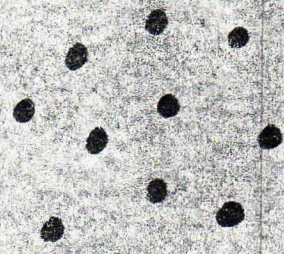


WAYS TO BUILD A UNIVERSE WITH GRAVITY AS ONLY LONG-RANGE FORCE

1. STATIC

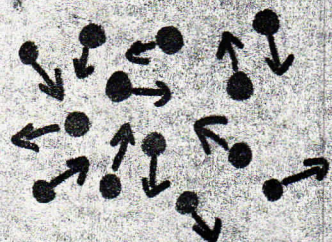


NOW

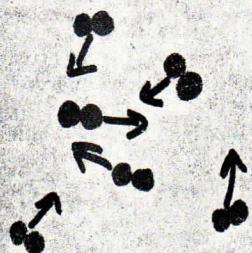


LATER

2. CHAOTIC



NOW

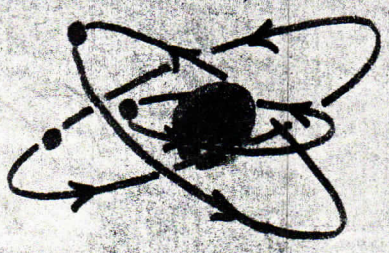


LATER



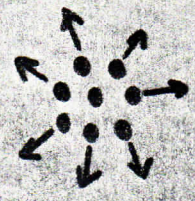
MUCH LATER

3. SPINNING

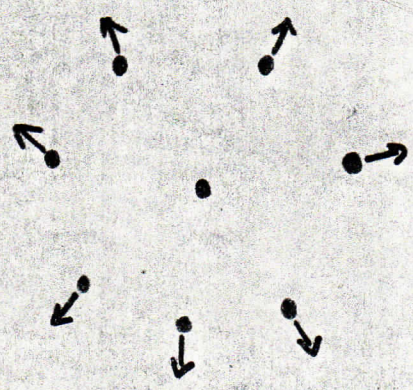


STABLE !

4. EXPANDING



NOW



LATER

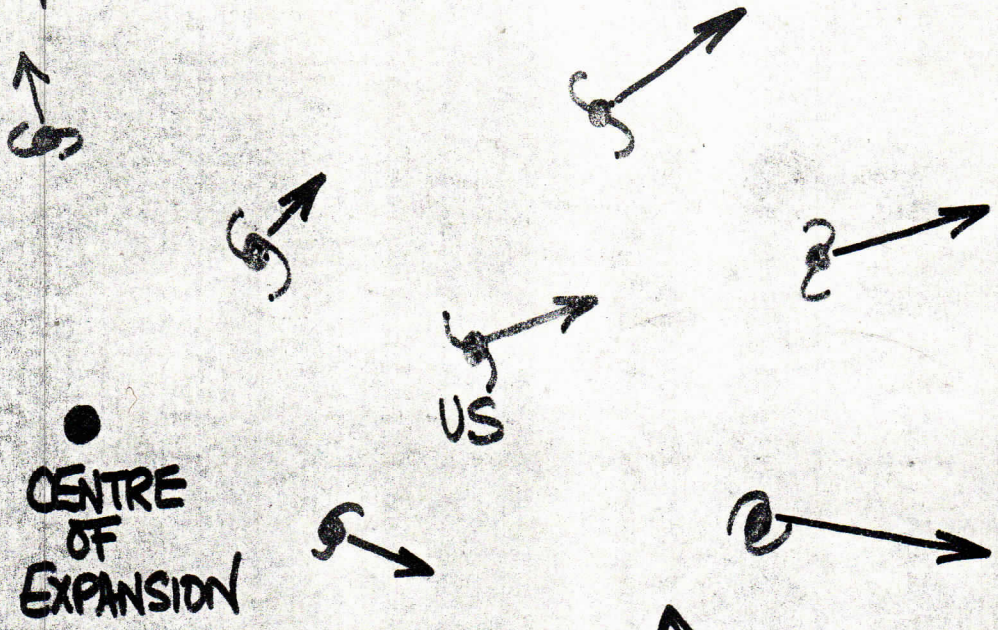
MUCH LATER ?

Growth of Extragalactic Astronomy

- 1781 Messier catalogues 103 "nebulae"
- 1845 Lord Rosse discovers spiral structure of some nebulae.
- 1899 Scheiner obtains first spectrum of Great Nebula in Andromeda. (Messier #31)
- 1923 Hubble identifies Cepheid variables in the Andromeda nebula \rightarrow distance.
- 1929 Hubble publishes "a roughly linear relation between velocities and distances among nebulae which appears to dominate the distribution of velocities."

