hi

today, 25 April

input:

expanding universe

output:

nothing

Feynman used to ask suppose civilization disappeared

but you could prepare our successors with crucial knowledge
what would it be?

Three most important things of the latter 20th century:

1. matter is made of quarks governed by 4 forces implemented by the primacy of symmetry
2. the universe is expanding
3. the universe had a beginning

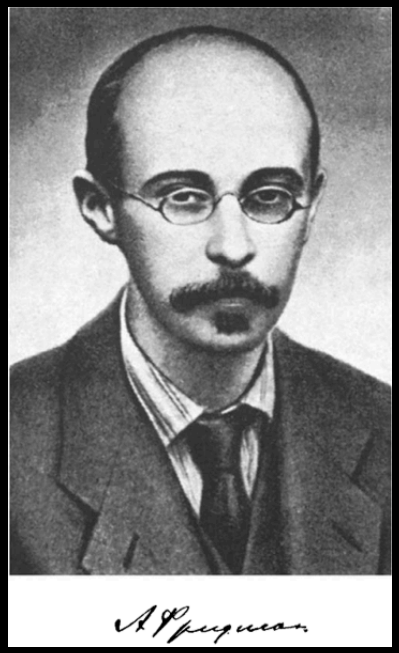
in 1915
scientific cosmology
didn't exist

Alexander Friedmann (1888–1925)

1922, 23

finds a whole class of solutions!

with and without Λ



$$G = T$$
$$G + \Lambda = T$$

Einstein didn't take it well.

Now, the modern basis of solutions.

GR plus the "Cosmological Principle"

a working assumption:

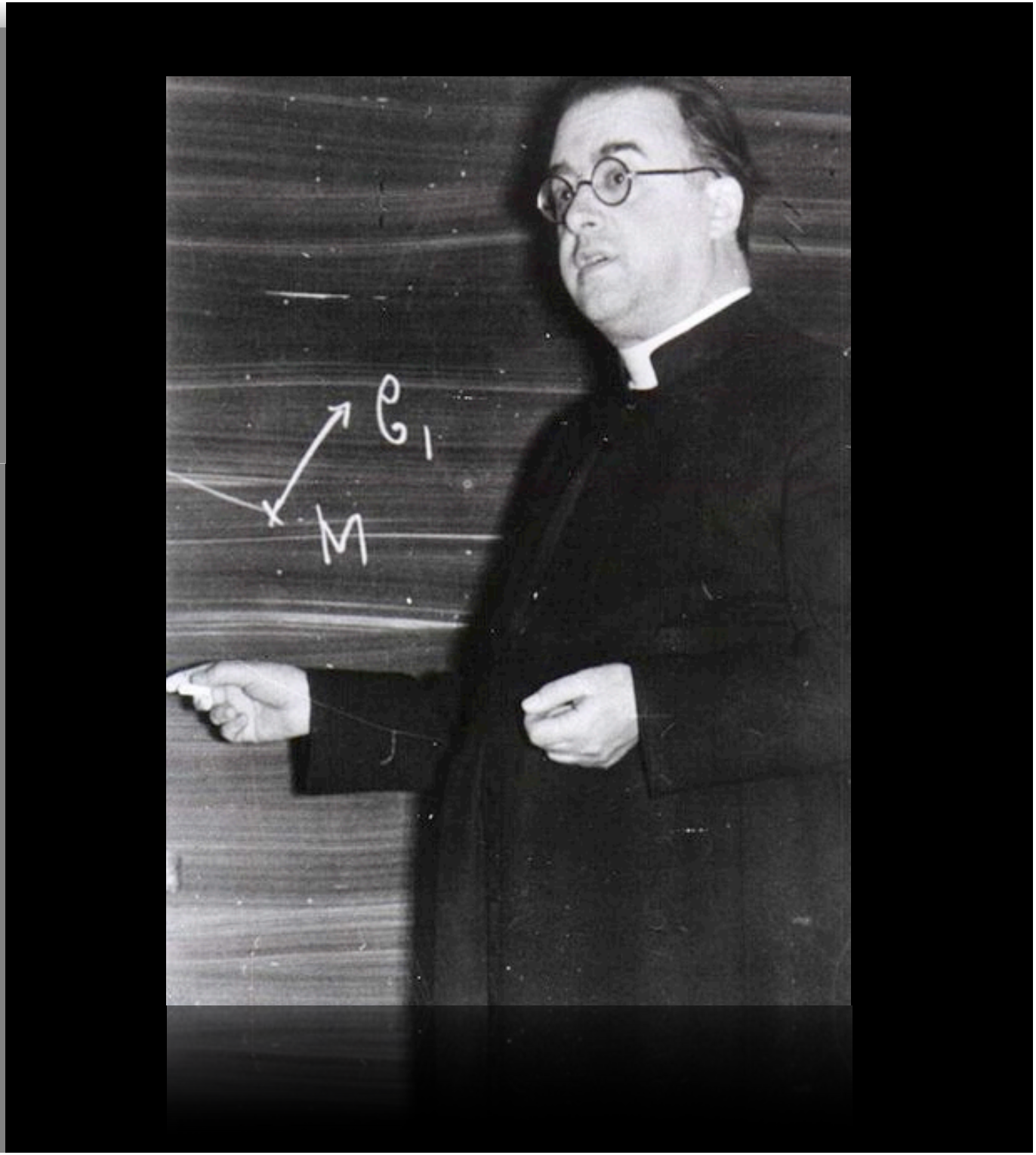
on a large scale, the properties of the Universe do not depend on an observer's location

so what we can observe can be extrapolated to a presumption that the whole Universe is like that

Georges Lemaître
(1894-1966)

The father of the Big Bang

get it?



"redshift," z
an astronomical definition

For relativistic speeds, the full version is:

$$\frac{\lambda_O - \lambda_e}{\lambda_e} = \sqrt{\frac{1+\beta}{1-\beta}} - 1 \qquad \rightarrow \beta$$

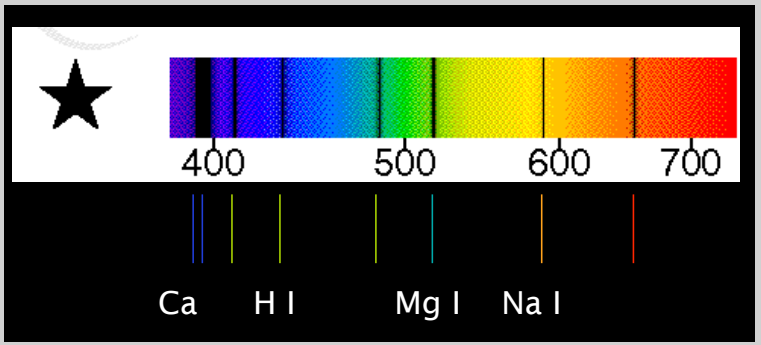
This is called the "redshift," z:

$$z \equiv \frac{\Delta\lambda}{\lambda_e}$$

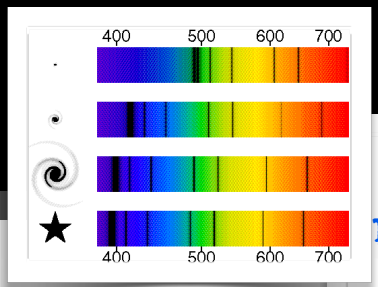
$$z = \sqrt{\frac{1+\beta}{1-\beta}} - 1$$

So, if you saw a spectrum of a star was shifted to the red by measuring $\Delta\lambda$

You'd conclude that it's moving away from you and could determine how fast: β



http://www.astro.ucla.edu/~wright/doppler.htm



FROM PRESUMED DOPPLER-SHIFTED SPECTRA

HUBBLE'S CONSTANT = 1/T

Hubble's Law

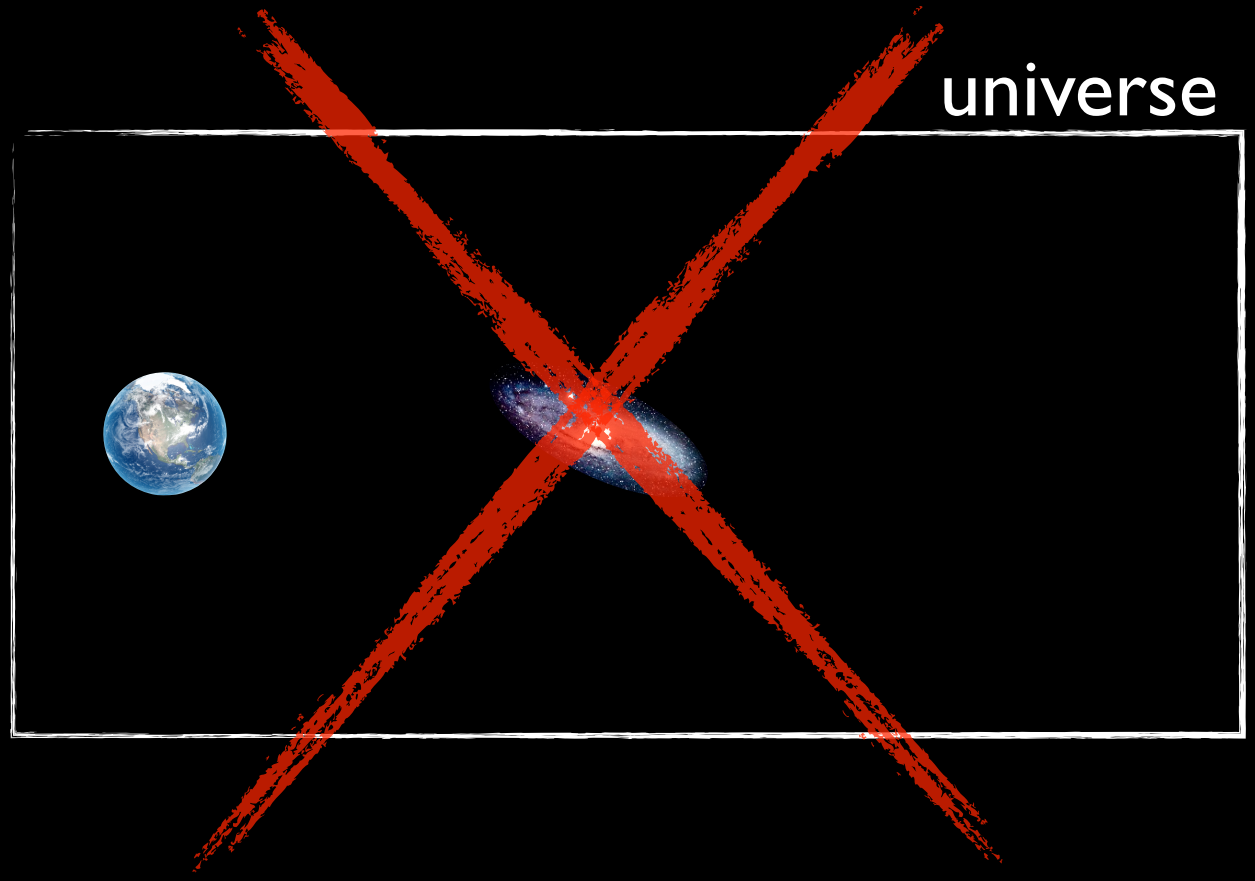
H: a measure of the time a galaxy has been "traveling"

$$v = dH$$

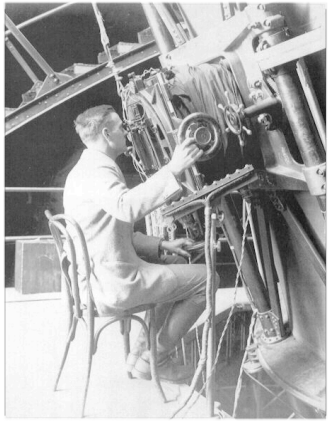
FROM LEAVITT'S CEPHEID VARIABLE RELATION

galaxies are not "moving away"

inside of the universe



Lemaitre was the first to realize that Hubble had demonstrated:



1. spacetime is stretching

The entire kit and caboodle is expanding

2. Therefore, it must have **come** from something smaller

what stretching means

is complicated!

universe

$$1 \text{ light year} = c \times 1 \text{ year} = 9.5 \times 10^{15} \text{m}$$

original results:

$$H = 160 \text{ km/Mly} \quad \Rightarrow \quad \frac{1}{H} = 2 \times 10^{9} \text{years}$$

