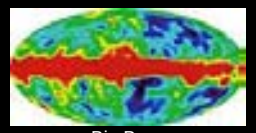
From the Big Bang to the Nobel Prize and the End of the Universe

John C. Mather
Senior Project Scientist, James Webb Space Telescope,
NASA's Goddard Space Flight Center
Mar. 22, 2010

Astronomical Search For Origins


First Galaxies


Big Bang


Galaxies Evolve


Life

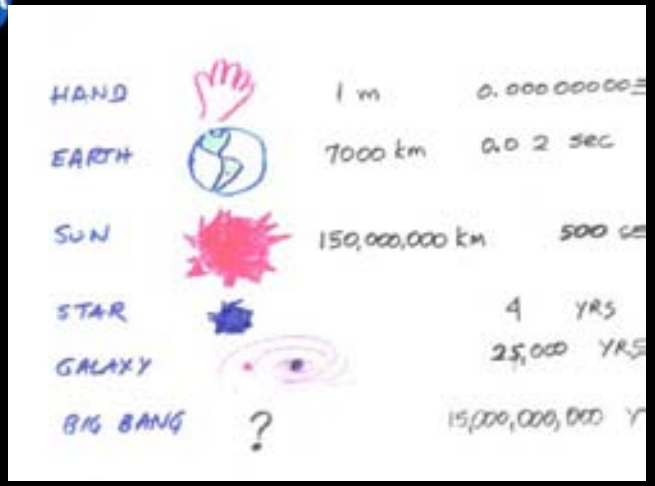

Planets


Stars

Can you imagine?

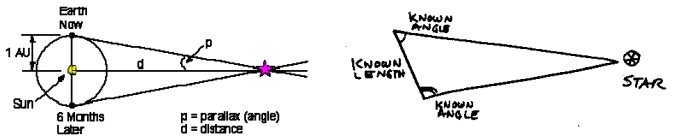
Your chin is made of exploded stars!