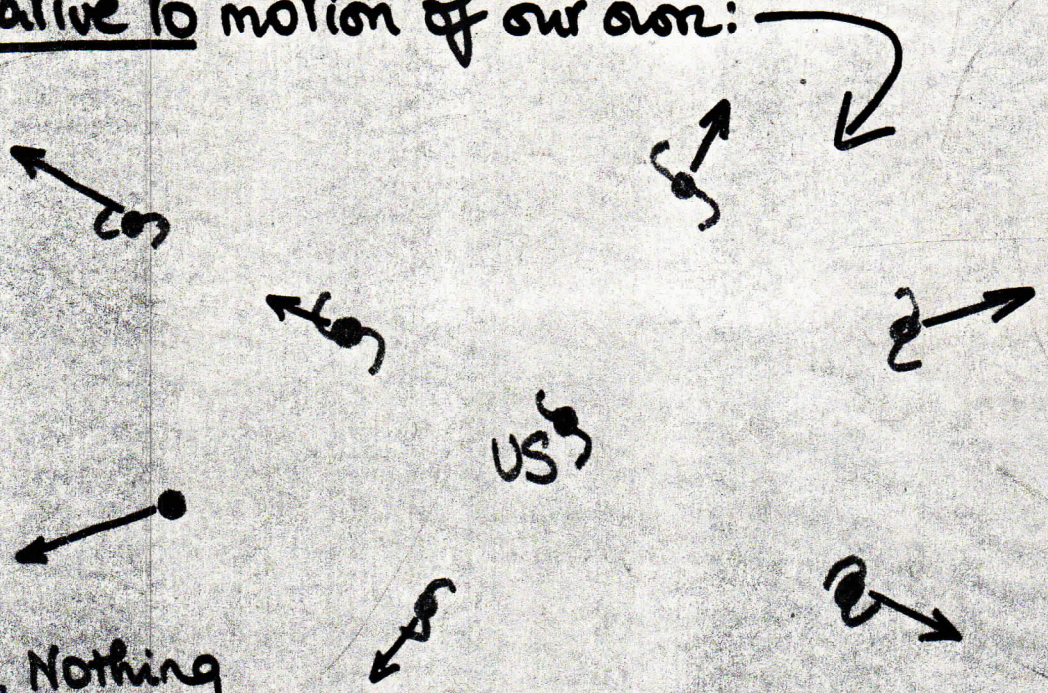
HUBBLE CONSTANT H	Velocity = H x Distance
1930	558 km/sec/Mpc (Hubble + Humason)
1950	180 km/sec/Mpc (Baade)
1970	95 km/sec/Mpc (van der Bergh)
1975	45 km/sec/Mpc (Abell)

Velocity-distance relation for galaxies



1. The "ACTUAL" Expansion
 Velocity increases with distance from "The Centre"
 — BUT —

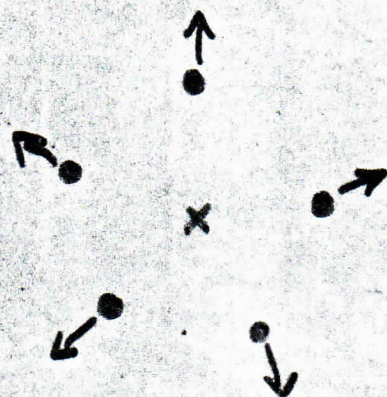
2. What we observe — the motion of other galaxies relative to motion of our own:



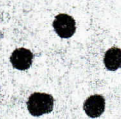
N.B. Nothing "odd" about apparent motion of the "actual centre"

NAIVE COSMOLOGY (1975 style)

We see everything in Universe moving as if receding from one point with velocity proportional to distance