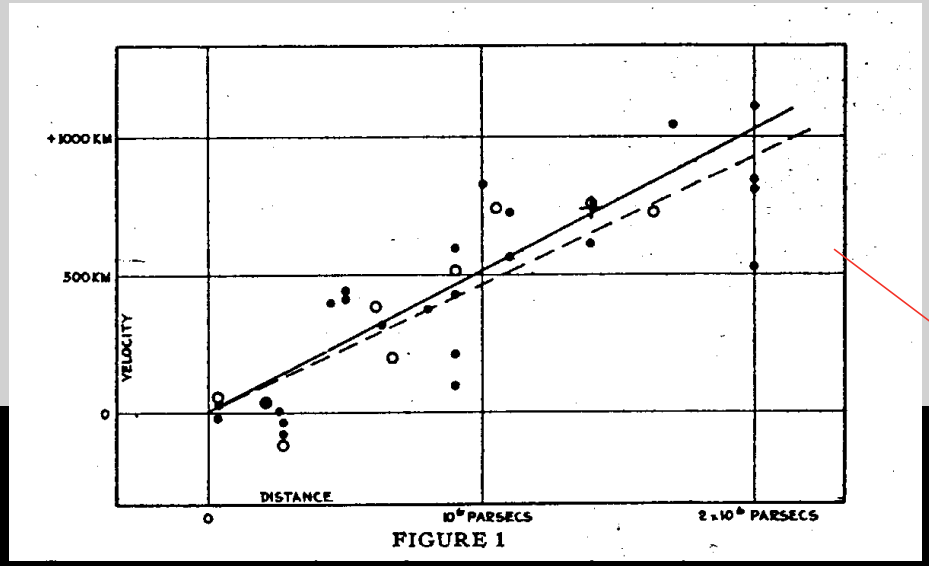
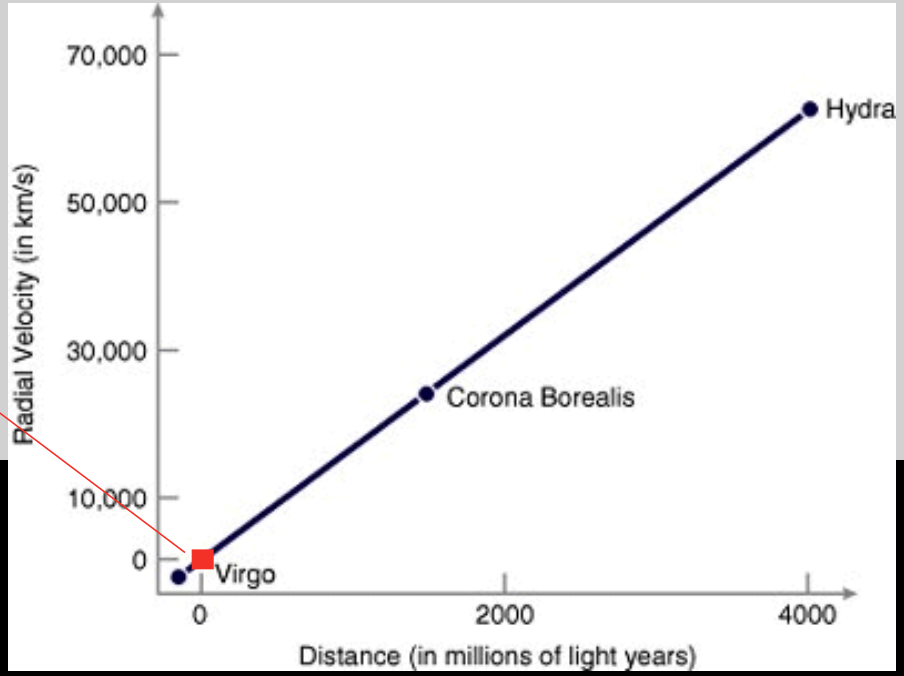


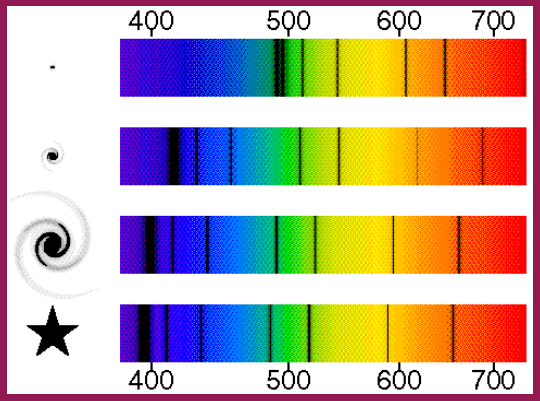
FIGURE 1



the “red shift”

isn’t a Doppler velocity

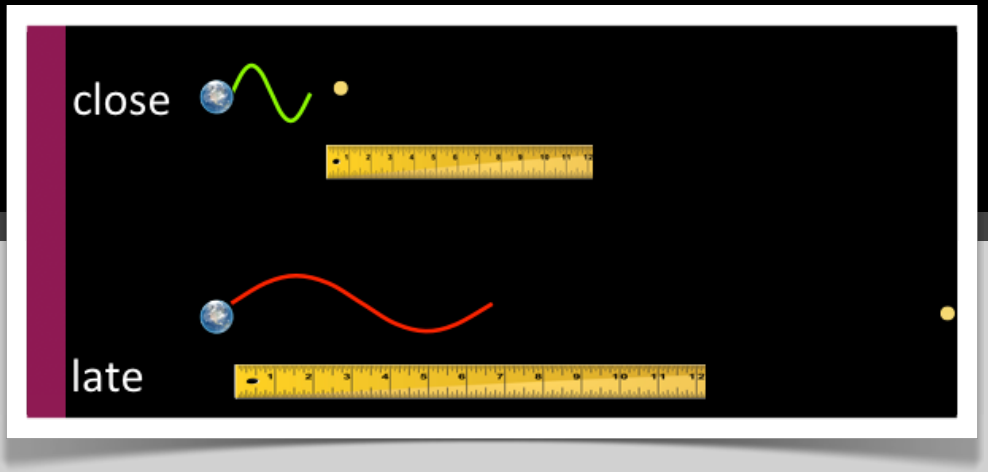
it’s geometry



close

late

early



The further away a galaxy is:

the more red-shifted its spectrum will be

and the faster it will appear to be receding

the older it will be

and the younger it will appear to be!

Measuring the Hubble Constant is an important cottage industry in astronomy

current best result:

$H_0 = 70.4 \pm 1.4$ km/sec/Mpc → the age of universe is

13.7 ± 0.13 B years

1 megaparsec (Mpc) = 10^6 parsec = 3.26 x 10^6 light years = 3.086 x 10^{16} m

look up

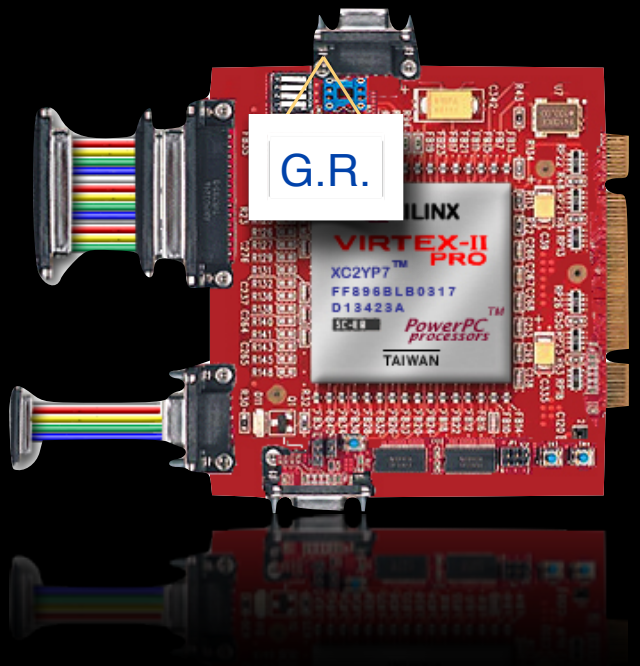
Why is the sky dark at night?

because there were no stars in the very early universe

energy/mass/pressure

energy/mass/pressure

$G = T$



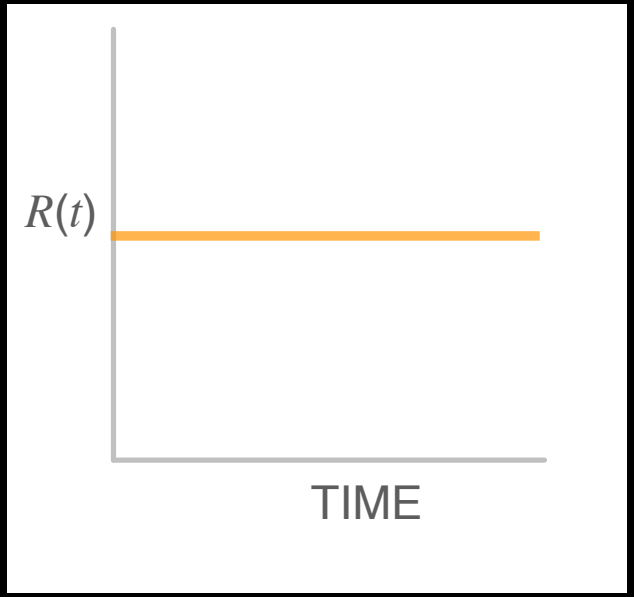
TIME

$R(t)$

R_0

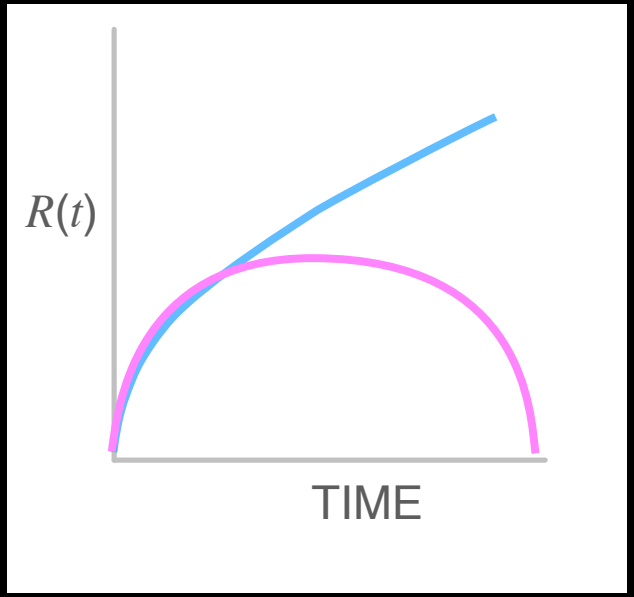
characterize R

Einstein



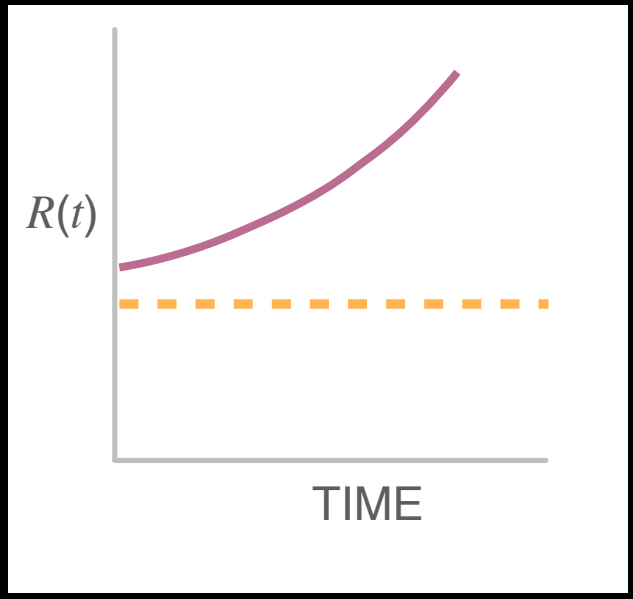
characterize R

Friedmann



characterize R

Lemaitre$_1$

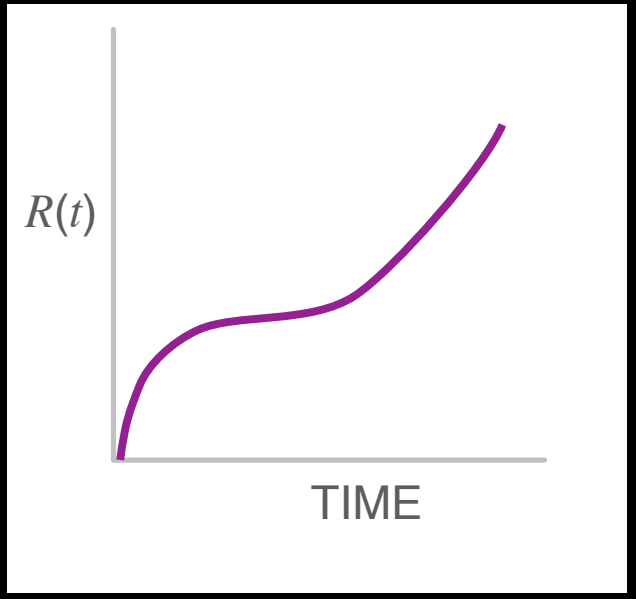


Lemaitre$_2$ model

used Λ as a "force" to tune the acceleration

"Primeval Atom"

