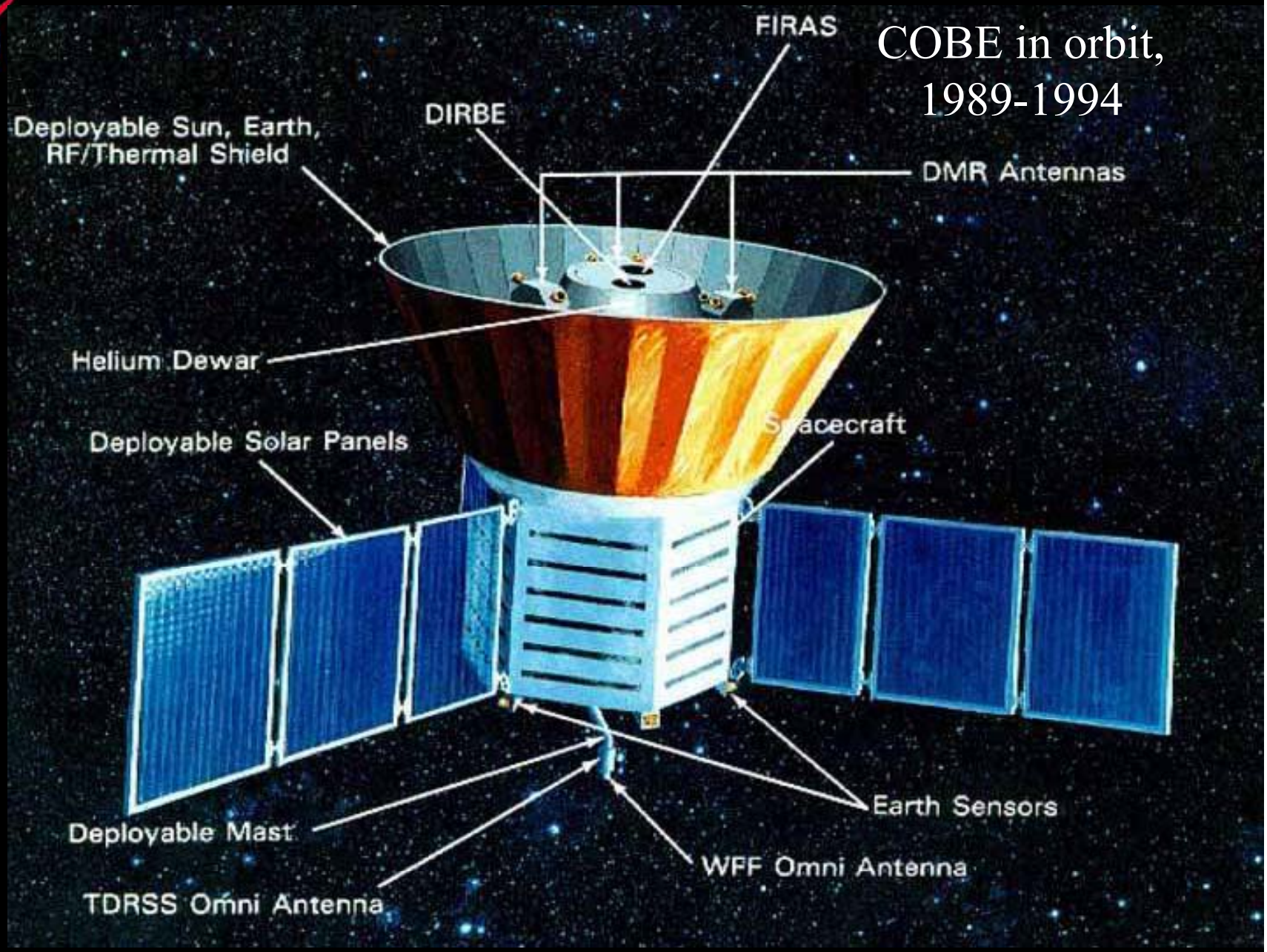
Ed Guinan 2009

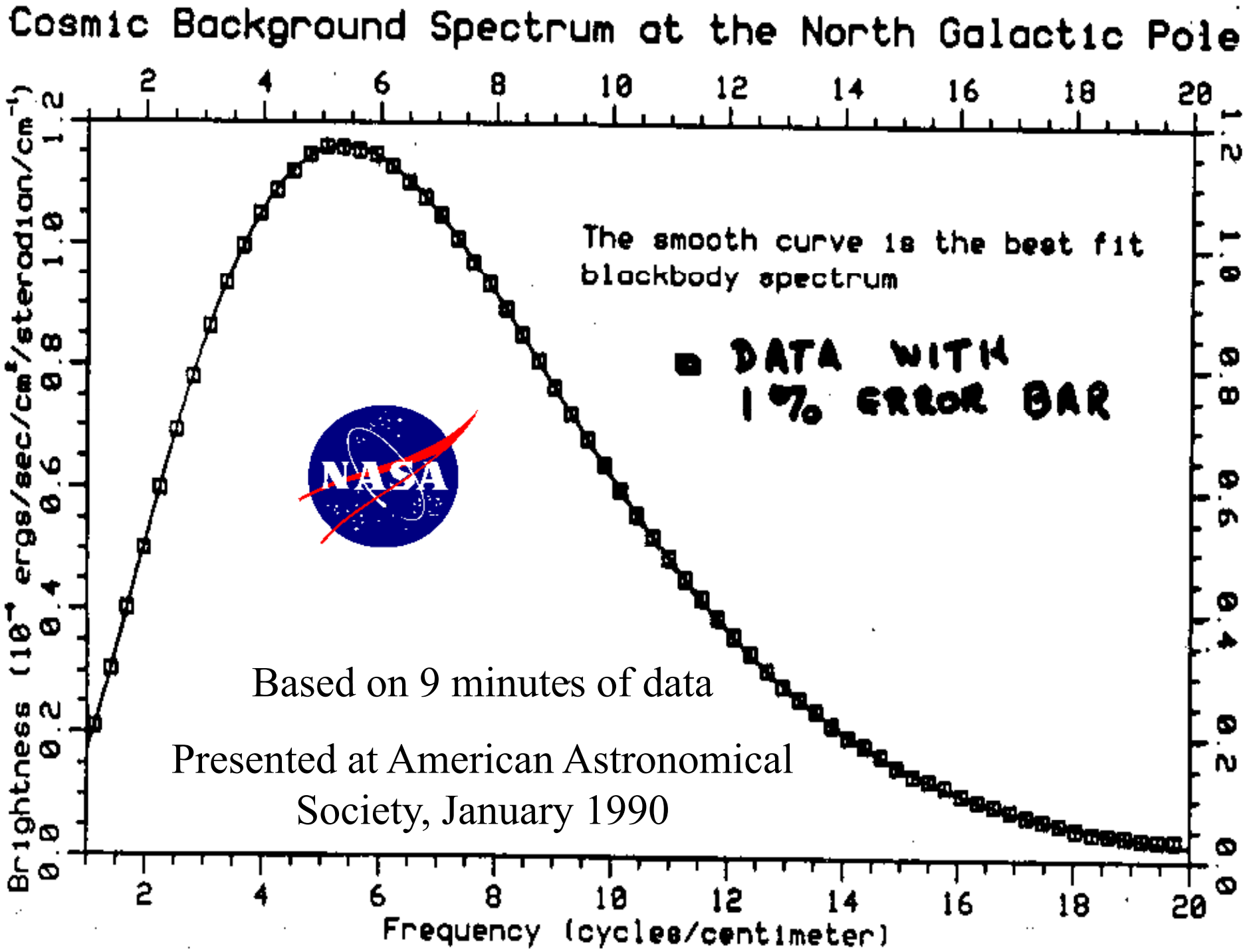
Continents Floating and Moving

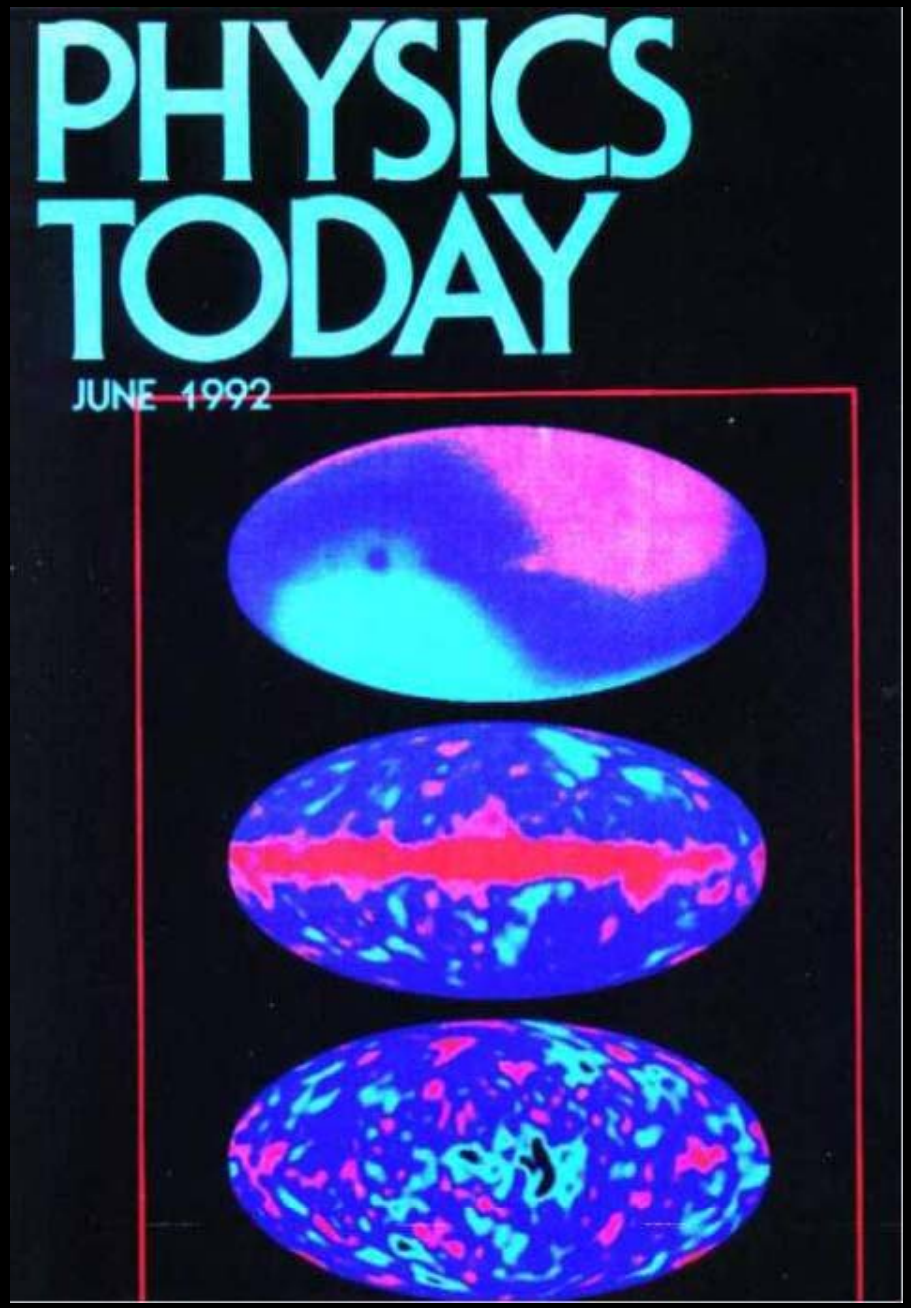
- Huge volcanic effects on atmospheric composition (CO_2, H_2S, etc. fluctuate)
- Vaalbara, 3.3-3.6 billion years ago
- Rodinia, 1100 – 750 million years ago, split into proto-Laurasia, proto-Gondwana, and Congo Craton "Re-unite Gondwanaland"
- Pangaea, 250 MY ago
- Atlantic Ocean opens, ~ 100 MY ago

Ice Ages, Civilization, & the Future

- Huronian Ice Age, 2.7 – 2.3 BYA
- Cryogenian, 850 – 630 MYA, possible "snowball Earth"
- Volcanism releases CO_2, enables Cambrian explosion of life
- Andean-Saharan Ice Age, 460 – 430 MYA
- Current Ice Age, 2.58 MYA, ending 10,000 YA
  - Riss, 180,000 – 130,000 YA (when Homo Sapiens developed?)
  - Wurm, 70,000 – 10,000 YA (begin modern civilization)
- Galileo's telescope 1609 (2009 International Year of Astronomy)
- 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

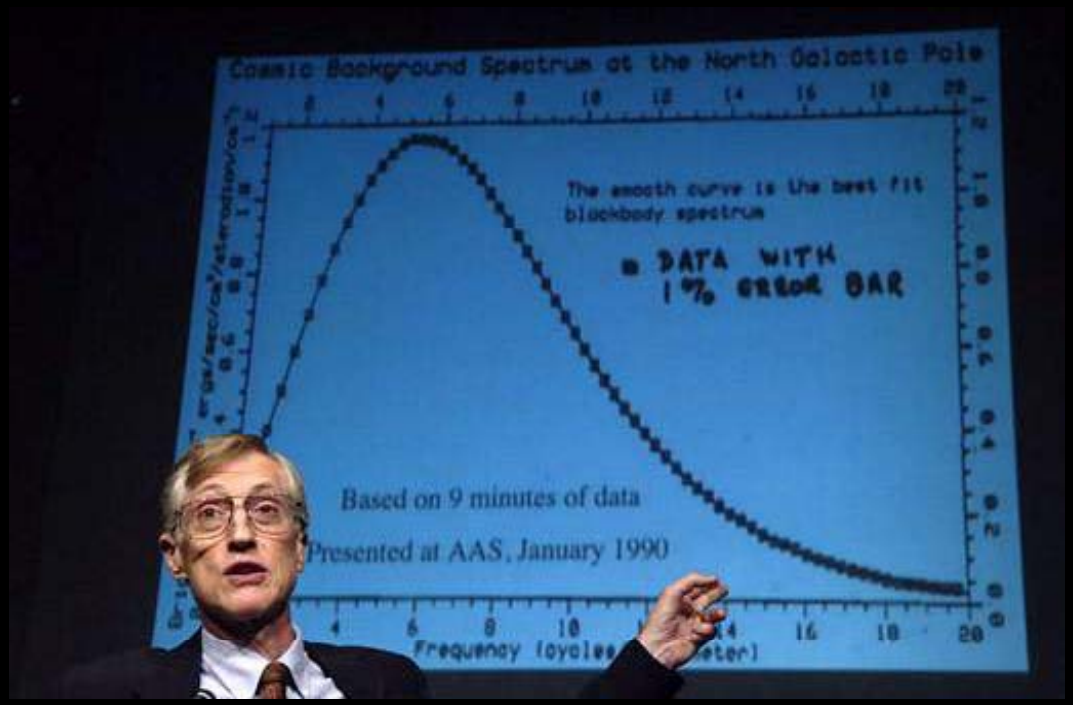
Doppler Effect of Sun's motion removed (v/c = 0.001)