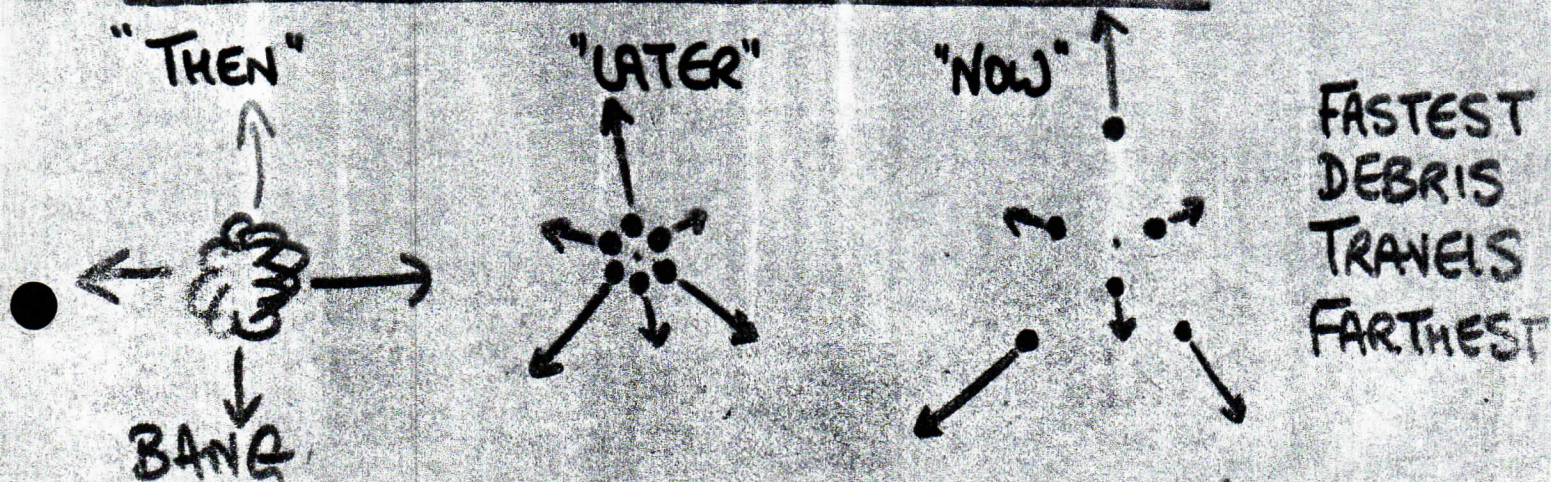
Galaxies we see receding now must have been closer in the past



and still closer before that



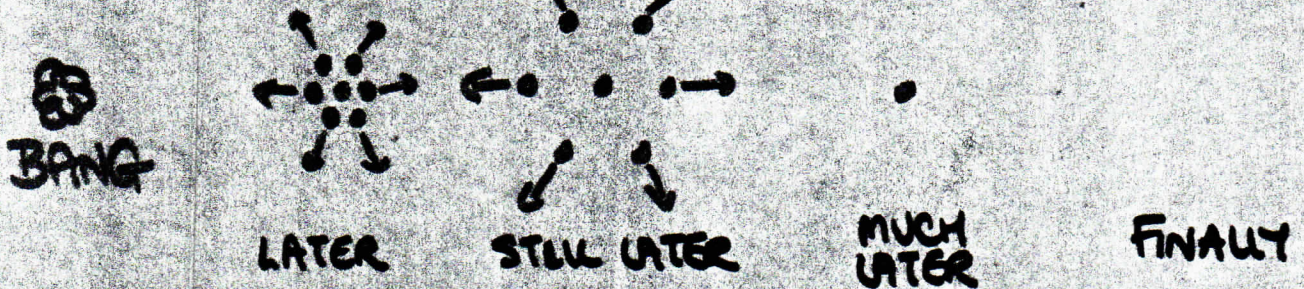
As velocities now are proportional to distances now, then there was a time ~ 20 billion yrs ago when ALL PRESENTLY VISIBLE MATTER WAS IN SAME PLACE.



COSMOLOGIES BEGINNING WITH "BIG BANG"