cold, decayed



the geometry of the universe can be measured

stay tuned

balloon boy

tough to draw a 4 dimensional world

3d world

but 2-d ants

no "up"

no "down"

interesting place:

parallel lines meet

infinite in extent

finite in volume

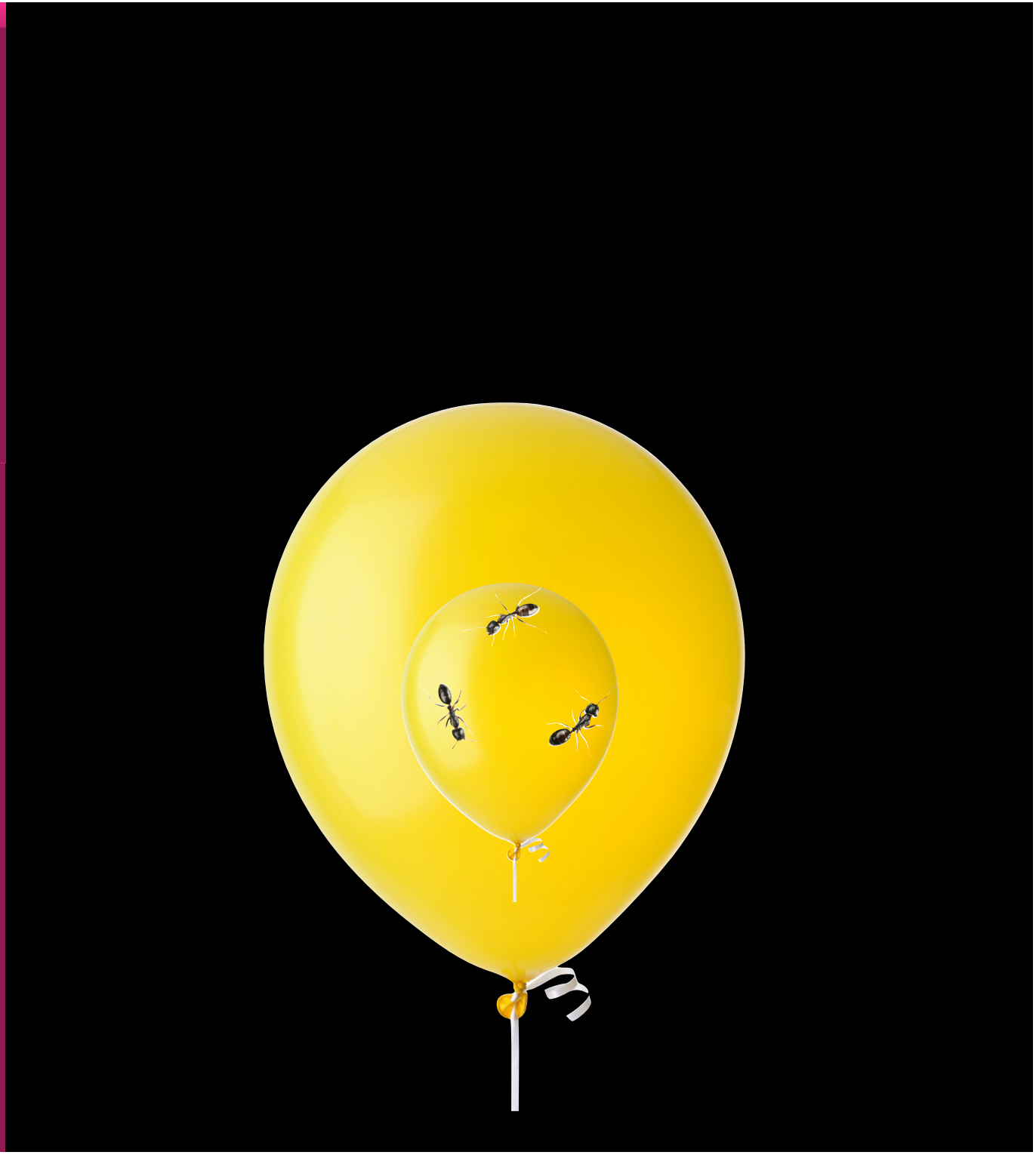
"closed" – they come back

expands?

ants don’t change

distances between them do

“positive curvature”

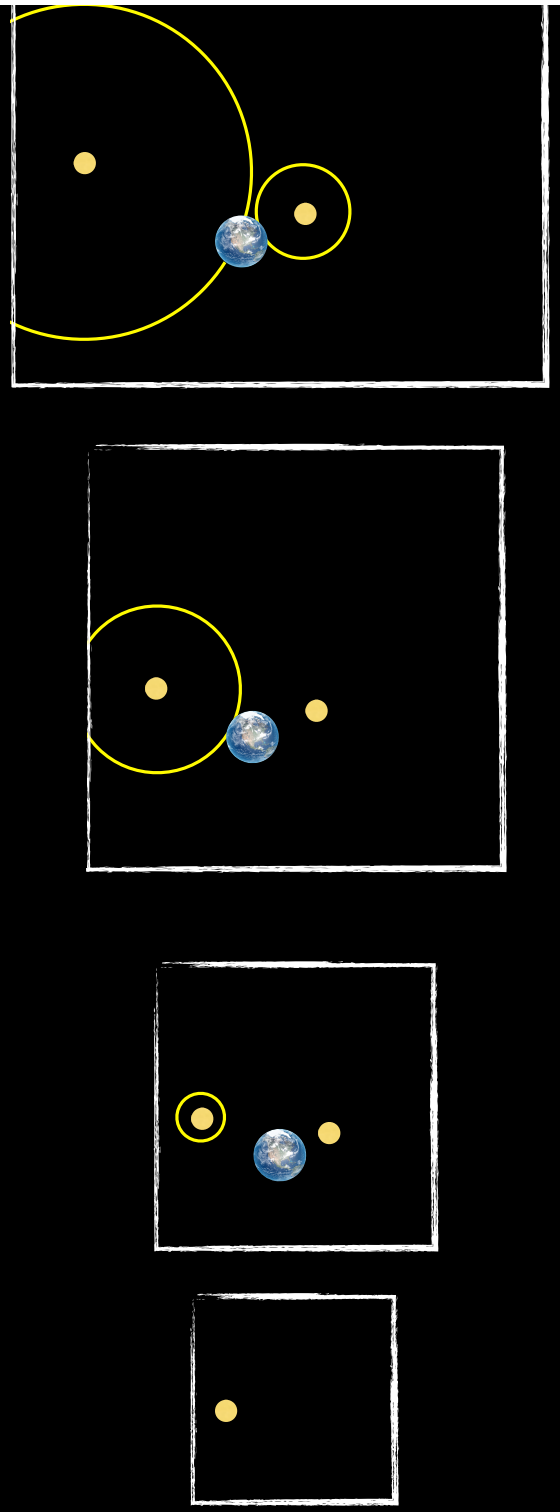


moving away?