Looking Back in Time



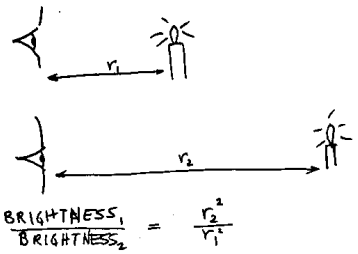
Measuring Distance

1. TRIANGLES

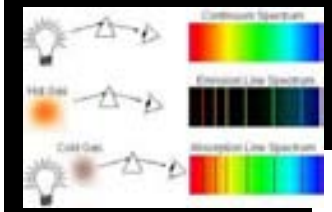


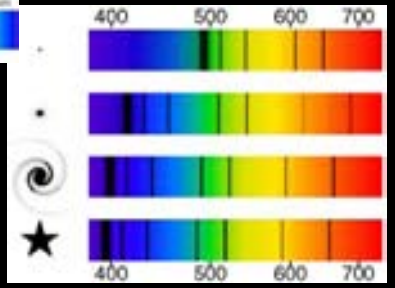
2. STANDARD CANDLES

This technique enables measurement of enormous distances



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

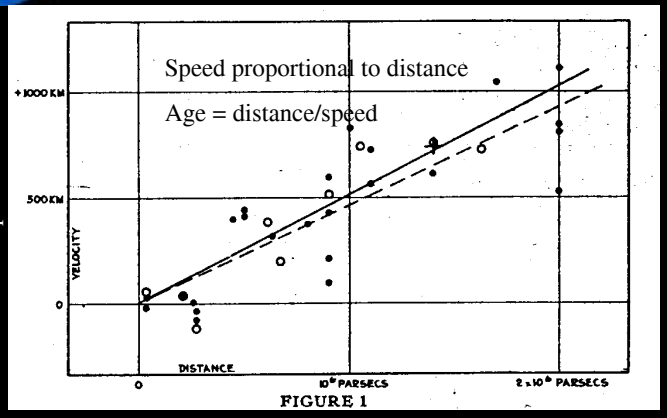


FIGURE 1

Speed -->

Distance -->

The Power of Thought


Alexander Friedman

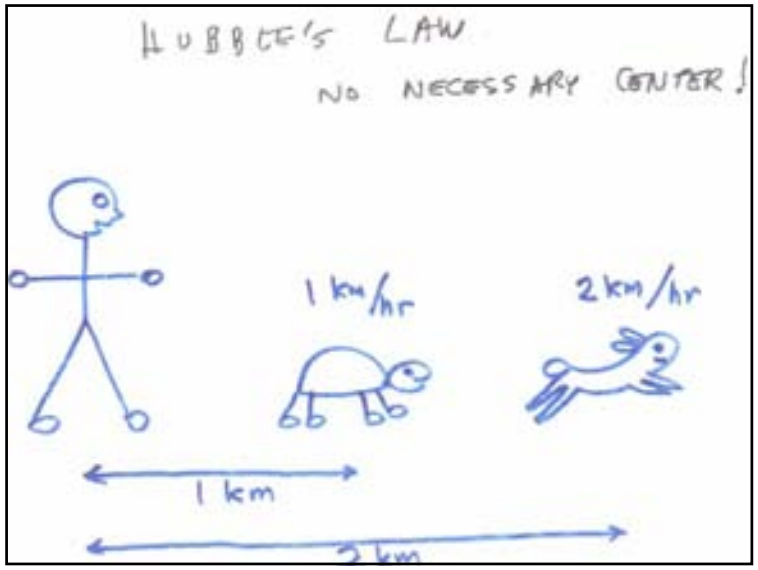

Georges Lemaître & Albert Einstein


George Gamow


Robert Herman & Ralph Alpher


Rashid Sunyaev


Jim Peebles



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?

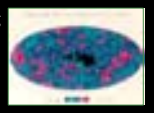
- Space is mostly empty - stars are very very far apart
- Atoms are mostly empty - atomic nuclei are very tiny compared to size of atoms
- Squeeze very hard, and compression can create antimatter and rip quarks apart inside protons and neutrons
- Higher temperatures fit more particles into given volume
- 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



?

Galaxy assembly

?

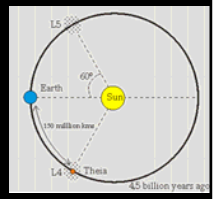
Galaxies, stars, planets, life

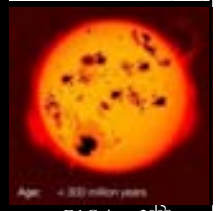
- Horrendous Space Kablooey - exponential expansion, primordial fluctuations, matter/antimatter, dark matter, dark energy, 13.75 ± 0.11 billion years ago (WMAP7)
- Annihilation of antiparticles, 1 part per billion matter remaining
- Formation of Helium nuclei, 3 minutes, redshift z = 10^9
  - [1+z = 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 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); all life uses same genetic code! (we are related to bugs)
- Young Sun very active, gets steadily brighter with time, warming Earth