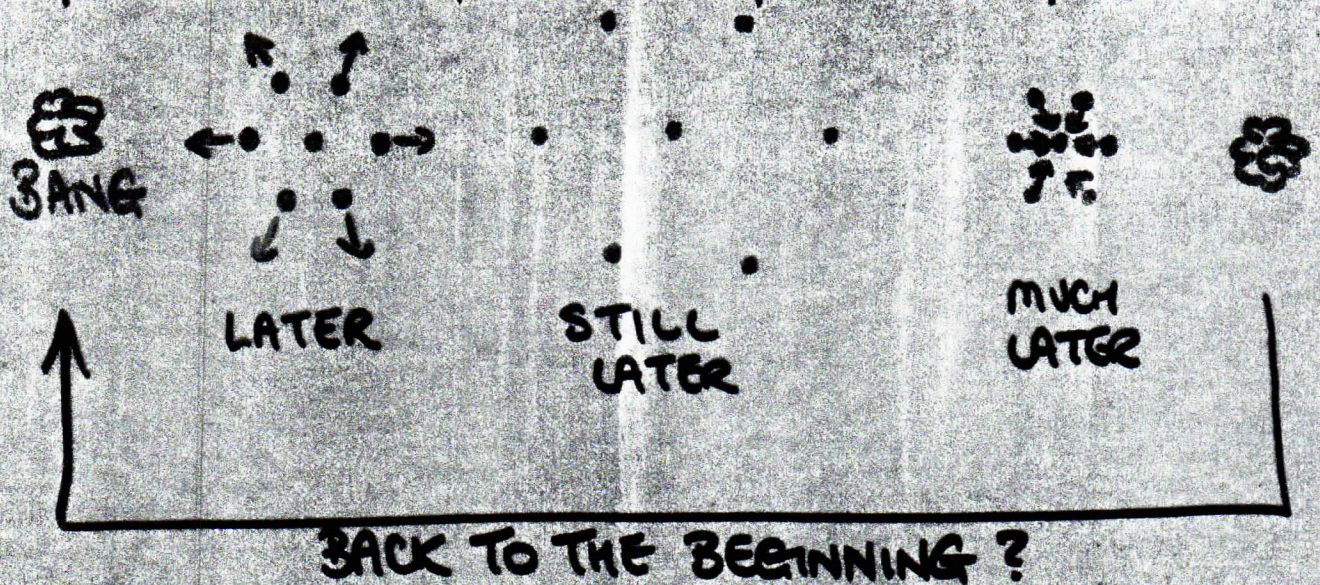
1. One Big Bang

Gravitational attraction of matter does not stop the expansion — expands for ever.



2. Oscillating

Gravitational attraction of matter is enough to stop expansion → collapse and reformation of dense state



TESTING "BIG BANG" THEORY

I. Ages of Things in Universe

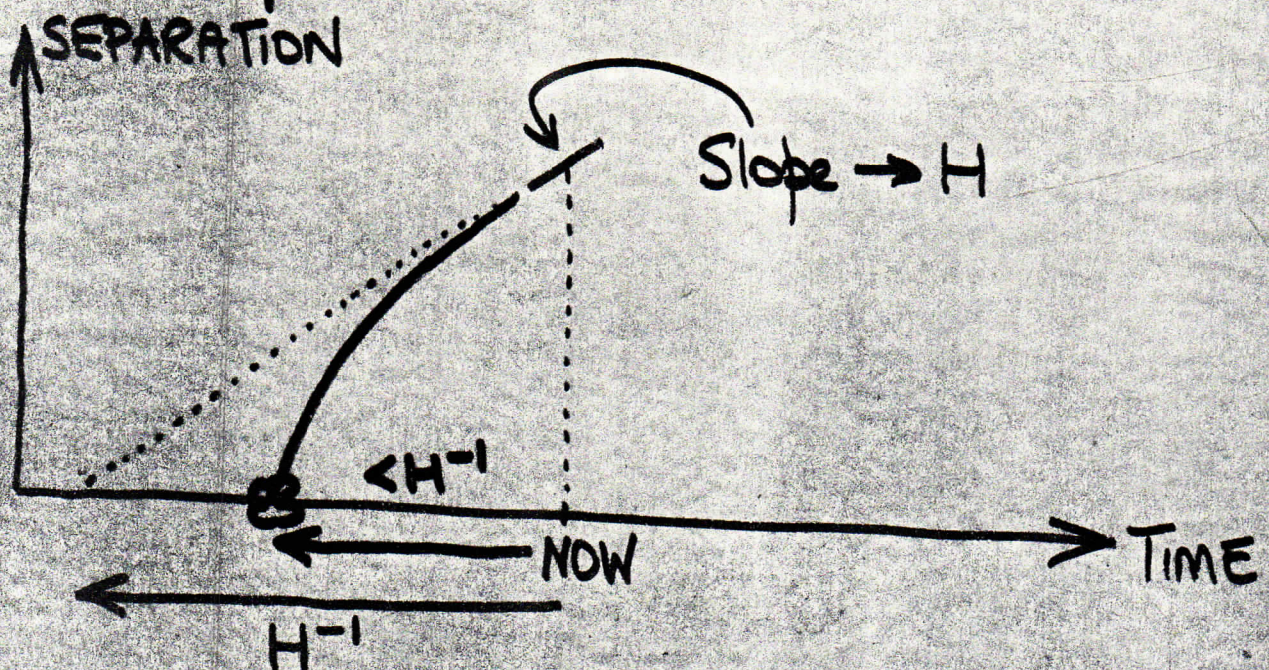
Age of Earth (from crustal rock radioactivities) 4.6 billion yrs
(\rightarrow TROUBLE when $H^{-1} = 2$ billion years!)
This \rightarrow Steady-State Theory (1945-50)

Ages of oldest stars (theory of stellar energy production) in globular clusters 11 billion yrs.

