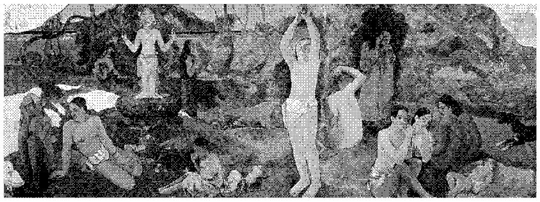
Where do we come from?
What are we? Where are we going?



Friday, December 5

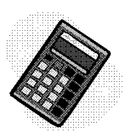
Pick up a copy of the practice mini-exam; answers available on the course website.

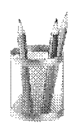
Tue, Dec 8, 9:30 am

Final Exam

Comprehensive

Same format as midterm





t = 0

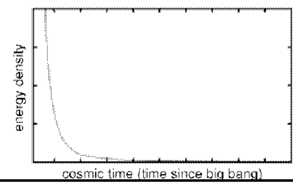
The Big Bang

The moment in time when the universe started expanding from its initial extremely dense state.

t=0: The Big Bang

How do we know that this happened?

Universe was denser in the past; if we daringly extrapolate backward to infinite density, that was a finite time ago.



t=0: The Big Bang

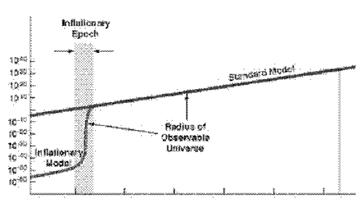
Why do we care that this happened?

If the universe had remained dense, it wouldn't have cooled enough for nuclei, atoms, galaxies, and **us** to form.

t ≈ 10^{-34} seconds

Inflation

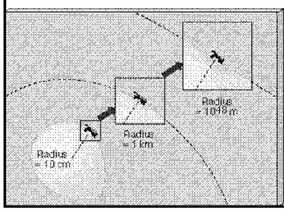
A brief period when the expansion of the universe was greatly accelerated.



t≈10^{-34} sec: Inflation

How do we know?

The universe is nearly flat now;
it was *insanely* close to flat earlier.

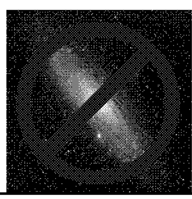


Inflation flattens the universe.

t=10^{-34} sec: Inflation

Why do we care?

If the universe hadn't been flattened, it would have long since collapsed in a Big Crunch or fizzled out in a Big Chill.

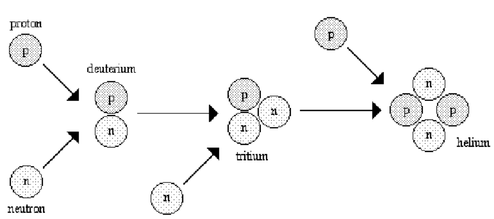


No inflation, no galaxies.

t = 3 minutes

Big Bang Nucleosynthesis

A period when protons & neutrons fused to form helium.



t=3 min: Big Bang Nucleosynthesis

How do we know?

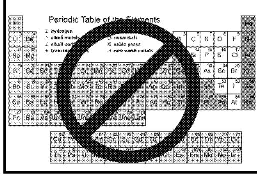
The earliest stars contain 75% hydrogen, 25% helium, as predicted from Big Bang Nucleosynthesis.

(Later stars contain more helium, made in previous generations of stars.)

t=3 min: Big Bang Nucleosynthesis

Why do we care?

It shows we understand what the universe was like when it was less than 15 minutes old.



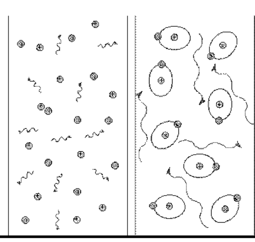
No nucleosynthesis, no periodic table (until the 1st stars).

t = 400,000 years

Transparency

A period when protons & electrons joined to form neutral atoms.

before

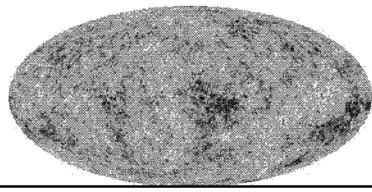


after

t=400,000 years: Transparency

How do we know?

Cosmic Microwave Background is the “leftover light” from when the universe was hot & opaque.



t=400,000 years: Transparency

Why do we care?

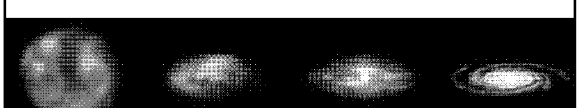
If the universe were still opaque, we wouldn’t be able to see distant galaxies.

