

# Age of the Universe

## And How We Know It

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*Photo from NASA  
Hubble Ultra Deep Field*



UNIVERSITY OF  
OREGON

# How old is the universe?

- Age-old question.
- 19th century - Heinrich Olbers.
  - German astronomer (1758-1840).
  - He reasoned the standard scientific assumption (Steady State Theory) suggests the night sky should be uniformly bright.
    - But it is dark, except for points of stars. Why?
    - ***Olbers Paradox.***
  - His reasoning - universe has finite age and light from most distant stars hasn't had time to reach us.



# Einstein's *general relativity*

- Early 20th century development theory of gravity (***general relativity***) suggested universe should be either expanding or contracting.
- Einstein didn't like that (physicists generally favored steady state) so he added fudge factor to make universe static (***cosmological constant***).
- Others took notion of ***expansion*** more seriously.



# Prediction of early universe

- 1927- Georges Lemaître
  - Belgian physicist and Roman Catholic priest.
  - From Einstein's **general relativity** deduced **expanding universe** - before observational evidence!
- 1931 - Lemaître reasoned:
  - **Expansion** projected back in time, at some past time all the mass of the universe was concentrated into a single point.
  - "Primeval atom" where and when the fabric of time and space came into existence. - finite age to universe.
    - Today we refer to this as the moment of the **Big Bang**.



# Edwin Hubble's discovery

- 1924-25 - Established some nebula were actually galaxies outside the Milky Way.



Messier 31 (The Andromeda Galaxy)



Hubble at  
Mount Wilson

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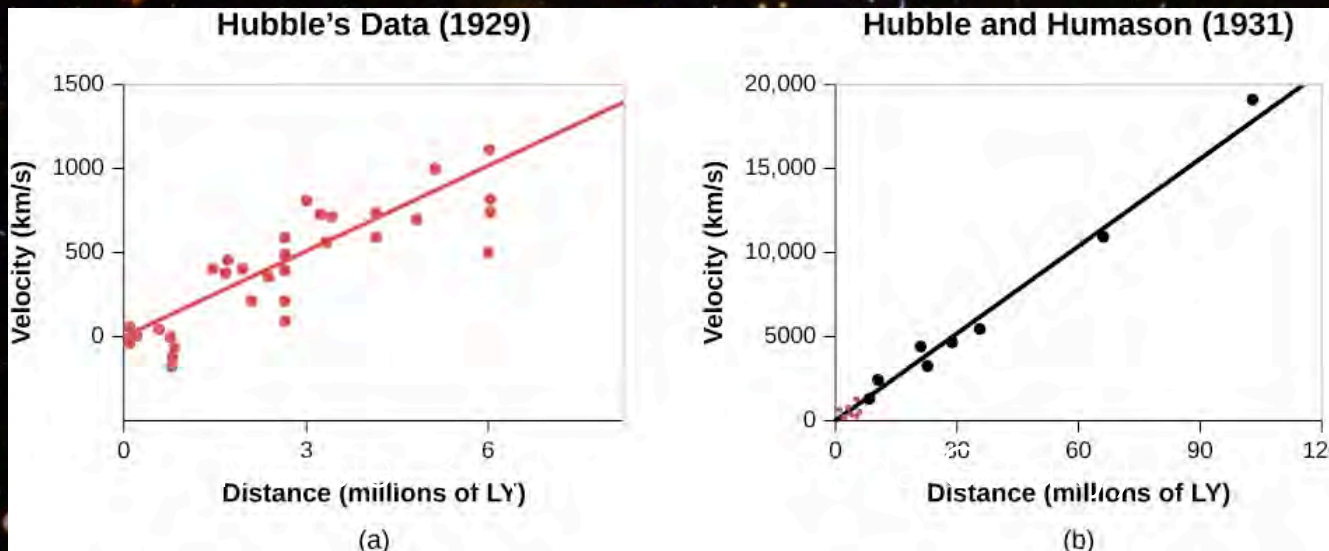
Hubble at  
Mount Wilson

# Edwin Hubble's discovery

- 1924-25 - Established some nebula were actually galaxies outside the Milky Way.
- 1929 - Then measured velocity they were traveling away from us.
  - Found farthest away were fastest.



