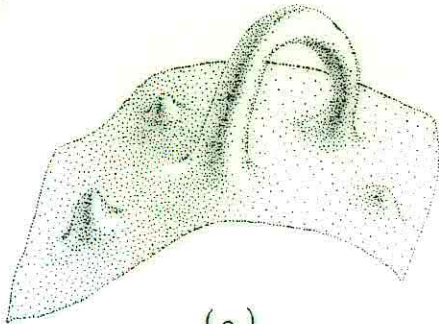


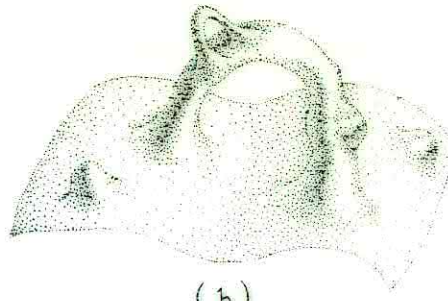
BEYOND BIG BANG.

①

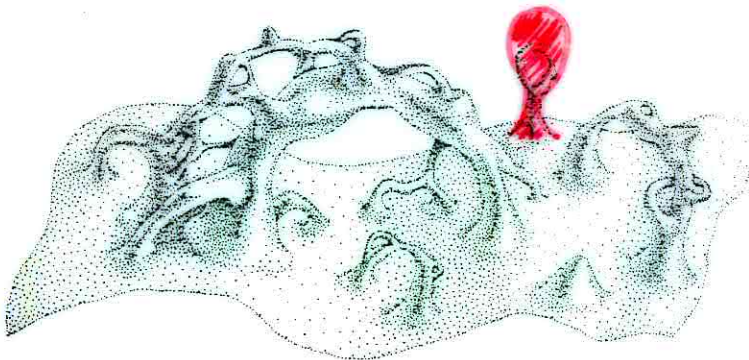
14.3 (Same as Figure 15.7.) Embedding diagrams illustrating quantum foam. The geometry and topology of space are not definite; instead, they are probabilistic. They might have, for example, a 0.1 percent probability for the form shown in (a), a 0.4 percent probability for (b), a 0.02 percent probability for (c), and so on.



(a)

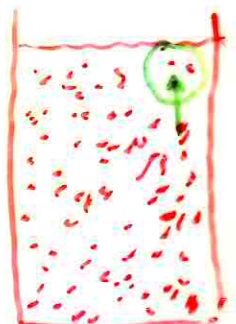
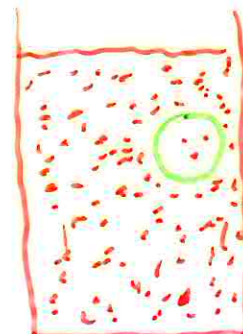
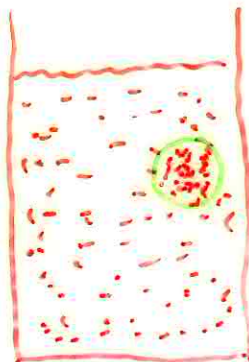
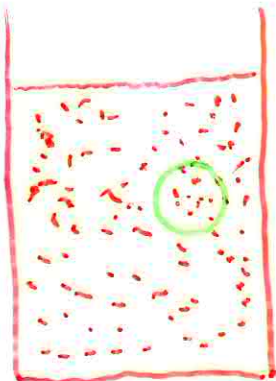


(b)



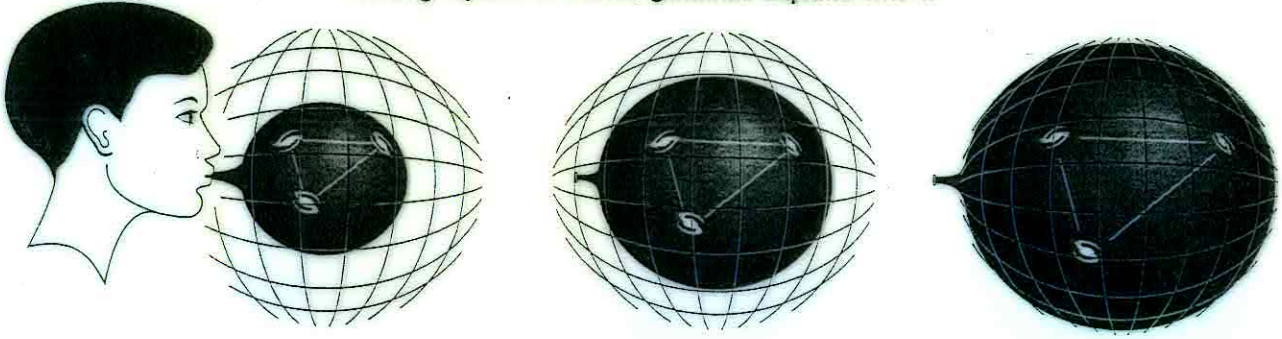
(c)

