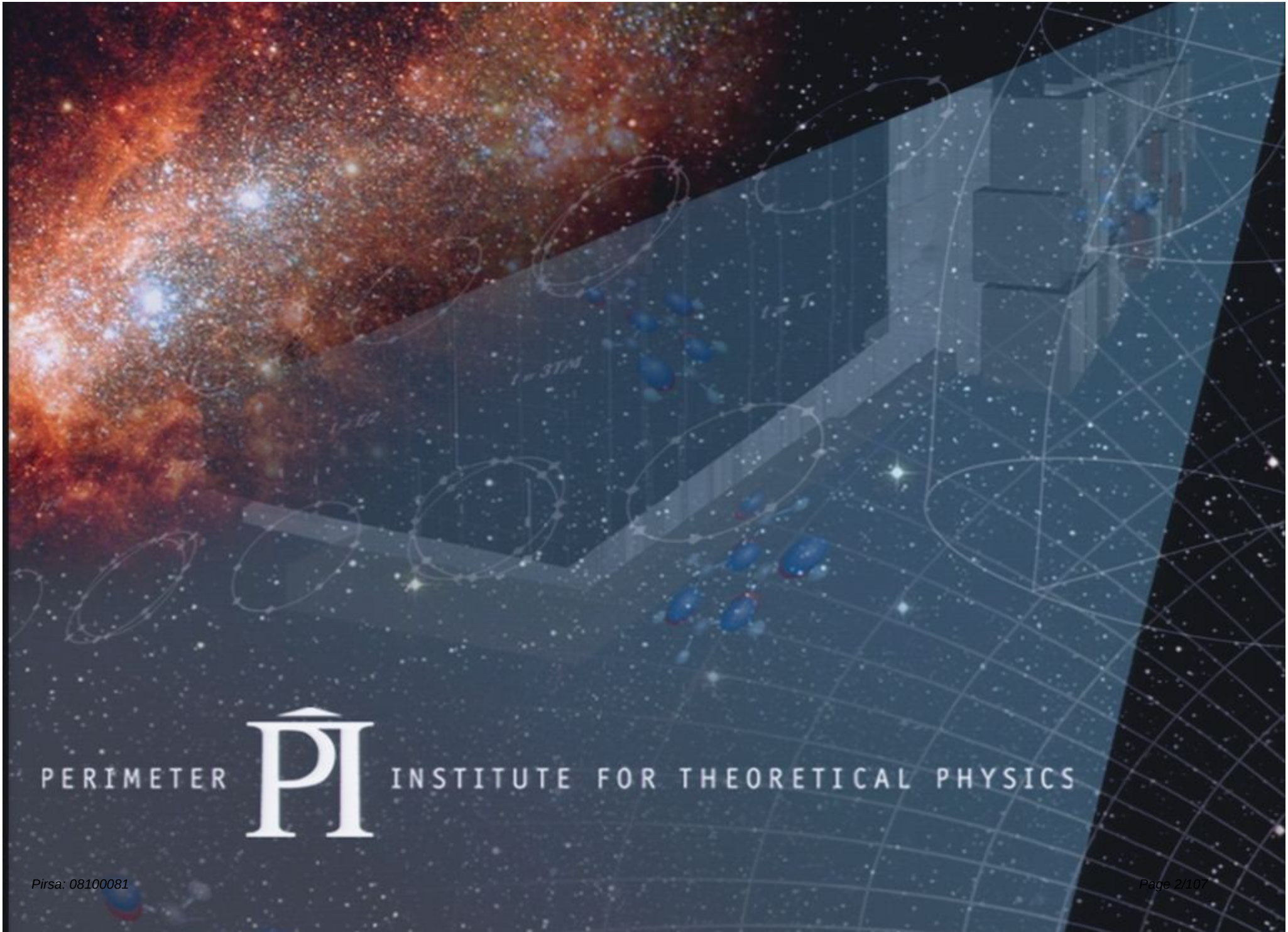
Title: Before the Big Bang: Is There Evidence For Something And If So, What?

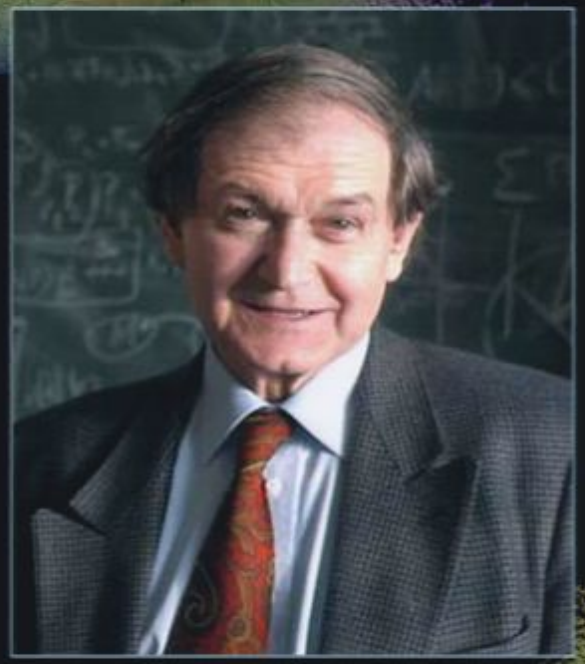
Date: Oct 01, 2008 07:00 PM

URL: http://pirsa.org/08100081

Abstract: There is now a great deal of evidence confirming the existence of a very hot and dense early stage of the universe. Much of this data comes from a detailed study of the cosmic microwave background (CMB) - radiation from the early universe that was most recently measured by NASA\'s WMAP satellite. But the information presents new puzzles for scientists. One of the most blatant examples is an apparent paradox related to the second law of thermodynamics. Although some have argued that the hypothesis of inflationary cosmology solves some of the puzzles, profound issues remain. In this talk, Professor Penrose will describe a very different proposal, one that suggests a succession of universes prior to our own. He will also present a recent analysis of the CMB data that has a profound bearing on these issues.