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

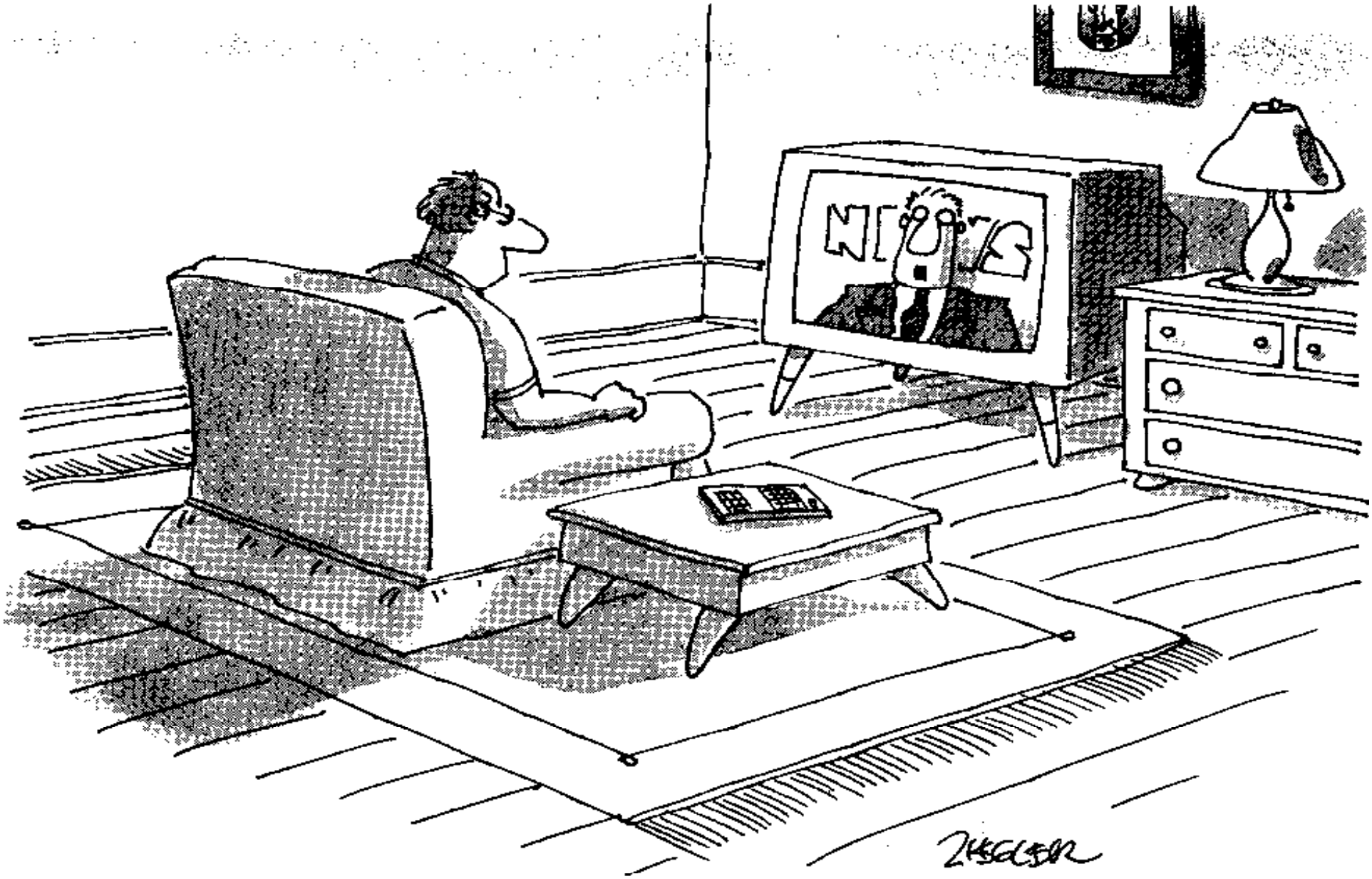
Nobel Prize Press Release

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2006 jointly to **John C. Mather,** NASA Goddard Space Flight Center, Greenbelt, MD, USA, and **George F. Smoot,** University of California, Berkeley, CA, USA *"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation".*

From Press Conference to Stockholm



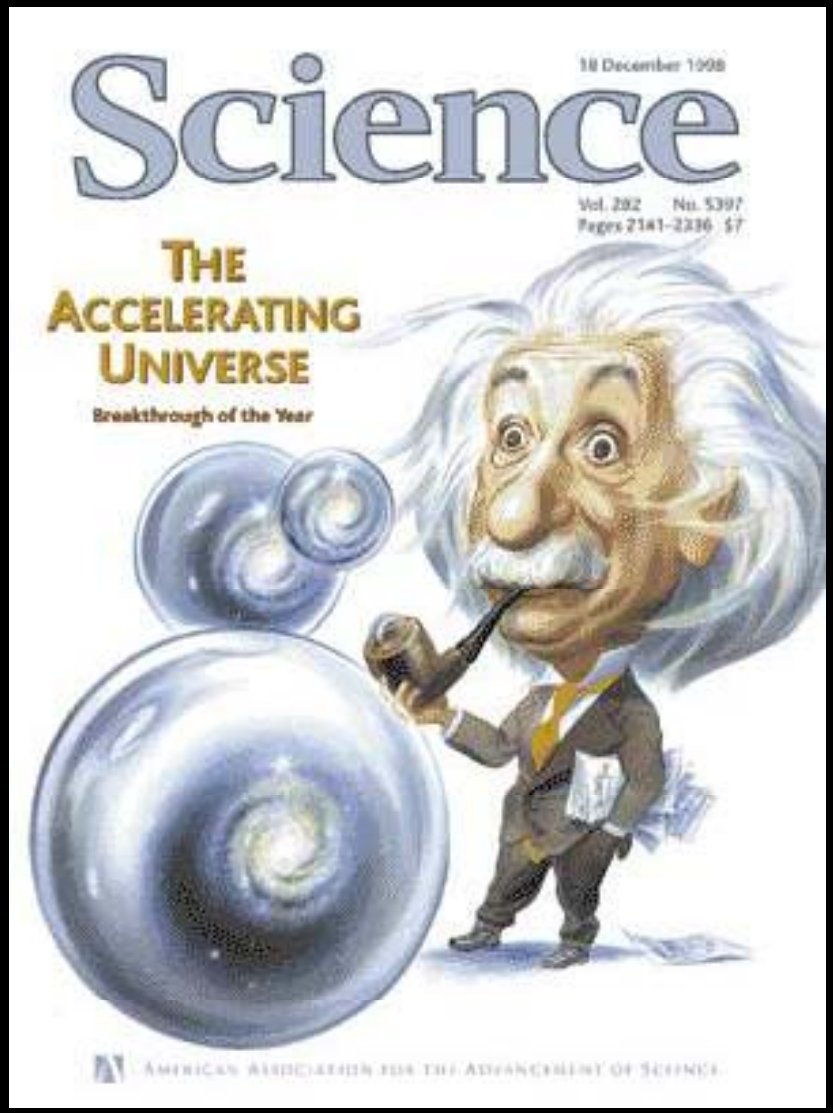
© Nobel Foundation
Photo by Hans Mehlin



"Scientists confirmed today that everything we know about the structure of the universe is wrongedy-wrong-wrong."

Dark Energy!

MacArthur Fellow
2008 - Adam Riess



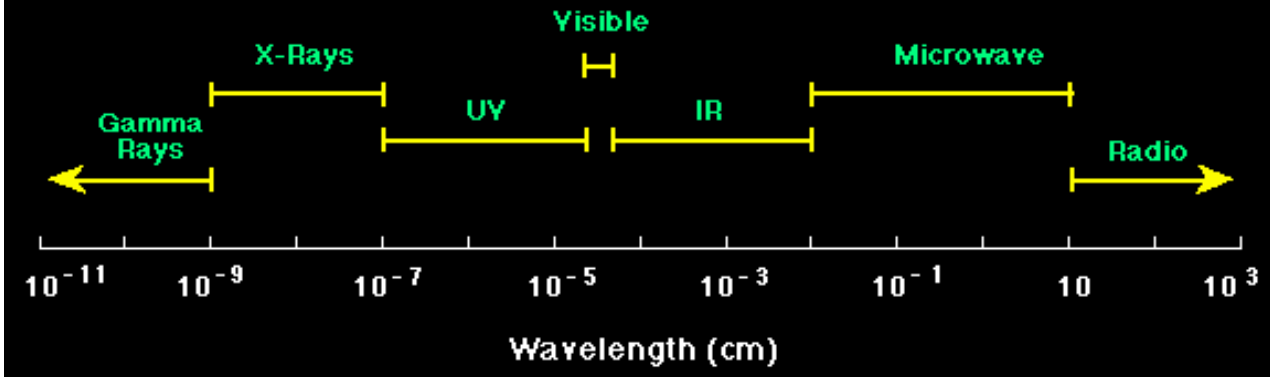
S. Perlmutter, A. Riess, B. Schmidt

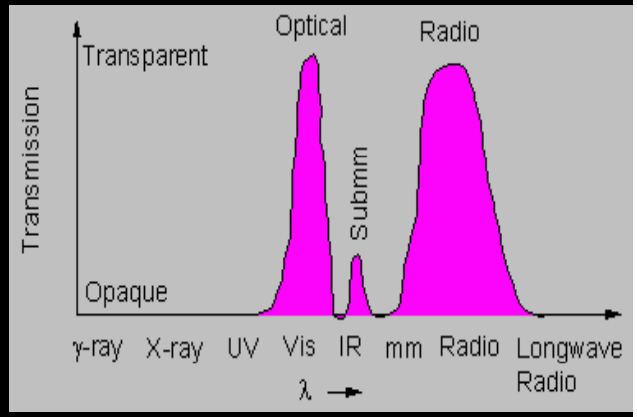
A few big mysteries…

- Why is there matter and no antimatter?
- What is dark matter?
- What is dark energy?
- Was Einstein right about relativity?
- How did we get here?
  - Formation of stars, chemical elements, galaxies, planets, …
- Are we alone?
  - How did Earth become habitable?
  - Any other places that could support life?
- What happens next?

Light comes in more colors than our eyes can see

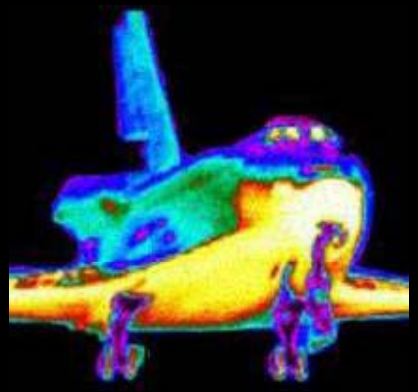
Light from the first galaxies is redshifted from the visible into the infrared.



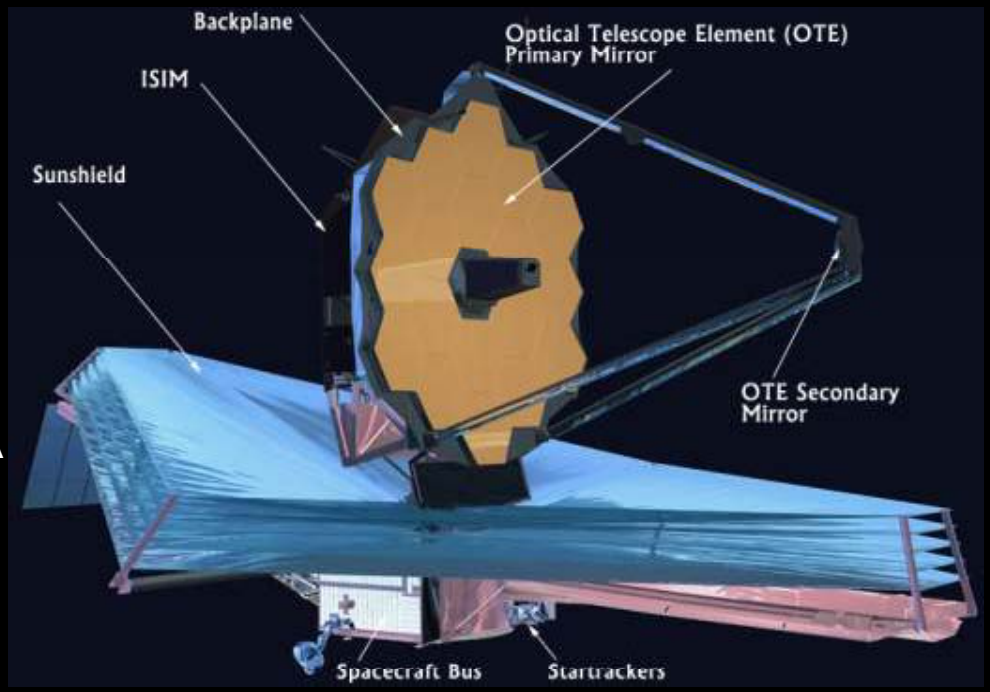


Infrared is heat radiation

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



James Webb Space Telescope (JWST)



Organization

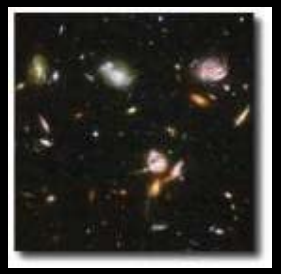
- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Space Technology
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - 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 June 2014 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



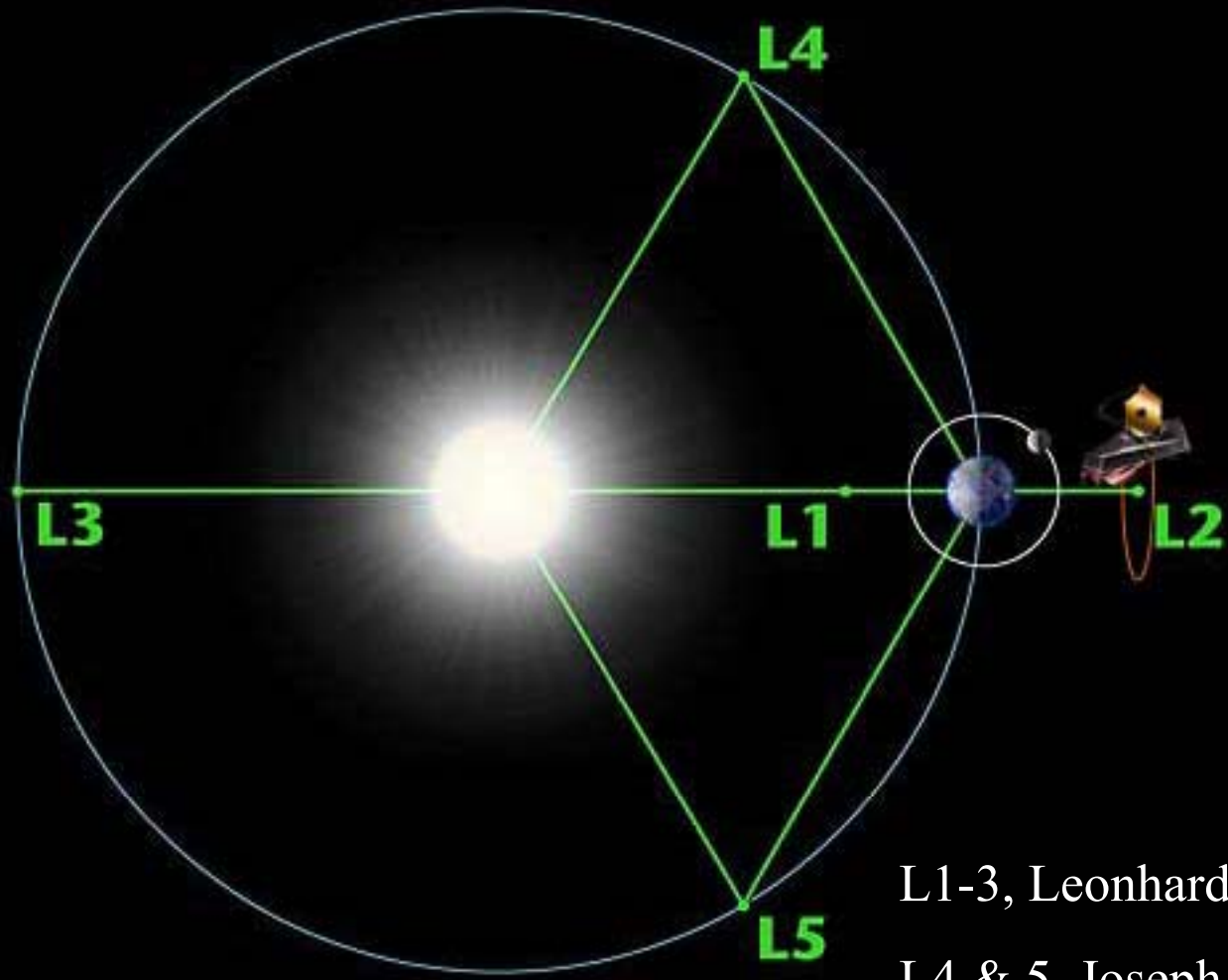
End of the dark ages: First light and reionization

The assembly of galaxies

Birth of stars and proto-planetary systems

Planetary systems and the origin of life

JWST Orbits the Sun-Earth Lagrange Point L2



L1-3, Leonhard Euler, 1750.