- ON LARGE SCALES, SPACE-TIME MAY LOOK SMOOTH, ON SMALL SCALES \rightarrow FROTHING!
- ENERGY FLUCTUATION \rightarrow BUBBLES, WORMHOLES

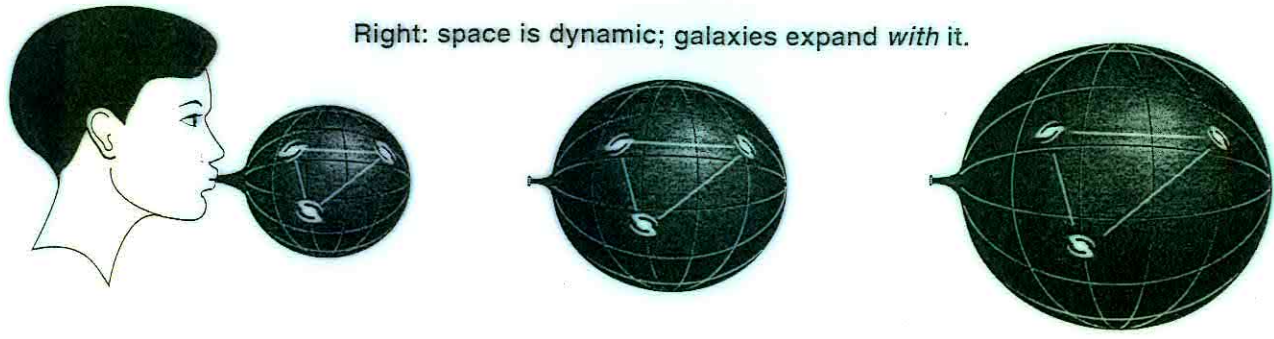


SELTZER WATER ANALOGY

Wrong: space is static; galaxies expand *into* it.



Right: space is dynamic; galaxies expand *with* it.



Many astronomy textbooks illustrate the Big Bang cosmology and the expansion of the universe by inflating a balloon with galaxies painted on it. This is a perfectly appropriate analogy, but only if care is taken to note that the galaxies are fixed at the same spatial coordinates during the expansion. They are not moving in the familiar sense by traveling through intergalactic space. Space itself is expanding and carrying the galaxies along with it.