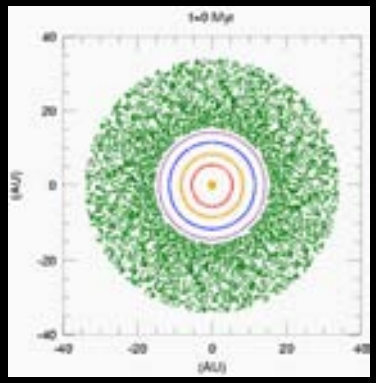
Hartman & Davis idea 1975





Ed Guinan 2009

Possible Early Solar System



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

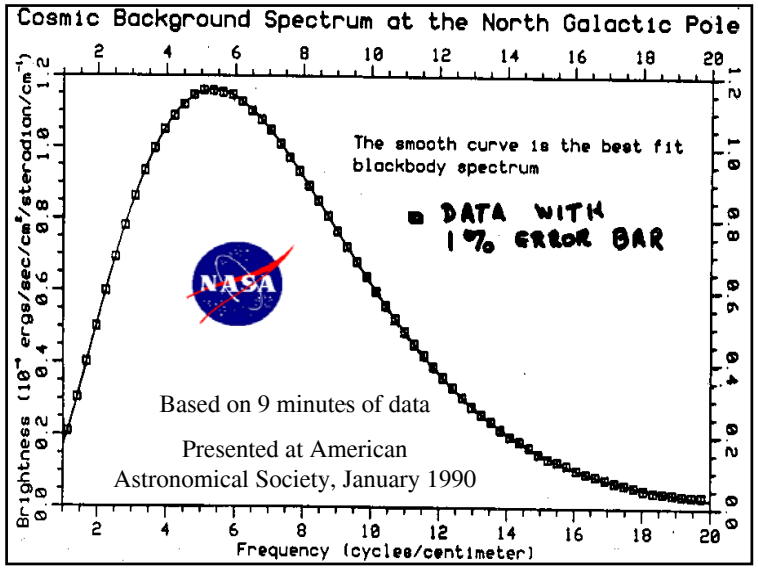
Ice Ages, Heat Ages, and Extinctions

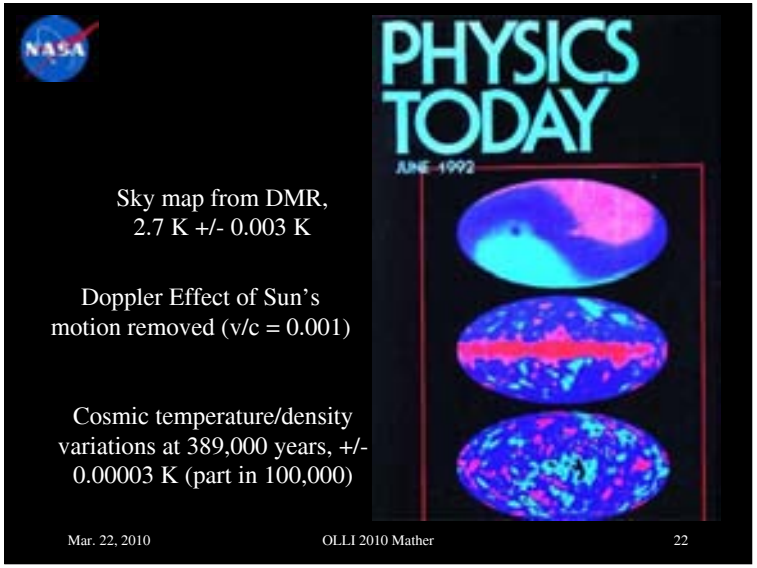
- Huronian Ice Age, 2.7 – 2.3 BYA
- Cryogenian, 850 – 630 MYA, possible "snowball Earth"
- Volcanism releases CO_2, warms Earth, enables Cambrian explosion of life, 530 MYA
- Andean-Saharan Ice Age, 460 – 430 MYA (an extinction event)
- Coal formation, 354 to 290 MYA
- Heat extinction event, 250 MYA, life retreats to Antarctica
- Dinosaur extinction, coincides with (multiple?) meteor events, 65 MYA
  - Chicxulub impact on the Yucatan Peninsula off Mexico?
  - Volcanic activity in Deccan Traps in India?
- Current Ice Age, 2.58 MYA, ending 10,000 YA
  - Riss, 180,000 – 130,000 YA (when Homo Sapiens developed in Africa?)
  - Wurm, 70,000 – 10,000 YA (begin modern civilization)

Civilization and the Future

- Galileo's telescope 1609 (2009 International Year of Astronomy)
- 2012, nothing happens!
- 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





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

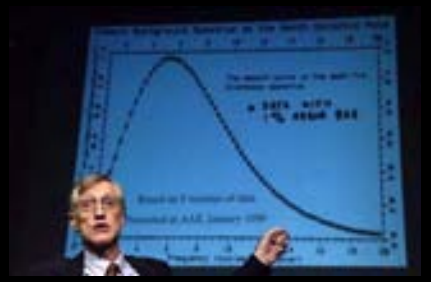
Doppler Effect of Sun's motion removed (v/c = 0.001)