a telescope

is a time machine

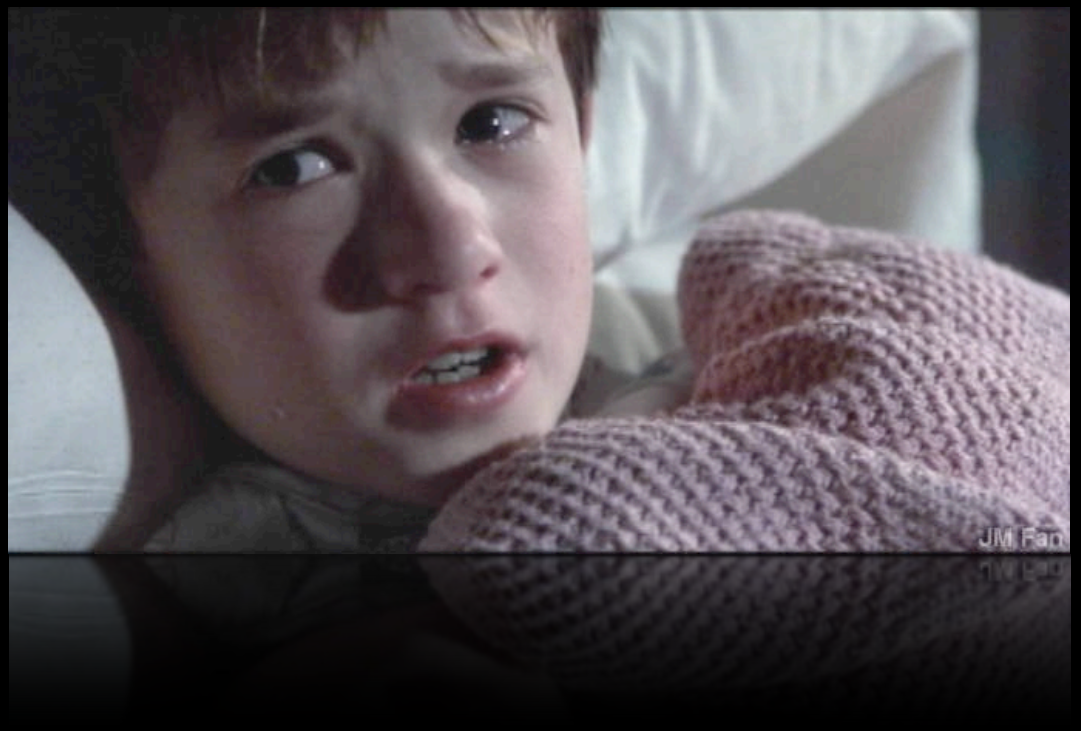
late



early

I see

dead stars

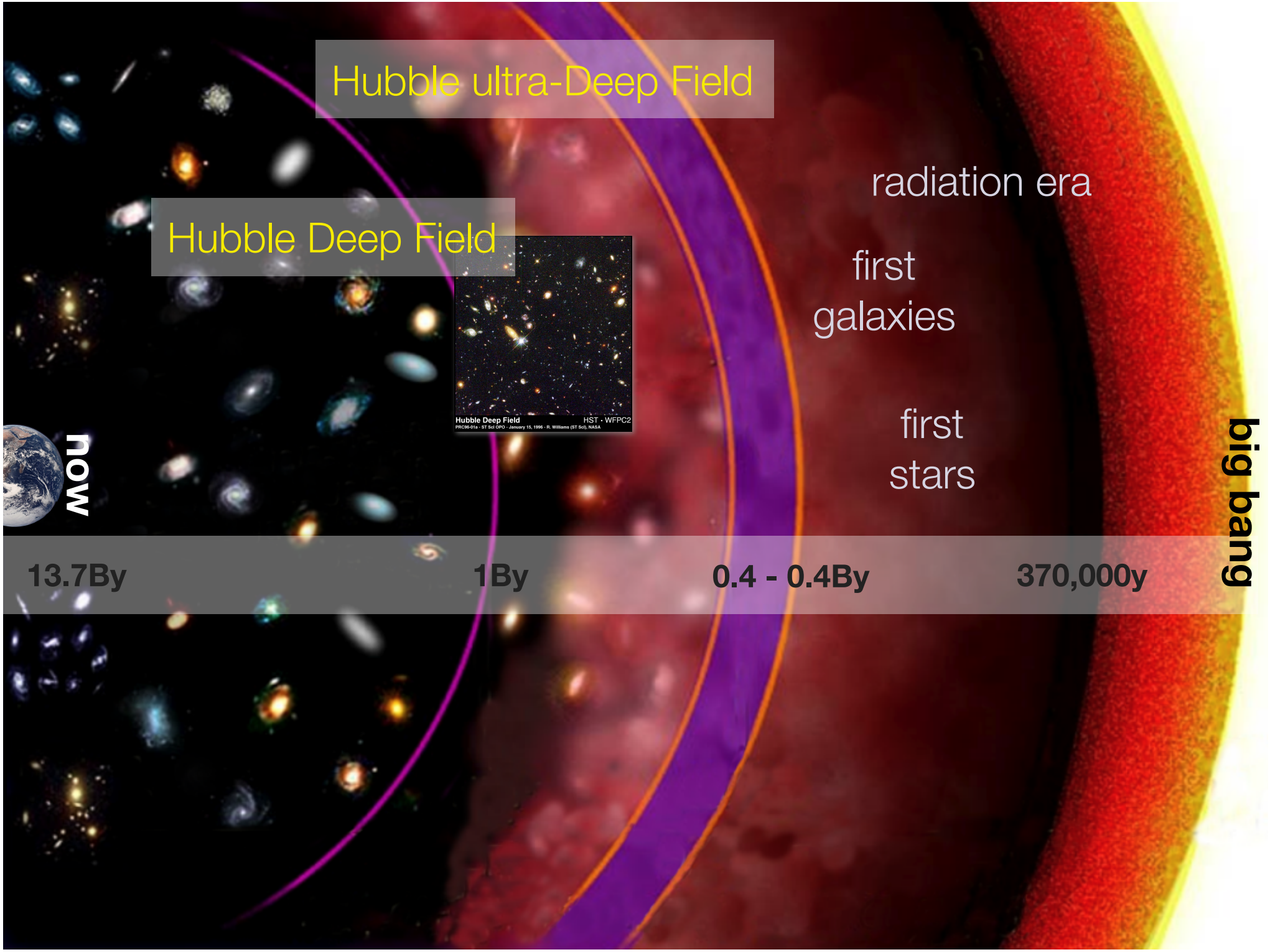


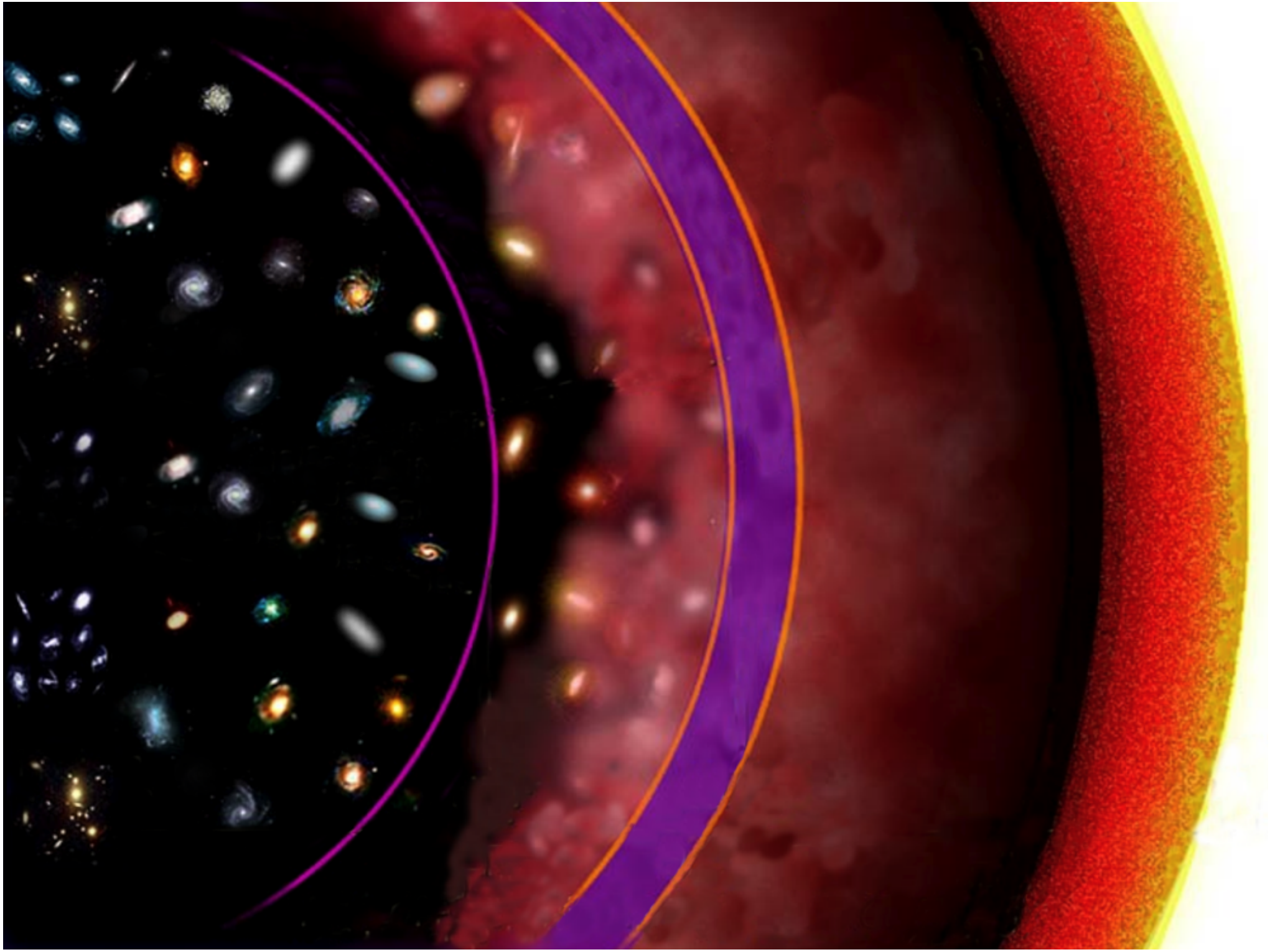
we see back in time

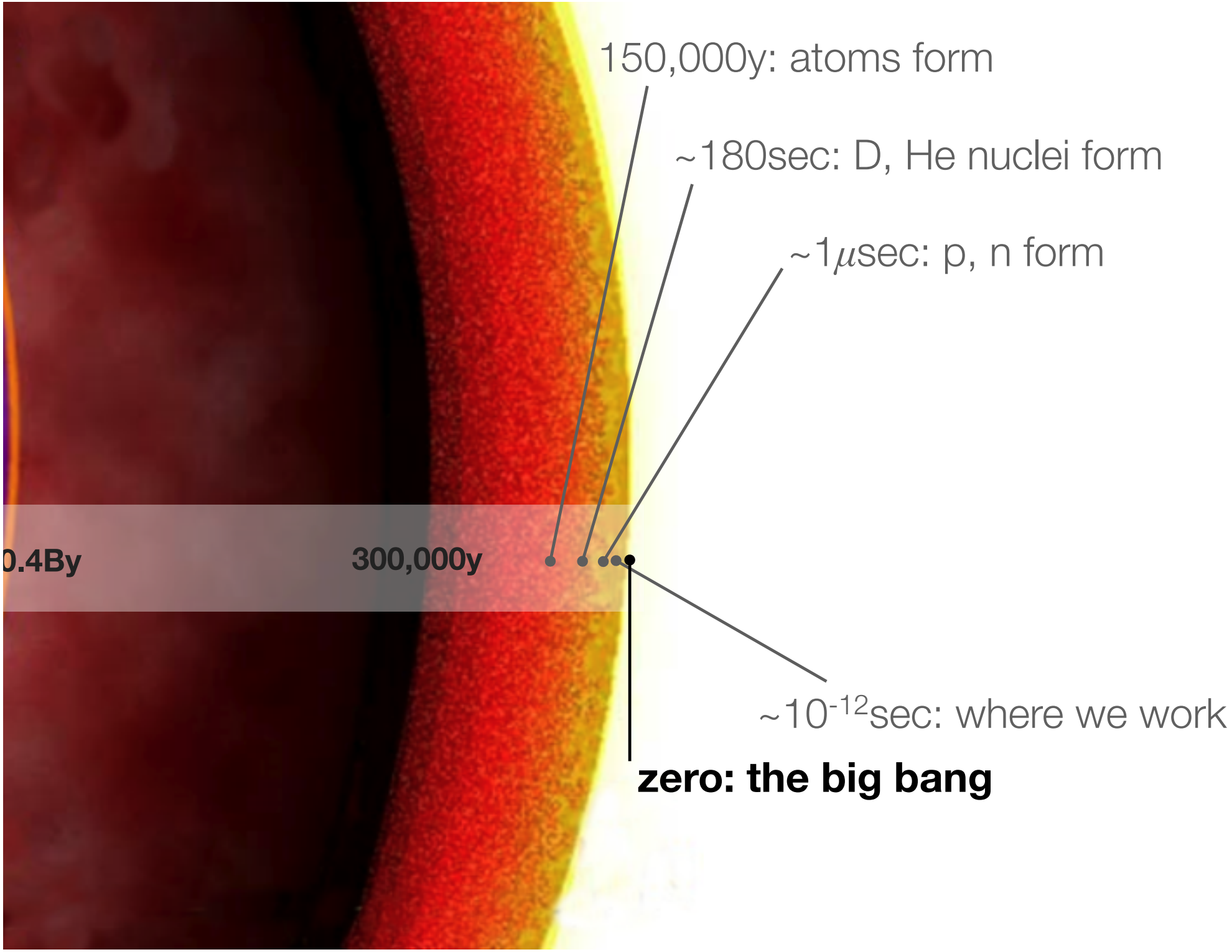
the further away,

the younger they are depicted.

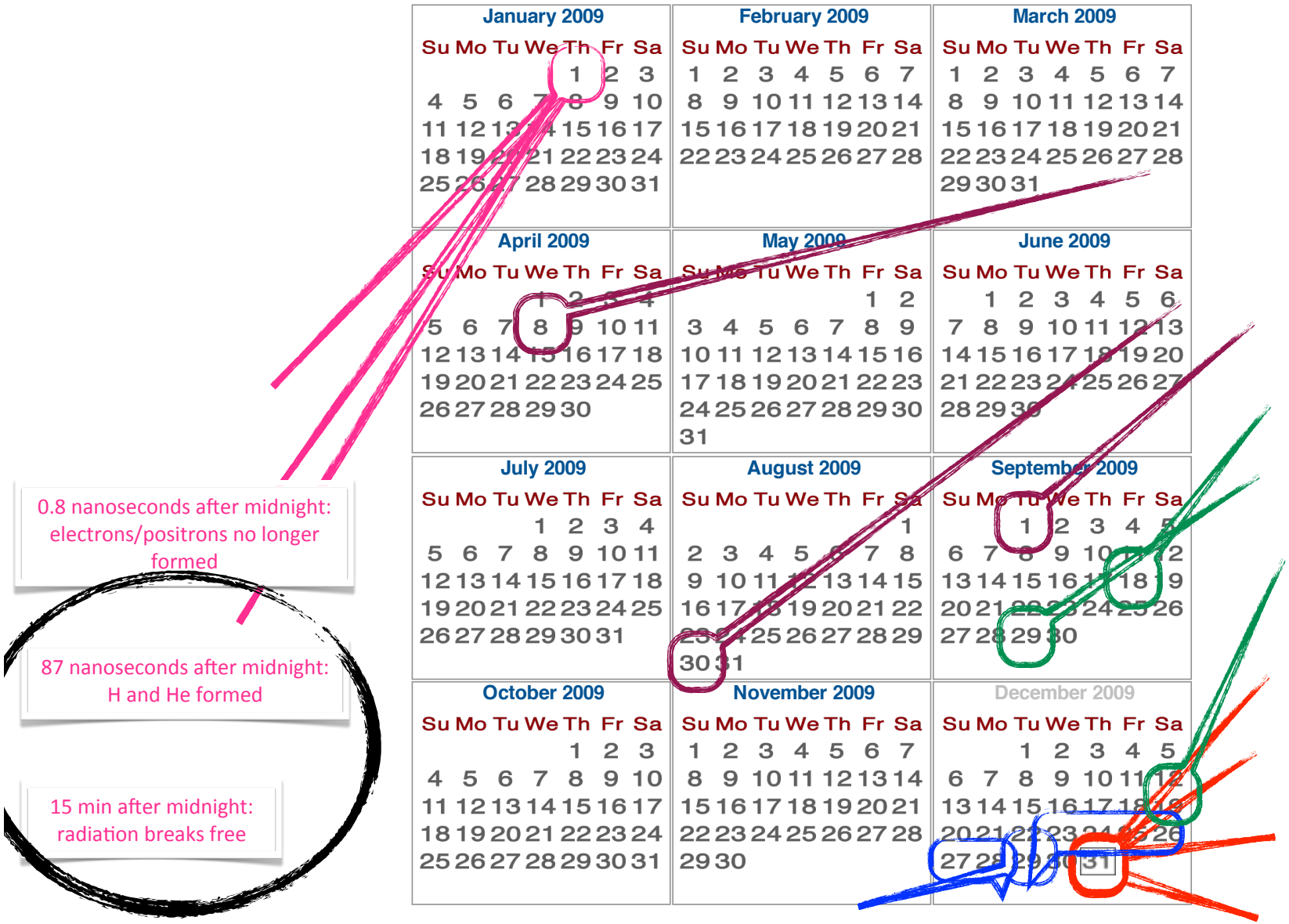
how can you tell what's further away?