• HUBBLE EXPANSION

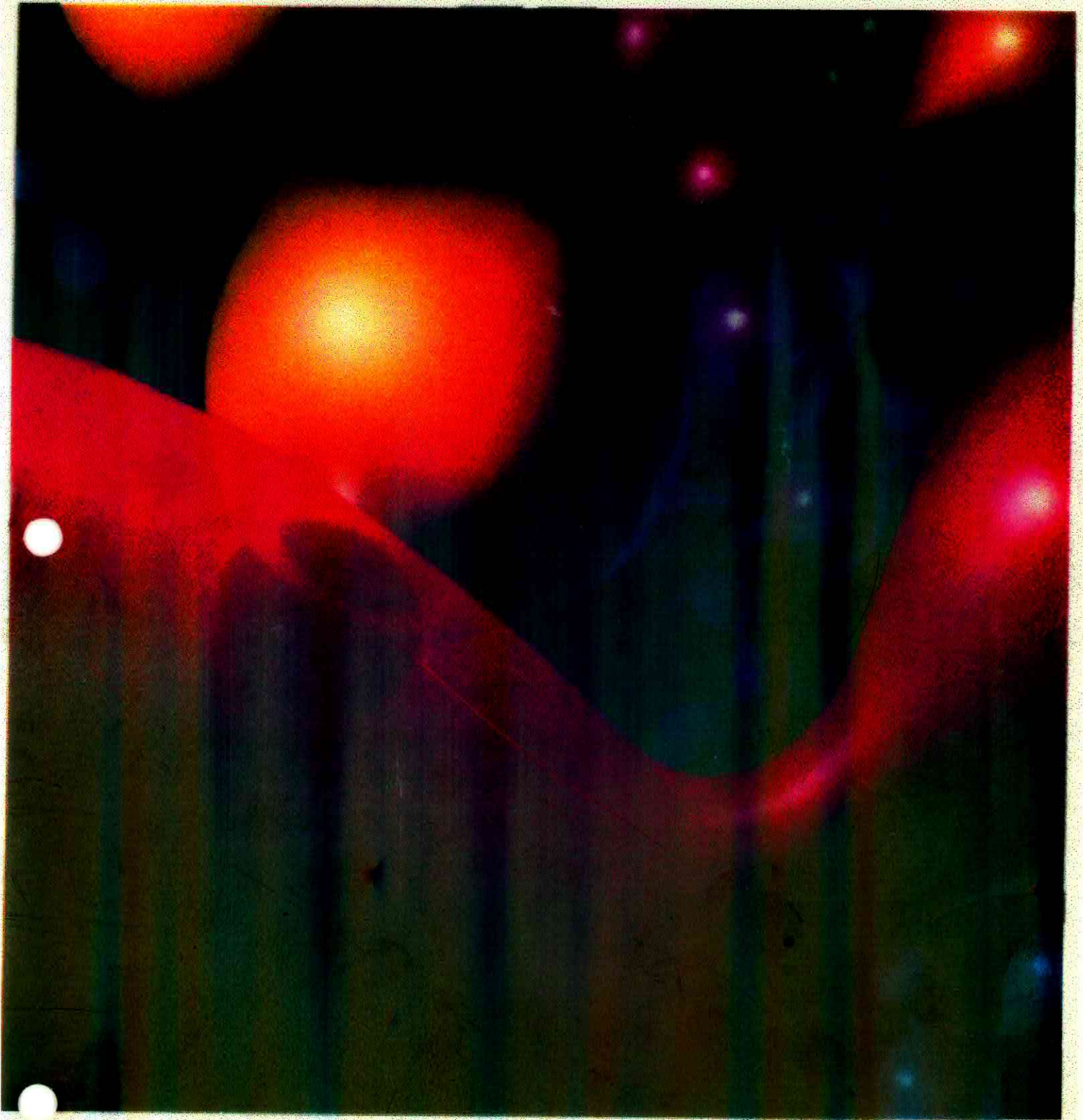
$$V_{HUB} = H \cdot R$$

• EXPANSION = VELOCITY

• IN GENERAL: $V = V_{PECULIAR} + V_{HUB}$

* ONE THEORY TO EXPLAIN CREATION OF OUR UNIVERSE (IE. BIG BANG) ③

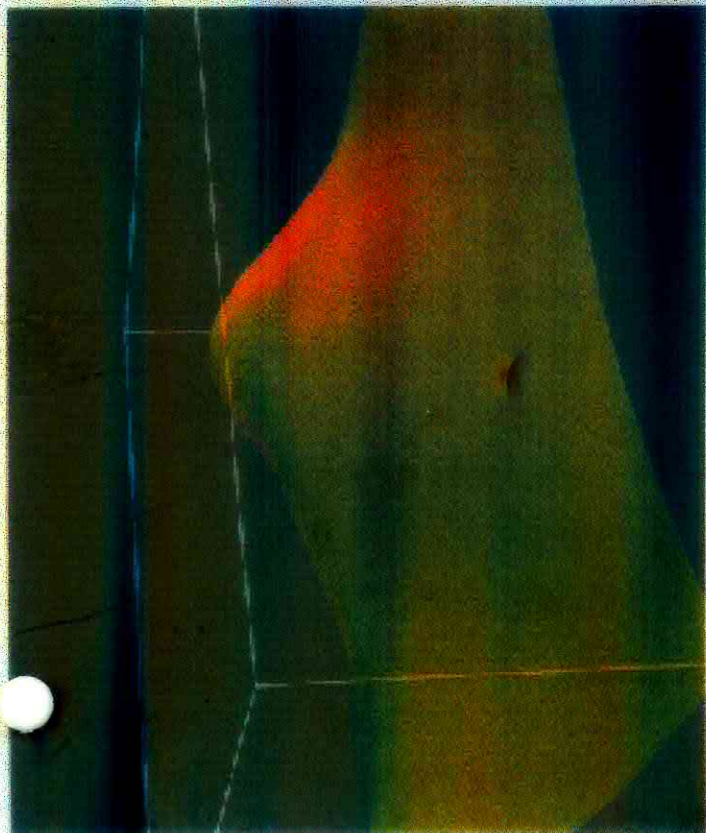
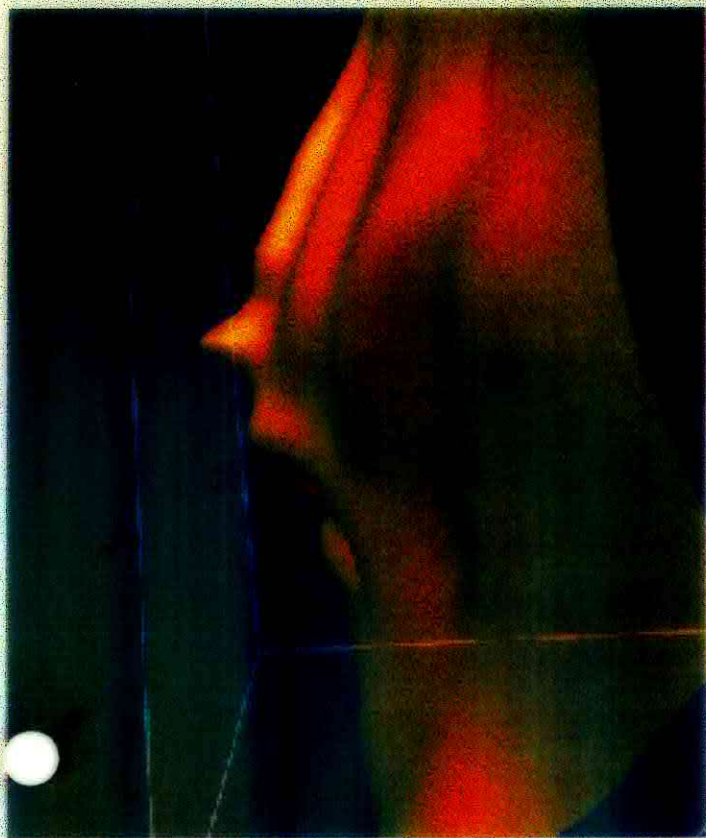
"META-UNIVERSE" EXISTS BEYOND TIME ("ETERNAL") BUT EACH INDIVIDUAL UNIVERSE IS ASSOCIATED WITH TIME, LOCATION IN



PARENT UNIVERSE BUT
TIME+SPACE ~~BEGINS~~ IN NEW UNIVERSE
BEGINS AT CREATION (BIG BANG).

New universes constantly burst
from the old in an inflationary cosmos.

SCI-AMERICAN Nov 1994



- ONE POINT IN PARENT UNIVERSE EXPAND TO FOR ALL OF SPACE-TIME IN NEW UNIVERSE
- EXPANSION IS CAUSED BY "ENERGY FLUCTUATION" IN PARENT UNIVERSE
- IF ENERGY FLUCTUATION IS NOT TOO LARGE
 - LITTLE UNIVERSE FORMS
 - EXPAND A LITTLE
 - CONTRACTS AND POPS OUT OF EXISTENCE
- IF ENERGY FLUCTUATION IS LARGE ENOUGH
 - LITTLE UNIVERSE POPS INTO BEING
 - EXPANDS, EXPANDS, EXPANDS
 - STAYS AROUND LONG ENOUGH FOR
 - MATTER TO FORM
 - GALAXIES, QUASARS, TO FORM
 - STARS INSIDE GALAXIES TO FORM
 - PLANETS AROUND STARS TO FORM
 - LIFE TO FORM ON PLANETS
 - LIFE TO EVOLVE INTO CIVILIZATION THAT INVENTS TELESCOPES AND LOOKS OUT INTO SPACE AND ASKS HOW WE WERE CREATED.
 - UNIVERSE THEN SHRINKS → POPS OUT OR CONTINUES TO EXPAND ?