Hubble at  
Mount Wilson



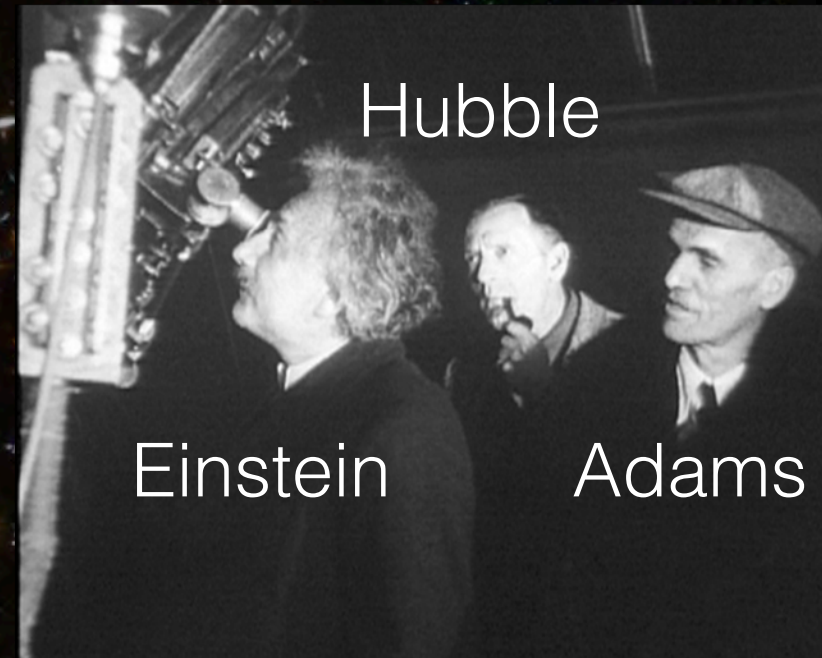
***Hubble's Law***

$$V = H \cdot d$$

H is Hubble's constant

# Einstein's biggest blunder

- Hubble's discovery provides evidence the universe is **expanding**.
- It is said, after Hubble's discovery Einstein called his "fudge factor" his biggest blunder.
- "I could have been famous if I'd predicted the universe was **expanding** before it was observed"

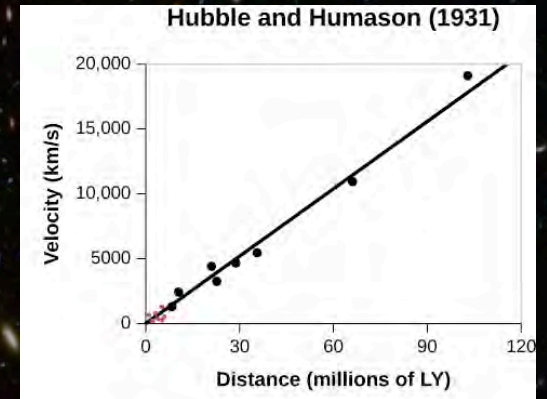


Einstein visits Caltech in 1931,  
at Mt. Wilson Observatory  
with Edwin Hubble and Walter Adams.  
Credit: Caltech archives



# Estimating age

- **Hubble's Law:**  $v = H \cdot d$
- Measure H, Hubble's constant
- Maximum possible velocity is speed of light = c
- Then - distance to max velocity is  $d = c/H$ ,
  - but time to travel distance d is  $t = d/v$
- So:  $t = d/c = 1/H$  - so Hubble's constant tells us the age of the visible universe - 13.8 billion years.



# Hubble Space Telescope



**Launched into low Earth orbit in 1990**

- Important role in recent refinement of Hubble's constant - and therefore measurement of Age.