Hubble ultra-Deep Field
Hubble Deep Field
Hubble Deep Field
HST · WFPC2
PRC96-01a - ST ScI OPO - January 15, 1996 - R. Williams (ST ScI), NASA
radiation era
first
galaxies
first
stars
big bang
now
13.7By
1By
0.4 - 0.4By
370,000y




150,000y: atoms form
~180sec: D, He nuclei form
~1μsec: p, n form
0.4By
300,000y
~10-12sec: where we work
zero: the big bang

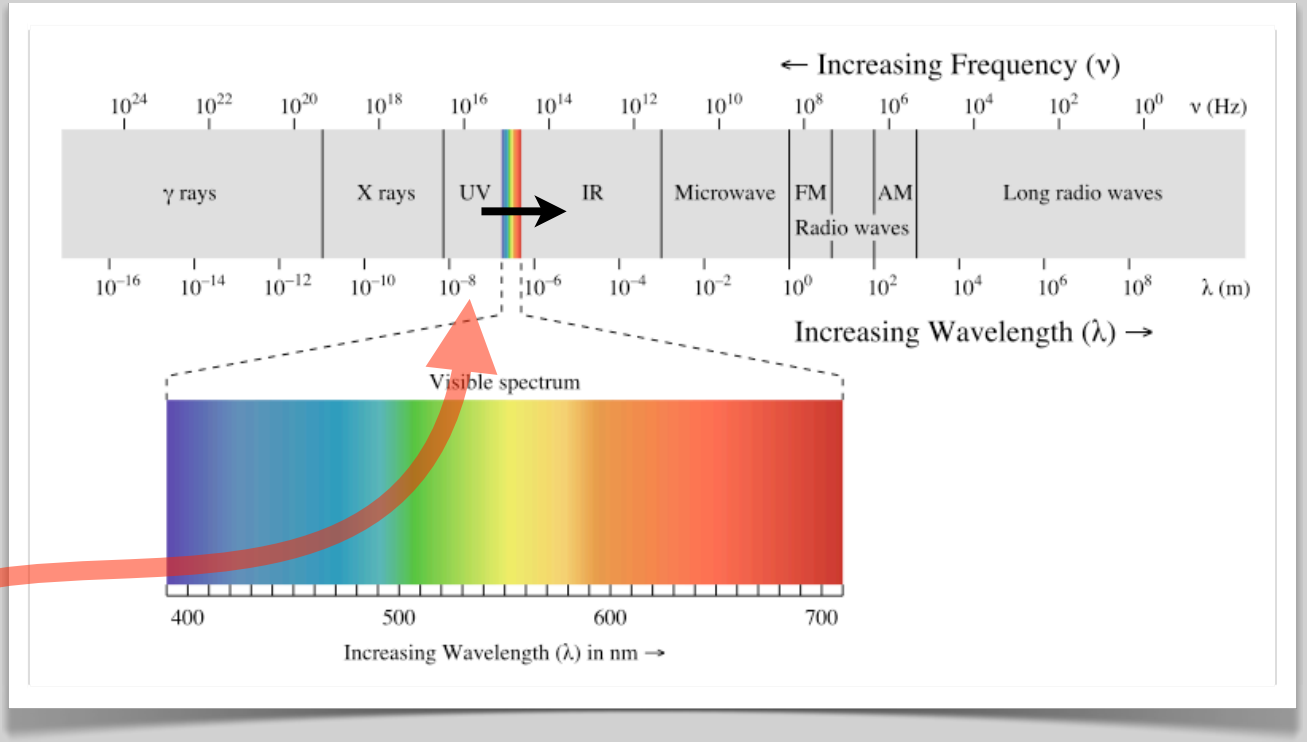
our cosmic calendar: 12 months = 13.6 By

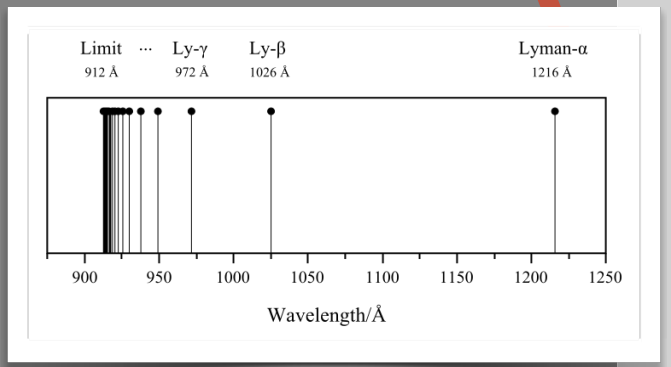


how far back?

redshift tells us

Hydrogen emission Lyman alpha line is key for the farthest objects





$1216\ \text{Å} = 121.6\ \text{nm}$

Why Hydrogen?

Thought to be among the newest galaxies in the universe – lots of hydrogen left from the first nucleosynthesis

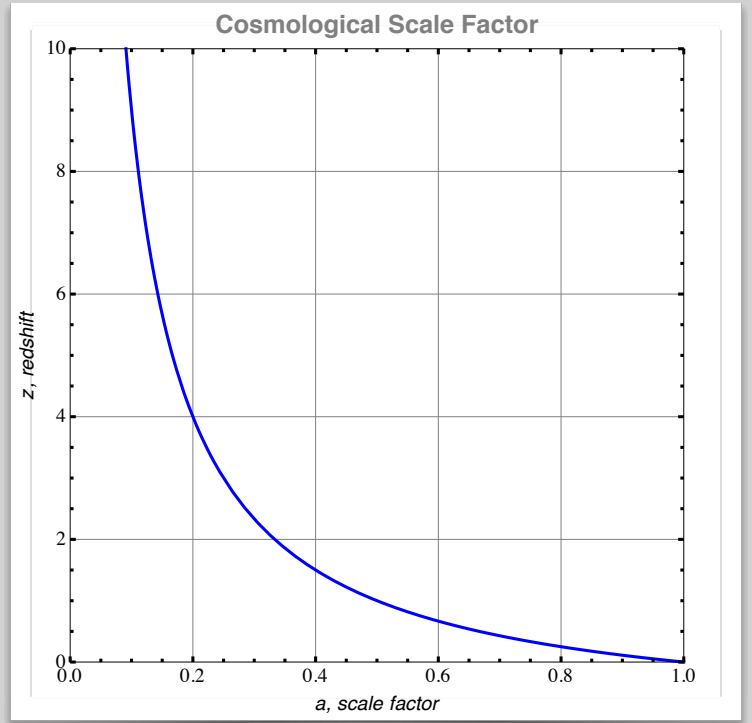
rules of thumb

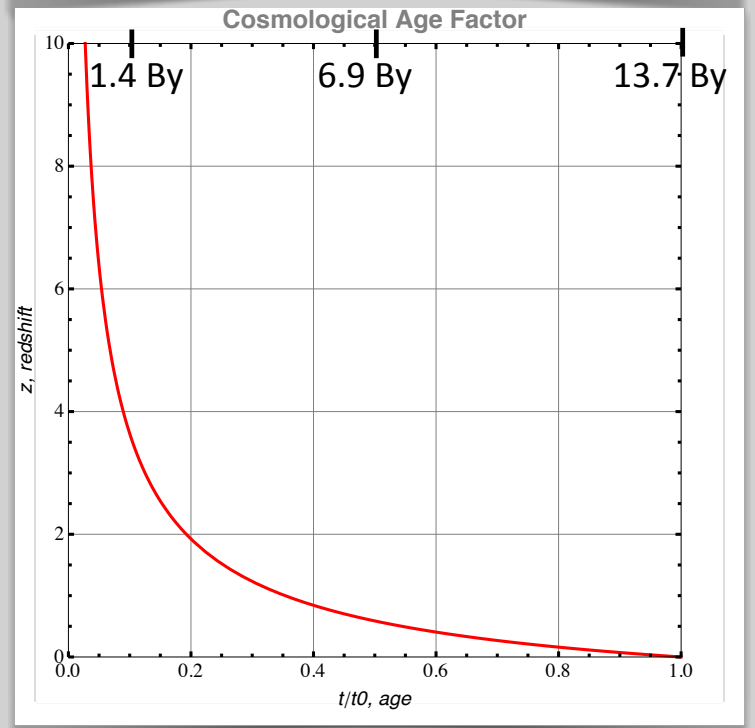
redshift to:

the scale factor

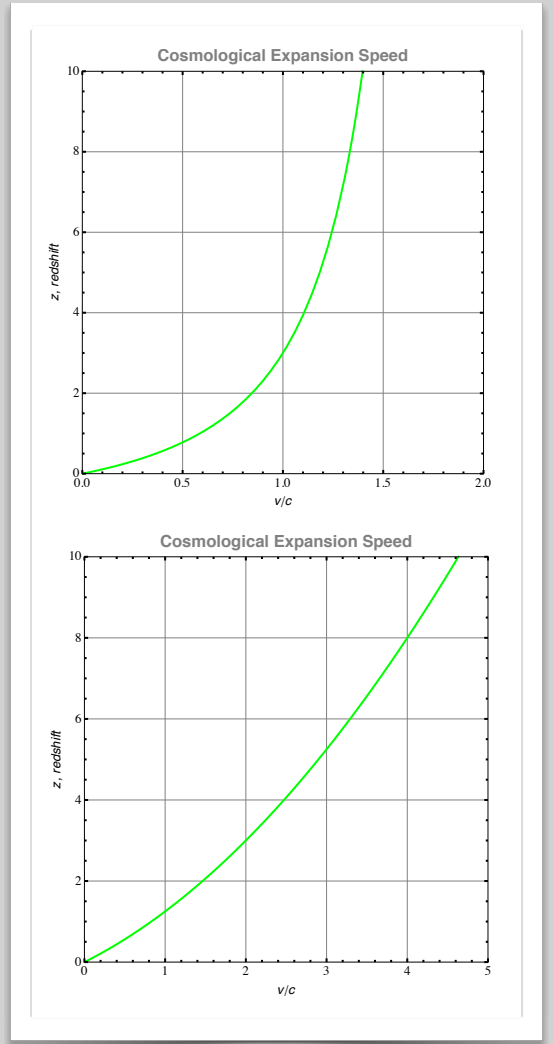
the age

"speed"



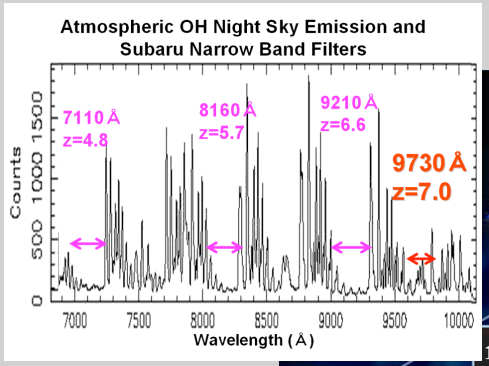


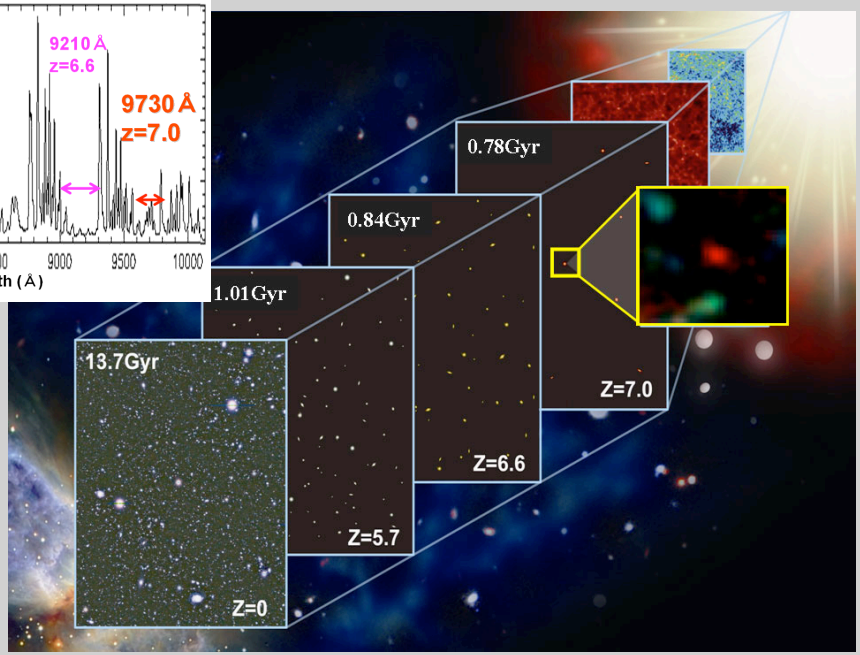
(Universe expansion speed is a tricky concept and open to different interpretations. These are examples.)