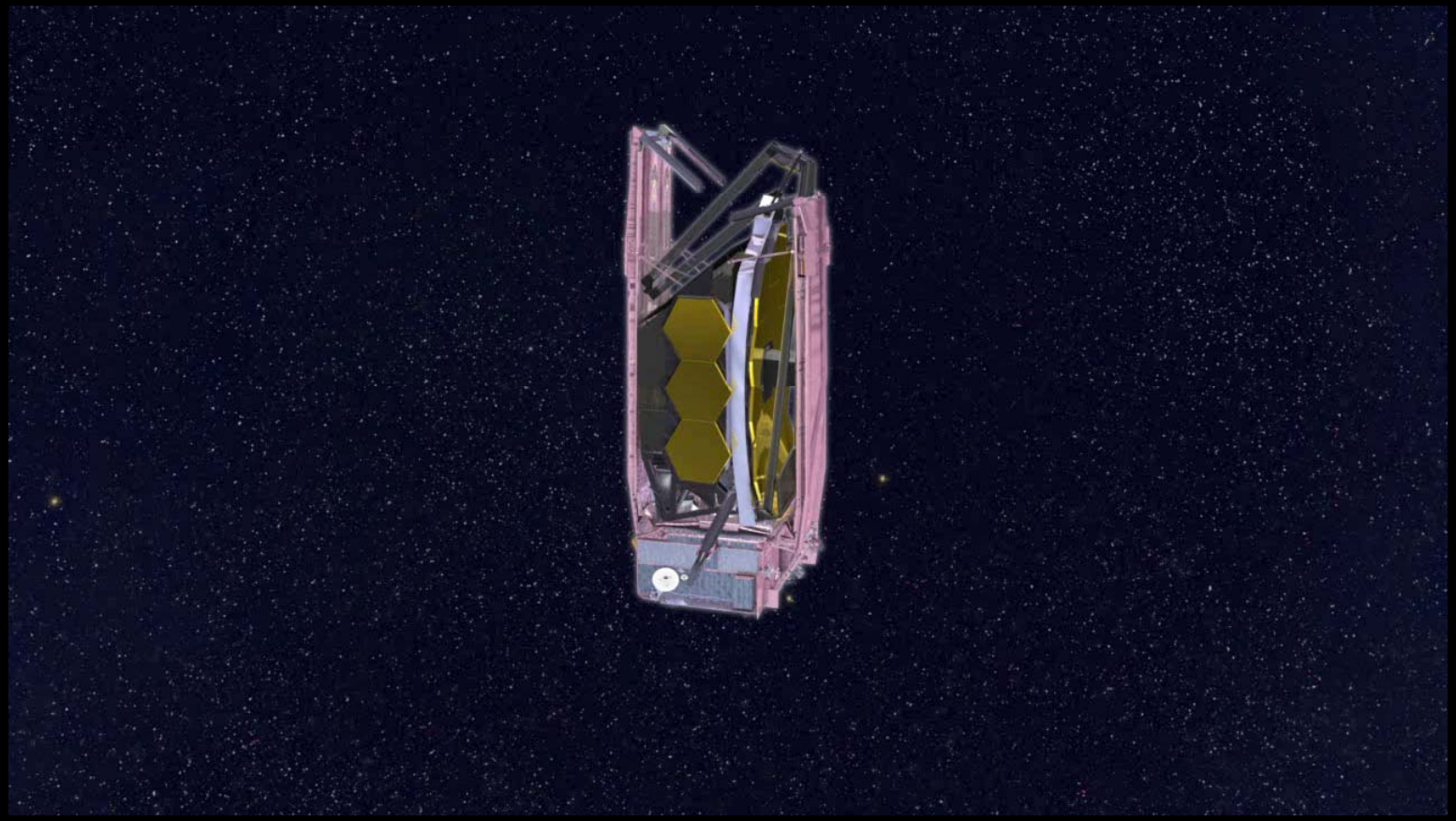
L4 & 5, Joseph-Louis Lagrange, 1772

Northrop Grumman's JWST model

Washington, DC 2007

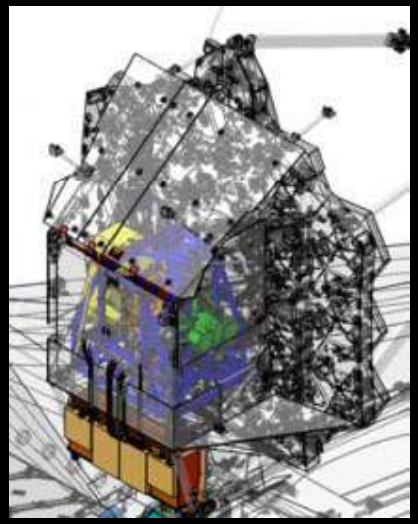
Munich, Germany 2008

JWST Deployment

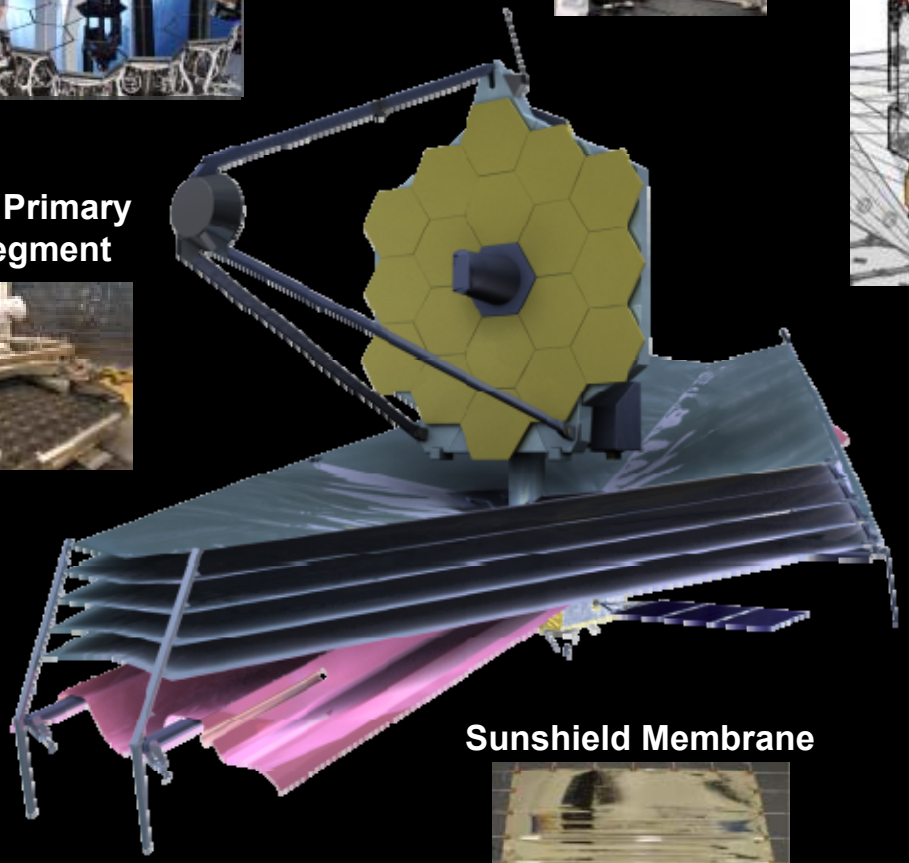


JWST Technology

Backplane



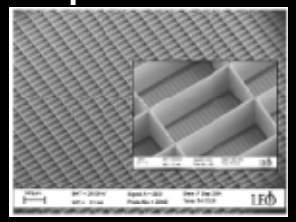
Mirror Phasing Algorithms



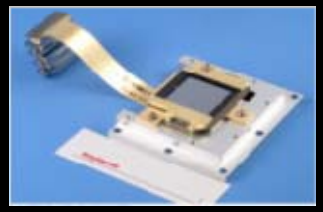
Near-Infrared Detector

Beryllium Primary Mirror Segment

µShutters

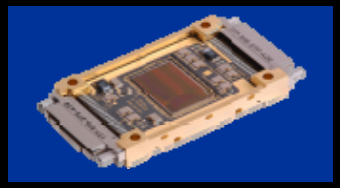


Mid-Infrared Detector



Cryocooler

Cryogenic ASICs

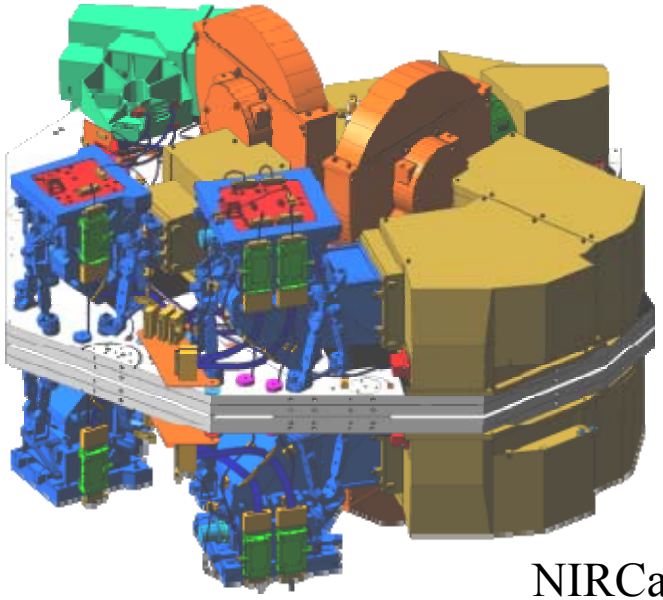


Sunshield Membrane

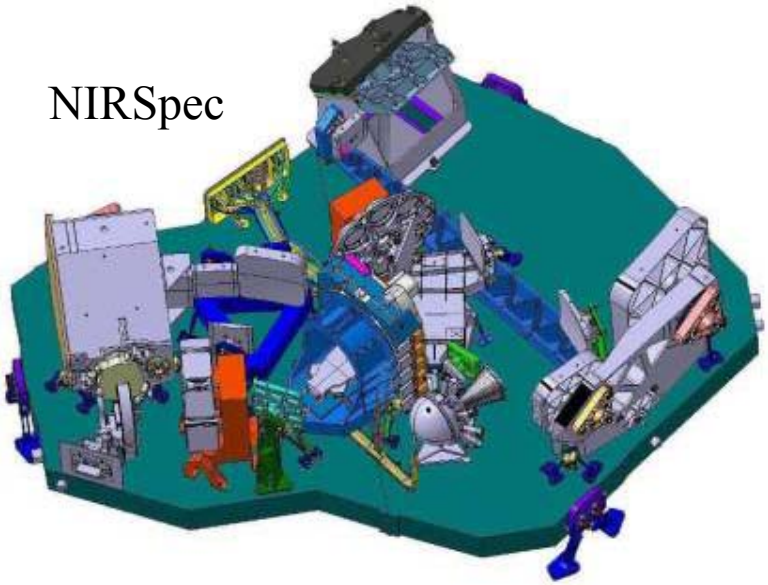
Testbed Telescope

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

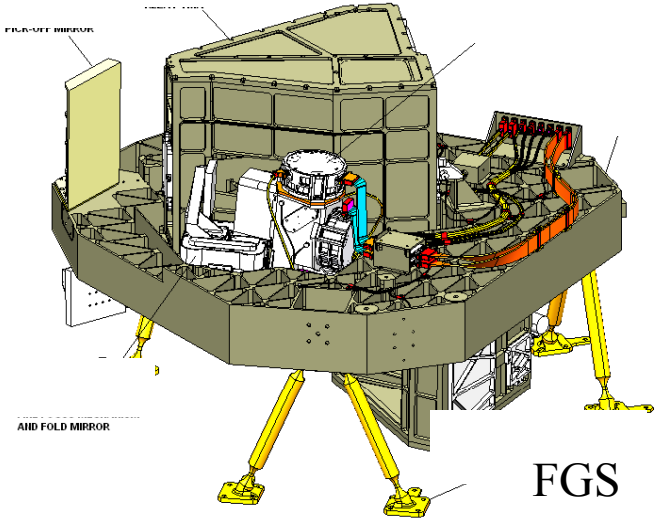
Four science instruments enable imagery and spectroscopy over the 0.6 – 29 micron spectrum