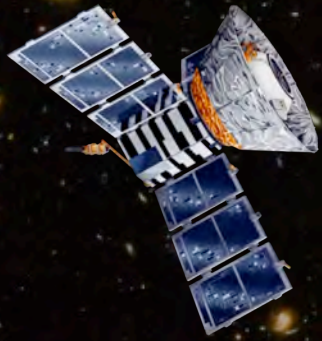
# Discovery of *big bang* fireball Cosmic microwave background

- 1964 - Arno Pezias & Robert Wilson
  - Extremely sensitive microwave detector - working to reduce “noise” for Earth-based communications.
  - Serendipitous discovery of strange microwave radiation.
  - Coming from all directions.
  - With VERY NEARLY same properties in all directions.
  - Radiation from hot **Big Bang** - known as the **cosmic microwave background**. (at age 375,000 yrs)

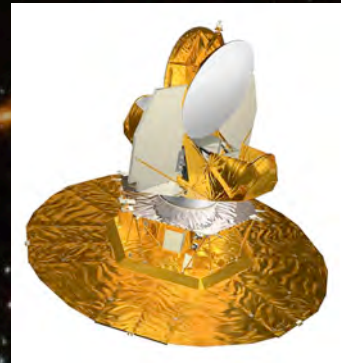


1978 Nobel Prize

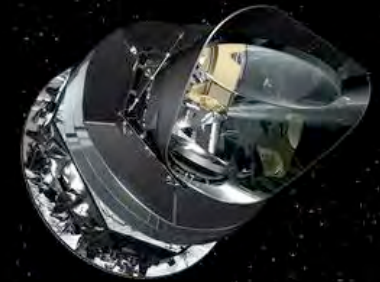
# Advanced study of *big bang* fireball (the *CMB*)