BROTHER BELIEVER, WHEN THE LORD FIRST BROUGHT CREATION INTO BEING, THERE WAS DARKNESS. THERE WAS NOTHING ELSE; THERE WAS JUST ONE FORMLESS BEING

BROTHER BELIEVER, THEN THE LORD, OUT OF LOVE STIRRING IN HIS HEART, CONCEIVED THE CREATION OF THE UNIVERSE. THEN FROM HIS MOUTH, HE TOOK A BALL OF FOAM (SPIT) AND BY BLOWING, HE FASHIONED THE FORM OF AN EGG.

BROTHER BELIEVER, THE LORD CREATED THE EGG AND HELD IT IN HIS HANDS FOR A LONG TIME. THERE THE LORD SAT IN SELF-CONTEMPLATION; THERE HE NURTURED THE EGG WITH LOVE.

BROTHER BELIEVER, THE LORD ROLLED THE EGG ON HIS HAND AND MADE IT EXPAND GREATLY. THEN IT OCCURRED TO THE MIND OF THE LORD THAT HE WOULD MAKE FROM THIS EGG A BOUNDLESS CREATION.

TRANSLATION FROM MUMAN CIT-YEA
"POEM" BY ISMAILI MUSLIM MYSTIC
SADR-AL-DIN.

* DETAILS NOT IMPORTANT; FOCUS ON IMAGERY

- FOAM (COLLECTION OF BUBBLES)
- FROM WHICH ONE BUBBLE CREATED (BLOWN)
- BUBBLE WAS EXPANDED GREATLY TO CREATE "OUR" UNIVERSE.

THEN, AGAIN SCIENCE ALSO AFFECTS HOW POETRY IS INTERPRETED :

AND THE HEAVEN, WE DID
RAISE IT UP WITH OUR MIGHT,
AND VERILY, WE ARE THE
EXPANDERS OF THE EXPANSE (OF SPACE)

MIR AHMED ALI

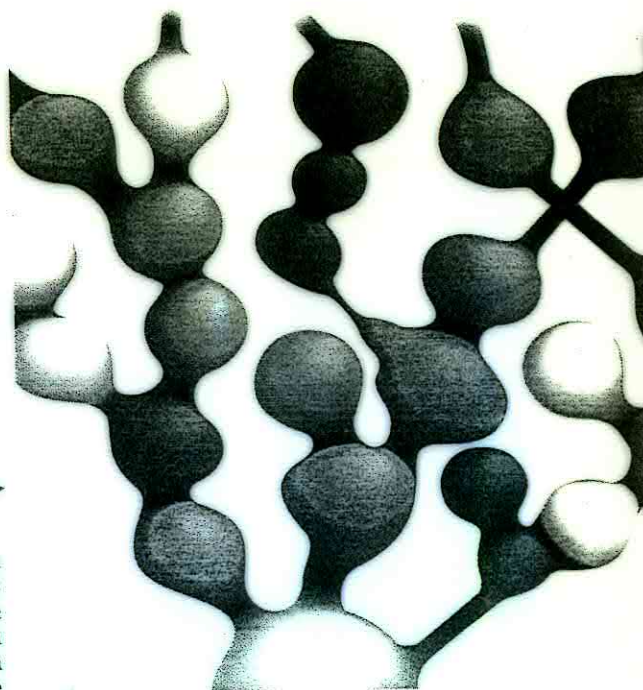
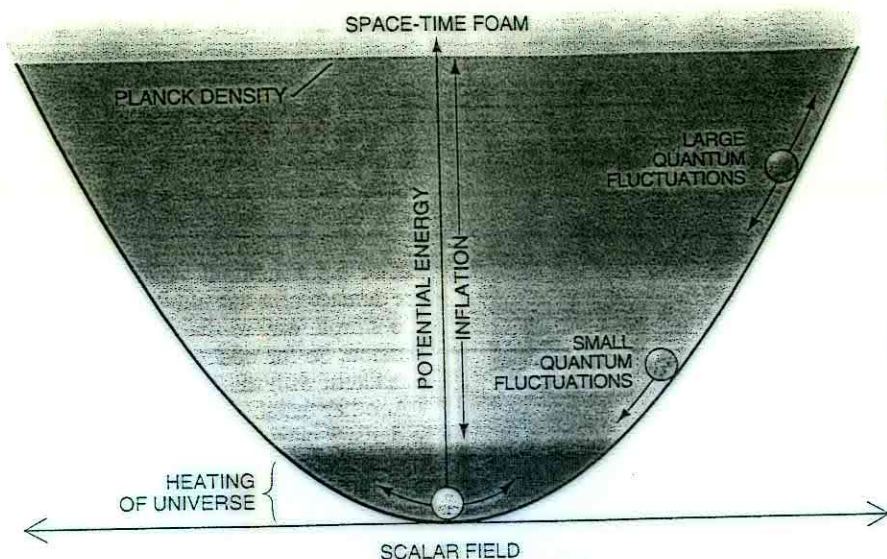
WITH POWER AND SKILL
DID WE CONSTRUCT THE
FIRMAMENT : FOR IT IS WE
WHO CREATE THE VASTNESS OF
SPACE