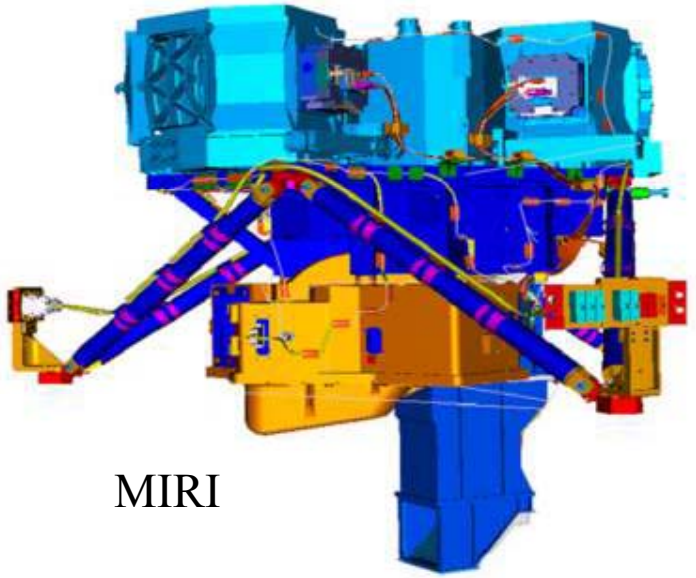
NIRCam



NIRSpec

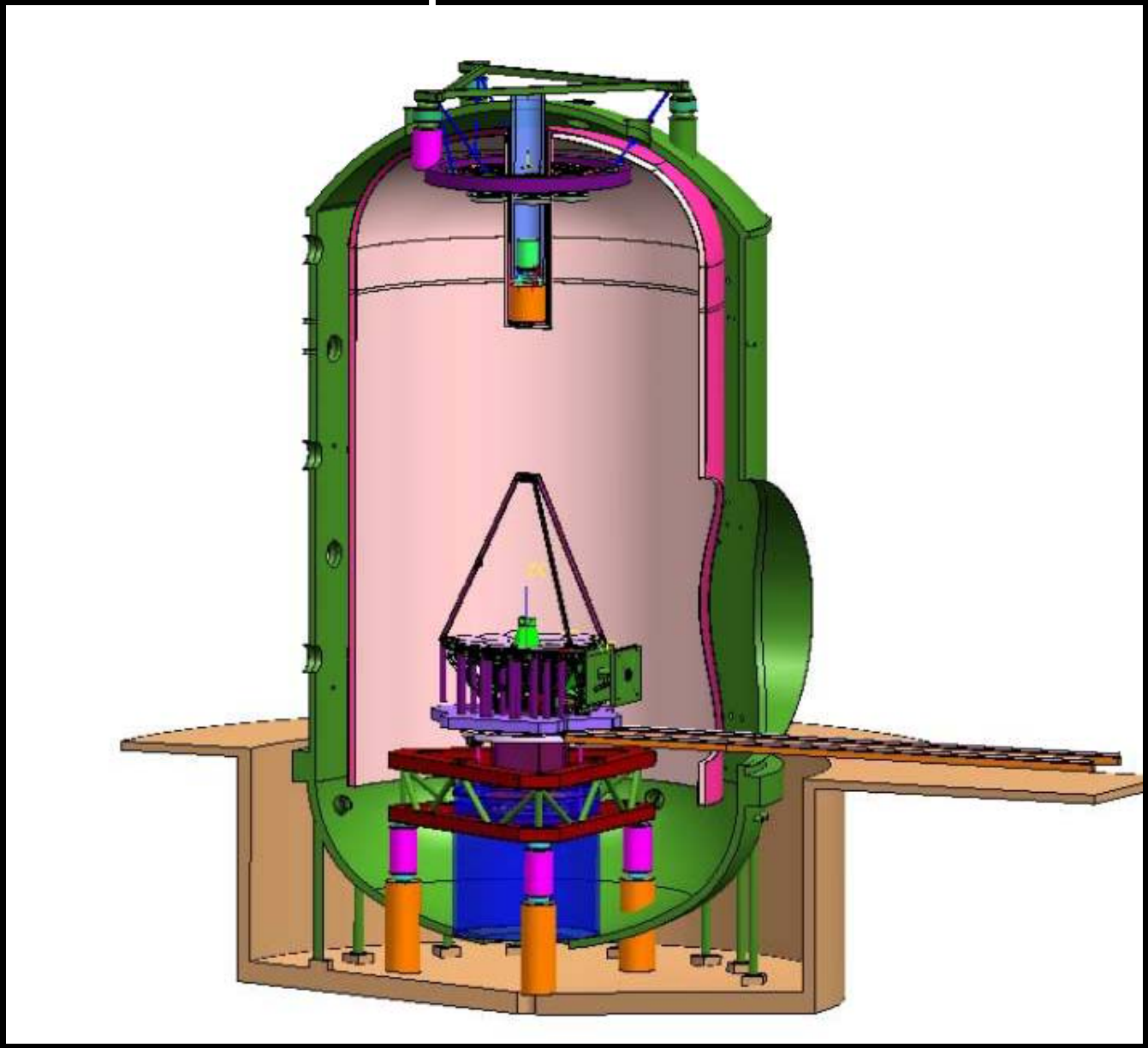


FGS

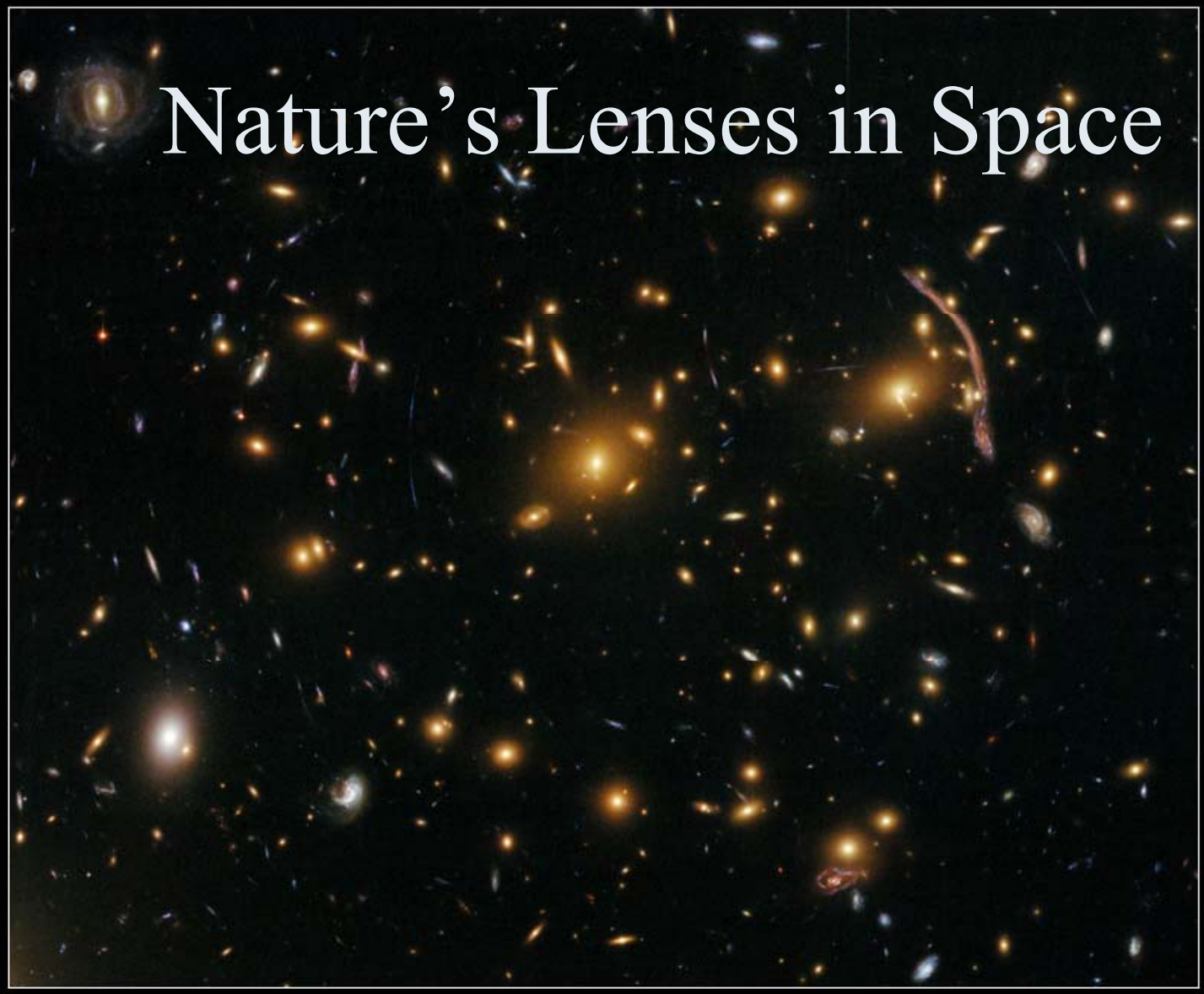


MIRI

JWST cold optical test in Houston



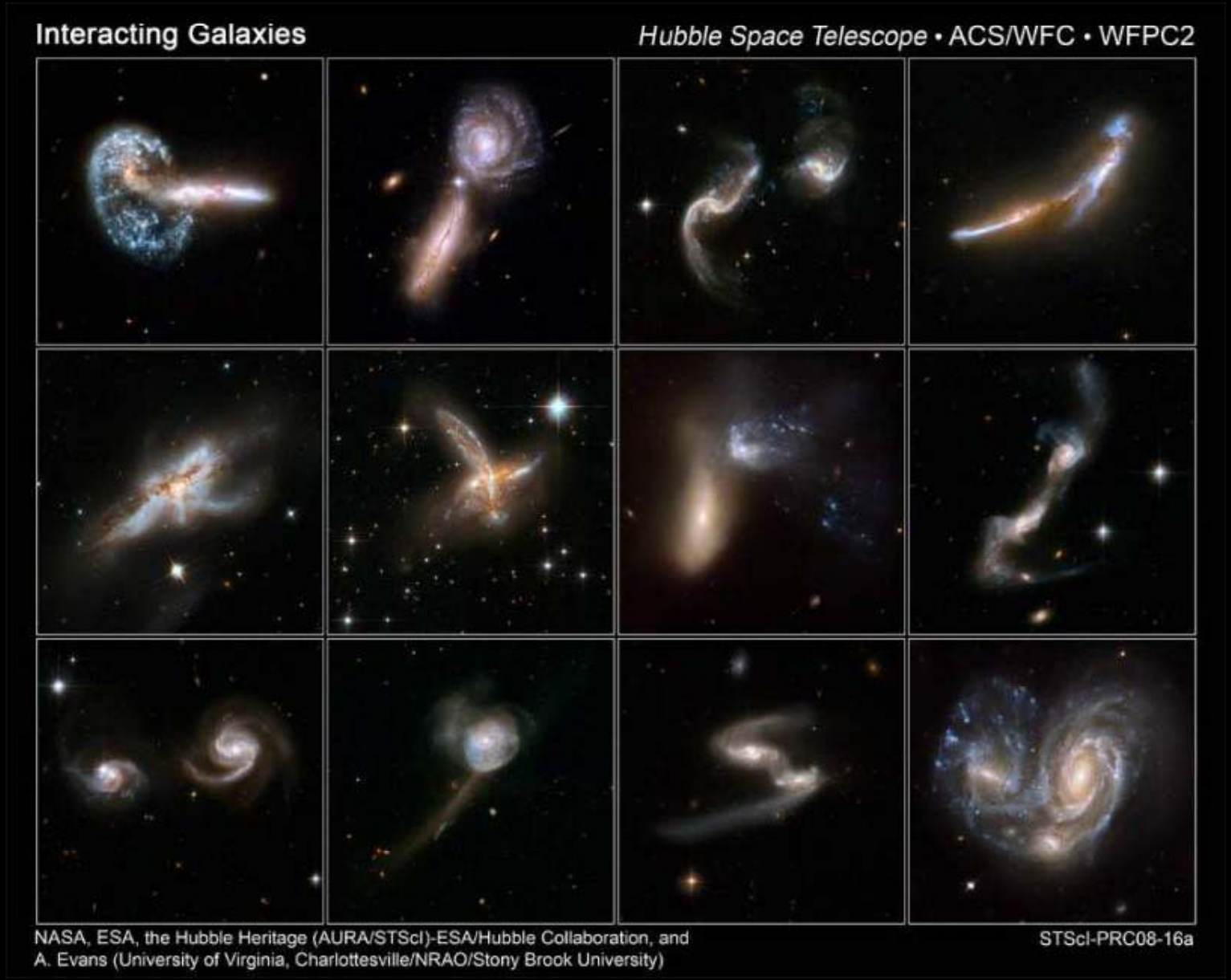
Nature's Lenses in Space



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

Dwarf Galaxies with Dark Matter

How do galaxies evolve?

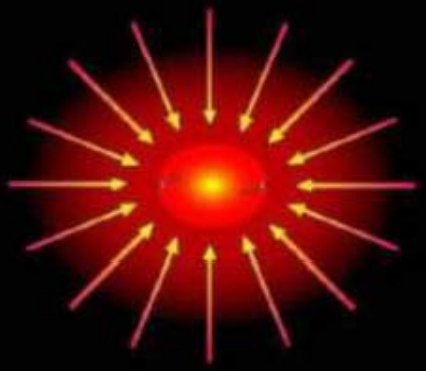


Where and when did the Hubble Sequence form? How did the heavy elements form?

- Galaxy assembly is a process of hierarchical merging
- Components of galaxies have variety of ages & compositions
- Observations:
  - NIRCam imaging
  - Spectra of 1000s of galaxies

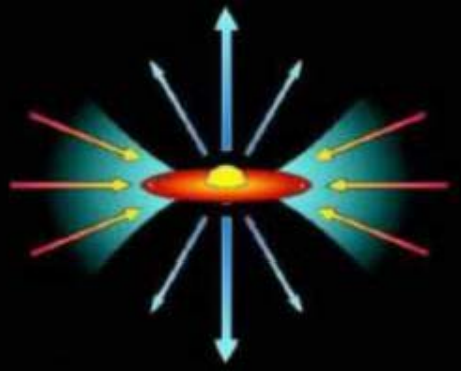
How stars and planets form?