1989 - COBE



2001 - WMAP

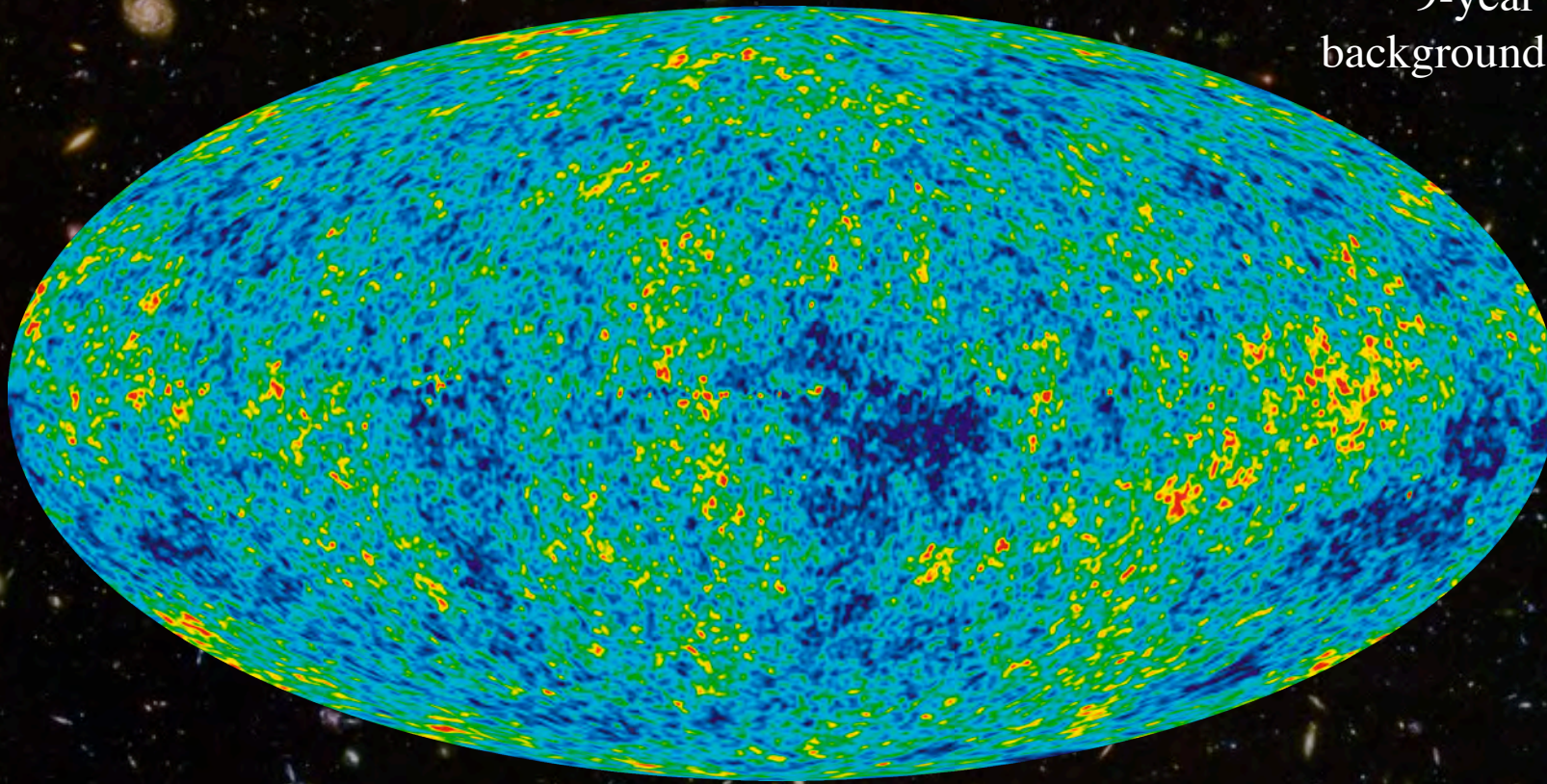


2009 - Planck

- Satellites making ever more sensitive measurements.
- **CMB** also measured by numerous ground and balloon detectors.

# Advanced study of *big bang* fireball

9-year WMAP image of  
background cosmic radiation  
(2012)

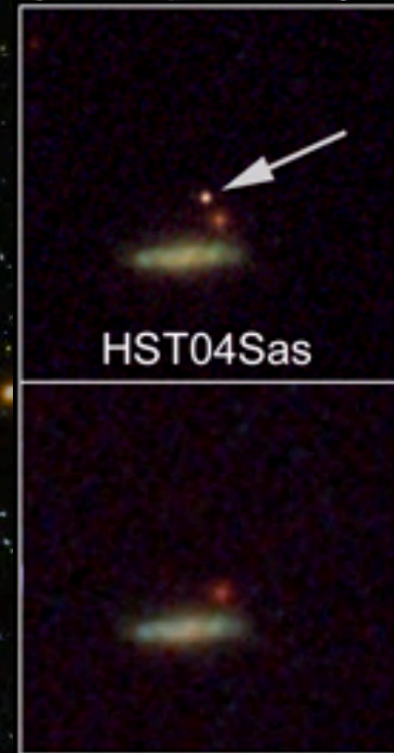


Emitted by  
Big Bang  
Fireball when  
Universe was  
300,000 yrs. old

- Extremely uniform - fluctuations less than 1/10,000
- Age of universe = 13.8 billion years