PERIMETER
INSTITUTE FOR THEORETICAL PHYSICS

Public Lecture Series

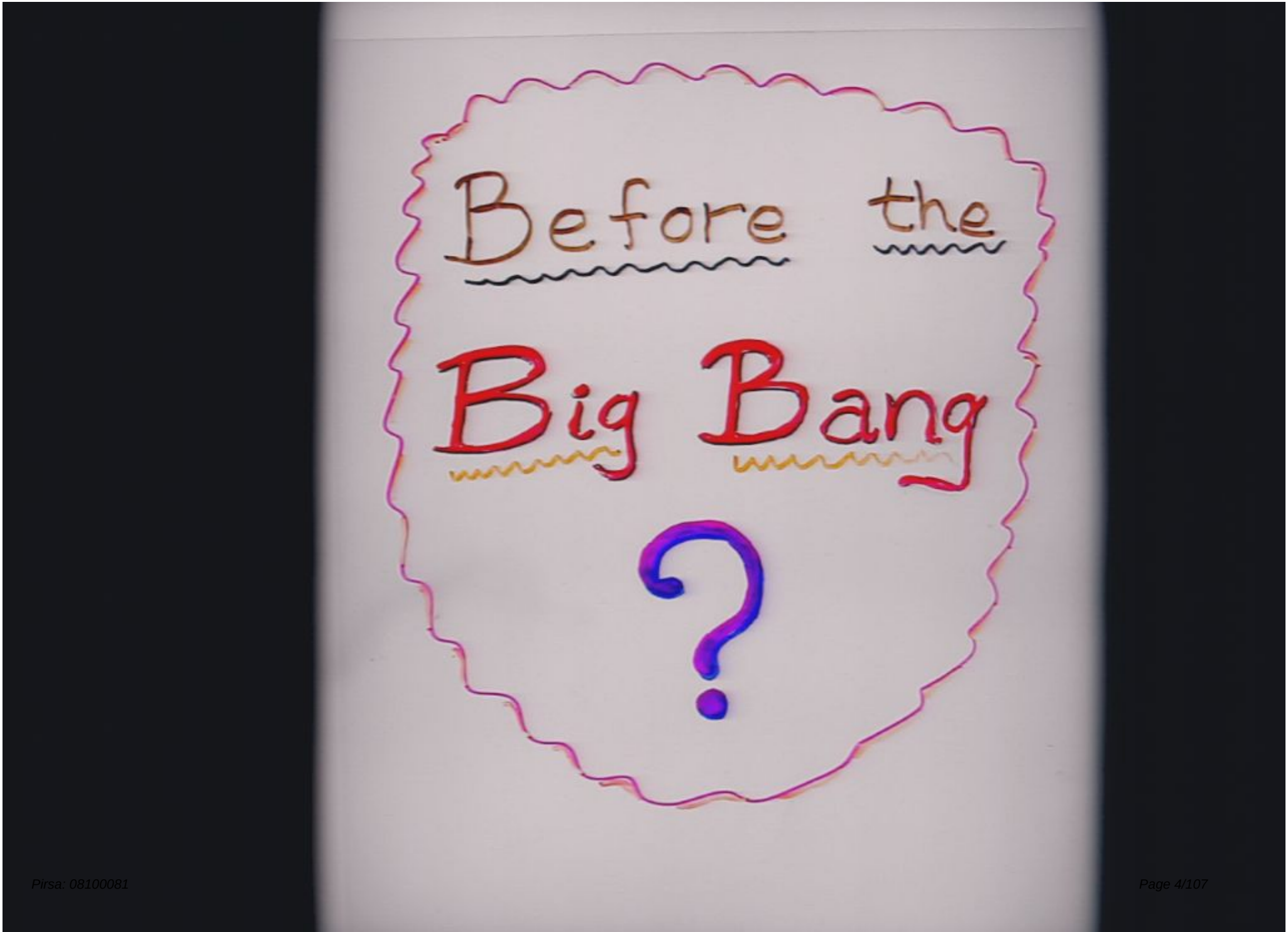


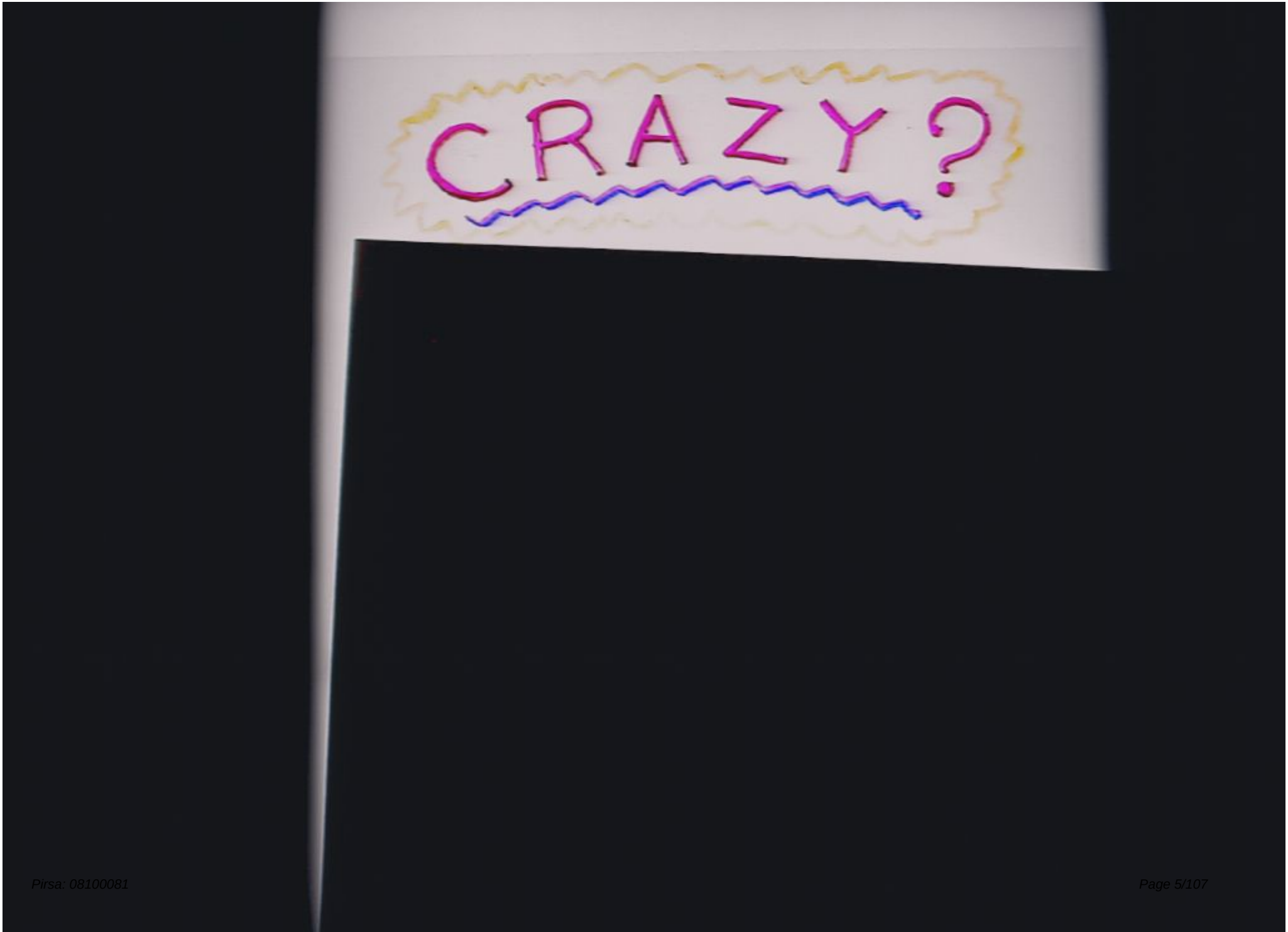
October 1, 2008

Sir Roger Penrose

Oxford University

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS


Before the
Big Bang
?


CRAZY?

CRAZY?

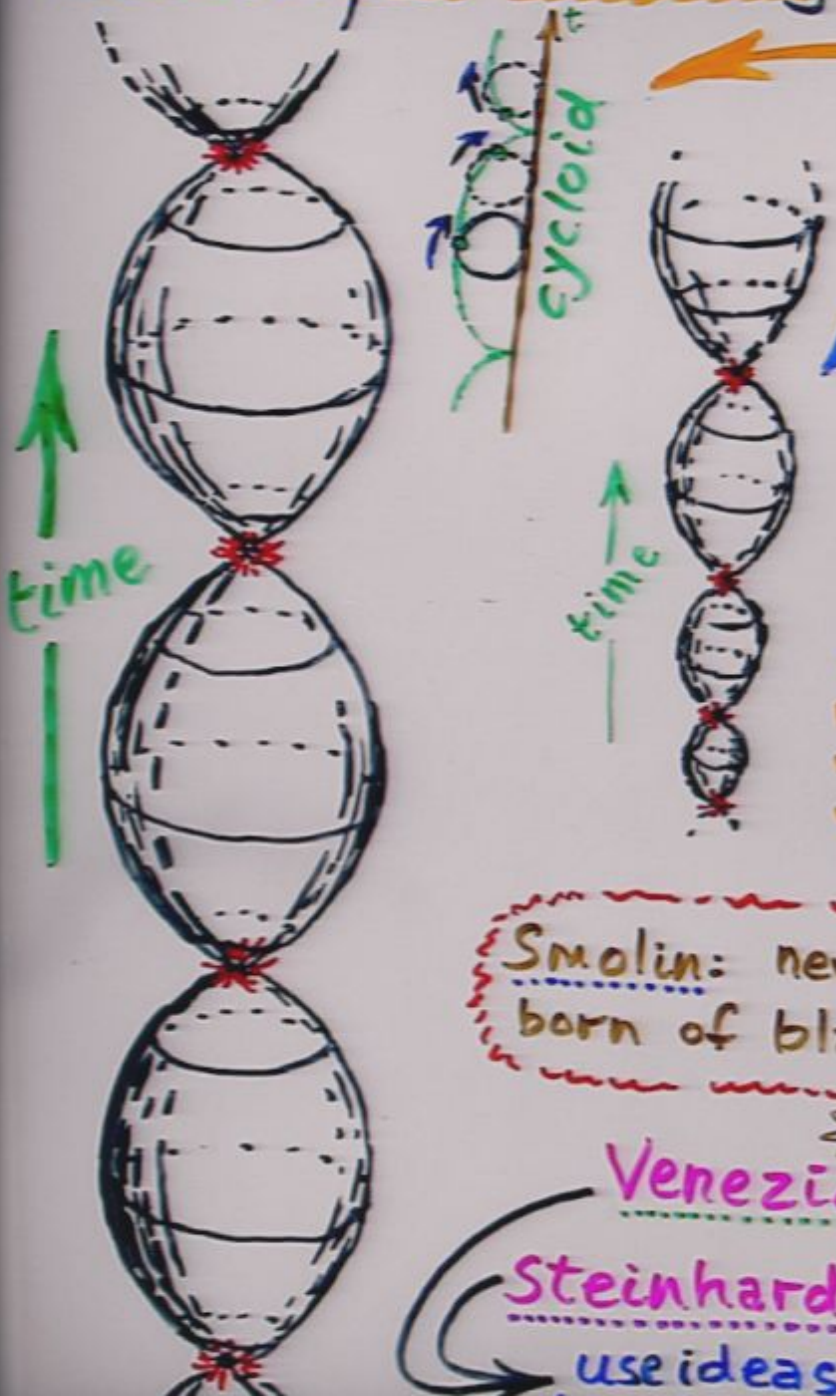
Yes, but.....

- 2nd Law of thermodynamics (with gravitational degrees of freedom suppressed)
- positive cosmological constant ("dark energy")
- dark matter
- Cosmic Microwave Background temperature/density variations
  - near isotropy
  - near scale invariance
  - lop-sided low multipoles ["axis of evil"]
  - acausal correlations (without inflation)
- black-hole evaporation, with "information-loss paradox"
- very slow decay of mass

But, is it

TRUE?

Friedmann "oscillating" model



Tolman model:
attempts to address 2nd Law

Wheeler: do consts. of nature get re-set?

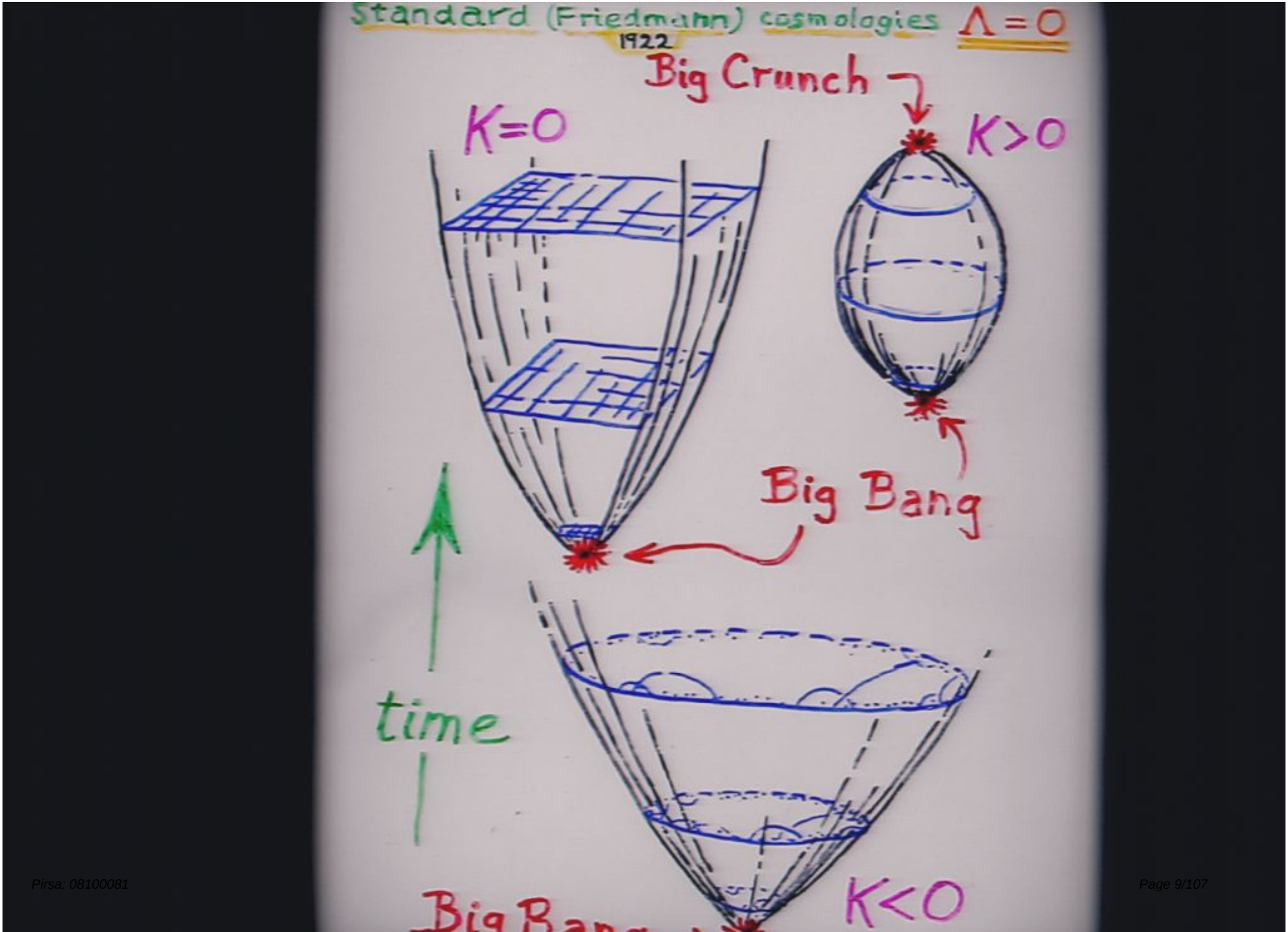
Smolin: new universes born of black holes??