Deeply embedded protostar



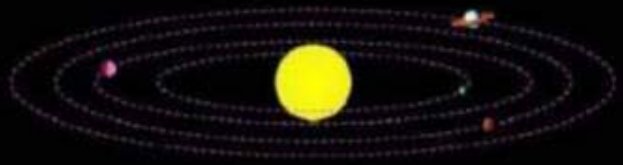
10^4 yrs; 10–10^4 AU; 10–300K

Circumstellar disk



10^{5-6} yrs; 1–1000AU; 100–3000K

10^{6-7} yrs; 1–100AU; 100–3000K

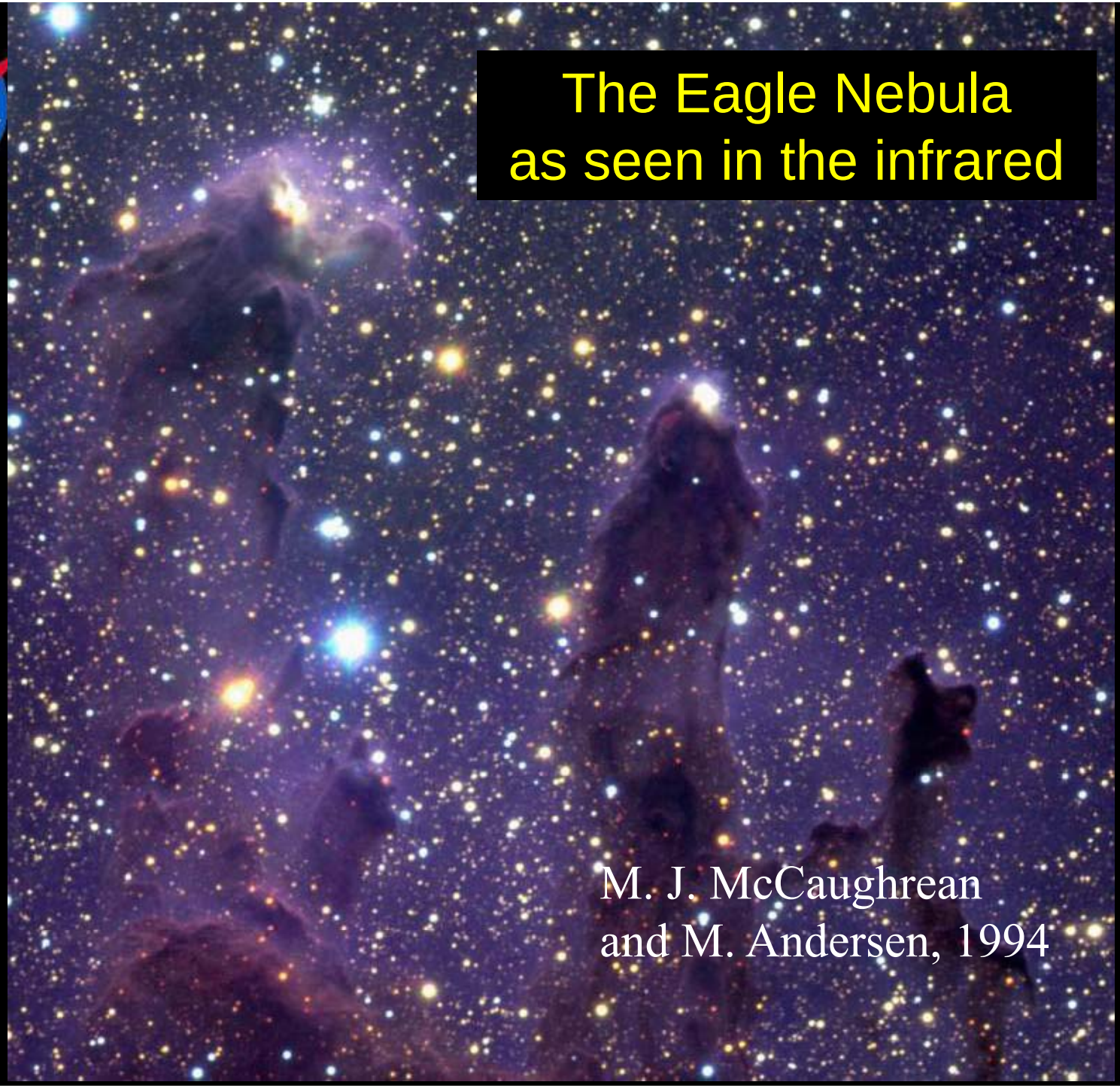


10^{7-9} yrs; 1–100AU; 200–3000K

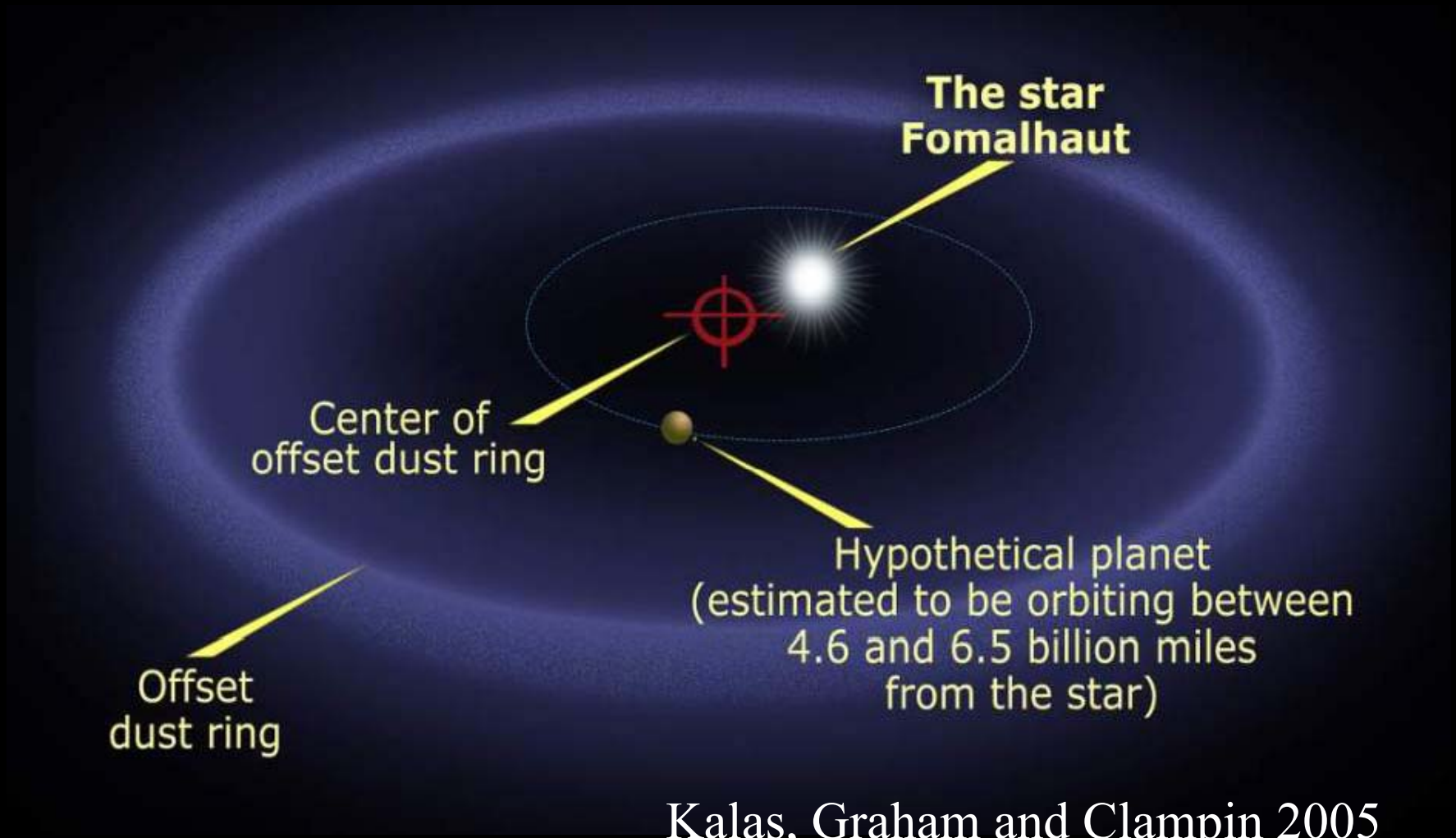
Agglomeration & planetesimals

Mature planetary system

The Eagle Nebula as seen with Hubble


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

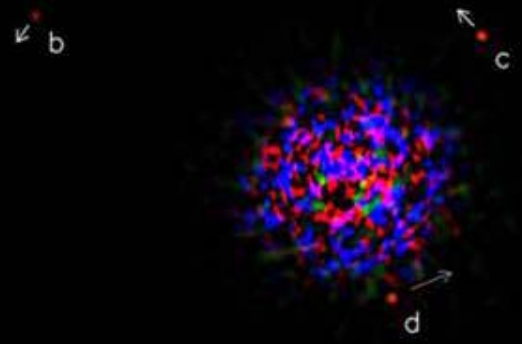
Planetary systems and the origins of life

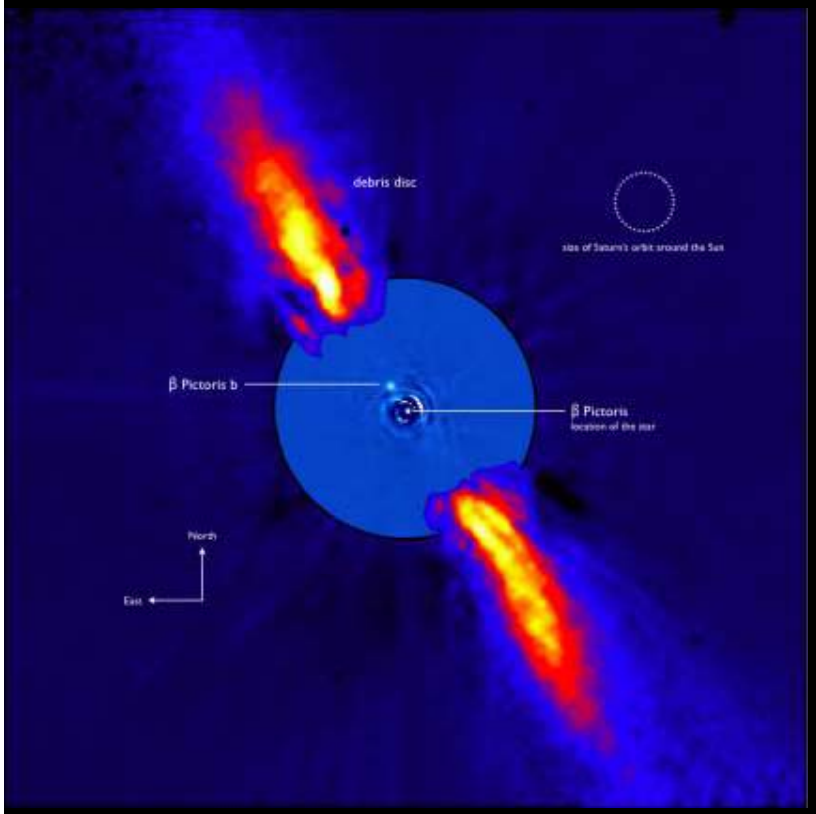


Kalas, Graham and Clampin 2005

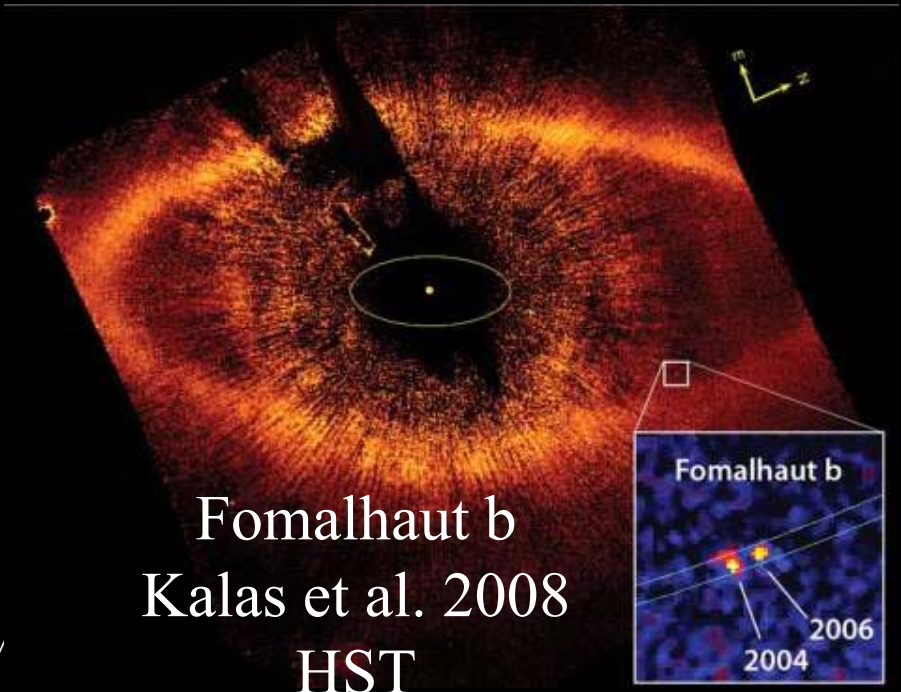
Planets Seen!

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



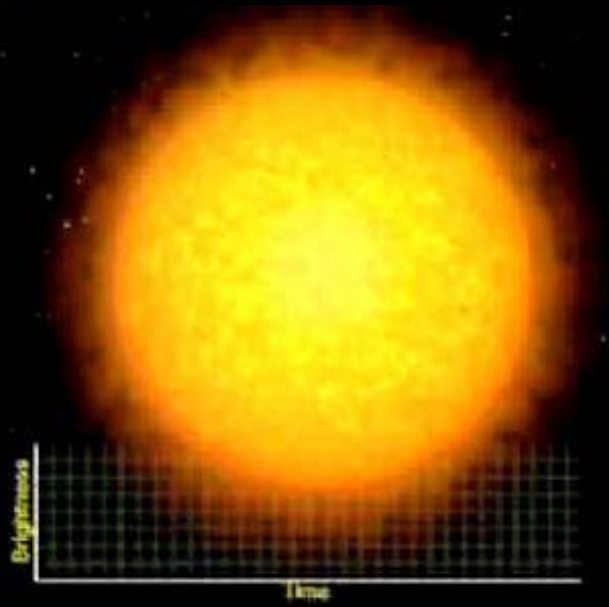


β Pictoris b
A.-M. Lagrange et al. 2008
VLT



Fomalhaut b
Kalas et al. 2008
HST

Primary



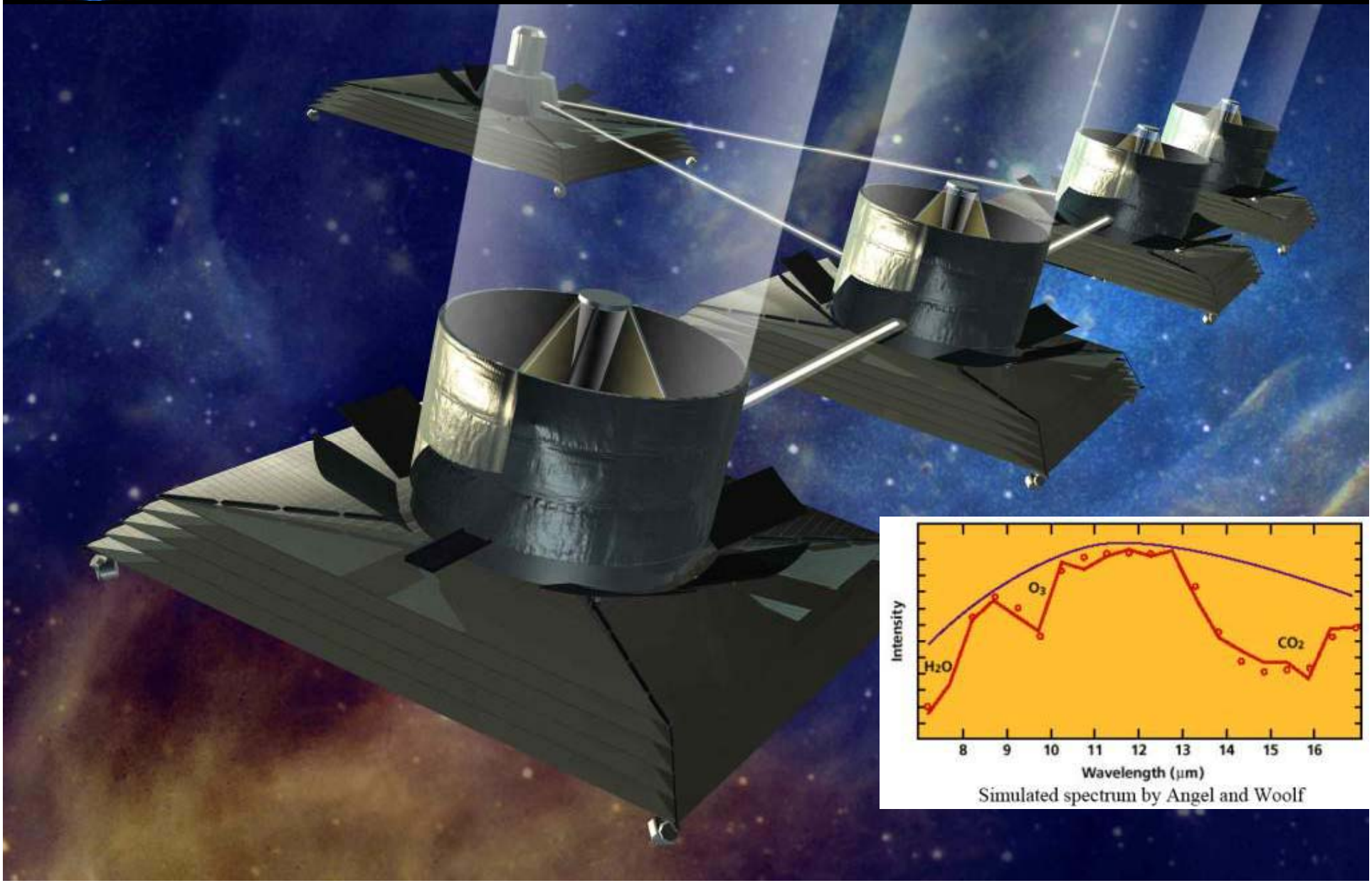
- Planet blocks light from star
- Visible/NIR light (Hubble/JWST)
- Radius of planet/star
- Absorption spectroscopy of planet's atmosphere
- JWST: Look for moons, constituents of atmosphere, Earth-like planets with water