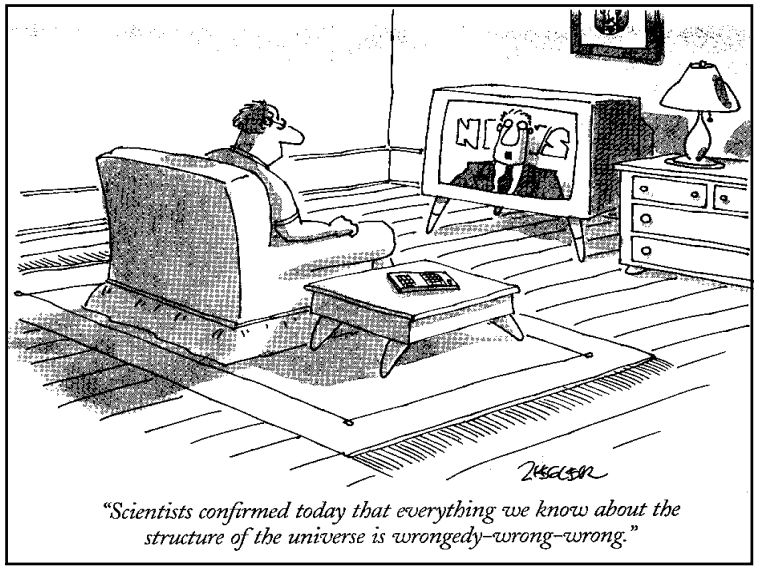
Cosmic temperature/density variations at 389,000 years, +/- 0.00003 K (part in 100,000)

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





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

Dark Energy!

MacArthur Fellow 2008 - Adam Riess

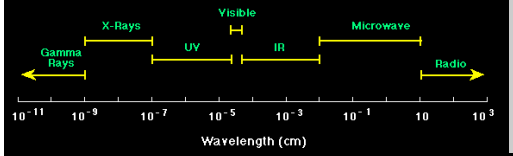
S. Perlmutter, A. Riess, B. Schmidt

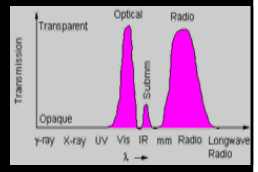
A few big mysteries…

- 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.





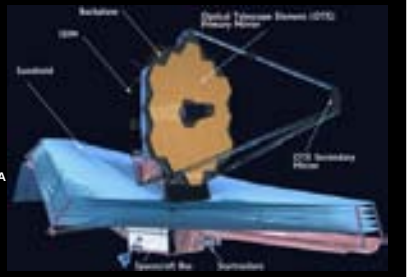
Infrared is heat radiation

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 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

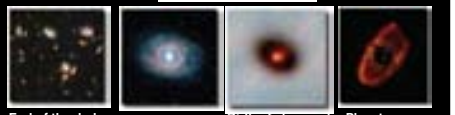


Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch 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



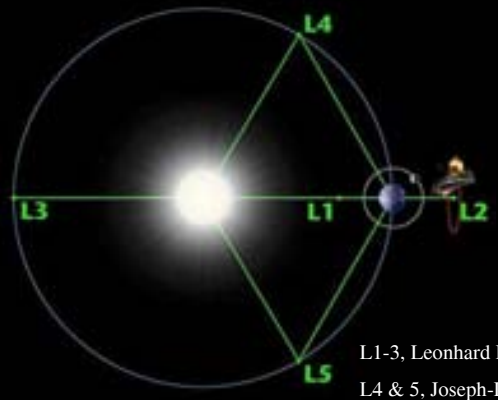
End of the dark ages: First light and reionization

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.