Veneziano

Geometry doesn't fit

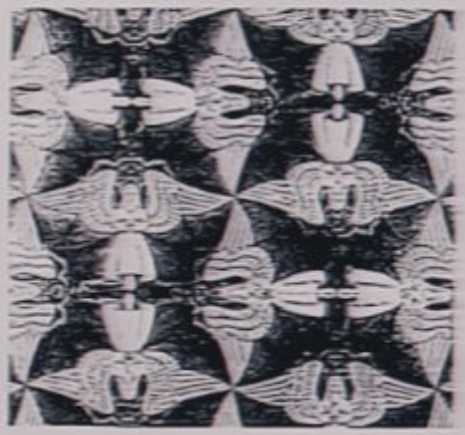
Steinhardt-Turok

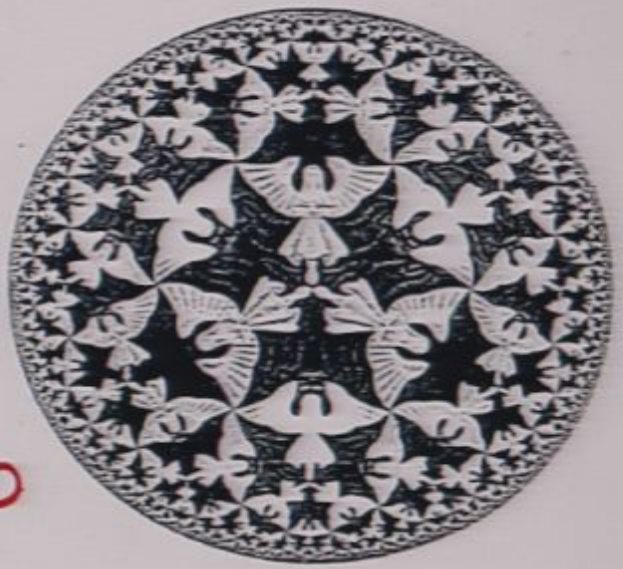
use ideas from higher-


Standard (Friedmann) cosmologies Λ=0
1922
Big Crunch
K=0
K>0
Big Bang
time
K<0
Big Bang

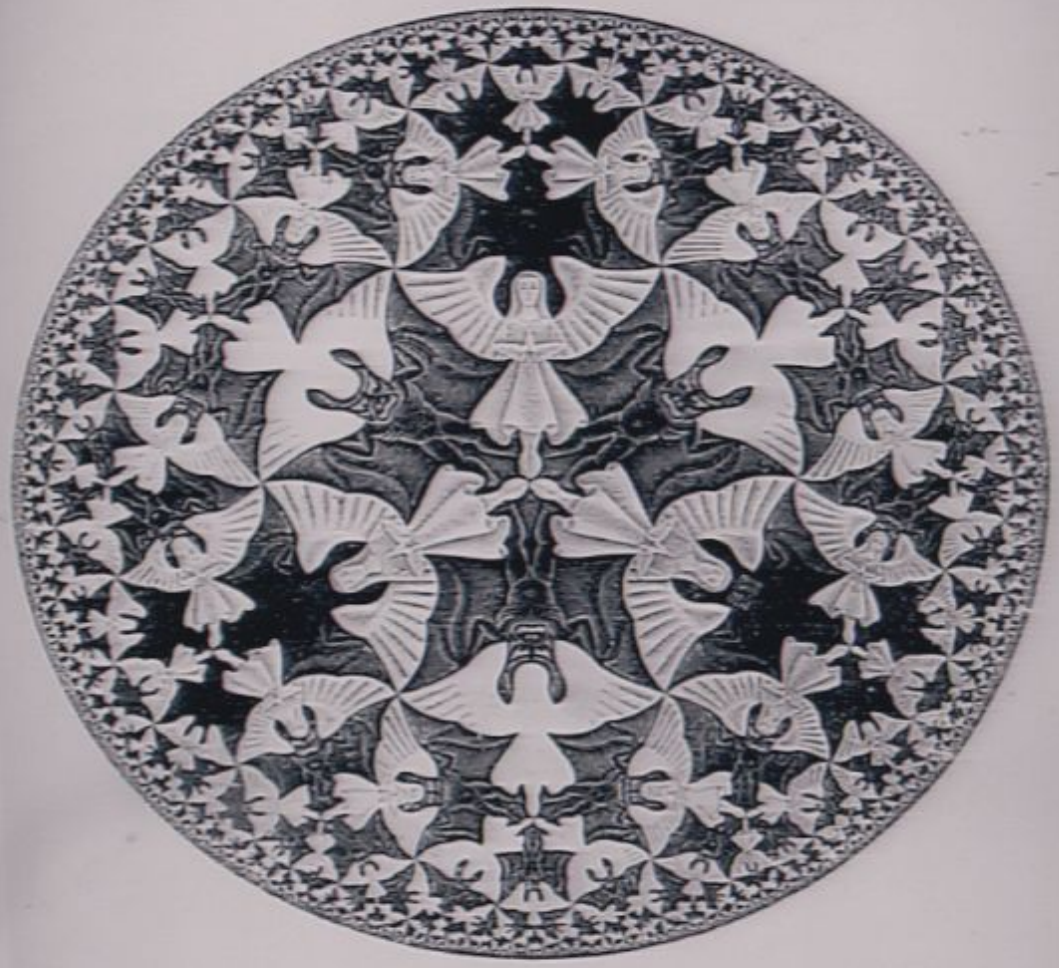
$K>0$

$K=0$





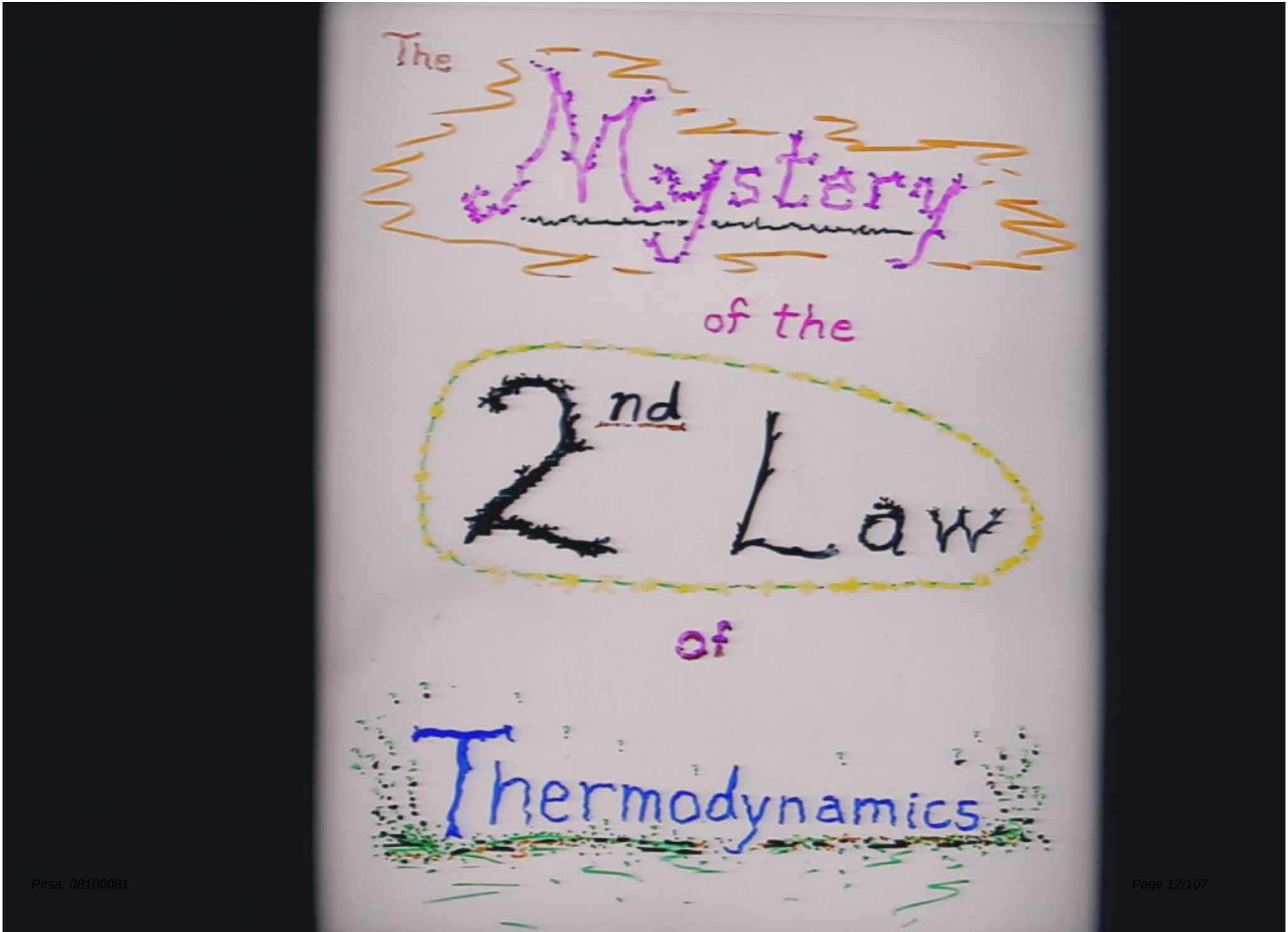
$K<0$



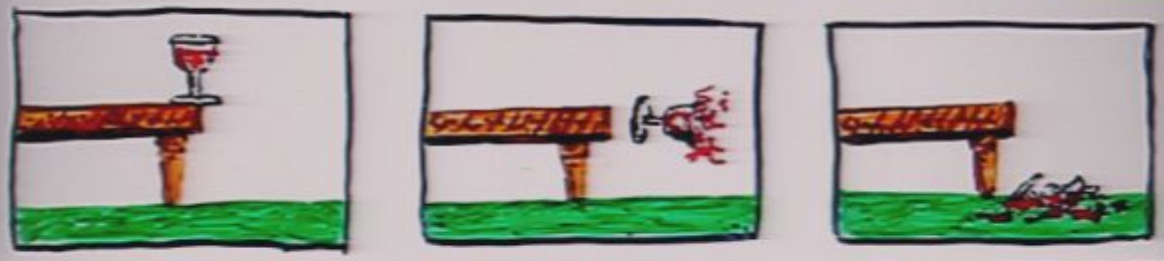
12. CIRCLE LIMIT IV (*Heaven and Hell*), woodcut printed from two blocks, diam. 42 cm., 1960.

Starting from the six central figures — three white angels and three black devils — the circle can be divided into six sectors in which alternately the white and the black figures function as 'background' and as 'object' (see captions of prints 1 and 2). In these sectors the white angels reveal, in their others the black devils. The notions 'heaven' and 'hell' constantly alternate, via stages in which angel and devil figures are equivalent.