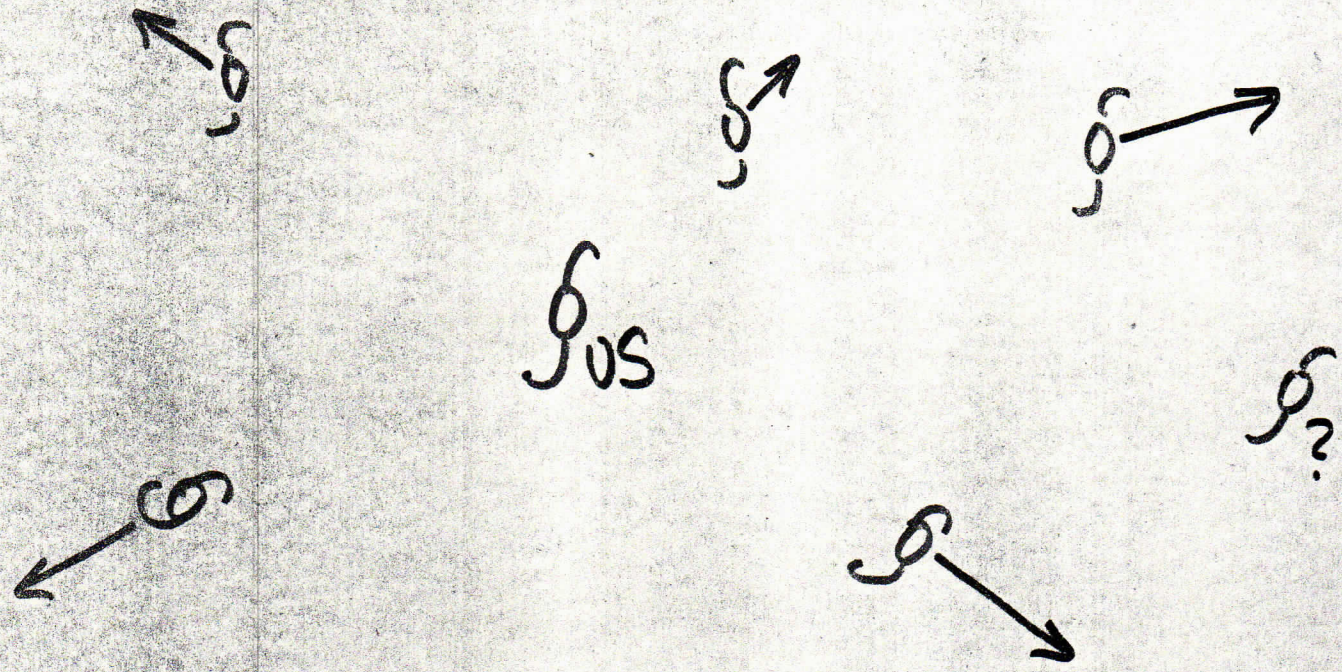
Ages of heavy chemical elements (theory of stellar element production) 10-15 billion yrs.

H^{-1} (1973 value) = 19 billion years

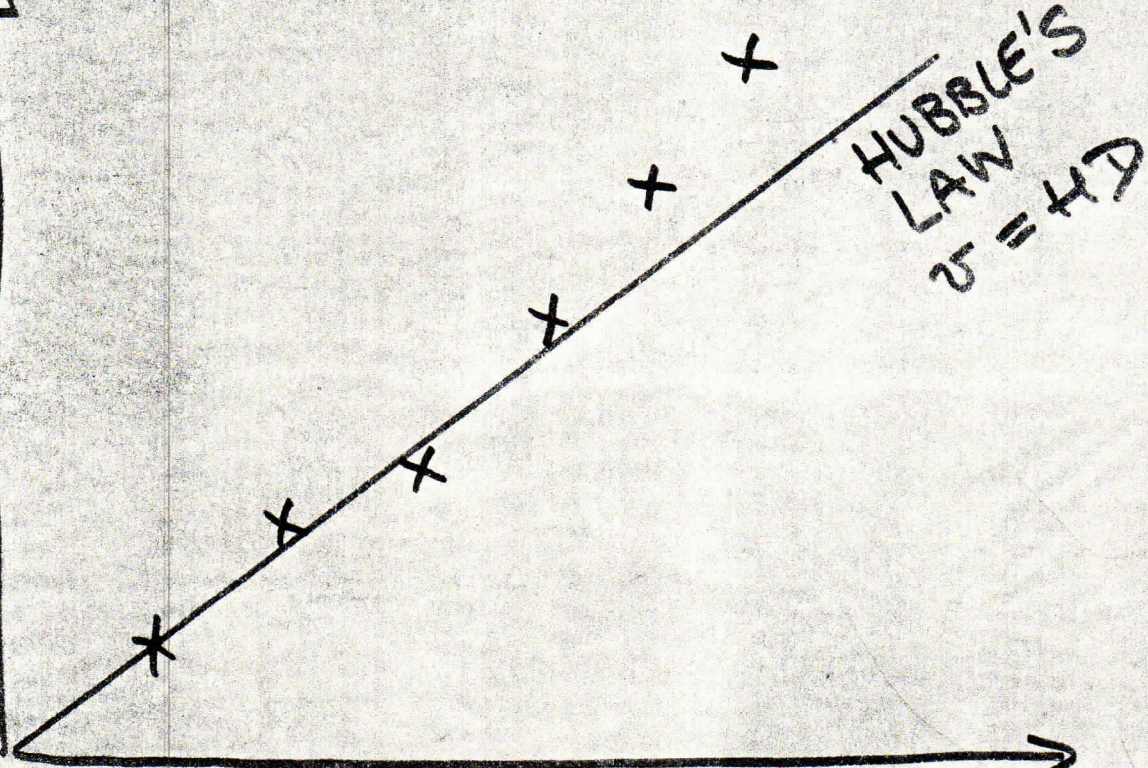
BUT - is gravity of galaxies slowing down the expansion?