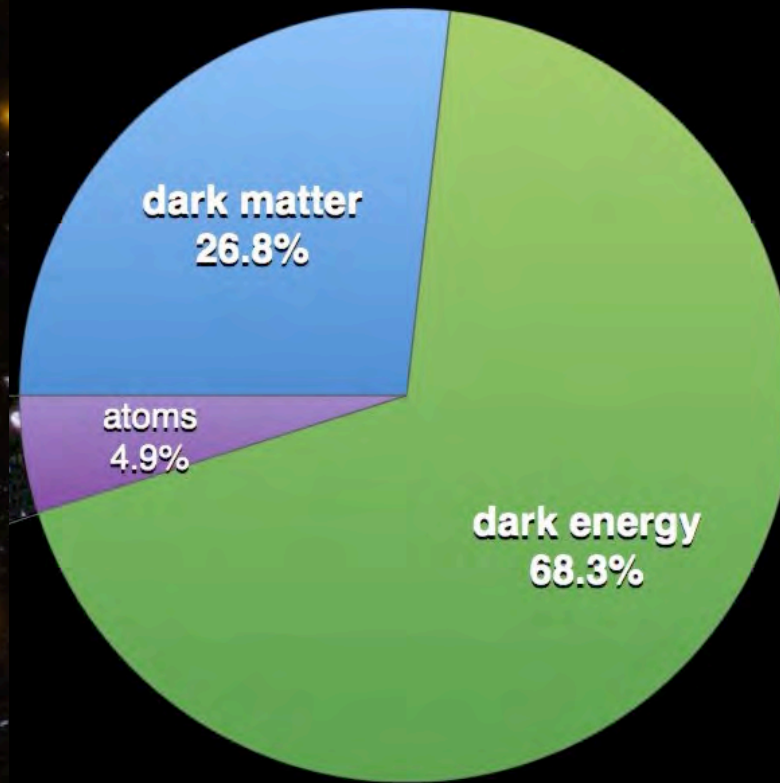
# Revisit “biggest blunder”

- On 8 January 1998, researchers announced a startling discovery:
  - From measurements of distant supernovae.
  - The universe’s expansion is speeding up.
  - 2011 Nobel Prize
    - - Saul Perlmutter, Brian Schmidt & Adam Riess
- Theoretical explanation of **acceleration**:
  - **Dark energy**, a form of Einstein’s cosmological constant.