K<0


The Mystery
of the
2nd Law
of
Thermodynamics

Entropy and the 2nd Law of Thermodynamics

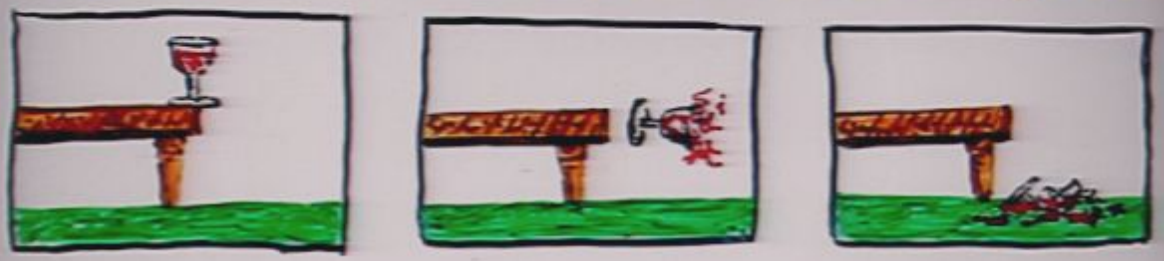


Entropy and the 2nd Law of Thermodynamics

time increasing

entropy (= "disorder") increasing

Entropy and the 2nd Law of Thermodynamics



time increasing

entropy (= "disorder") increasing

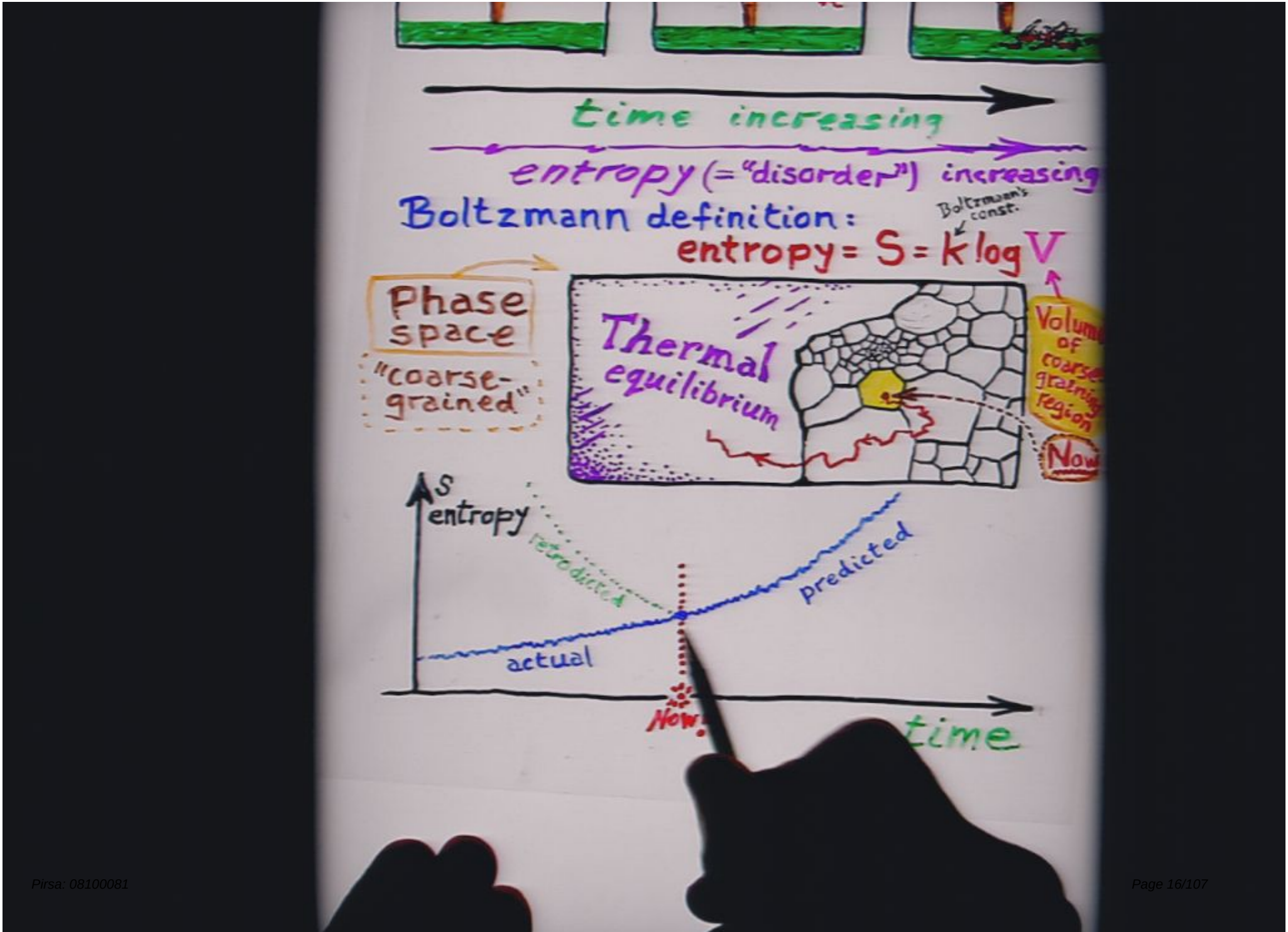
Boltzmann definition:

Boltzmann's const.

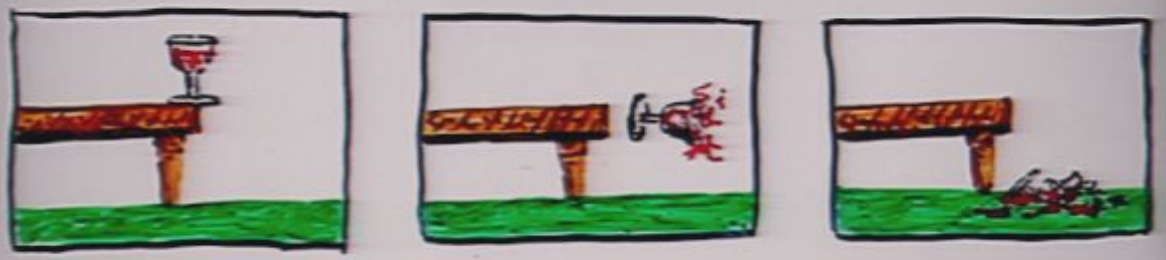
$$\text{entropy} = S = k \log V$$

Phase space

"coarse-grained"


time increasing
entropy (="disorder") increasing
Boltzmann definition:
Boltzmann's const.
entropy = S = k log V
Phase space
"coarse-grained"
Thermal equilibrium
Volume of coarse-graining region
Now
S
entropy
retrodicted
predicted
actual
Now
time