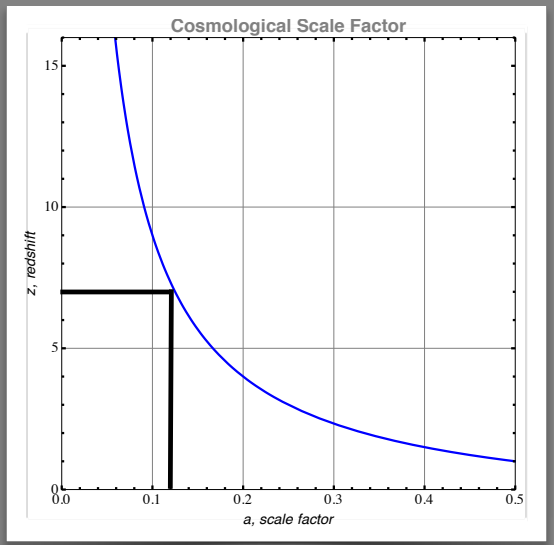
high redshift quasar hunting

a team sport

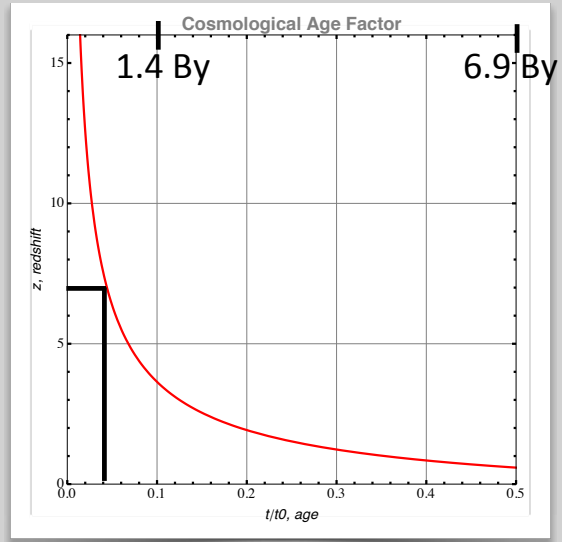




Xiaohui Fan, Arizona
From Sloan Digital Sky Survey



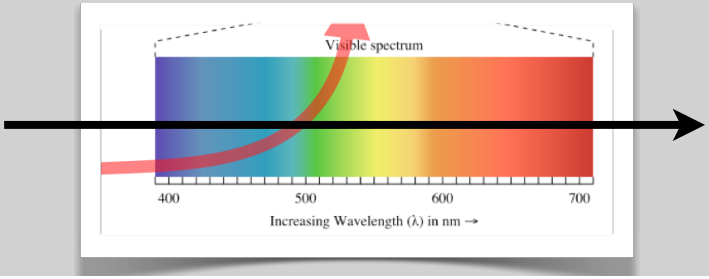
~10% of current size



~700 My old

$$z = \frac{9730 - 1216}{1216} = 7.002$$

from the UV to the near IR



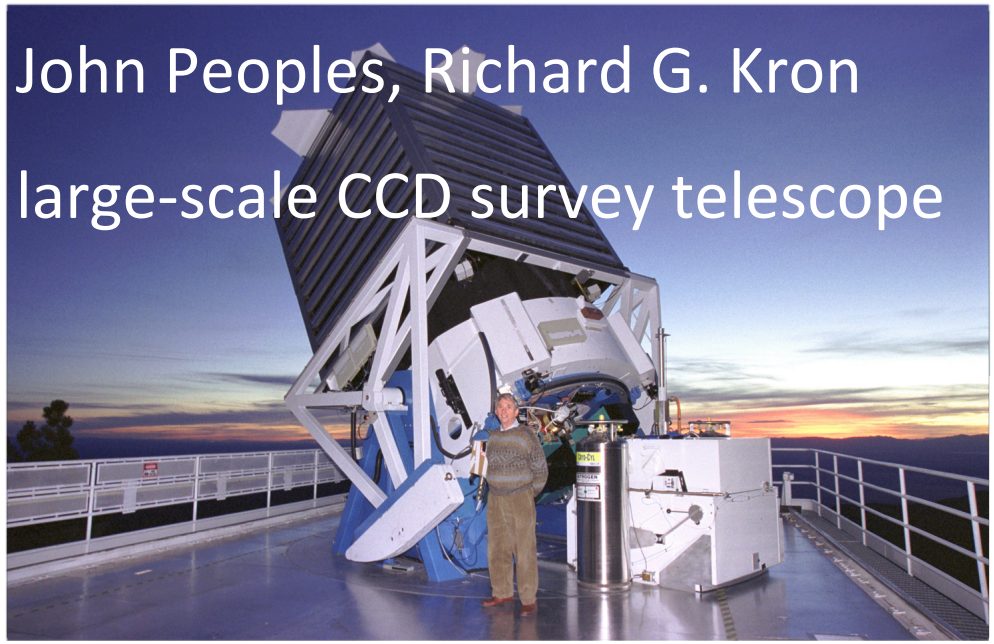
laboratory: **Sloan Digital Sky Survey aka SDSS**

location: Apache Point Observatory, NM

established: 2000

notable directors: John Peoples, Richard G. Kron

type of lab: large-scale CCD survey telescope



George Gamow

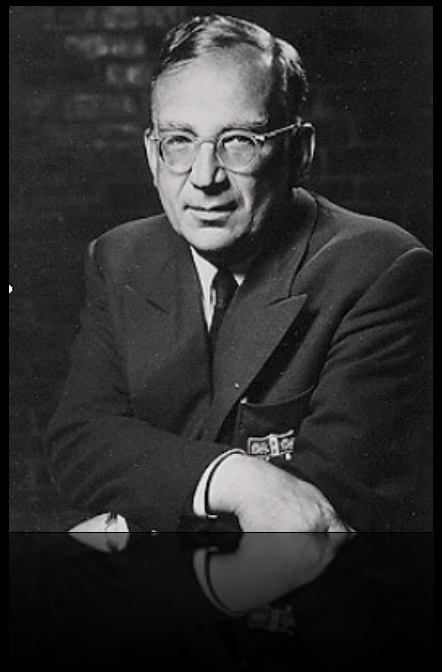
universe born

hot primordial soup

Fred Hoyle

steady state model, continuous creation of matter.

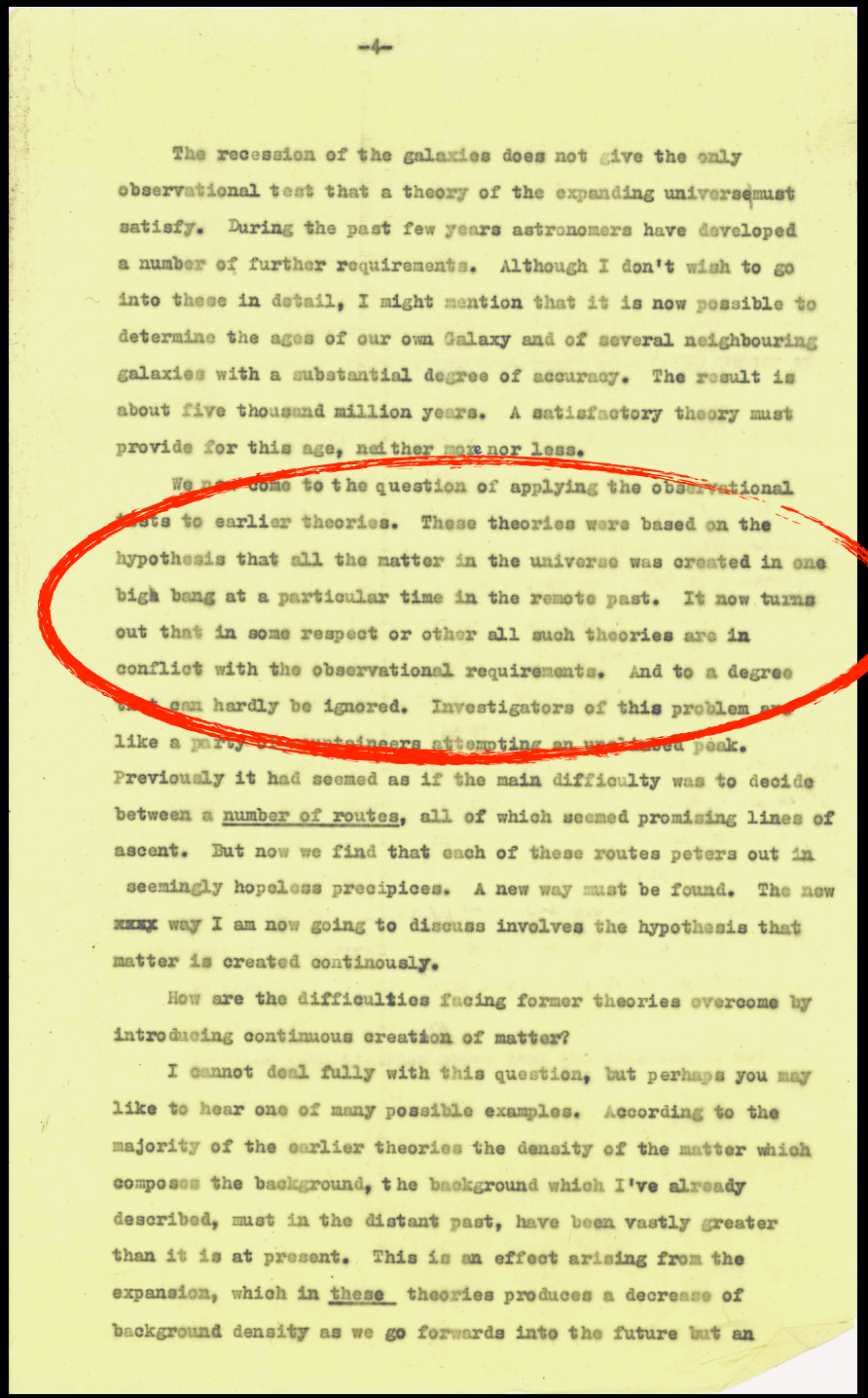
*"**big bang**" was ironically Hoyle's quip*



To Hoyle: the Big Bang implied a creator.

“Big Bang” was coined by Fred Hoyle in a

BBC radio broadcast for the general public in 1948



-4-

The recession of the galaxies does not give the only observational test that a theory of the expanding universe must satisfy. During the past few years astronomers have developed a number of further requirements. Although I don't wish to go into these in detail, I might mention that it is now possible to determine the ages of our own Galaxy and of several neighbouring galaxies with a substantial degree of accuracy. The result is about five thousand million years. A satisfactory theory must provide for this age, neither more nor less.