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


Europa
Europa has an ocean and ice sheets

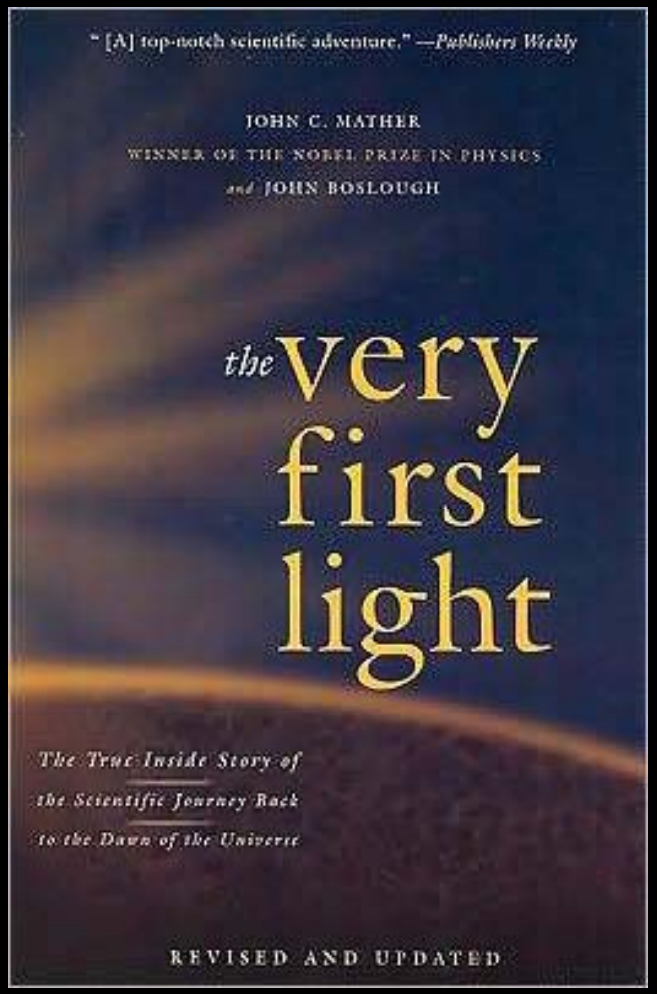
Terrestrial Planet Finder Concept -Interferometer



Simulated spectrum by Angel and Woolf

More Info:

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



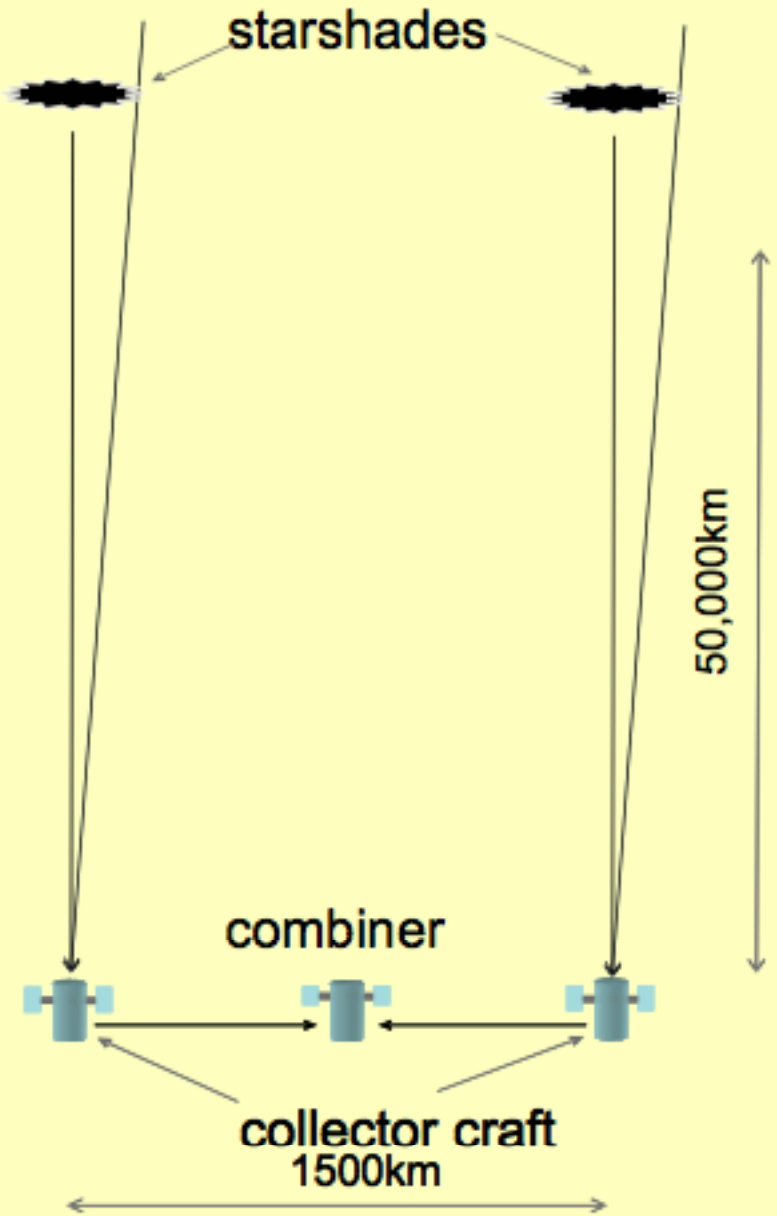
The End

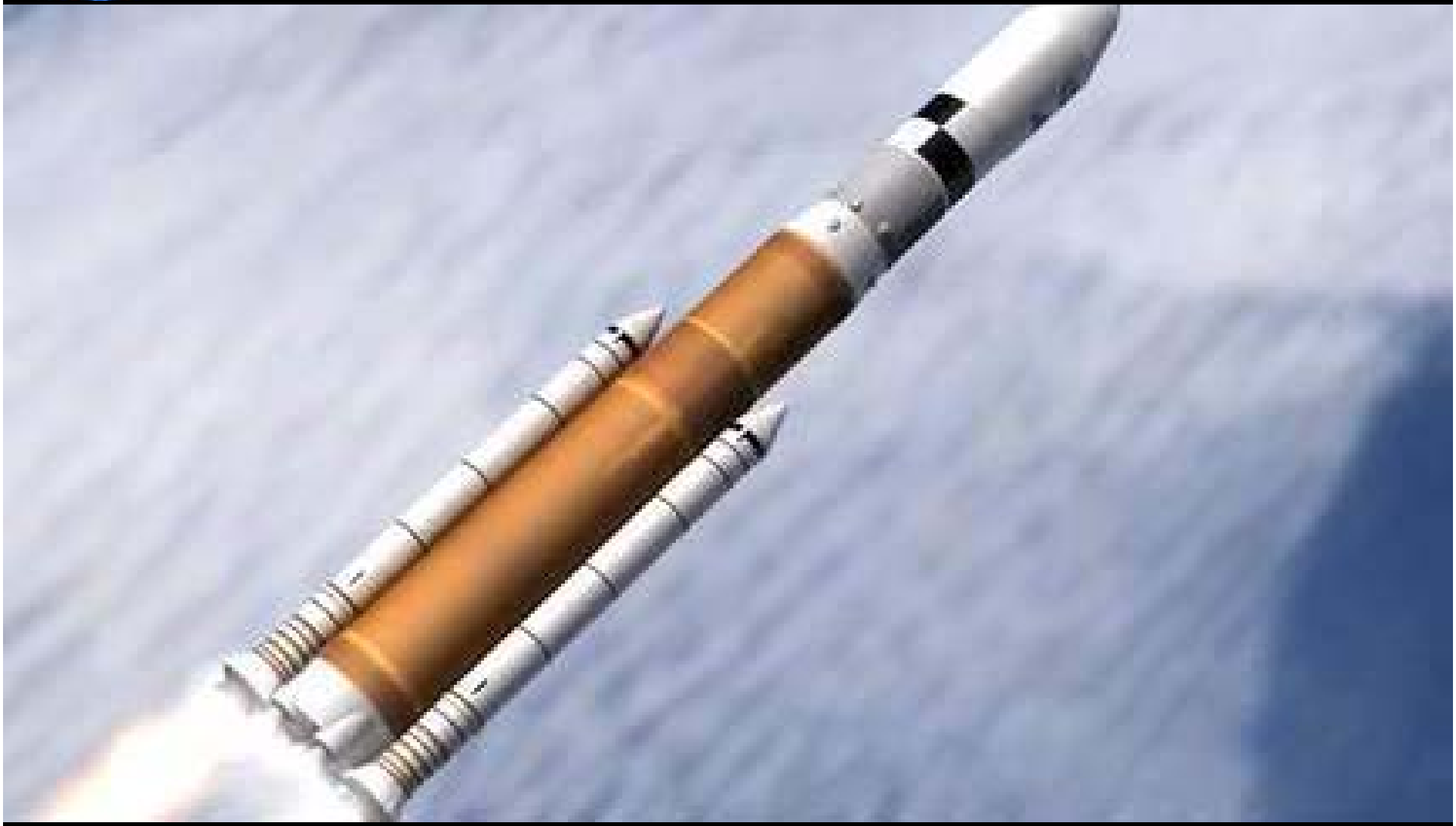
And the beginning!