Entropy and the 2nd Law of Thermodynamics



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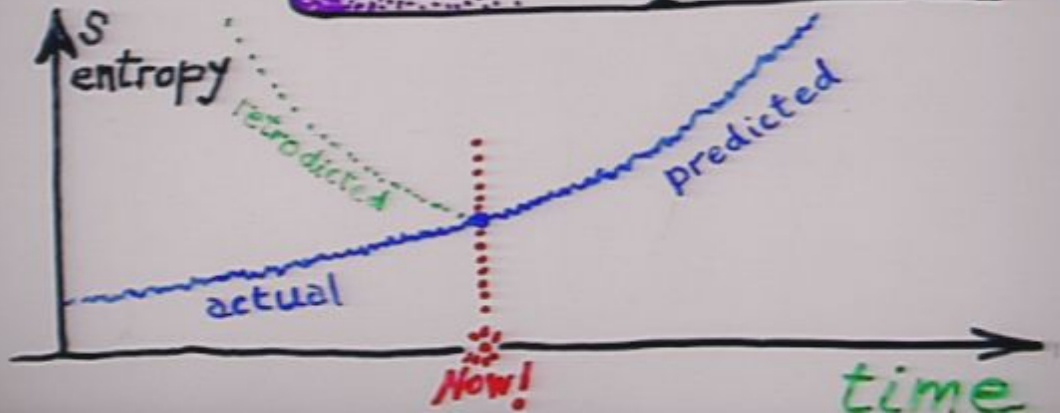
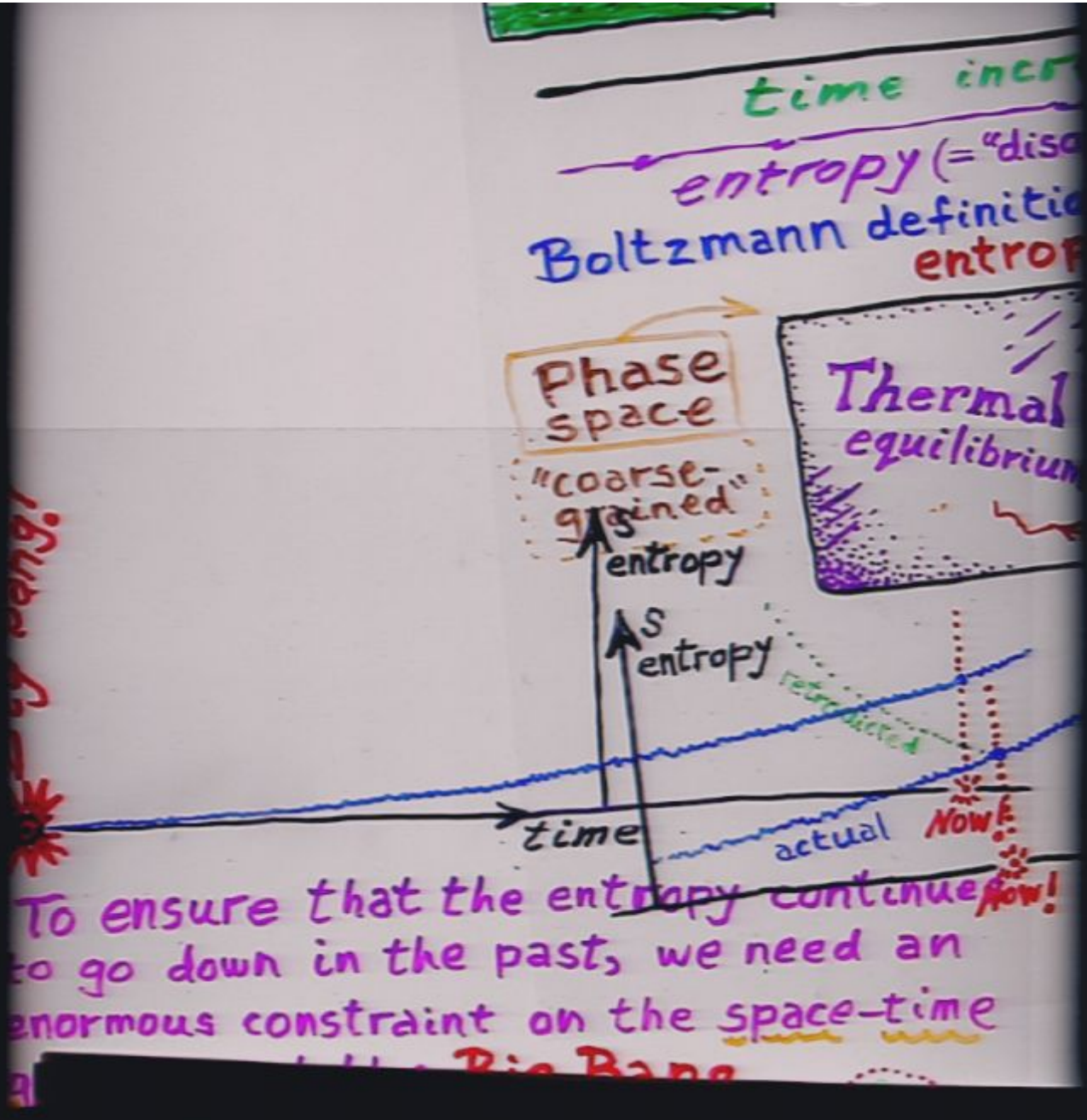
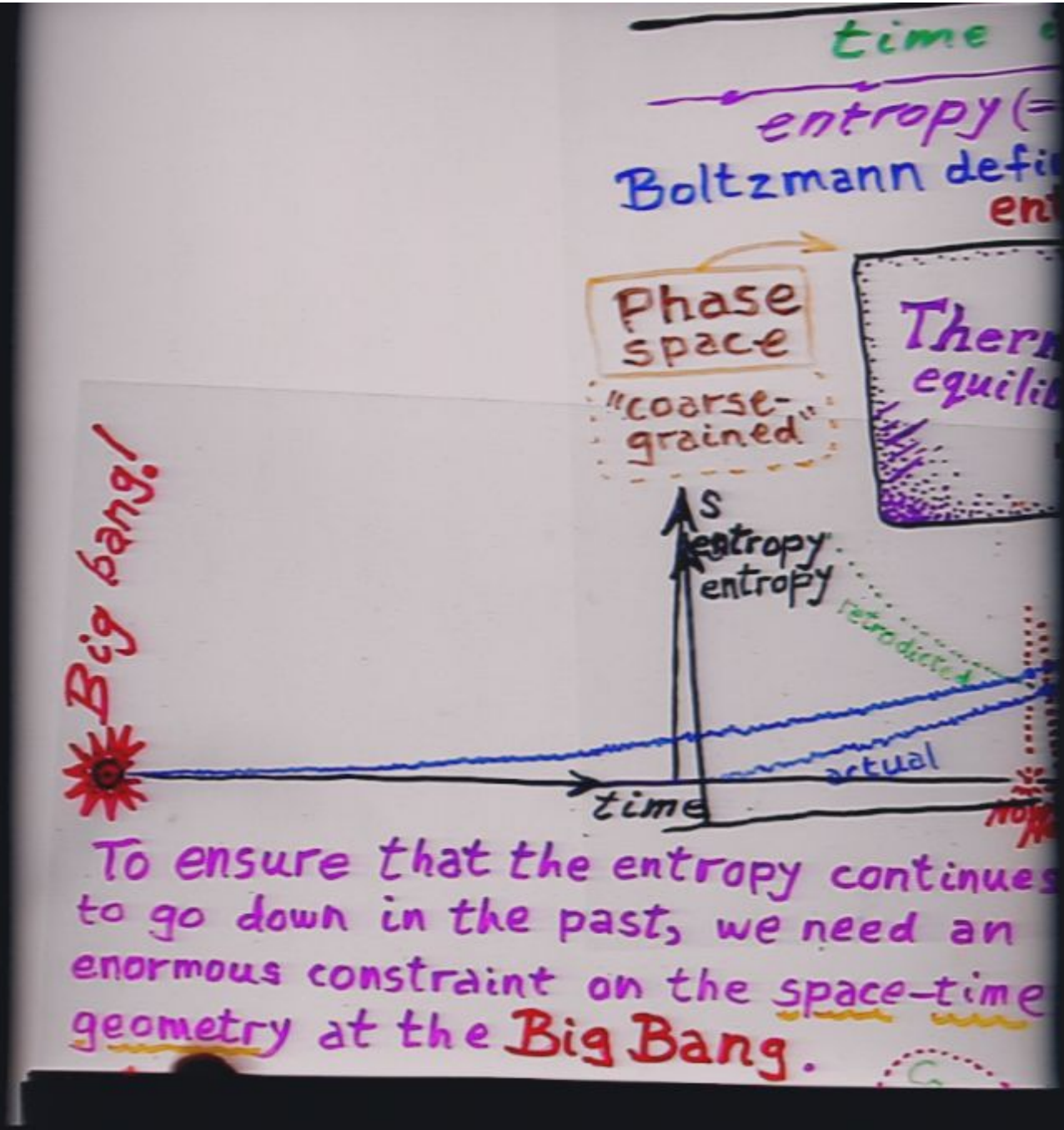
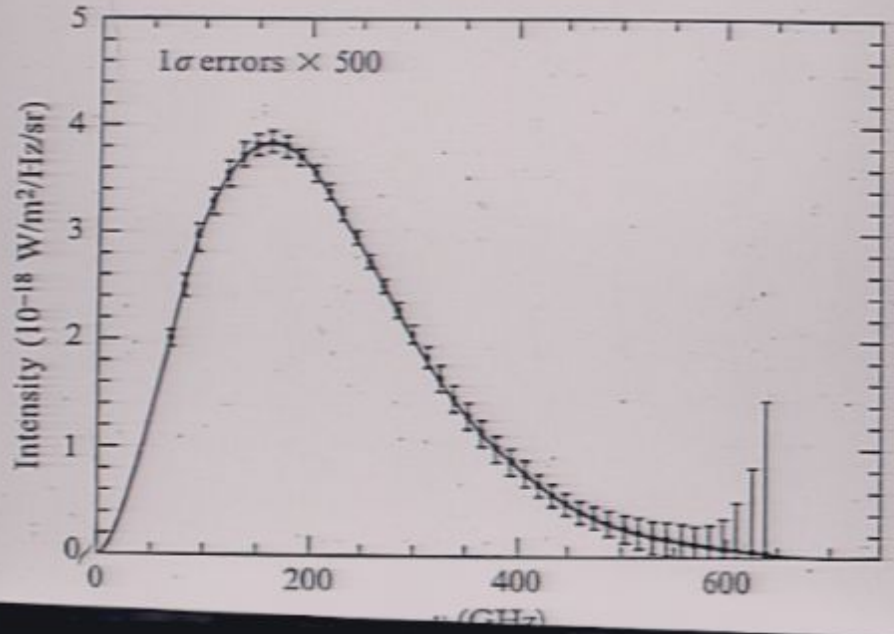


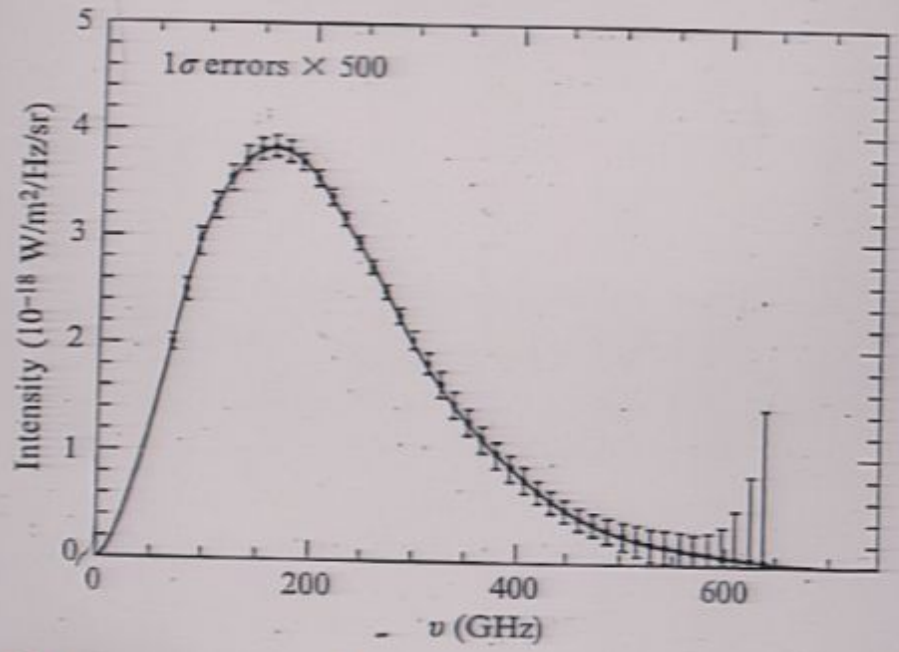

time incr
entropy (= "disc
Boltzmann definitio
entrop
Phase space
"coarse-grained"
Thermal
equilibrium
S entropy
S entropy
time
actual
Now!
To ensure that the entropy continue
Now!
to go down in the past, we need an
enormous constraint on the space-time


time
entropy (=
Boltzmann defi
ent
Phase space
"coarse-grained"
Therm
equili
Big bang!
S
entropy
entropy
retrodicted
actual
time
To ensure that the entropy continues to go down in the past, we need an enormous constraint on the space-time geometry at the Big Bang.

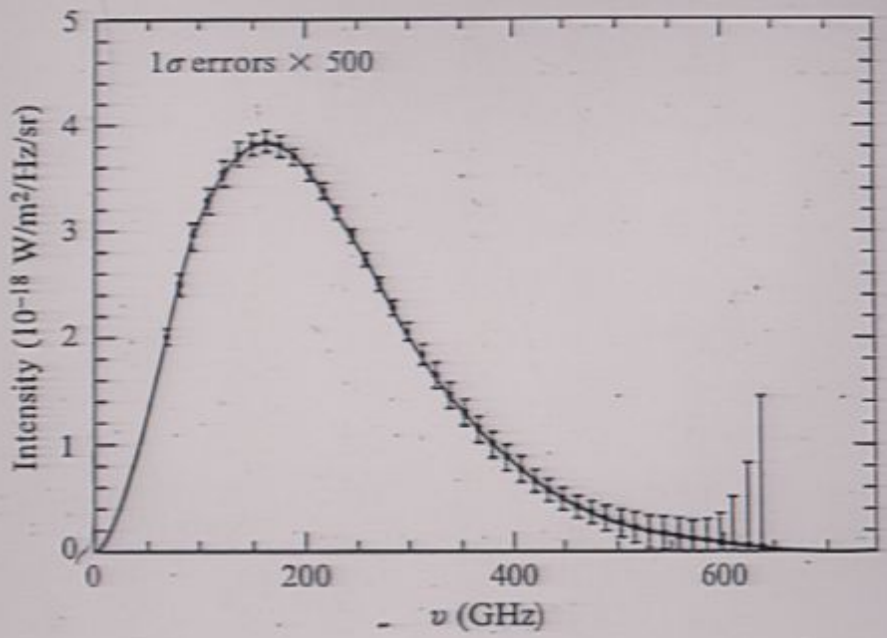
Spectrum of the Microwave Background



Spectrum of the Microwave Background



Note: error bars are exaggerated by a factor of 500.