Deflecting Slowdown (neglecting relativity complications)



VELOCITY



nearby, "now"
POINTS FOLLOW
HUBBLE LAW

distant
"then"
FASTER

DISTANCE

Was There Really A "Big Bang"?

FINITE VELOCITY OF LIGHT MEANS WE SEE DISTANT UNIVERSE AS IT WAS, NOT AS IT IS. Distance \equiv Backwards Time-Travel.

1. Density of galaxies in past appears to be greater than density now.

2. Radiation from Big Bang Era.

Then in equilibrium with dense matter \rightarrow Planck Curve at 10^{10} K.

NOW should be seen IN ALL DIRECTIONS
FAINT

RED-SHIFTED BUT STILL PLANCK CURVE

1965 Penzias and Wilson detected faint isotropic background radiation at radio wavelengths.

SINCE FOUND TO BE ISOTROPIC
PLANCK CURVE !

97

Big Bang Development

TIME	CONDITION OF MATTER	
0	BIG BANG	NO ATOMS, NUCLEI SINGLE PARTICLES, PHOTONS
1 sec	$T \sim 10^{10} K$	$\gamma + \gamma \rightleftharpoons e^+ + e^-$ $n + e^+ \rightleftharpoons p + \bar{\nu}$ $p + e^- \rightleftharpoons n + \nu$
		} PARTICLE EQUILIBRIUM
1 hour	$T \sim 10^8 K$	BUILDUP OF NUCLEI TO He^4
1 day	$T \sim 3 \times 10^7 K$	UNCHANGED
1 year	$T \sim 10^6 K$	UNCHANGED

100,000 yrs	$T \sim 5000 K$	ATOMS OF H AND He CAN FORM BY CAPTURING ELECTRONS

1 million yrs	$T \sim 1800 K$	GALAXIES BEGIN TO AGGREGATE UNDER GRAVITY
1 billion yrs	$T \sim 50 K$	STARS FORMED. FIRST MASSIVE STARS "COOK" H AND He TO HEAVY ELEMENTS
10 billion yrs	$T \sim 10 K$	FORMATION OF SUN, SOLAR SYSTEM, ETC.

PARTICLES AND NUCLEI
ATOMS
GALAXIES AND STARS

} structures formed

Big Bang Cosmology -

- ✓ EXPLAINS OBSERVED "HUBBLE FLOW"
- ✓ EXPLAINS OBSERVED BACKGROUND RADIATION
- ✓ EXPLAINS WHY HYDROGEN-HELIUM UNIVERSE BEFORE STELLAR NUCLEOGENESIS
- ✓ ALLOWS ~ 20 BILLION YEARS FOR LATER NUCLEOGENESIS, AS REQUIRED

Was the "Big Bang" the Creation of Matter?

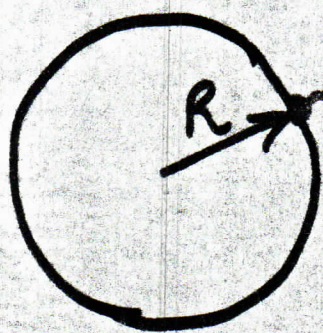
Did Space and Time exist before it?

Could "The Universe" all be in one place at one time and still be describable?

Will the "Big Bang" conditions return?