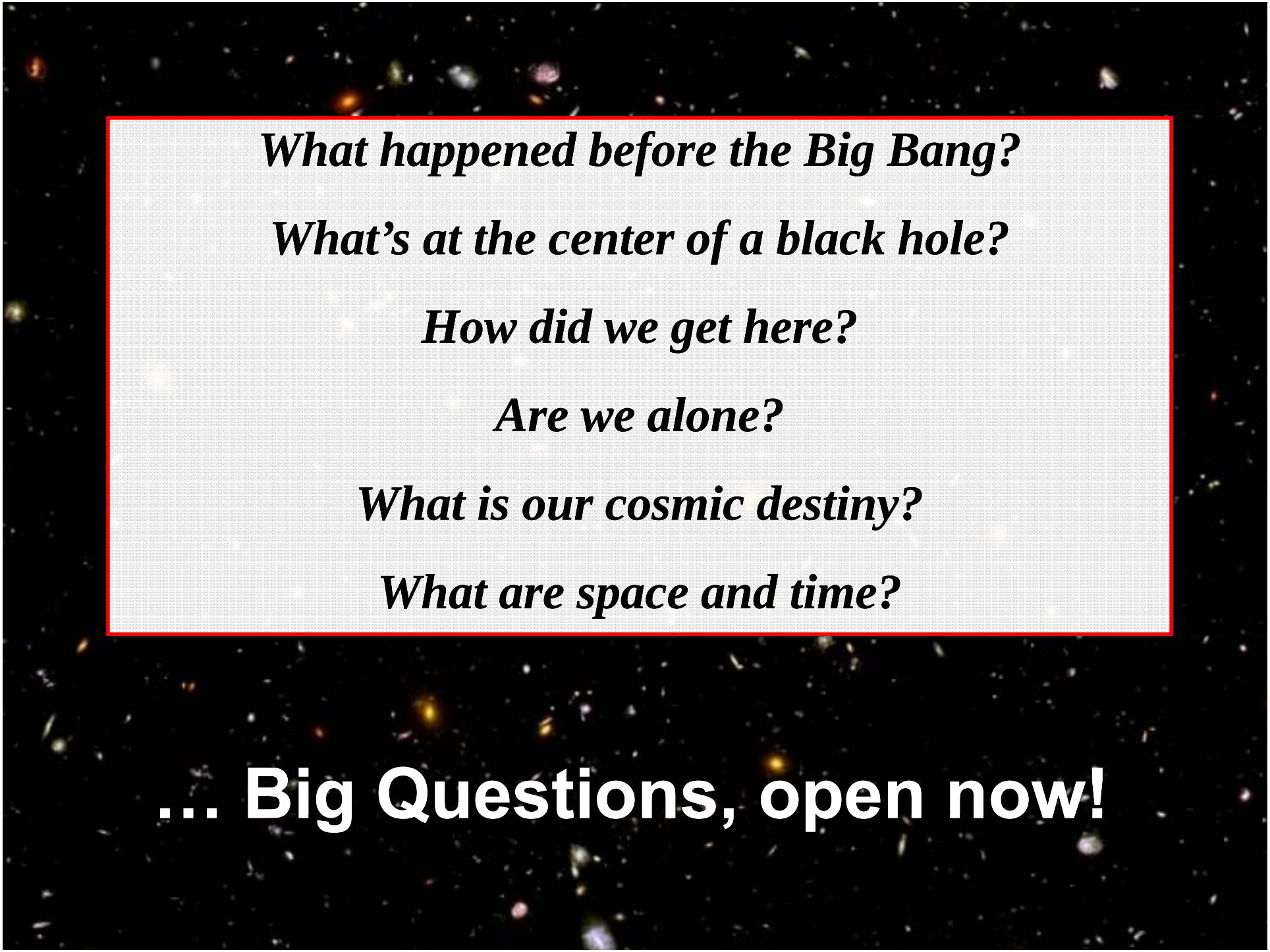
NWI Concept

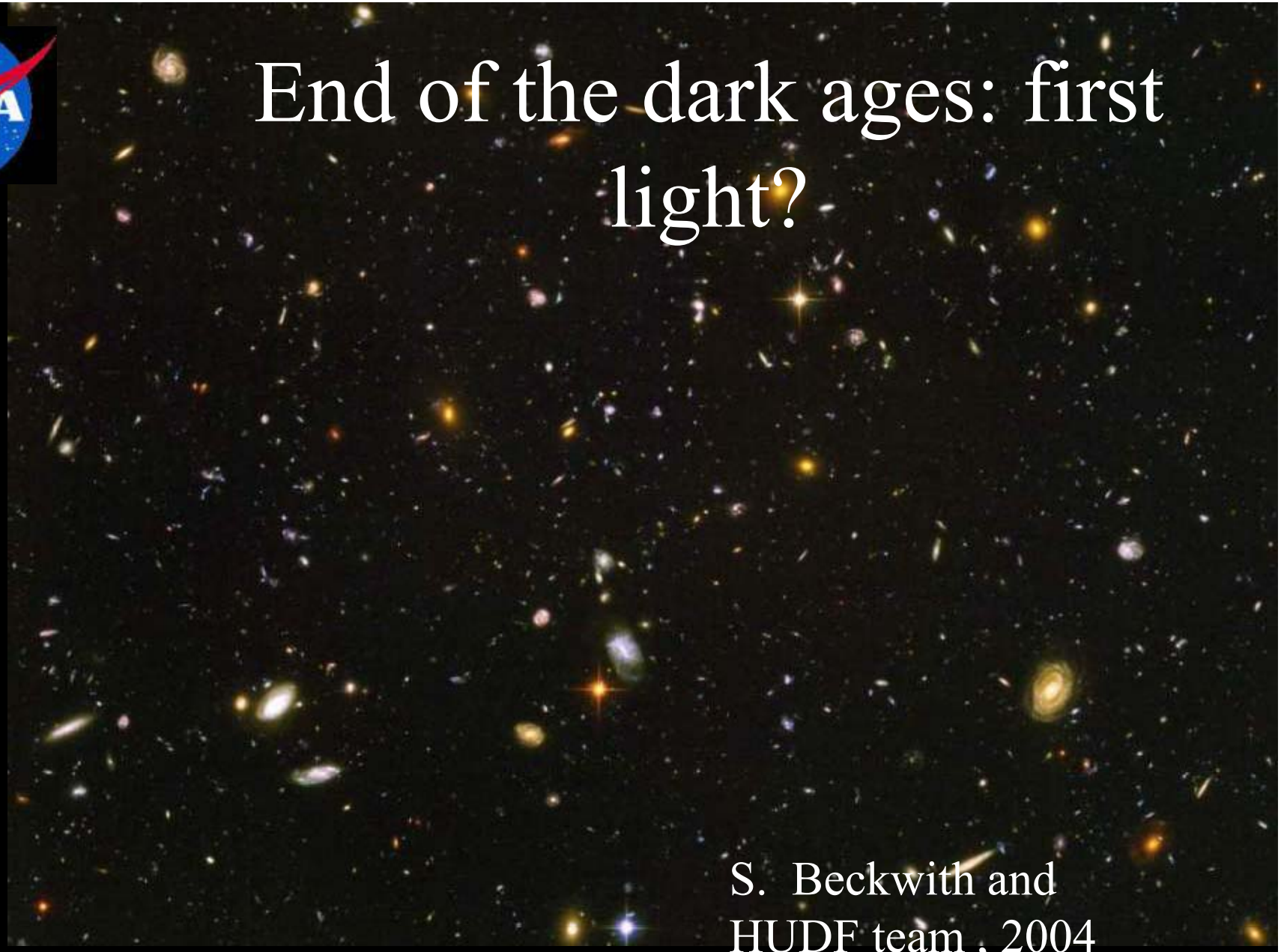
New Worlds Imager

Webster Cash concept, University of Colorado



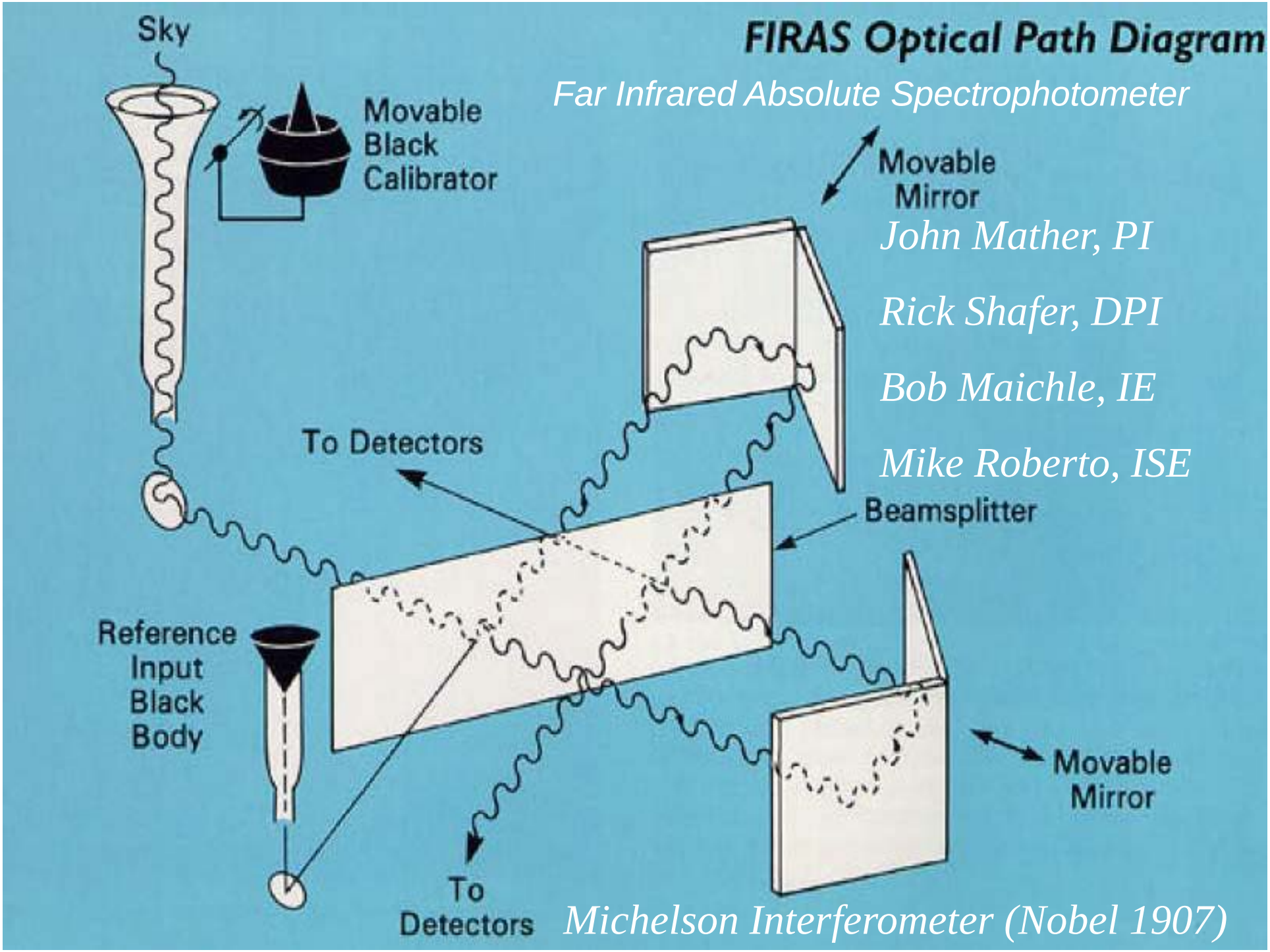



What happened before the Big Bang?
What's at the center of a black hole?
How did we get here?
Are we alone?
What is our cosmic destiny?
What are space and time?
… Big Questions, open now!

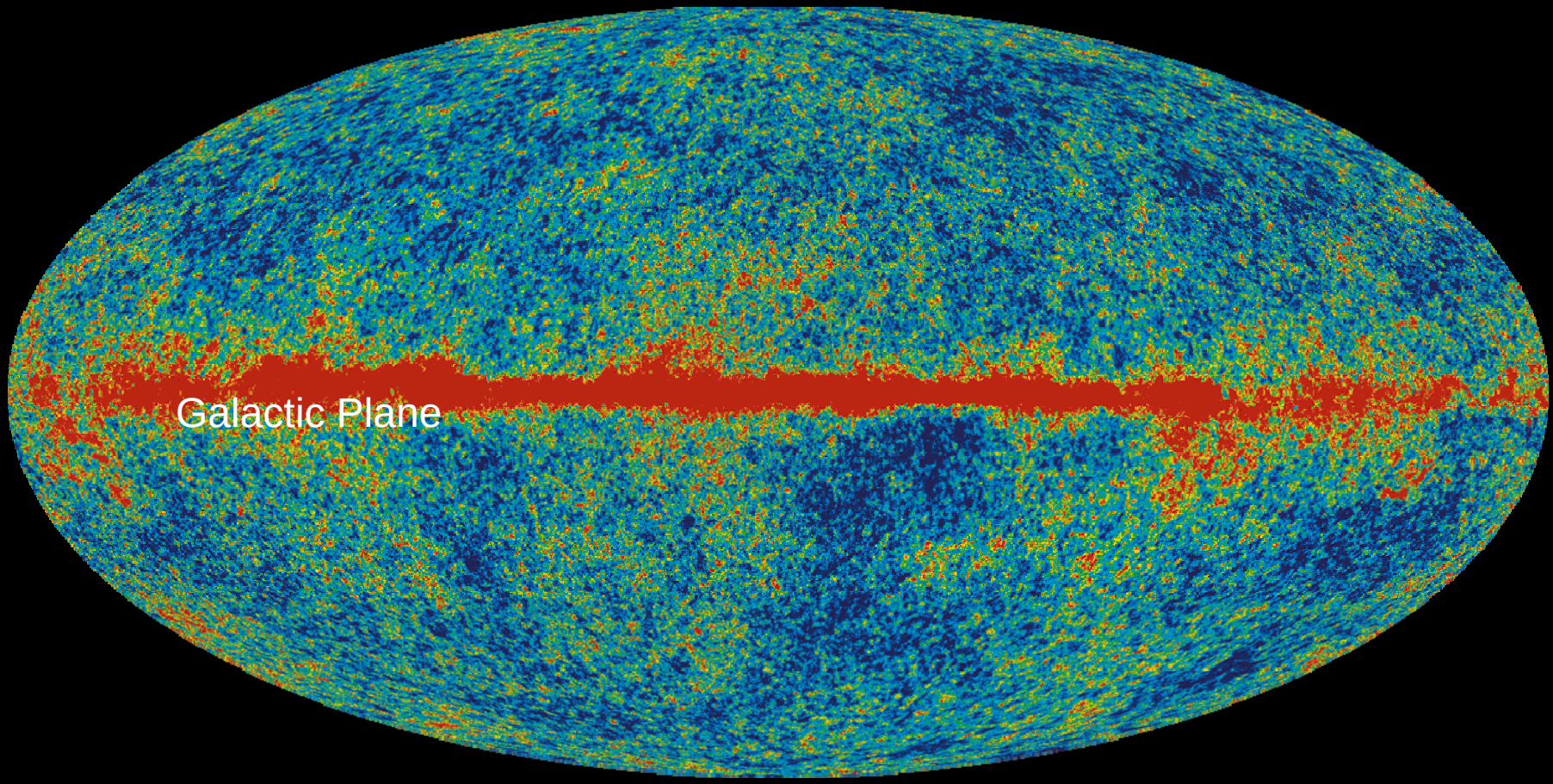


End of the dark ages: first light?

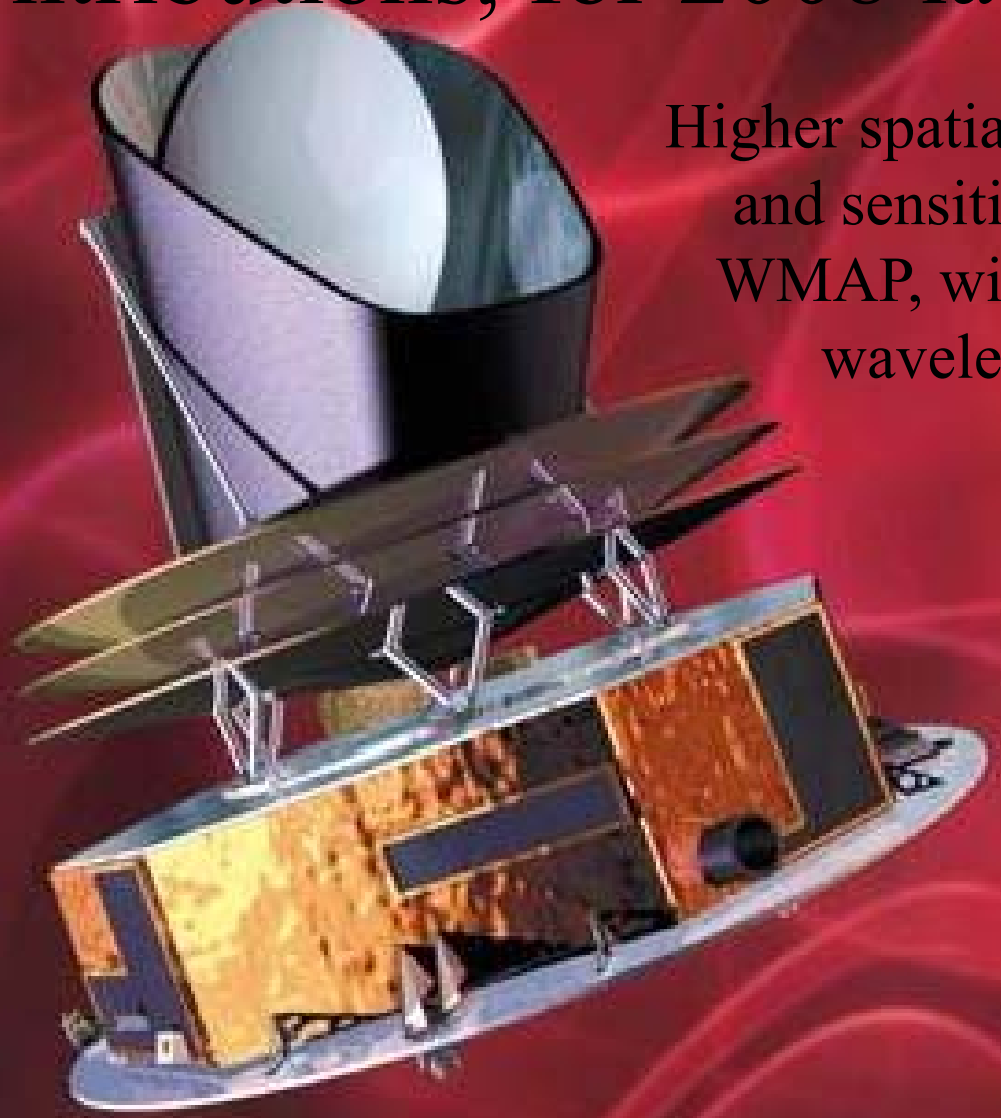
S. Beckwith and HUDF team , 2004


FIRAS Optical Path Diagram
Far Infrared Absolute Spectrophotometer
Sky
Movable
Black
Calibrator
Movable
Mirror
John Mather, PI
Rick Shafer, DPI
Bob Maichle, IE
Mike Roberto, ISE
To Detectors
Beamsplitter
Reference
Input
Black
Body
Movable
Mirror
To
Detectors
Michelson Interferometer (Nobel 1907)

The Universe at age 380,000 years as seen by Wilkinson Microwave Anisotropy Probe (3 years of data)