YUSUF ALI

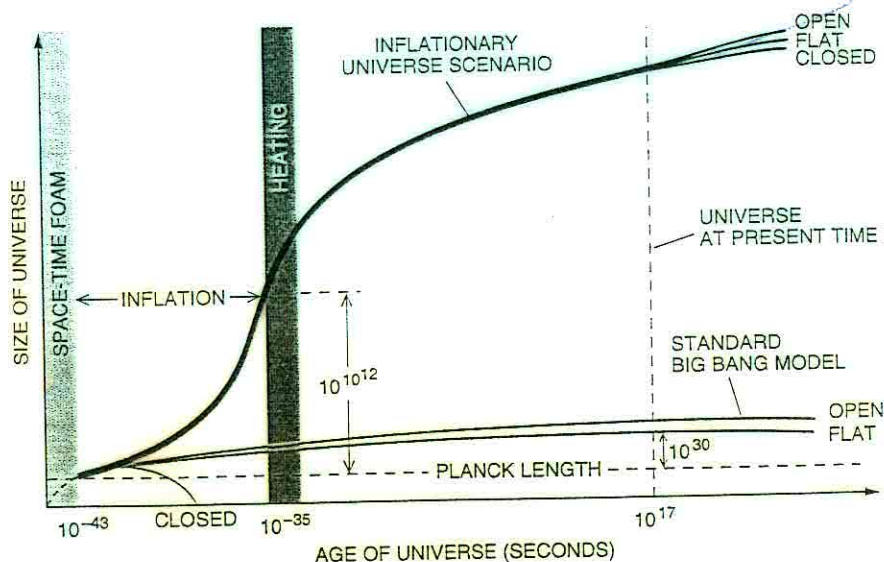
QURAN: LI: 47

* ANOTHER ONE (QURAN: 21, 104)

- UNIVERSE IS CREATED, THEN DESTROYED.
- CREATED, DESTROYED THEN ANOTHER UNIVERSE CREATED.



SCALAR FIELD in an inflationary universe can be modeled as a ball rolling down the side of a bowl. The rim corresponds to the Planck density of the universe, above which lies a space-time "foam," a region of strong quantum fluctuations. Below the rim (green), the fluctuations are weaker but may still ensure the self-reproduction of the universe. If the ball stays in the bowl, it moves into a less energetic region (orange), where it slides down very slowly. Inflation ends once the ball nears the energy minimum (purple), where it wobbles around and heats the universe.



EVOLUTION OF THE UNIVERSE differs in the chaotic inflation scenario and the standard big bang theory. Inflation increases the size of the universe by $10^{10^{12}}$, so that even parts as small as 10^{-33} centimeter (the Planck length) exceed the radius of the observable universe, or 10^{28} centimeters. Inflation also predicts space to be mostly flat, in which parallel lines remain "parallel." (Parallel lines in a closed universe intersect; in an open one, they ultimately diverge.) In contrast, the original hot big bang expansion would have increased a Planck-size universe to only 0.001 centimeter and would lead to different predictions about the geometry of space.