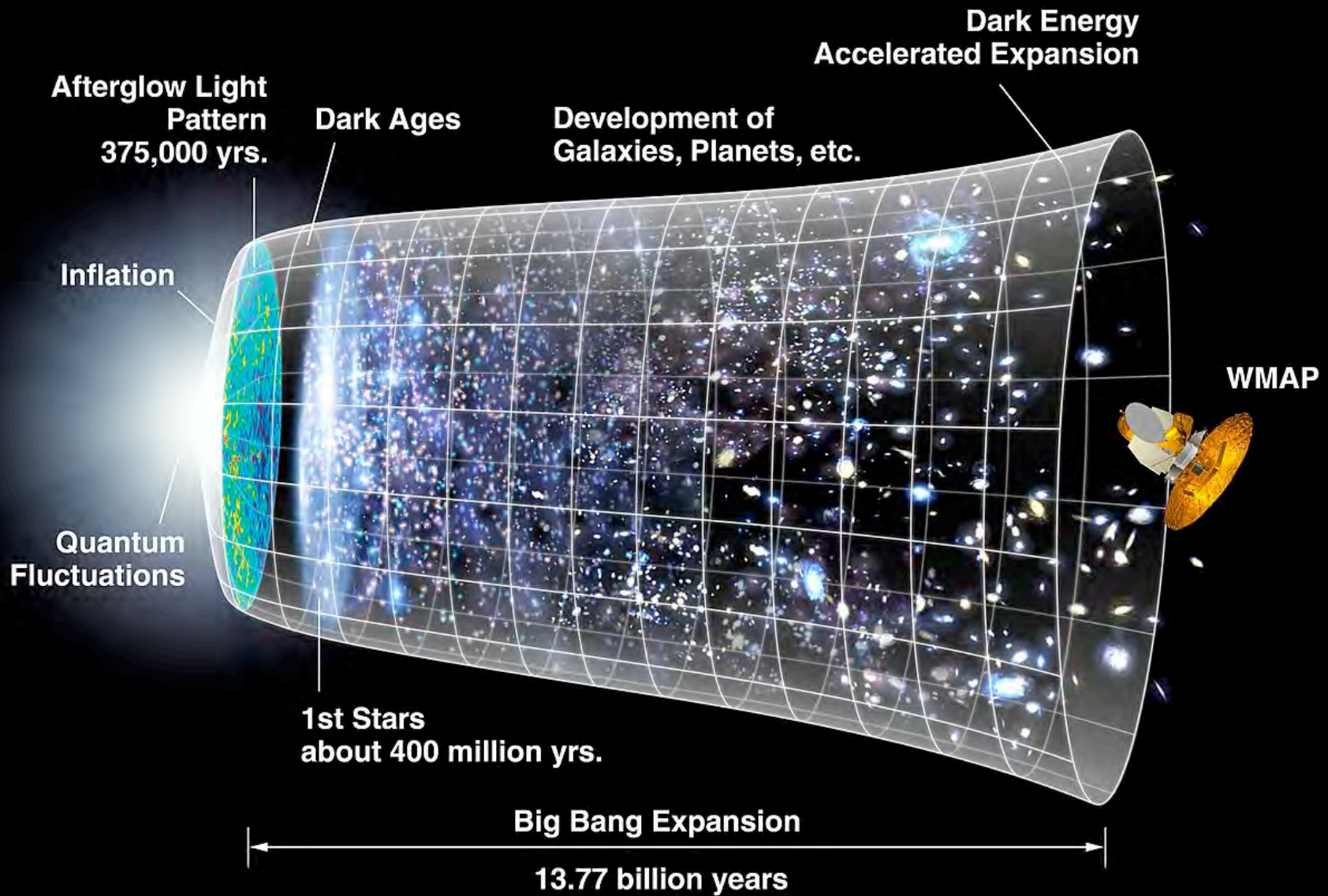
Hubble Space  
Telescope images

# Ingredients of universe



- **Ordinary Matter (atoms) accounts for only 4.9% of universe.**
- **Dark Energy dominates (68.3%) and accelerates expansion.**
- **Dark Matter 26.8%, more than five times as much as ordinary.**