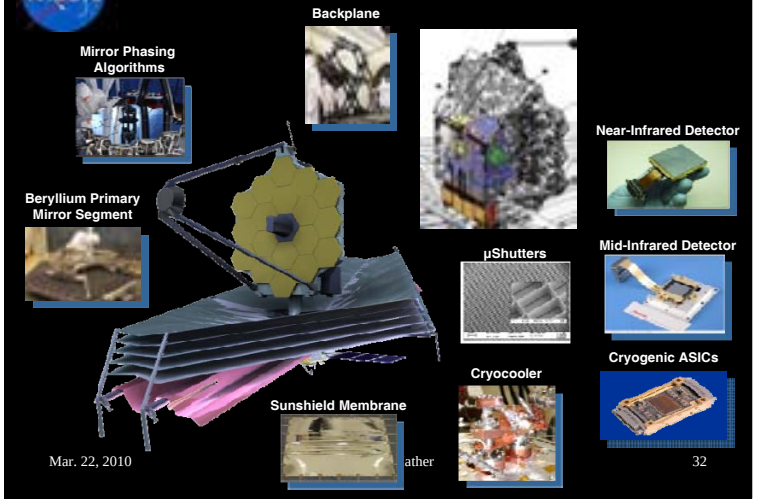
L4 & 5, Joseph-Louis Lagrange, 1772

Northrop Grumman's JWST model

Washington, DC 2007

Munich, Germany 2008

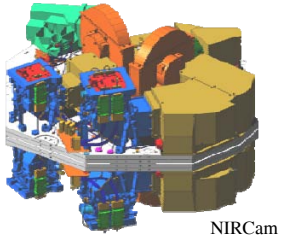
JWST Technology



Testbed Telescope

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

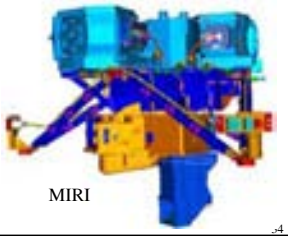
Four science instruments enable imagery and spectroscopy over the 0.6 – 29 micron spectrum



NIRCam

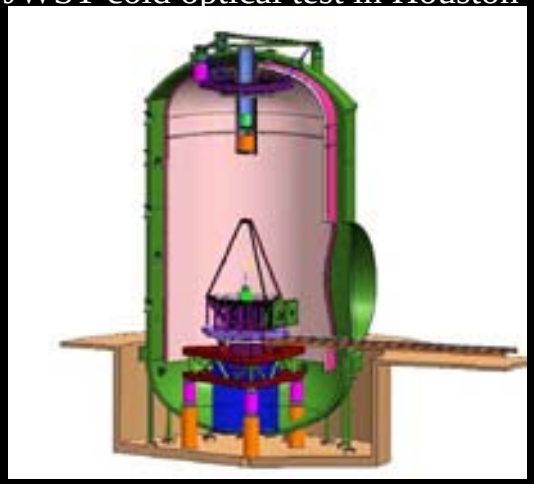
NIRSpec

FGS



MIRI

JWST cold optical test in Houston



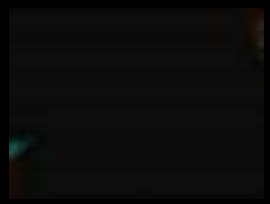
Nature's Lenses in Space

Dwarf Galaxies with Dark Matter

How do galaxies evolve?

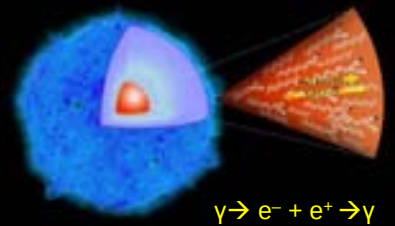
Where and when did the Hubble Sequence form? How did the heavy elements form?

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



SN 2006 gy – brightest supernova

- Could be the first observation of a pair-production instability, from the death of a very massive star.
  - Stars are normally held up by the balance of light pressure and gravity
  - Gamma rays producing electron/positron pairs scatters light, reducing pressure. Instability creates runaway collapse.
- A nearby analog for the first stars in the Universe.