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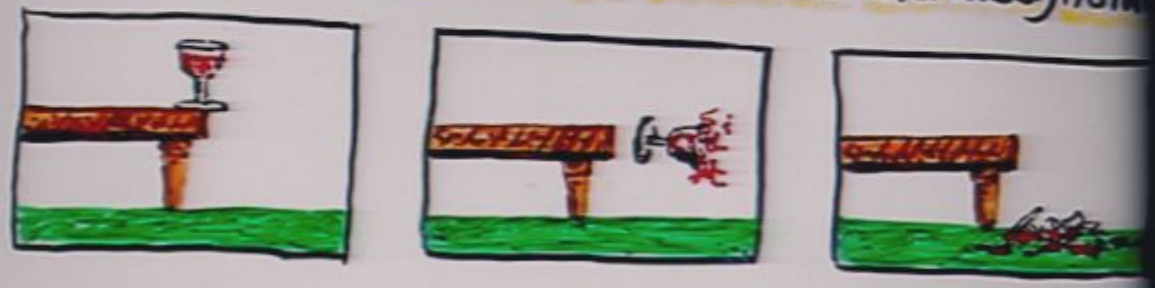
The solid curve displays the Planck black body spectrum of thermal equilibrium.

Entropy and the 2nd Law of Thermodynam



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"coarse-grained"

time

entropy (=

Boltzmann defi

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Phase space

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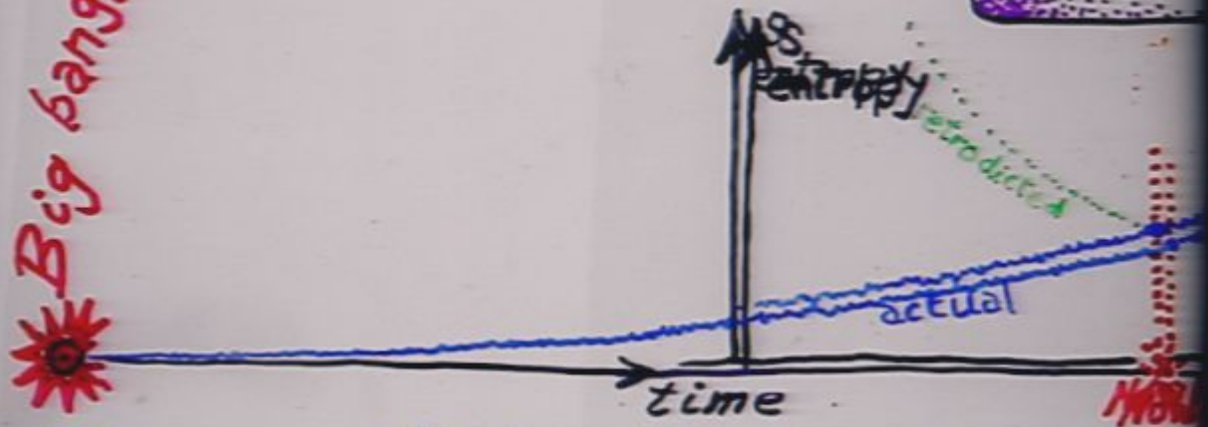
Therm

equilib



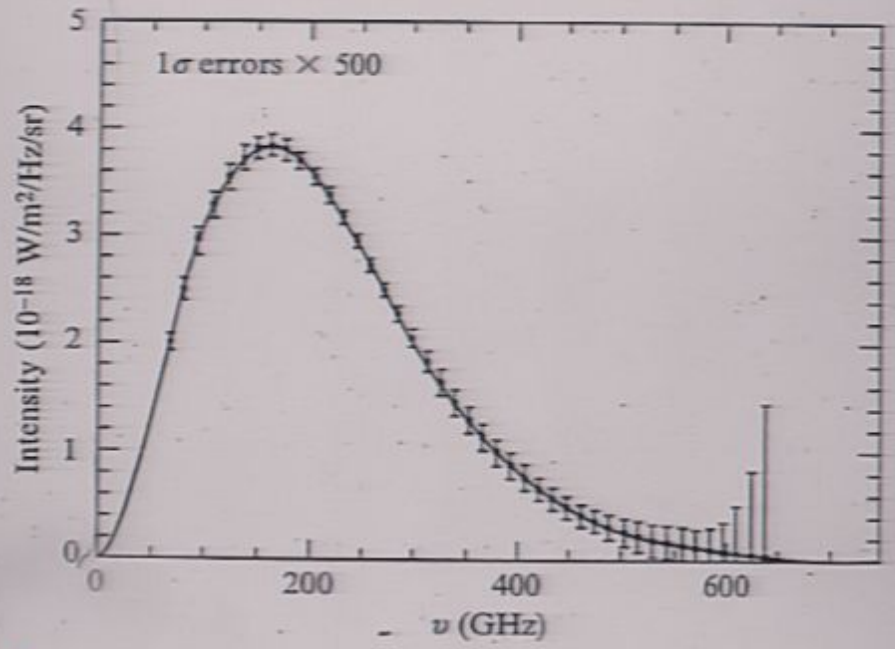
To ensure that the entropy continues to go down in the past, we need an enormous constraint on the space-time metry at the Big Bang.

Conformal curvature → 0

on the geometry?

e the matter itself

Spectrum of the Microwave Background



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The solid curve displays the Planck black body spectrum of *thermal equilibrium*.

2nd Law of Thermodynamics

Entropy increases with time

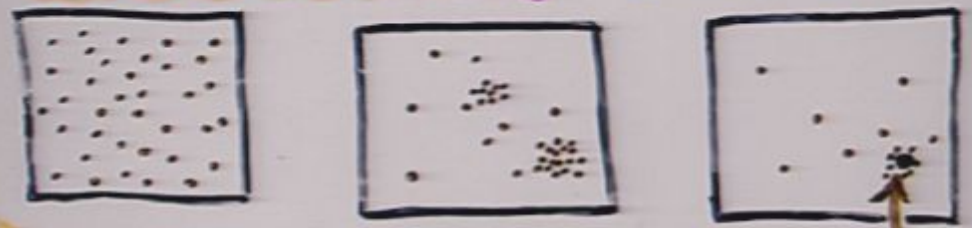
↑ = "disorder" (roughly speaking)

Gas in a box

time increases →

entropy increases →

Gravitating bodies



Maximum entropy:

BLACK HOLE

2nd Law of Thermodynamics

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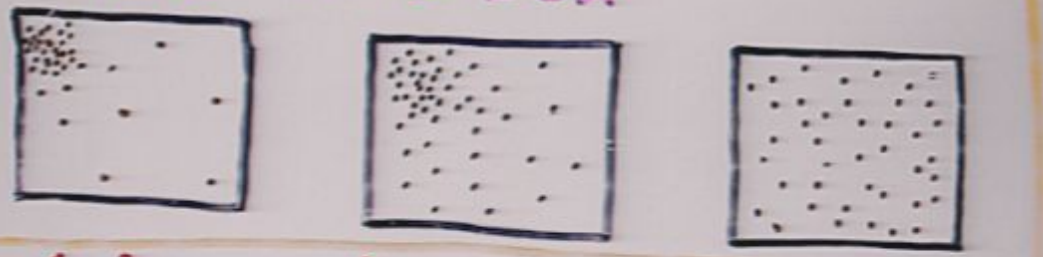

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Maximum entropy:

BLACK HOLE

Entropy increases with time

= "disorder" (roughly speaking)

Gas in a box

time increases

entropy increases

Gravitating bodies

Maximum entropy:

BLACK HOLE

Energy: conserved

Energy: conserved

As much energy goes back into space from the earth as comes in from the sun

Energy: conserved

As much energy goes back into space from the earth as comes in from the sun

Entropy: can keep it down by absorbing few high-energy photons & emitting many low-energy photons

Sun is hot spot in dark sky From GRAVITATIONAL clumping

2 Law of thermodynamics

Entropy increases with time

= "disorder" (roughly speaking)

Gas in a box

time increases →

entropy increases →

Gravitating bodies

Maximum entropy:

BLACK HOLE

Entropy increases with time

= "disorder" (roughly speaking)

Gas in a box

time increases →

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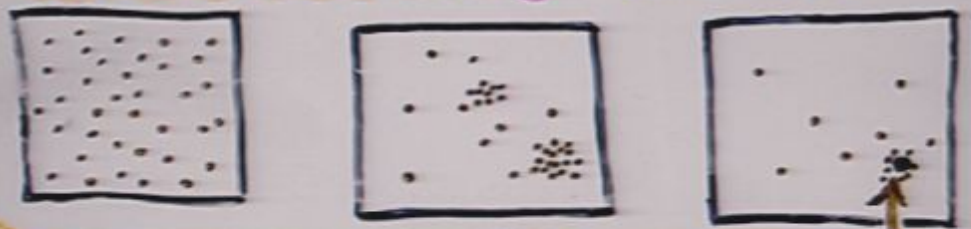
Gravitating bodies



Maximum entropy:

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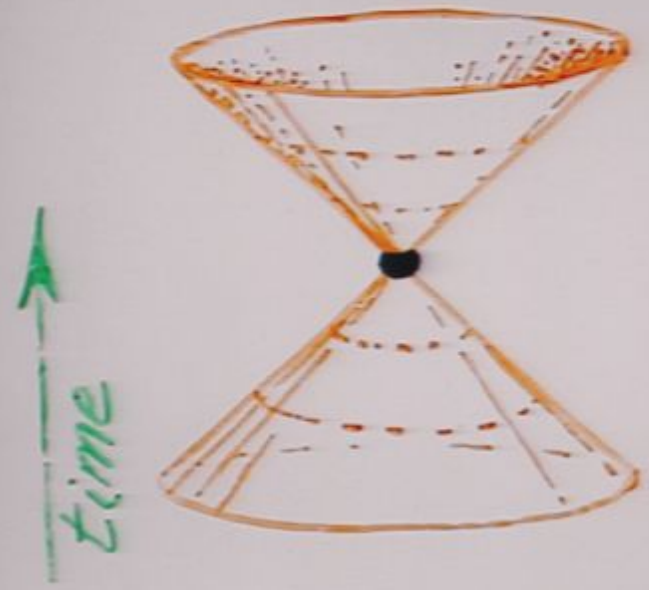
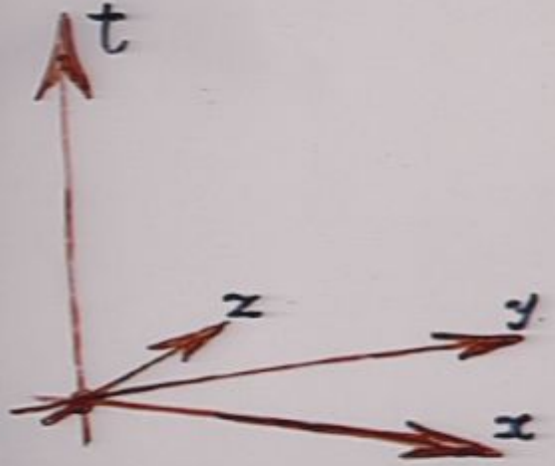
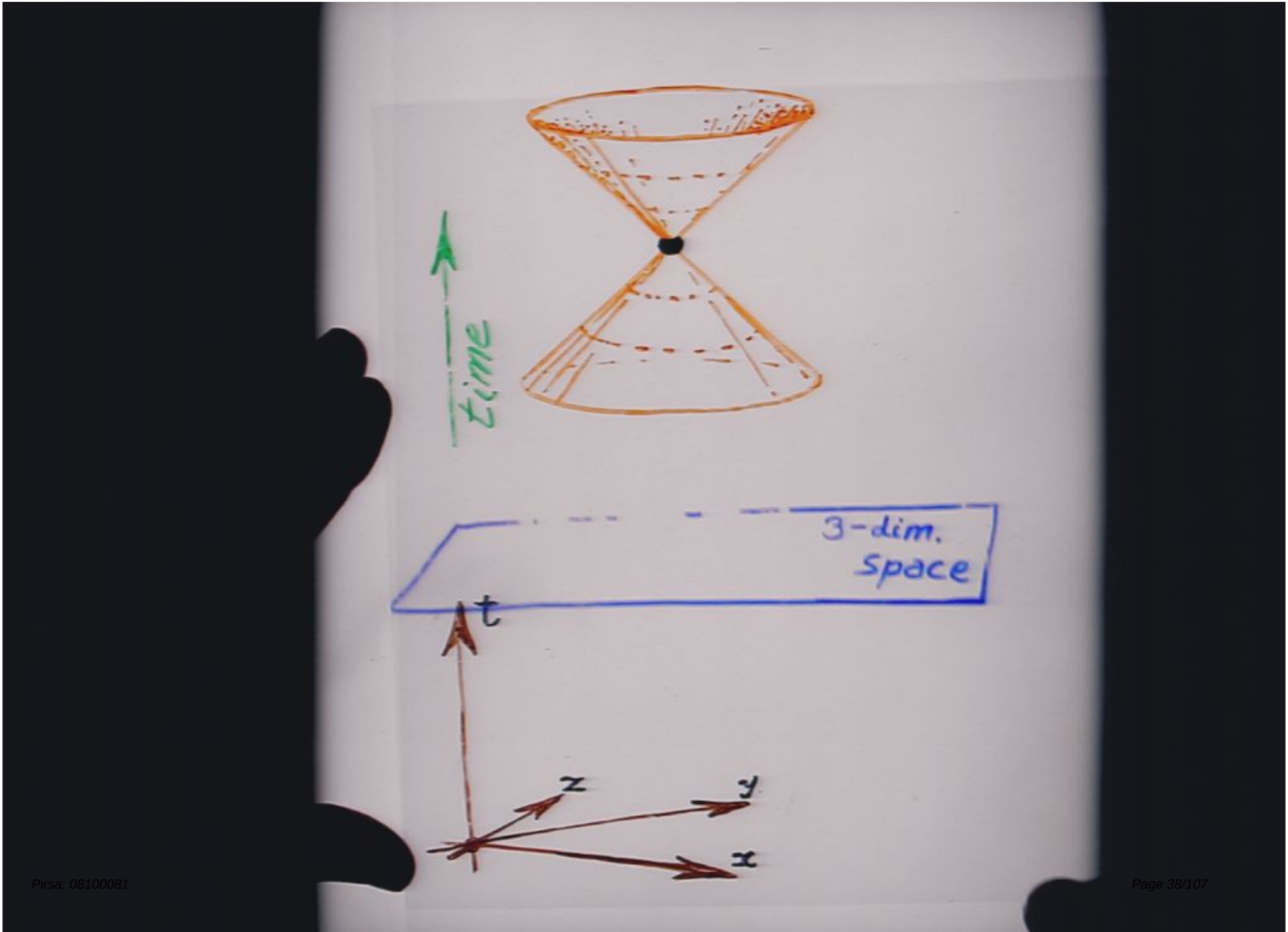
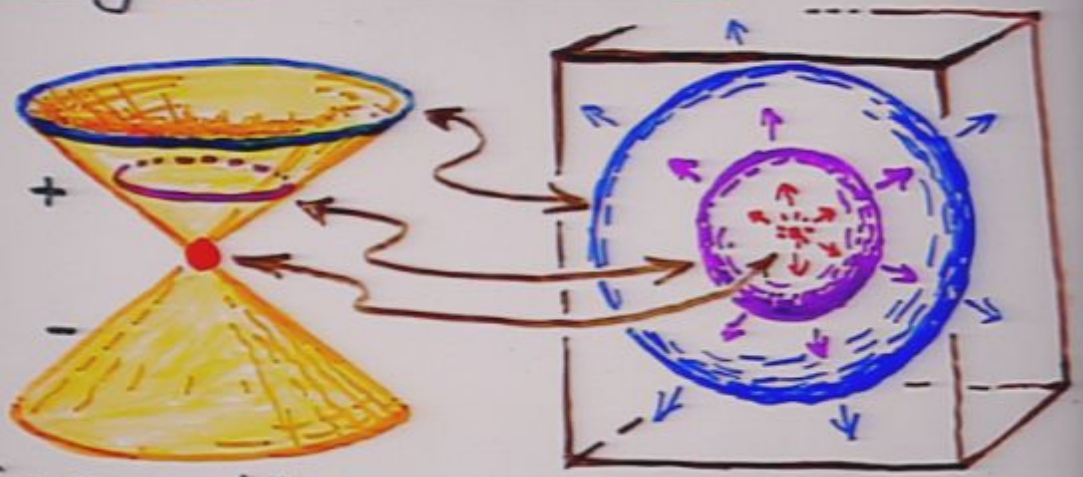