# History of universe





# LIGO - gravity waves

**Livingston, LA**

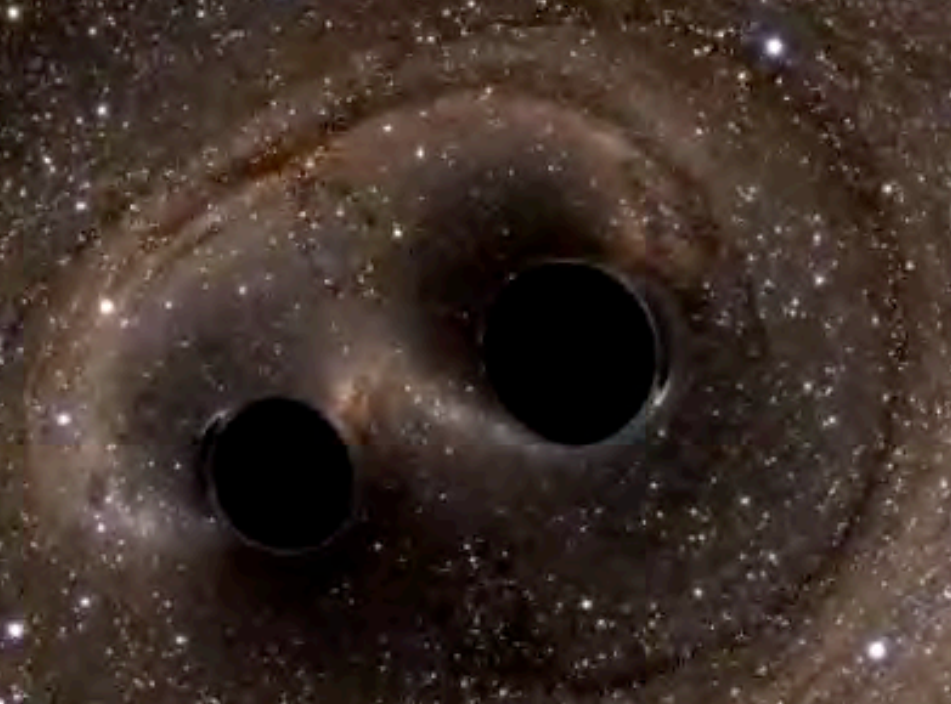
**Hanford, WA**

# LIGO - gravity waves



# Inspiral of two black holes

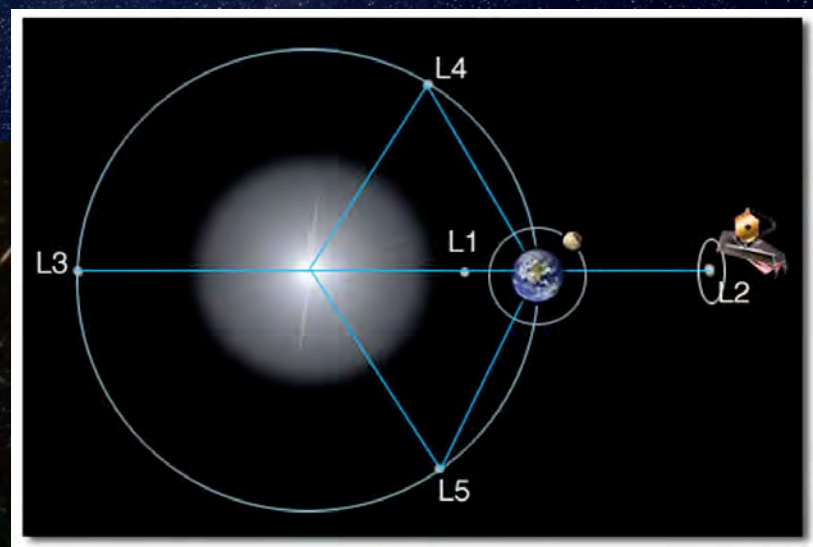
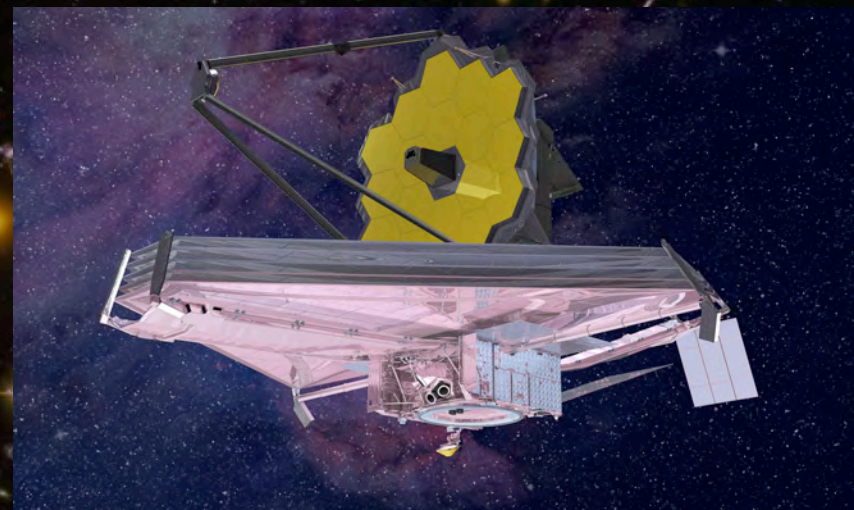
Black holes predicted by Einstein's *general relativity*.



Observing gravitational waves from distant universe  
2017 Nobel Prize - Rainer Weiss , Barry Barish , Kip Thorne

# Next - James Webb Telescope

- Launched Dec 25, 2021.
- Infrared telescope.
- Capable of detecting first stars in history of universe.
  - Starlight has red-shifted to infrared.
- Now 1,000,000 miles above Earth in night sky.
- First images in a few months.



# Status of knowledge today

- No doubt “visible universe” has a finite age:
  - $13.787 \pm 0.020$  billion years. (Planck)
    - Or between 13.767 and 13.807 b. yrs. (68%)
    - Let's call it 13.8 billion years!
- Remaining mysteries of time and space:
  - Was there existence before **Big Bang**?
  - How big is the universe - could be infinite?

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# Conclusion

- Fundamental scientific question has been history of the universe.
- Age of the visible universe is known from many complementary measurements - 13.8 b. yrs.
- Today the universe is expanding at an increasing rate due to a mysterious dominance of ***Dark Energy***.