We now come to the question of applying the observational tests to earlier theories. These theories were based on the hypothesis that all the matter in the universe was created in one bigh bang at a particular time in the remote past. It now turns out that in some respect or other all such theories are in conflict with the observational requirements. And to a degree that can hardly be ignored. Investigators of this problem are like a party of mountaineers attempting an unclimbed peak. Previously it had seemed as if the main difficulty was to decide between a number of routes, all of which seemed promising lines of ascent. But now we find that each of these routes peters out in seemingly hopeless precipices. A new way must be found. The new xxxx way I am now going to discuss involves the hypothesis that matter is created continously.

How are the difficulties facing former theories overcome by introducing continuous creation of matter?

I cannot deal fully with this question, but perhaps you may like to hear one of many possible examples. According to the majority of the earlier theories the density of the matter which composes the background, the background which I've already described, must in the distant past, have been vastly greater than it is at present. This is an effect arising from the expansion, which in these theories produces a decrease of background density as we go forwards into the future but an

“Big Bang cosmology is a form of religious fundamentalism ...and this is why these peculiar states of mind have flourished so strongly over the past quarter century. It is the nature of fundamentalism that it should contain a powerful streak of irrationality and that it should not relate, in a verifiable, practical way, to the everyday world. ...it would take an eternity of time to distill even one drop of sense...Big bang cosmology refers to an epoch that cannot be reached from any form of astronomy...

Fred Hoyle

Home is Where the Wind Blows 1994.

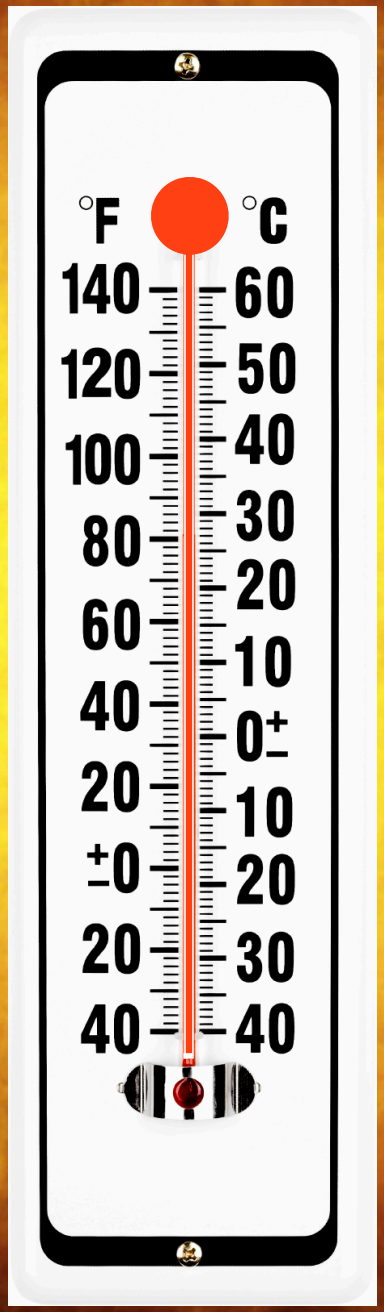
distinct from Lemaitre's idea about The Beginning

Gamow had it right:

the "hot big bang" is how we understand it today

except

nothing “banged.”


°F
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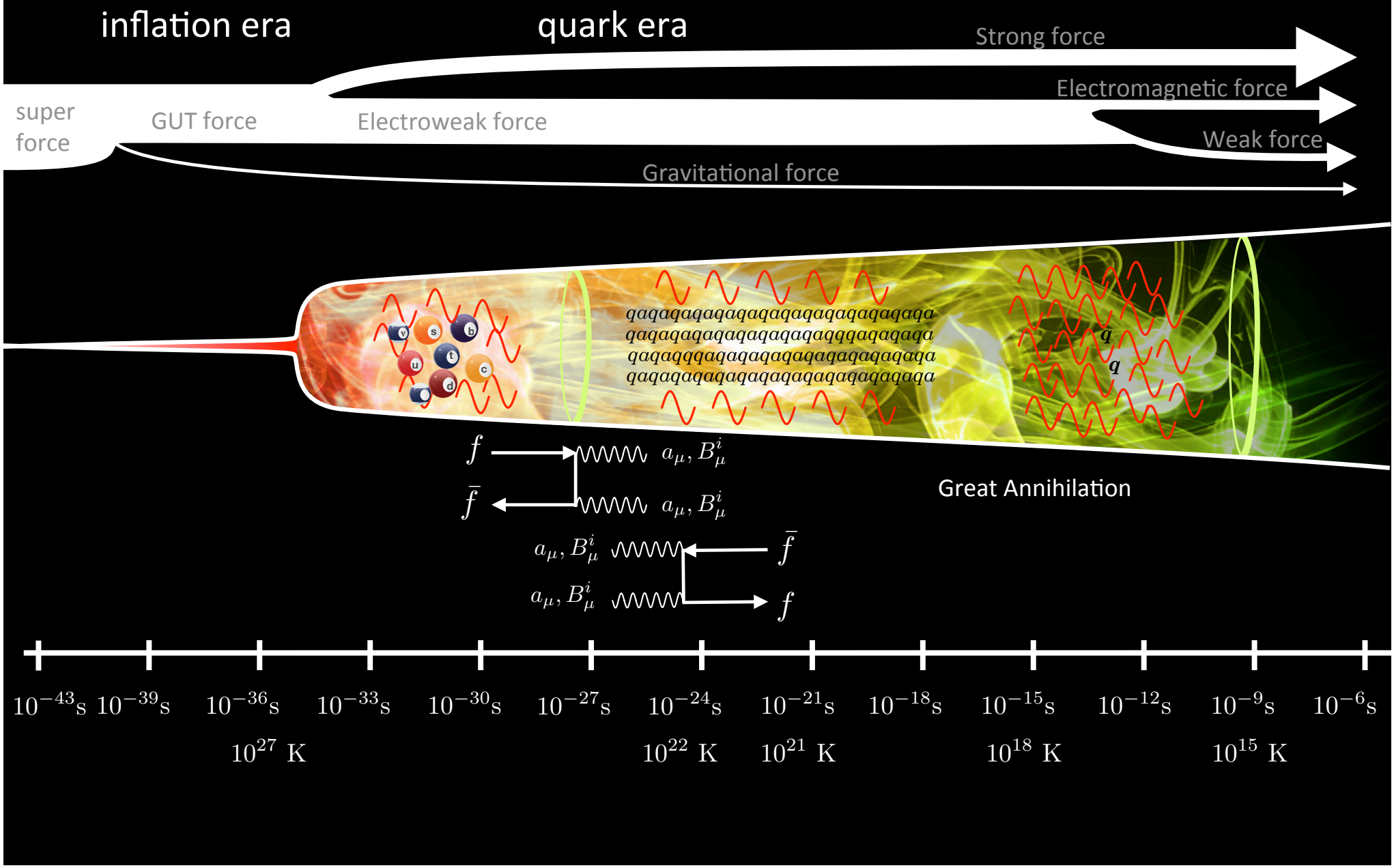
140
120
100
80
60
40
20
±0
20
40
60
50
40
30
20
10
0±
10
20
30
40

Mmmm, Mmmm Good....

the universe is a big place
and getting bigger.

but was originally tiny.