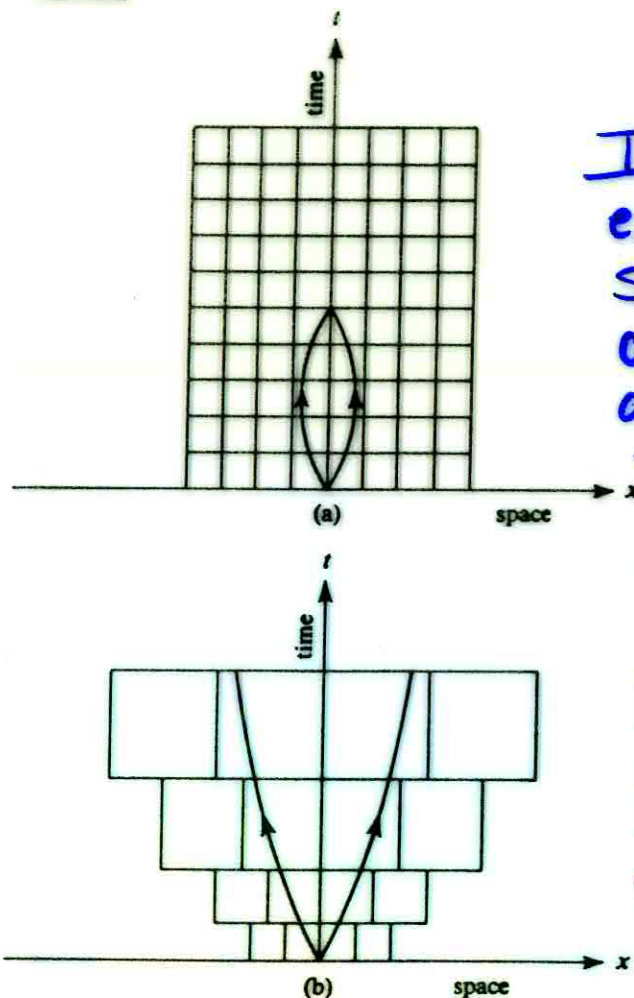


Figure 16.18. Pair creation from the vacuum. (a) In flat spacetime, only virtual pairs can result because there is not enough energy in the vacuum (by definition) to create the appearance of a real particle-antiparticle pair. (b) In expanding spacetime (which shouldn't be plotted on a sheet of flat paper, but we have to make do here), real particle-antiparticle pairs can be ripped apart by the violent expansion of spacetime itself.

In non-expanding or slowly expanding space, expansion of spacetime does not significantly affect separation between ~~the~~ a pair of "virtual" particles. They can come back together and annihilate each other well before they can be detected.

In rapidly expanding spacetime, particles are separated by the expansion of spacetime. If they cannot get back together and annihilate - if they survive for long enough - they will be detected \Rightarrow particle/anti-particle creation.

If matter comes in contact with antimatter, the two annihilate - converted into energy.

On particle scale, annihilation occurs only if particle comes in contact with its anti-matter partner:

eg. electron - positron
proton - antiproton



Figure 16.19. The annihilation of two good friends, one of which happened to be made of matter, the other of antimatter.

DURING "CREATION OF MATTER" PHASE:

- ① VIRTUAL PAIRS (MATTER/ANTI-MATTER) BECOME REAL AS RAPID EXPANSION OF SPACETIME PULLS PAIRS APART [RECALL 10^9 ASSYMETRY]
- ② REAL MATTER/ANTI-MATTER ANNIHILATE CREATING VERY HIGH ENERGY PHOTONS
- ③ VERY HIGH ENERGY PHOTONS CAN SPONTANEOUSLY DECAY INTO REAL MATTER/ANTIMATTER PAIRS

IS EXPANSION SLOWS DOWN, ① DECREASES & STOPS.
NO MORE MATTER CREATION

EXPANSION CAUSES PHOTON ENERGY TO DECREASE
(WAVE STRETCHING OR REDSHIFTING)

② & ③ CONTINUES UNTIL PHOTONS AREN'T ENERGETIC ENOUGH TO CHANGE BACK INTO PARTICLES.

② CONTINUES UNTIL ALL MATTER/ANTI-MATTERS HAVE ANNIHILATED \Rightarrow ENERGY

LEFT-OVER (UNPAIRED) MATTER PARTICLE & RADIATIONS!