HOW MUCH DO WE REALLY UNDERSTAND IN THIS PICTURE?

Black Hole



MASS M

$$Pur \Sigma (=h\nu) = mc^2$$

equivalent mass m
of photon

General Relativity \rightarrow m acted on by gravity.

LIMITING CASE (PHOTON 'TRAPPED')

$$mc^2 = \frac{GMm}{R}$$

No photon can escape from mass M in radius R if $GM = Rc^2$ (or more).

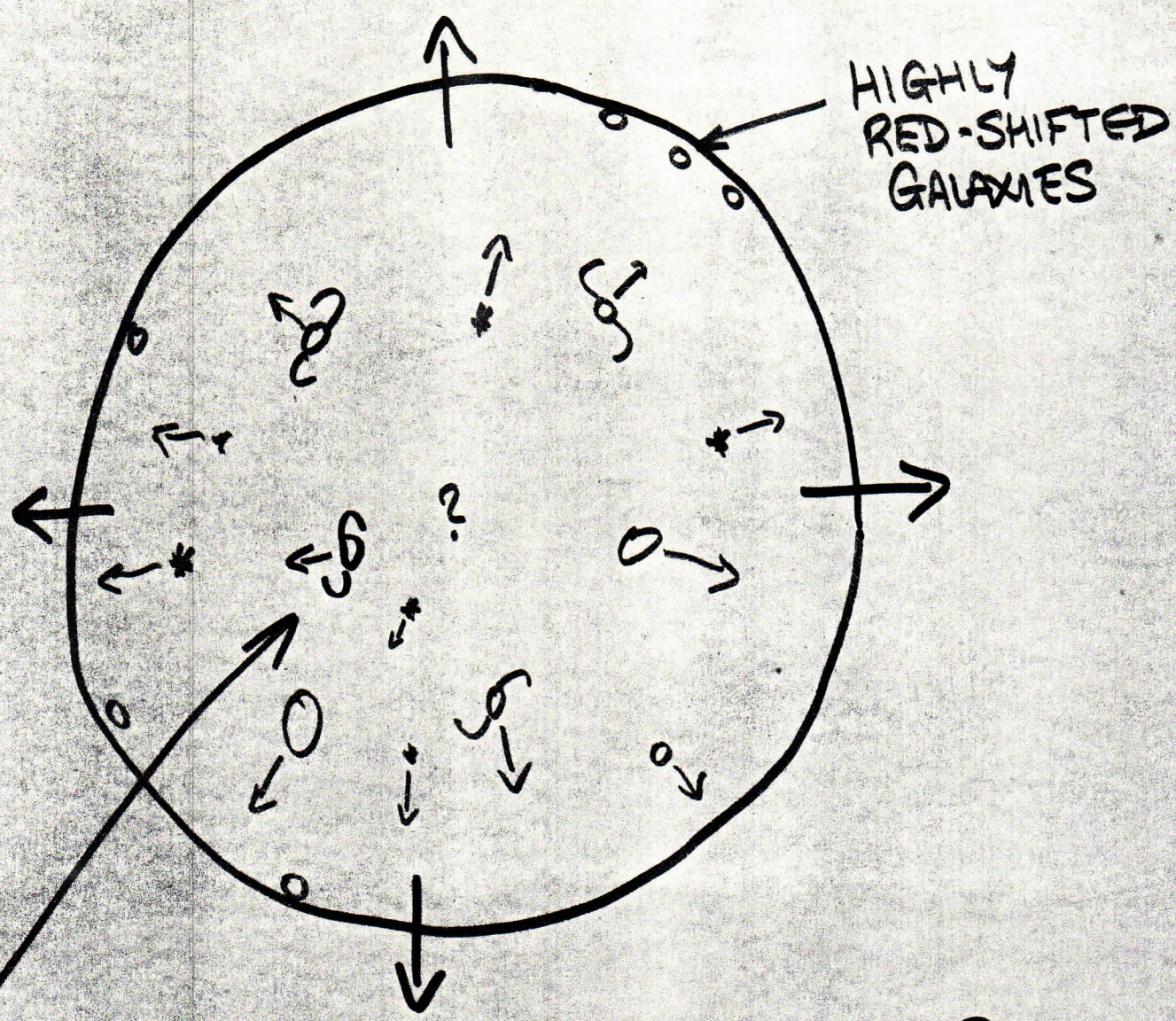
"BLACK HOLE" radius $R = \frac{GM}{c^2}$

Types of "Black Hole"

MASS	RADIUS	DENSITY
1 gram	7×10^{-29} cm	6×10^{83} g/cm ³
"Earth"	0.4 cm	2×10^{28} g/cm ³
"Sun"	1.5 km	1.5×10^{17} g/cm ³
"Spiral Galaxy"	2000 A.U.	4×10^{-6} g/cm ³
"Cluster of Galaxies"	3 light-years	4×10^{-10} g/cm ³
"The Universe"	20 billion light-yrs	4×10^{-30} g/cm ³

ARE WE INSIDE A BLACK HOLE ?