No transparency, no astronomers.

t = 750 million years

The First Galaxies

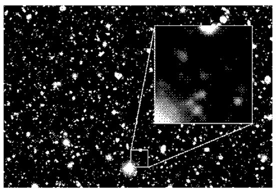
A period when gas cools, falls to the center of dark halos, and fragments into stars.



t=750 million years: First Galaxies

How do we know?

We see galaxies with large redshift
(implying large distance,
implying distant past).



t=750 million years: First Galaxies

Why do we care?

We live in a galaxy,
orbiting a star.

No stars,
no photosynthesis.

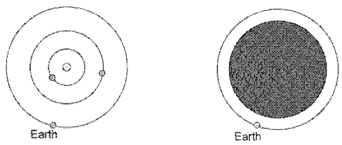
t = 13.7 billion years

Now

A period when intelligent life on Earth
wonders about how the universe works.

t = 19 billion years
(5 billion years from now)

Sun becomes a red giant star.



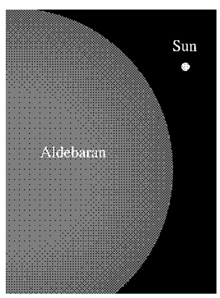
Sun now

Sun as red giant

t=19 billion years: Sun = red giant

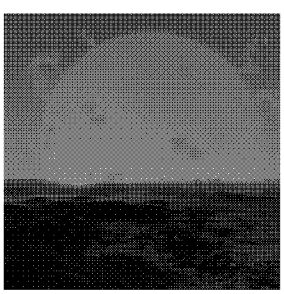
How do we know?

We see what happens to older stars when they run out of hydrogen.



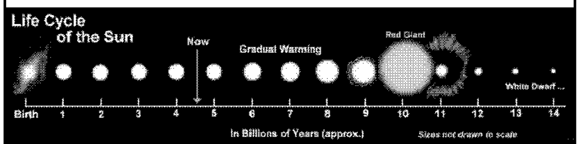
t=19 billion years: Sun = red giant

Why do we care?



The Earth will be toast.

After its last hurrah as a red giant, the remnants of the Sun will become a white dwarf.



t = 1 trillion years

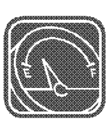
Last stars run out of fuel.

Galaxies remain filled
with stellar “corpses”:
White dwarfs,
neutron stars,
black holes.

t=1 trillion years: Last stars die.

How do we know?

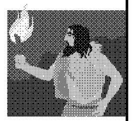
Lifespan is longest for the thrifty “subcompact” stars barely massive enough for fusion.



Eventually, though, they “run out of gas”.

t=1 trillion years: Last stars die.

Why do we care?

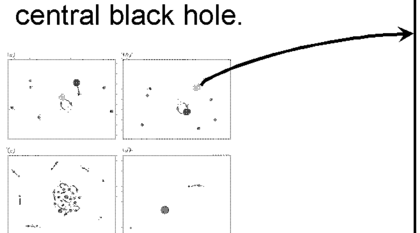


Even if our remote descendents huddle around a dim, low-mass star, the light will eventually go out.

t = 100 trillion trillion (10^{27}) years

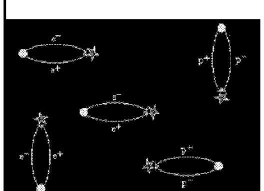
The end of galaxies.

Encounters between stellar remnants fling some of them out of galaxy, others into a central black hole.

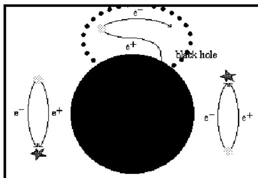


"Black holes ain't so black."
– Stephen Hawking

Black holes emit radiation - if quantum mechanics is taken into account.



Particle - antiparticle pairs pop out of vacuum, annihilate shortly afterward.



One member of a pair can fall into a black hole, while the other escapes.

The black hole appears to be spitting out particles & antiparticles. Where does the particles' energy come from?

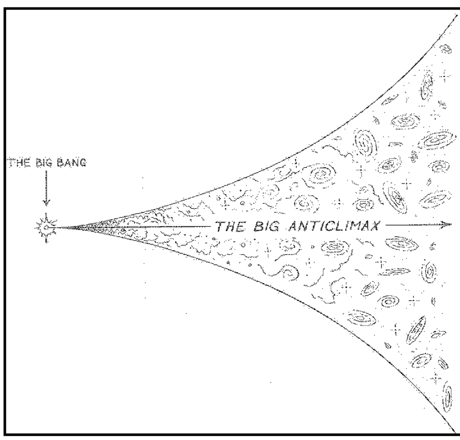
The mass of the black hole.

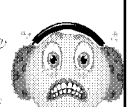
t = 10^{106} years

The end of black holes.

Supermassive black holes evaporate by the emission of particles & antiparticles.

An ever-expanding universe, containing elementary particles at ever-decreasing density.





Brrrr… The Big Chill