Telescopes
Black Holes
History of Astronomy
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Big Bang
we learned before that the universe is expanding
if we run the clock on the universe backward, we find that everything must have been compressed into a very small space
This is the reasoning for including the *Big Bang*

The Big Bang describes the time when the Universe was compressed into a very small volume.
(later we will talk in detail about the Cosmic Microwave Background, which is one of the major signposts of the big bang)
T=0

(literally) time started
when talking about A happening before B, we mean that A happened at a time that was less than when B happened

in this case it just doesn’t make sense to talk about what happened before T=0 because the definition of ‘before’ breaks down
T=0 -> 1e-43 sec
T=0 -> 1e-43 sec

The Universe has started but we don’t have the knowledge of physics to describe it (we need to be able to combine all four forces into one super force)
T=1e-43 -> 1e-10 sec

gravity decouples from the other three forces, which still stick together as a superforce
$T = 1\times10^{-43} \rightarrow 1\times10^{-10}$ sec

a period of very rapid expansion occurred, known as inflation

the size of the universe increased by 50 orders of magnitude
T=0.1 milliseconds

enough energy is floating around (mainly in the form of radiation) that particles could form out of this energy
T=0.1 milliseconds

(remember Einstein said that energy and mass are equivalent, so if you have enough energy, you can create a piece of mass)
\[ T = 0.1 \text{ milliseconds} \]
Why didn’t all energy become mass when it’s that dense?
It is true that some mass will get converted back into energy when a particle and antiparticle combine.
for unknown reasons the Universe created slightly more matter than anti-matter (about one extra proton for every billion proton-antiproton pairs)

This excess of matter is what makes up the matter we see in the Universe today.
T=0.1 milliseconds

cool enough for protons and neutrons to form
Most of the universe consisted of electrons, protons and neutrons
The density and temperatures are high enough for fusion to occur, creating deuterium (proton+neutron)

This deuterium is quickly converted into helium, creating much of the helium in the Universe
In fact, this helium production in the Big Bang is needed to account for the amount of helium we see today (fusion in stars is not enough)
T = 15 minutes

density and temperature are too low for fusion to continue
$T$ = few hundred thousand years

protons combine with electrons to form nuclei

radiation is no longer being constantly absorbed by protons and electrons, and is allowed to freely stream throughout the universe (we see this freely streaming radiation as the Cosmic Microwave Background)
$T = \text{few hundred thousand years}$
T = few hundred thousand years -> today

stars form, galaxies form, the Universe as we see it is created
primordial nucleosynthesis

cosmic microwave background
Important time points:

T=1e-43->1e-10 sec: Inflation

T~2 minutes: Nucleosynthesis (making almost all of the Helium in the Universe, and the amount of deuterium/lithium depends on the amount of ‘ordinary matter’)

T~400,000 years: Cosmic Microwave Background
Evidence for Big Bang:

(1) Expansion of the Universe (ie. roll the clock back to zero and everything had to be in a small spot)

(2) Primordial Nucleosynthesis (ie. the amount of Helium in the Universe)

(3) Cosmic Microwave Background (ie. direct emission from the early Universe)
Big Bang Lecture Tutorial
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What started to form roughly 2 minutes after the Big Bang?

A. hydrogen
B. quasars
C. stars
D. galaxies
E. helium
Elements more massive than lithium were not formed in the early universe because the temperature was

A. too high
B. not related to density
C. unstable
D. too low
What was the big bang and what existed before it?

A. the big bang was a tremendous release of energy from a parallel universe, creating a point singularity that became our universe
B. the big bang occurred when a previous universe collapsed to a point singularity in a ‘big crunch’ starting the process all over again
C. the big bang was an explosion in space in part of our universe when it was much smaller
D. the big bang represented the beginning of our universe, but astronomers are unable to model the big bang event itself, and so cannot say what it was or what existed before hand