- At end of "rapid expansion", universe was full of particles and anti-particles and very high energy radiation

$$t = 10^{-4} \text{ s} = 0.0001 \text{ s} \quad T = 10 \text{ trillion Kelvin}$$

- ~~At~~ PARTICLE - ANTIPARTICLE NOT QUITE IN EQUAL NUMBERS
BILLION ANTIPARTICLES, BILLION+1 PARTICLE.
- Universe = space expands



TEMPERATURE DECLINES

$$E = \frac{hc}{\lambda}$$

[PHOTON ENERGY DECLINES]

$$\lambda(t) = \lambda_0 [\text{today}] \cdot R(t)$$

→ REDSHIFT

- AT SOME POINT, ENERGY DROPS & PHOTONS DO NOT FORM PARTICLES.
- PARTICLES - ANTIPARTICLES ANNIHILATED ($t=1\text{s}$)
"LEAVING EXTRA UNPAIRED MATTER PARTICLE"

RADIATION NOT ENERGETIC ENOUGH TO FORM PARTICLES.
MATTER/ANTI-MATTER ANNIHILATION LEAVES ONLY "EXCES" MATTER THAT CANNOT CONVERT TO ENERGY.

100,000 yrs after BIG BANG "THERE WAS LIGHT!"

TODAY: MICROWAVES $T=3\text{K}$

MATTER/RADIATION → PROTON, ELECTRONS, NEUTRONS + PHOTONS

• BY 100,000 yrs (10^5 yrs) → H + He + PHOTONS

↓
COMES DOWN TO US.

MATTER PARTICLES :

QUARKS (6 "FLAVOURS")
up, down, strange, charm, top, bottom

LEPTONS (6 KINDS)

↳ electron + e-neutrino
muon + μ -neutrino
tauon + τ -neutrino

Lepton participate in "weak" & electromagnetic
[if charged] interactions

quarks participate in strong & ~~weak~~ ^{electromagnetic} interactions

PROTONS & NEUTRONS ARE MADE UP OF 3 QUARKS.

ONLY MATTER CONTENT OF UNIVERSE IS SET :
SEA OF ENERGY, QUARKS & LEPTONS

UNIVERSE EXPANDS, RADIATION COOLS, PARTICLES COOL

QUARKS COME TOGETHER → PROTONS, NEUTRONS, ...

$p^+ \rightarrow n^0 + \nu^0 + e^+$
(positron)
PROTON IS HYDROGEN NUCLEUS  $[t_H \sim 1s]$

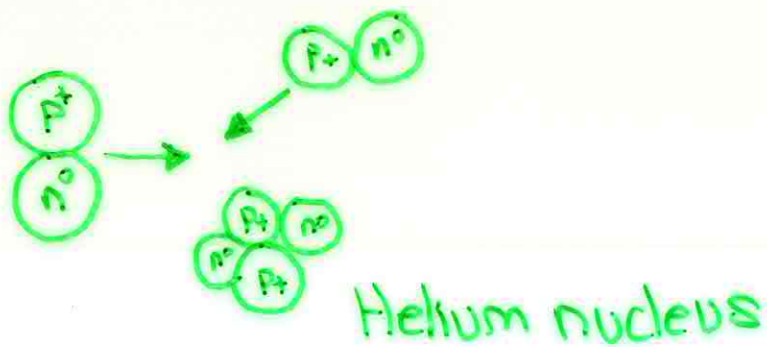
NEUTRON-NEUTRON PAIRS/TRIPLETS CAN ALSO FORM (ENERGY DECREASES FURTHER)

 DEUTERIUM



isotopes of Hydrogen
TRITIUM

EVEN MORE DIFFICULT IS



EVEN MORE DIFFICULT IS FORMATION OF
LITHIUM & BERYLLIUM [TRACE AMOUNTS]

AS SPACE EXPANDS, PARTICLES ARE SEPARATED.
COLLISIONS BECOME MORE INFREQUENT & CONTENT
OF UNIVERSE FREEZES OUT.

BARYONS \rightarrow 75% HYDROGEN
24% Helium
1% OTHER

by the time $t \sim 10^5$ yrs, cool enough for nuclei to capture
electrons \Rightarrow atoms.

\rightarrow DARK MATTER

A Short History of the Universe

3 First quasars form



5 YOU ARE HERE



2 Cosmic microwave background radiation is released

3°K

4 Galaxies ~~spark~~ form into being as matter collects in density wrinkles; universe as we know it appears



Present time



1 Dark matter produces density wrinkles, shells, and voids

Big BANG!

Gas cools

Universe expands

Time

Stable particles are first produced
Dark matter forms

3 mins.

300,000 yrs.

Helium and light elements are synthesized

Radiation decouples from matter

1-2 billion yrs.

15 billion yrs.