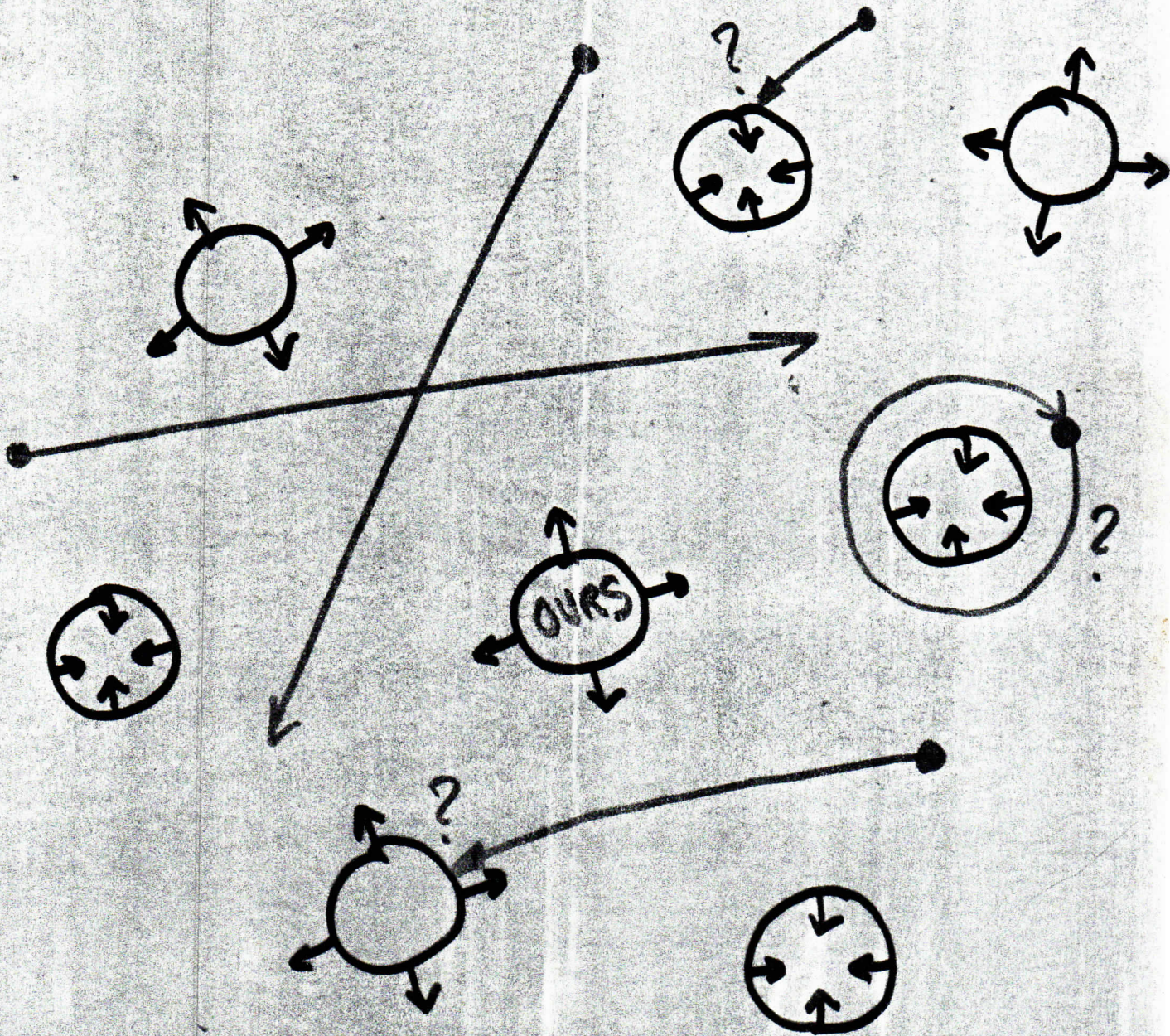
• A BLACK HOLE UNIVERSE?



US

$$GM \cong Rc^2$$

A "Universe" of "Black Hole Universes"



WHAT DO ● ARRIVALS
LOOK LIKE FROM INSIDE ?

Space-Time Boundaries of Man's Study of the Physical Universe