Planck Mission - ESA-led with NASA contributions, for 2008 launch

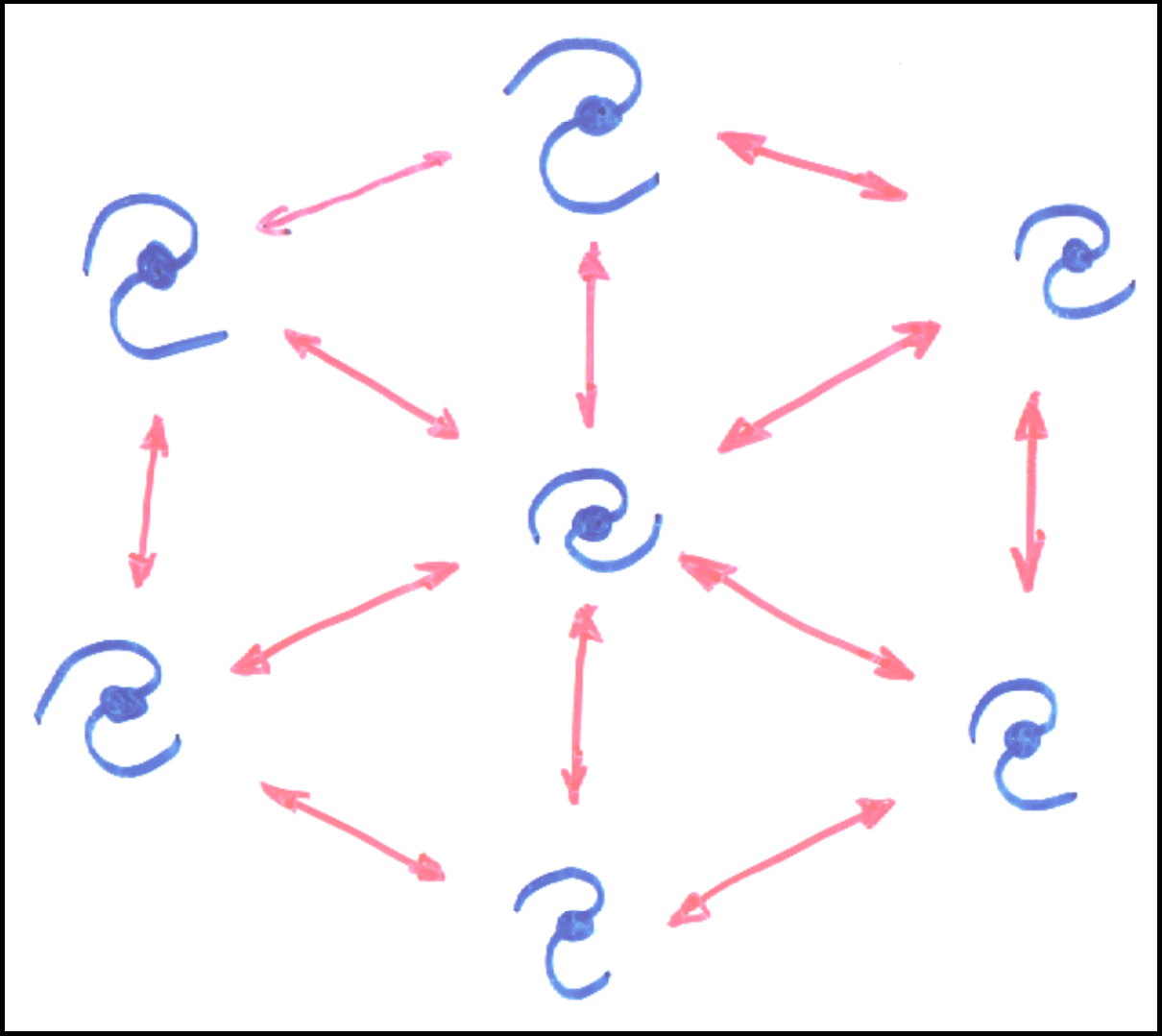


Higher spatial resolution and sensitivity than WMAP, with shorter wavelengths

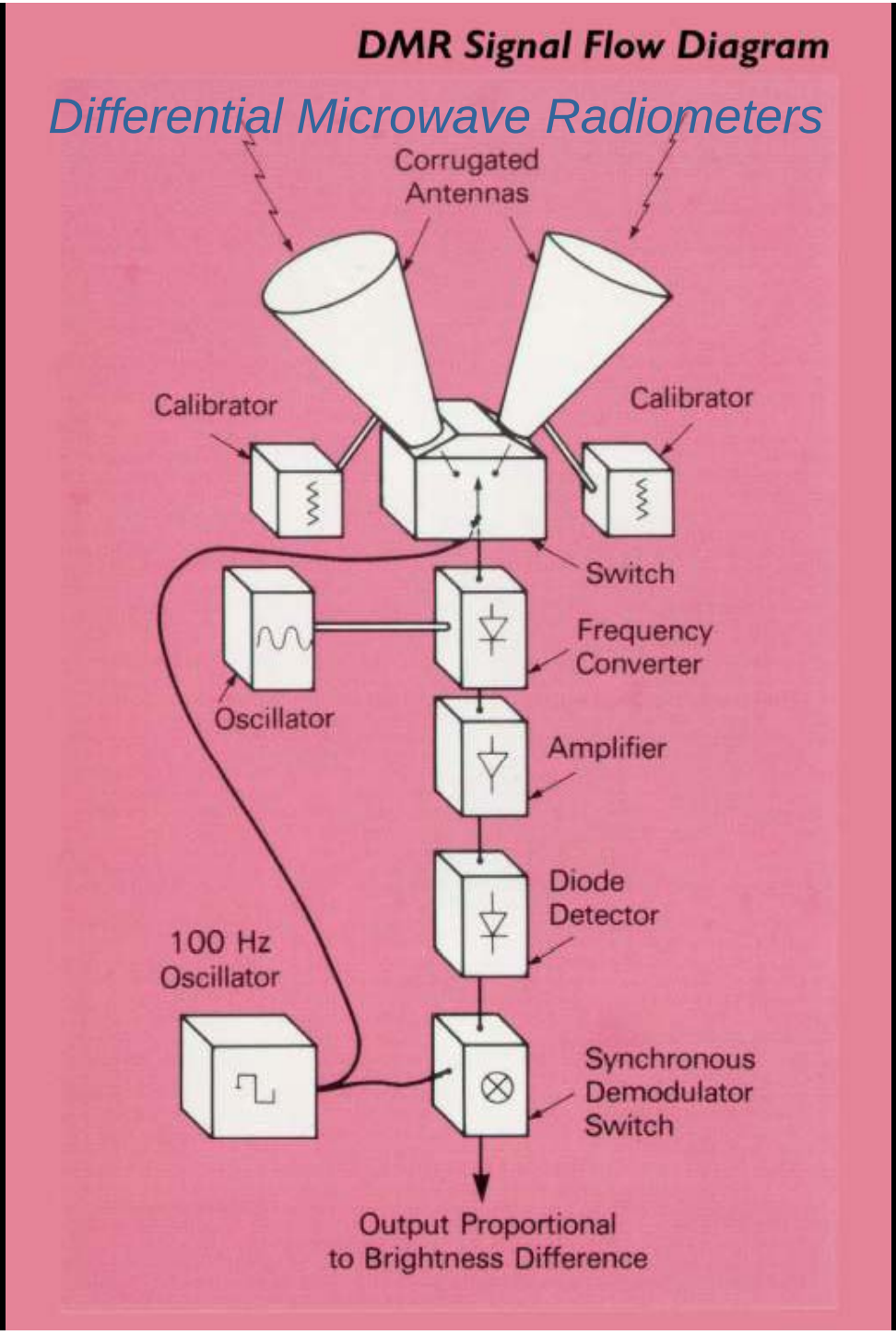
Galaxies attract each other, so the expansion should be slowing down -- Right??

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.



Differential Microwave Radiometers



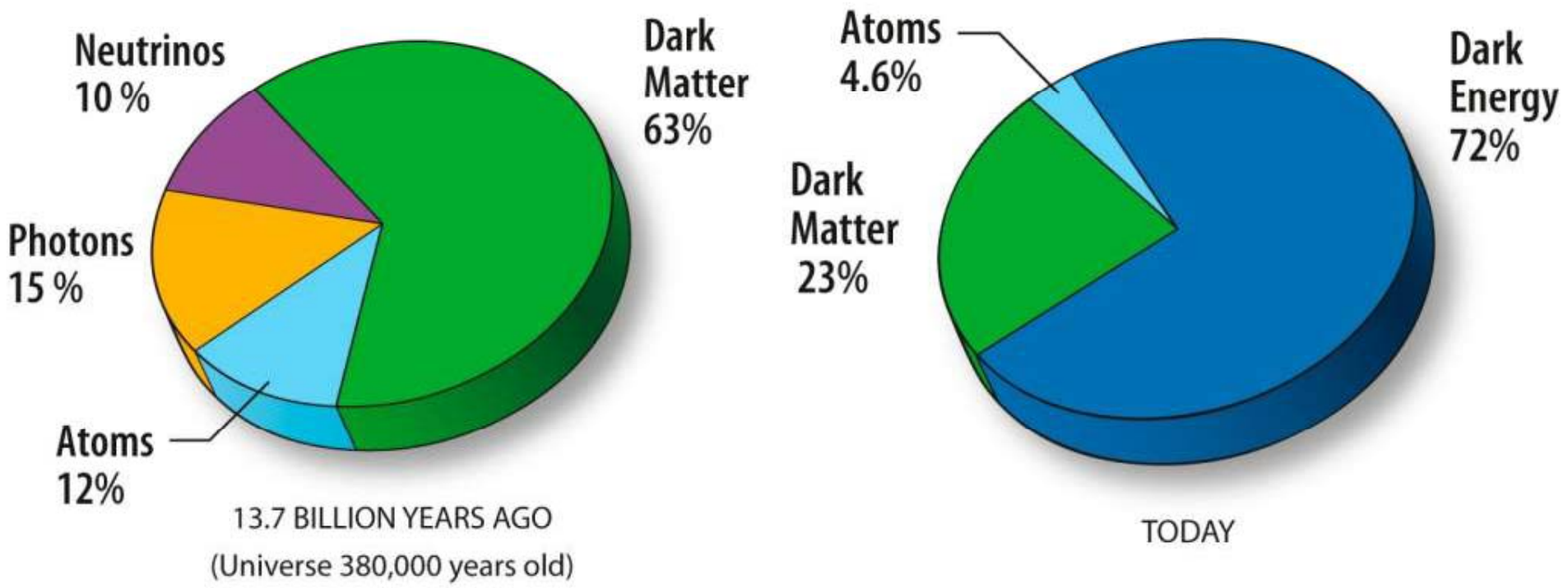
George Smoot

Chuck Bennett

Bernie Klein

Steve Leete

Changing Mix of Mysteries



- Photon and neutrino fractions diminish
- Dark Energy fraction grows with time

COBE (Cosmic Background Explorer) History

- 1974, proposals submitted to NASA
- 1976, Mission Definition Science Team selected by NASA HQ (Nancy Boggess, Program Scientist); PI's chosen
- ~ 1979, decision to build COBE in-house at Goddard Space Flight Center
- 1982, approval to construct for flight
- 1986, Challenger explosion, start COBE redesign for Delta launch
- 1989, Nov. 18, launch
- 1990, first spectrum results; helium ends in 10 mo
- 1992, first anisotropy results
- 1994, end operations
- 1998, major cosmic IR background results

Significance of Spectrum

- Old data were wrong! Old theories explaining bad data were wrong too!
- Hot Big Bang explains everything here. Steady State theory (main alternative) doesn't.
- It was all very "simple" - just a single giant, very uniform "explosion" of the whole universe!

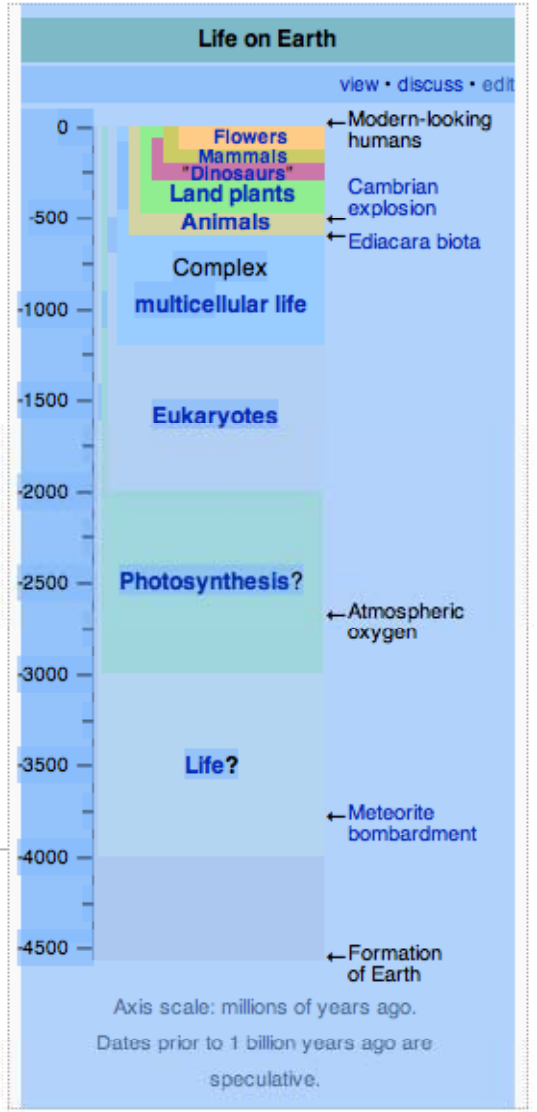

Stars in dust disks in Orion
C. R. Odell et al. 1994

Life on Earth – per Wikipedia

Basic timeline

The basic timeline is a 4.6 billion year old Earth, with (very approximate) dates:

- 3.8 billion years of simple cells (prokaryotes),
- 3 billion years of photosynthesis,
- 2 billion years of complex cells (eukaryotes),
- 1 billion years of multicellular life,
- 600 million years of simple animals,
- 570 million years of arthropods (ancestors of insects, arachnids and crustaceans),
- 550 million years of complex animals,
- 500 million years of fish and proto-amphibians,
- 475 million years of land plants,
- 400 million years of insects and seeds,
- 360 million years of amphibians,
- 300 million years of reptiles,
- 200 million years of mammals,
- 150 million years of birds,
- 130 million years of flowers,
- 65 million years since the non-avian dinosaurs died out,
- 2.5 million years since the appearance of the genus Homo,
- 200,000 years since humans started looking like they do today,
- 25,000 years since Neanderthals died out.



Wikipeida table of Genus Homo

Comparative table of *Homo* species

Species	Lived when (mya)	Lived where	Adult height	Adult mass	Brain volume (cm^3)	Fossil record	Discovery / publication of name
H. habilis	2.2 – 1.6	Africa	1.0–1.5 m (3.3–4.9 ft)	33–55 kg (73–120 lb)	660	many	1960/1964
H. erectus	1.4 – 0.2	Africa, Eurasia (Java, China, Caucasus)	1.8 m (5.9 ft)	60 kg (130 lb)	850 (early) – 1100 (late)	many	1891/1892
H. rudolfensis	1.9	Kenya				1 skull	1972/1986
H. georgicus	1.8	Republic of Georgia			600	few	1999/2002
H. ergaster	1.9 – 1.4	E. and S. Africa	1.9 m (6.2 ft)		700–850	many	1975
H. antecessor	1.2 – 0.8	Spain	1.75 m (5.7 ft)	90 kg (200 lb)	1000	2 sites	1997
H. cepranensis	0.9 – 0.8?	Italy			1000	1 skull cap	1994/2003
H. heidelbergensis	0.6 – 0.35	Europe, Africa, China	1.8 m (5.9 ft)	60 kg (130 lb)	1100–1400	many	1908
H. neanderthalensis	0.35 – 0.03	Europe, W. Asia	1.6 m (5.2 ft)	55–70 kg (120–150 lb) (heavily built)	1200–1700	many	(1829)/1864
H. rhodesiensis	0.3 – 0.12	Zambia			1300	very few	1921
H. sapiens sapiens	0.2 – present	worldwide	1.4–1.9 m (4.6–6.2 ft)	50–100 kg (110–220 lb)	1000–1850	still living	—/1758
H. sapiens idaltu	0.16 – 0.15	Ethiopia			1450	3 craniums	1997/2003
H. floresiensis	0.10 – 0.012	Indonesia	1.0 m (3.3 ft)	25 kg (55 lb)	400	7 individuals	2003/2004

Reaching Australia in the Ice Age

Perhaps only 3000 years from Africa to Australia, 40,000 YA

Full scale model at GSFC


JWST
JAMES WEBB SPACE TELESCOPE
2008 Spacecraft
Deployment Animation
NASA
NORTHROP GRUMMAN