elementary particle epoch

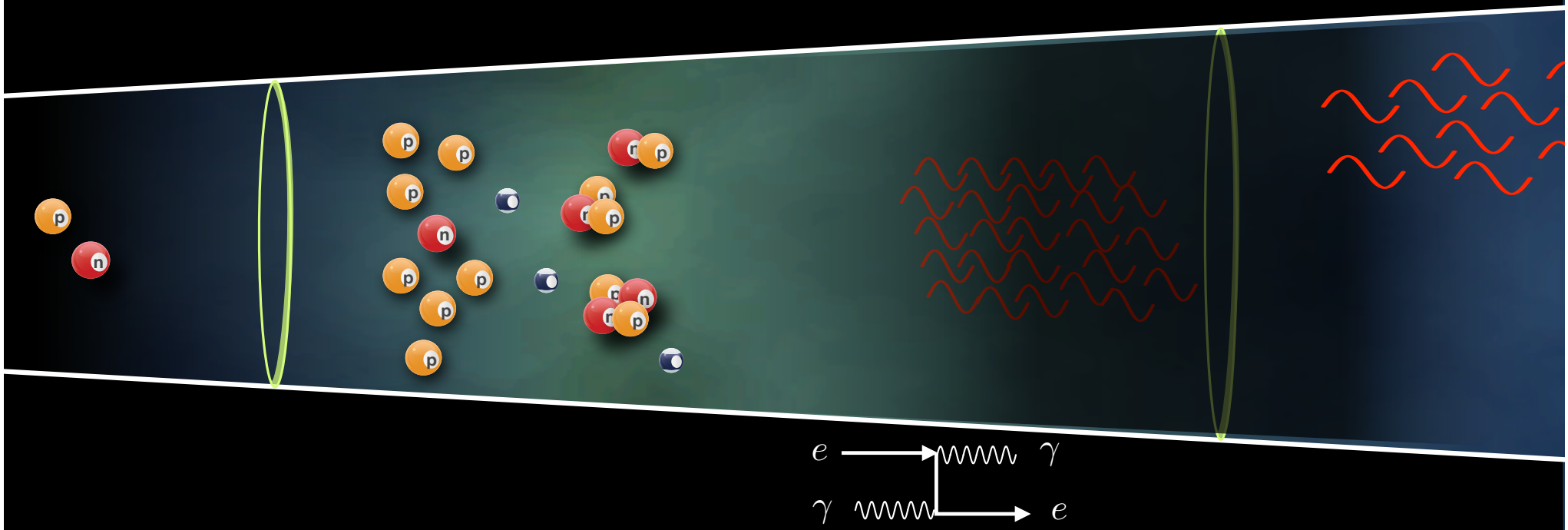


n u c l e o n e p o c h

hadron era

nucleosynthesis era

opaque era



10^{-6}s
10^{13} K

10^{-3}s
10^{12} K

10^{0}s
10^{10} K

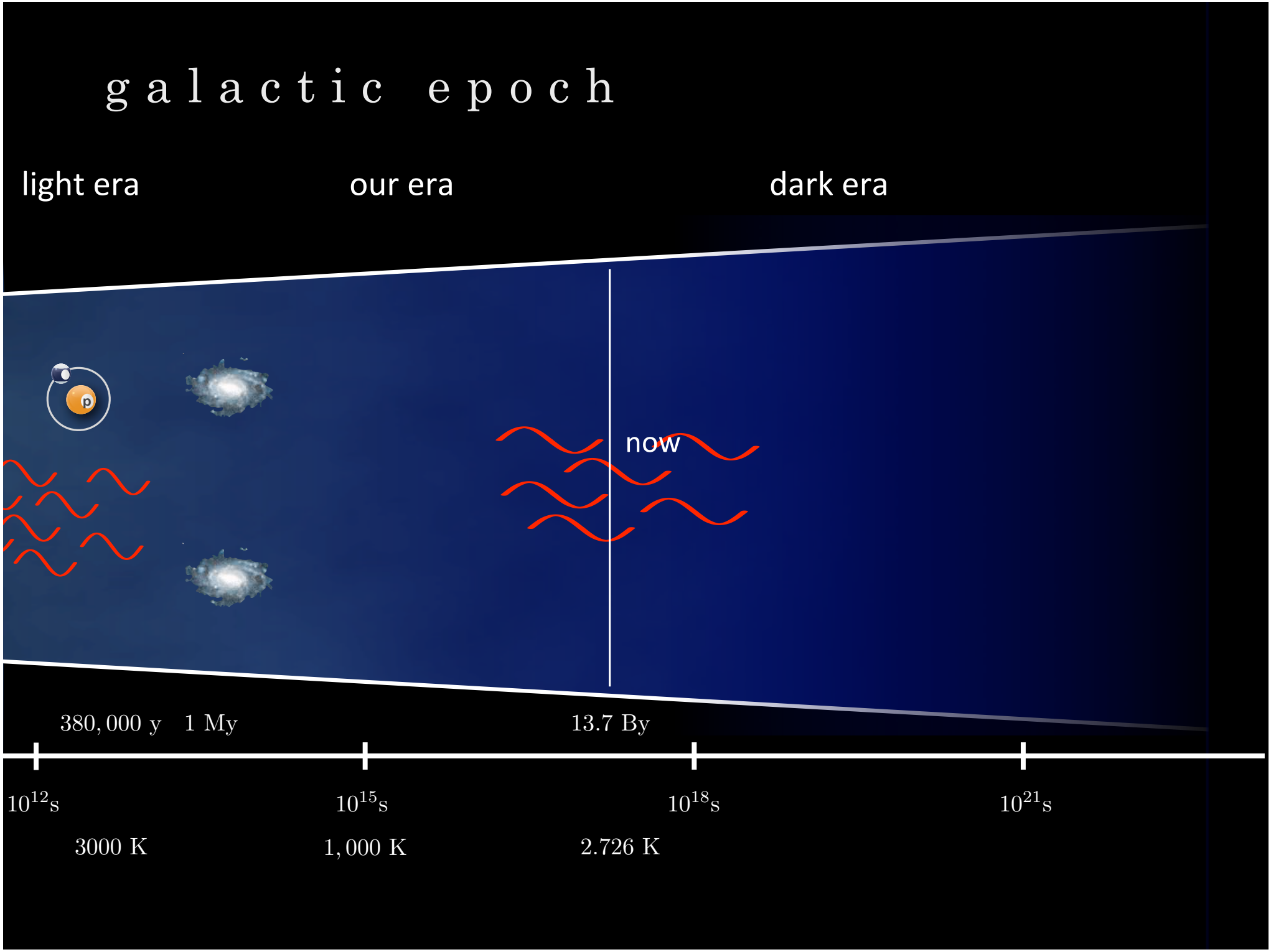
10^{3}s
10^{8} K

10^{6}s
10^{7} K

10^{9}s
10^{6} K

10^{12}s
$10,000$ K

galactic epoch



There are two critical times

that lead to the Big Bang

380,000 years
3 minutes

(all within the first 15 fake-minutes on my calendar)

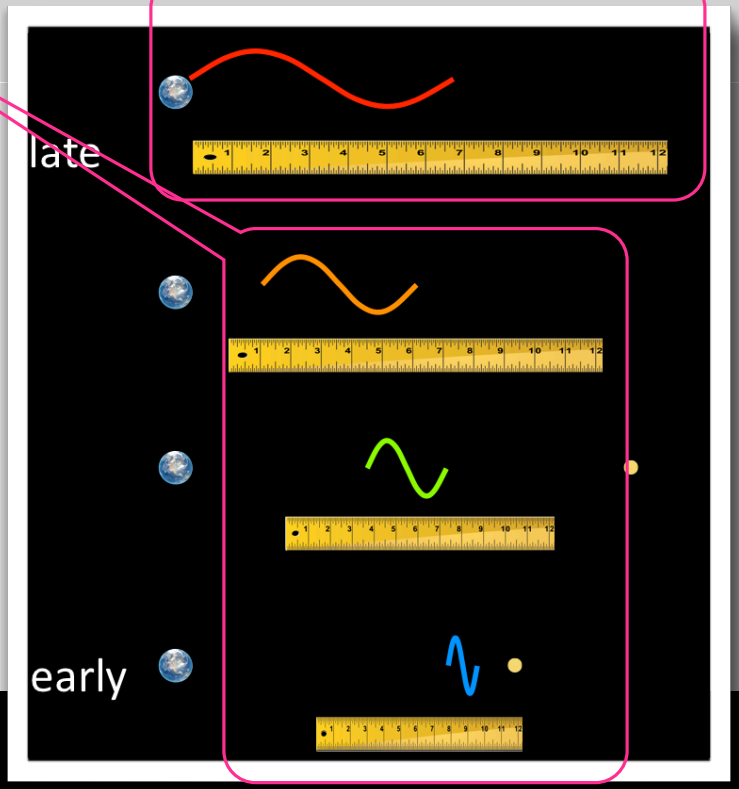
microwave background.

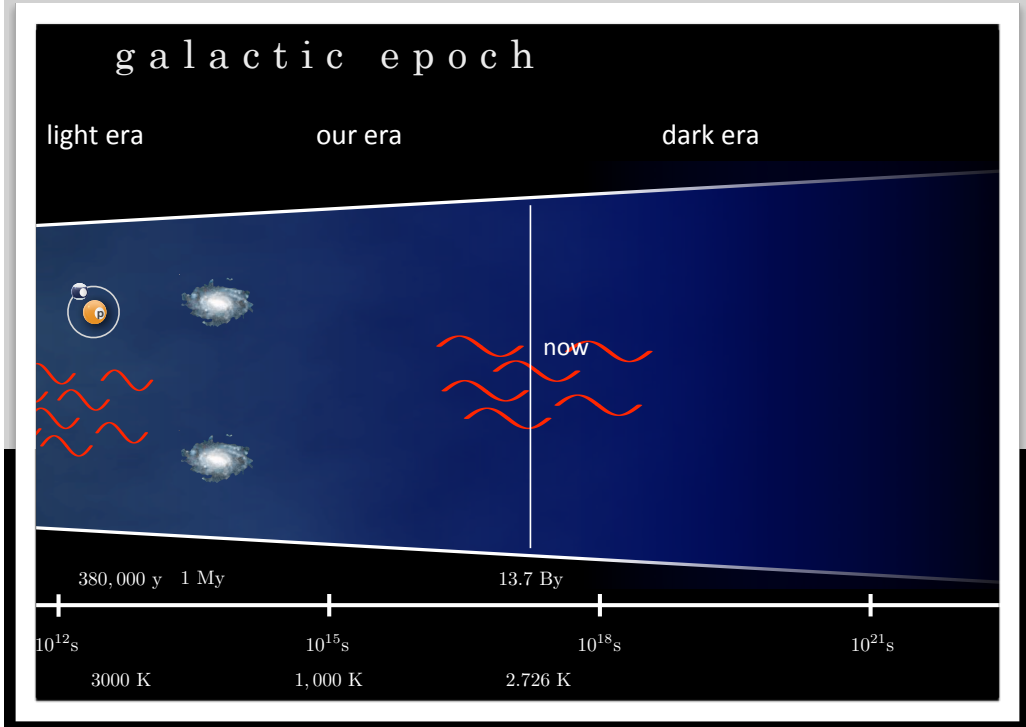
about 380,000 y after BB

at some point, they are too low in energy to do anything...they just hang around.
about 70,000 years after BB

many high energy photons: create new particles, ionize atoms, disintegrate nuclei

remember



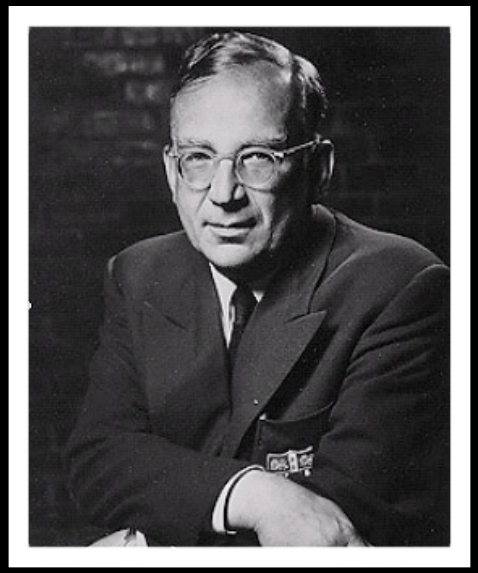


George Gamow

universe born

hot primordial soup

$\alpha\beta\gamma$



1948 with collaborators Alpher and Herman: predicted a left-over electromagnetic radiation: 5^0 K

nobody paid attention

or remembered.

so, all these cold photons

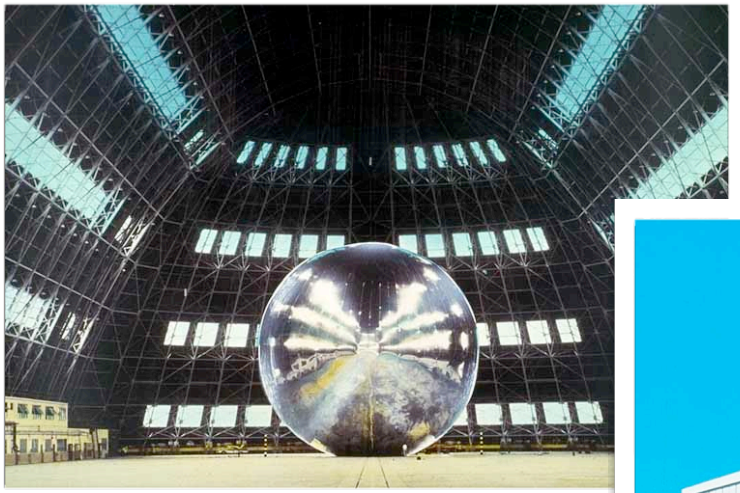
the phone company was the hero

the phone company

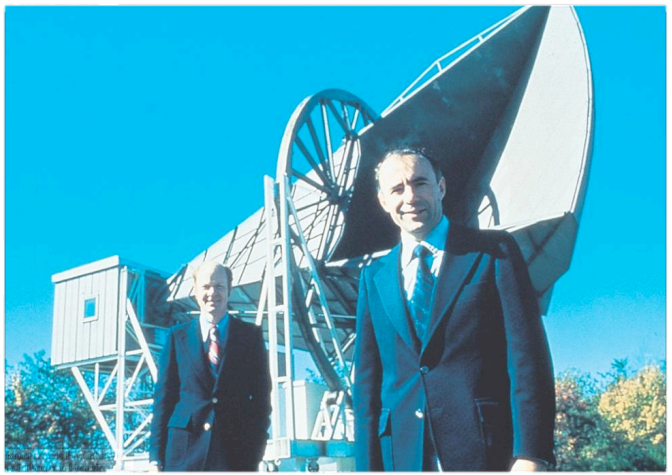
ATT Labs, Crawford Hill, New Jersey

1963

Arno Penzias
Robert Wilson



Echo



Giant ultra-sensitive horn-reflector antenna which received signals bounced off the satellite. It is located at Bell Telephone Laboratories, Holmdel, New Jersey.

BELL TELEPHONE LABORATORIES

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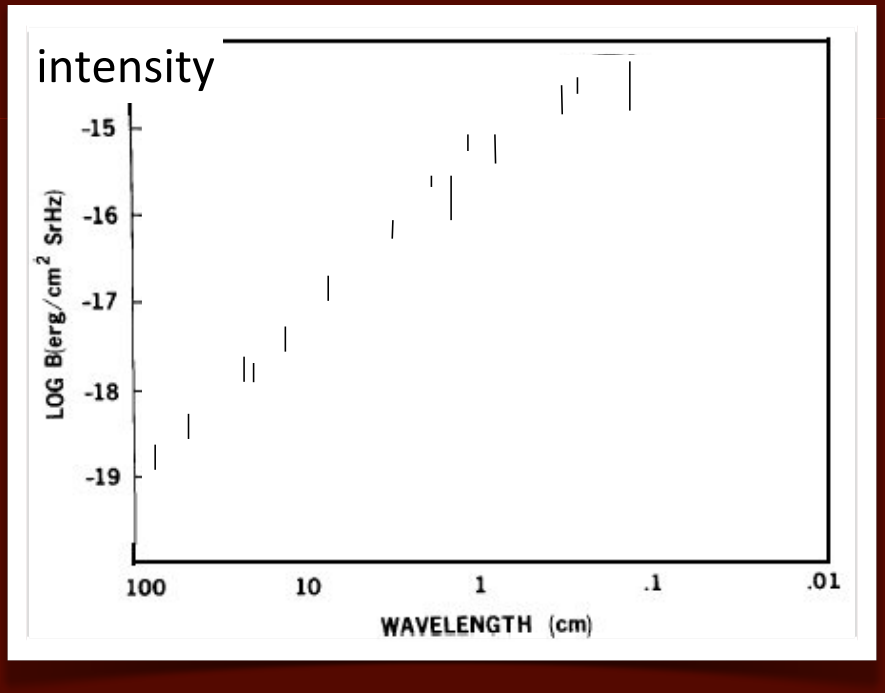
microwave hiss

everywhere...

with a special frequency distribution