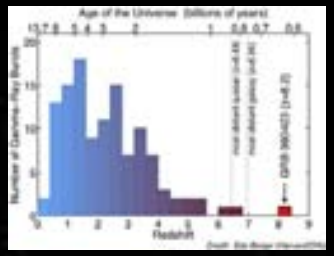


$\gamma \rightarrow e^- + e^+ \rightarrow \gamma$

Hubble Image of Eta Carina

- Progenitor was similar to Eta Carina.

Gamma Ray Burst 4/23/09 was one of the most distant objects yet found (z = 8.2) – supernova jet aimed at us!

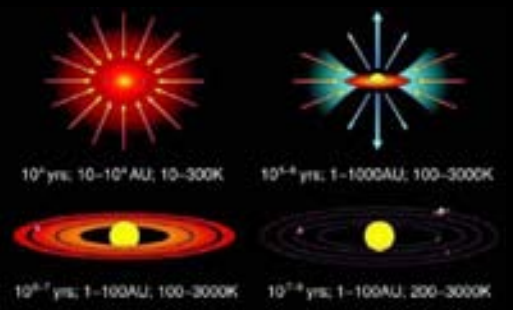


JANUS GRB (SMEX) search proposed, could see to z = 12

How stars and planets form?

Deeply embedded protostar

Circumstellar disk



Agglomeration & planetesimals

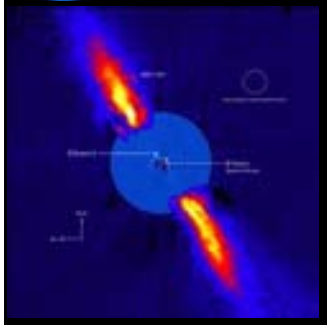
Mature planetary system

The Eagle Nebula as seen with Hubble

The Eagle Nebula as seen in the infrared

M. J. McCaughrean and M. Andersen, 1994

Planets Seen!

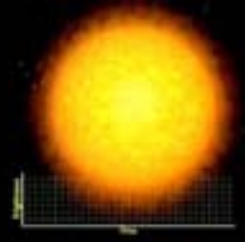


β Pictoris b
A.-M. Lagrange et al. 2008
VLT

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

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

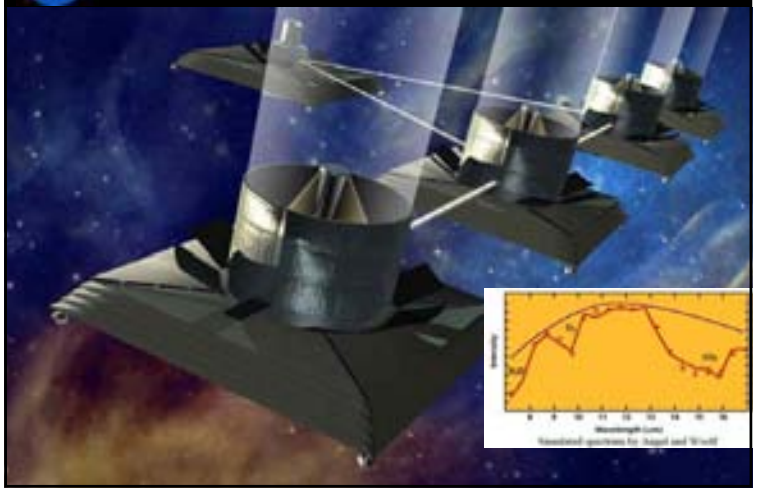
Secondary

- 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

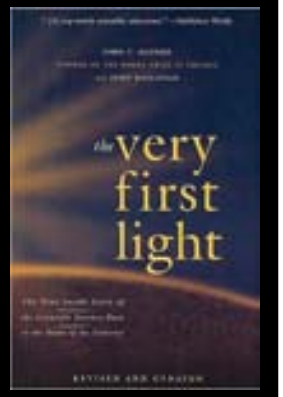
Europa has an ocean and ice sheets

Terrestrial Planet Finder Concept -Interferometer



More Info:

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



The End

And the beginning!

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

JWST Deployment