time


t
z
y
x

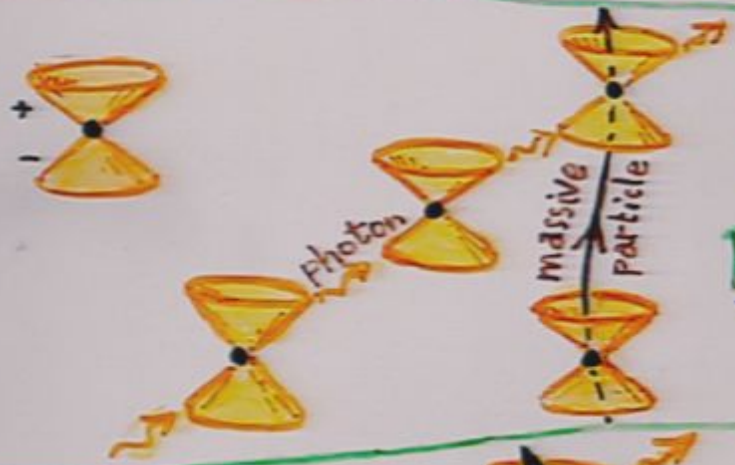

time
3-dim.
space
t
z
y
x

Light cones



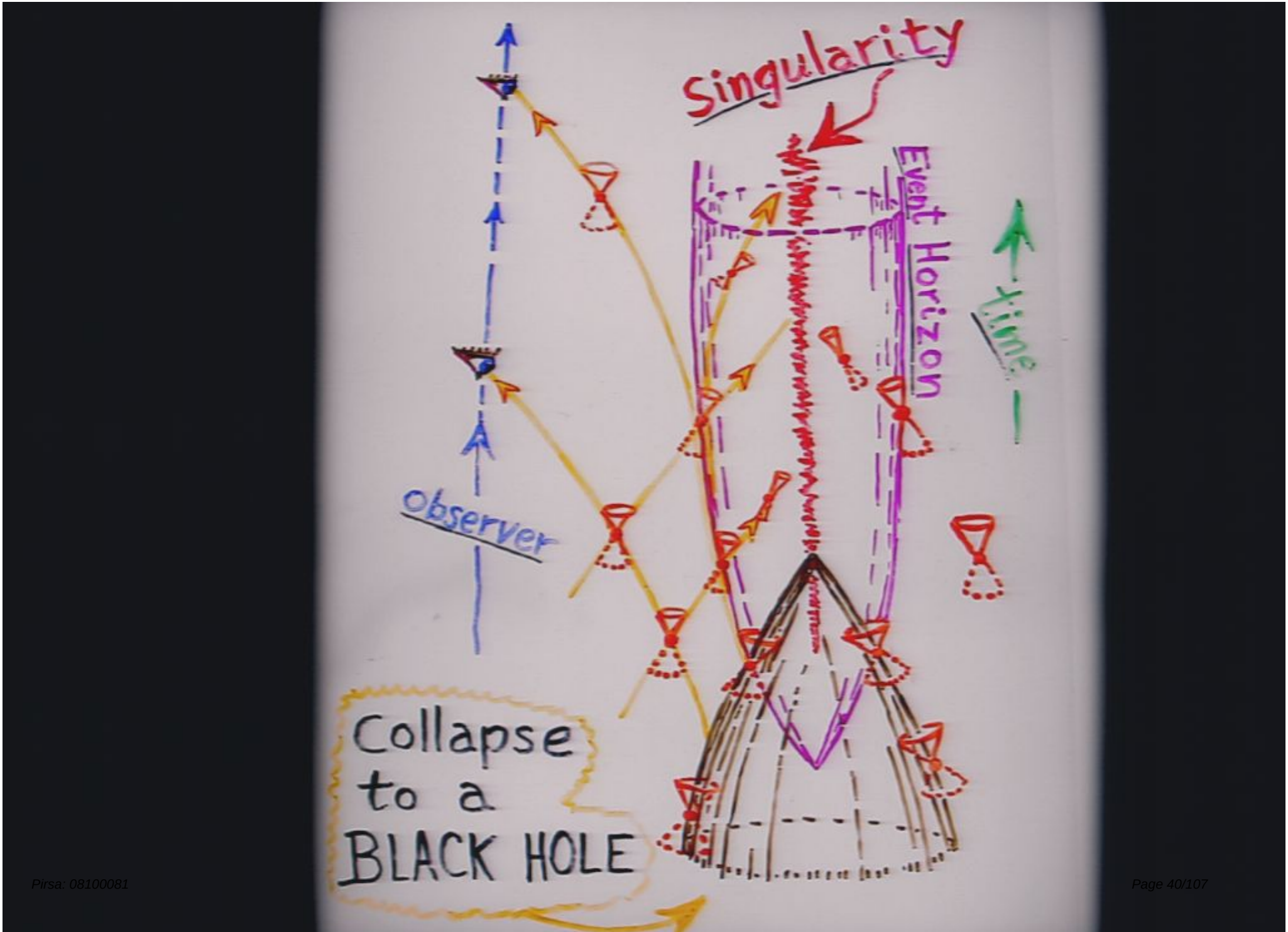
Space-time picture

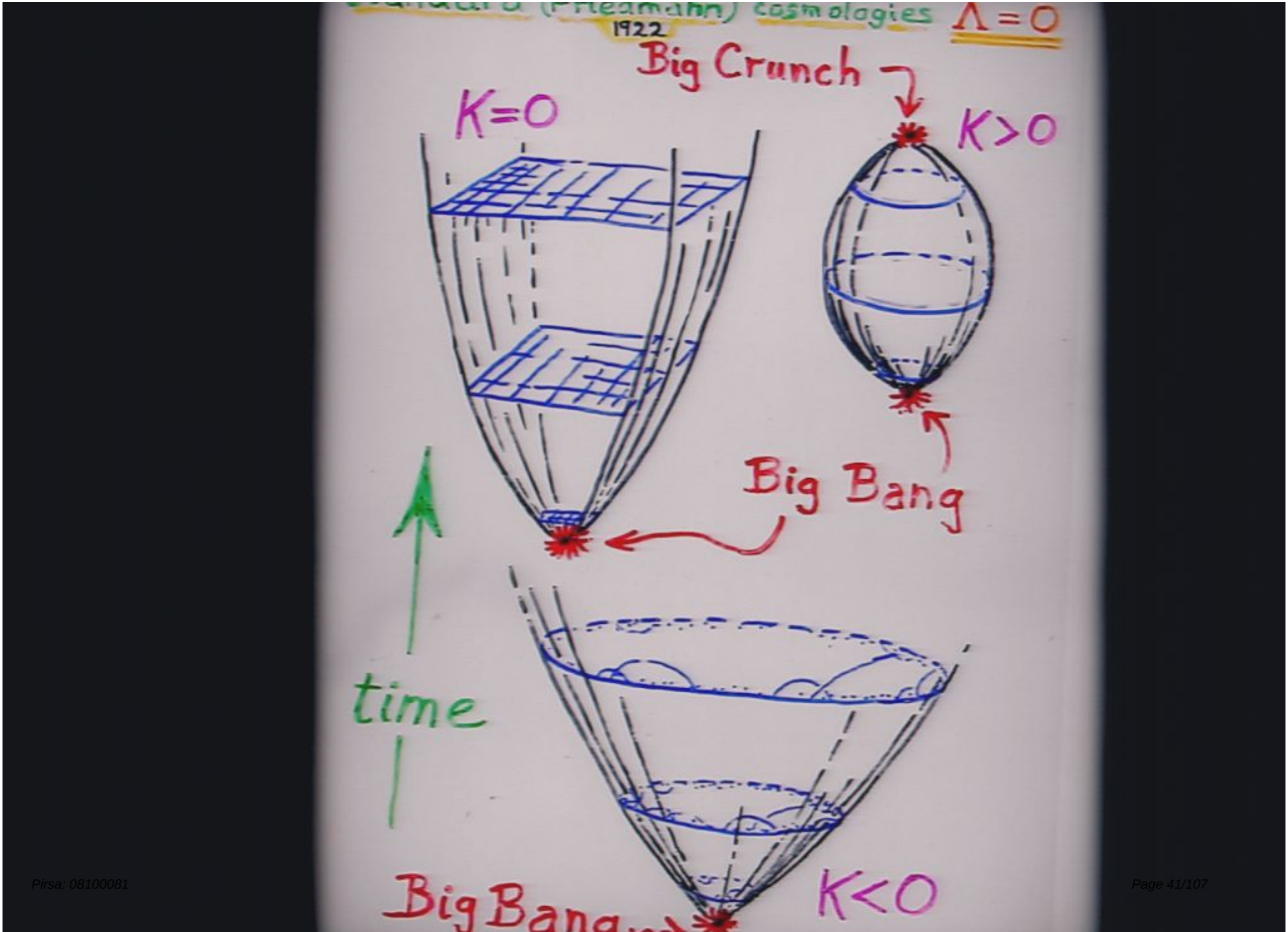
Space picture

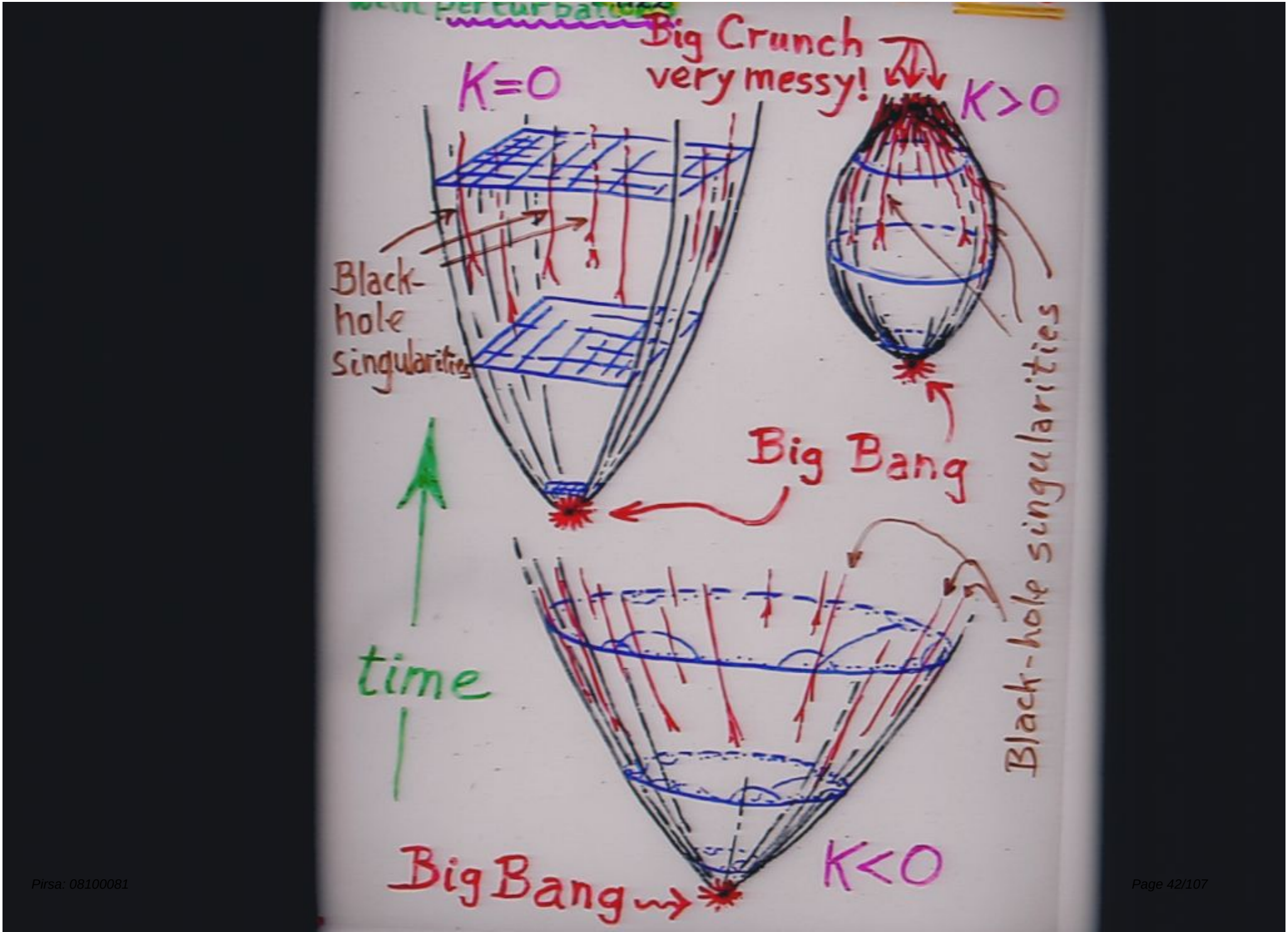


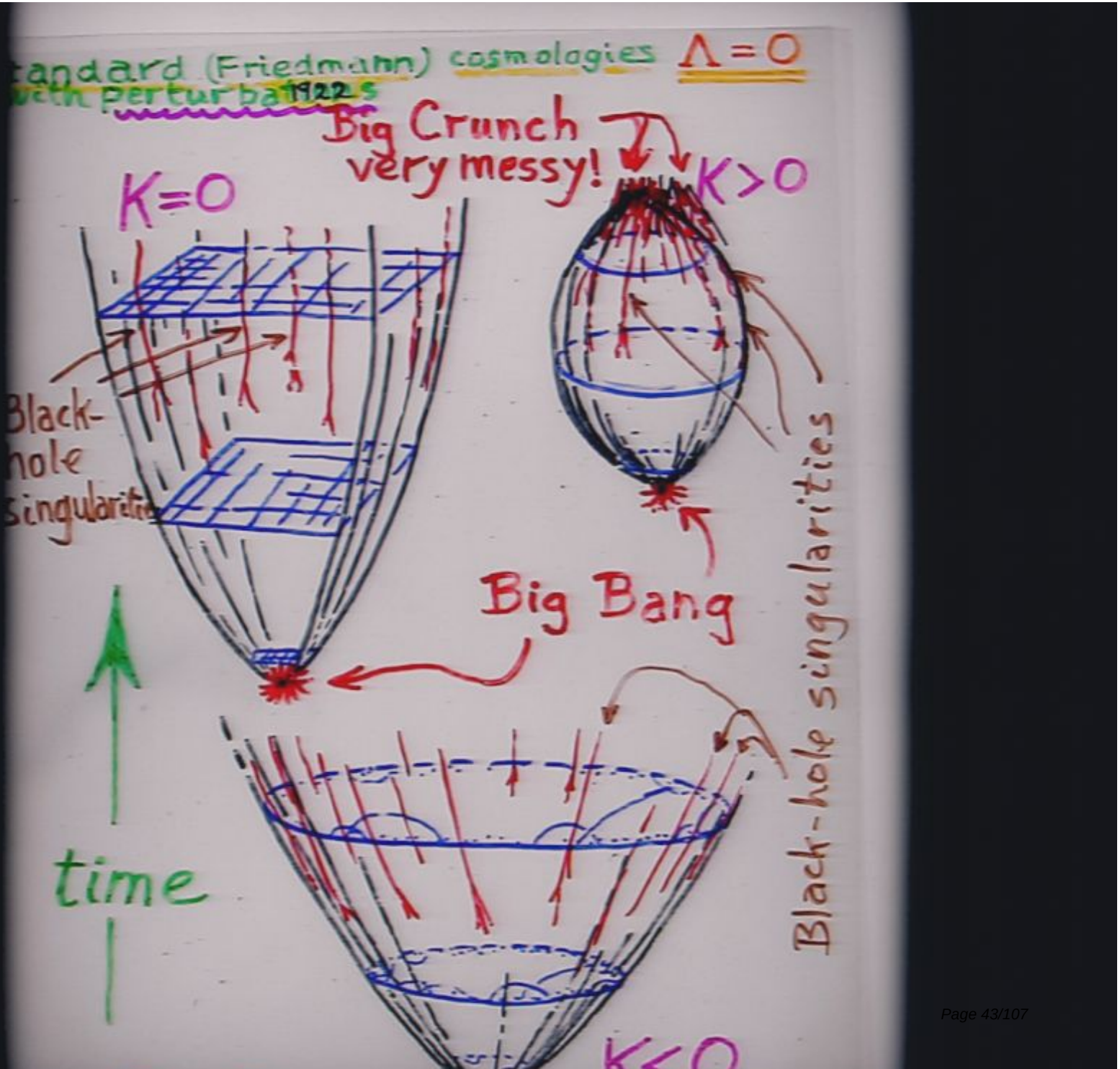
Special Relativity

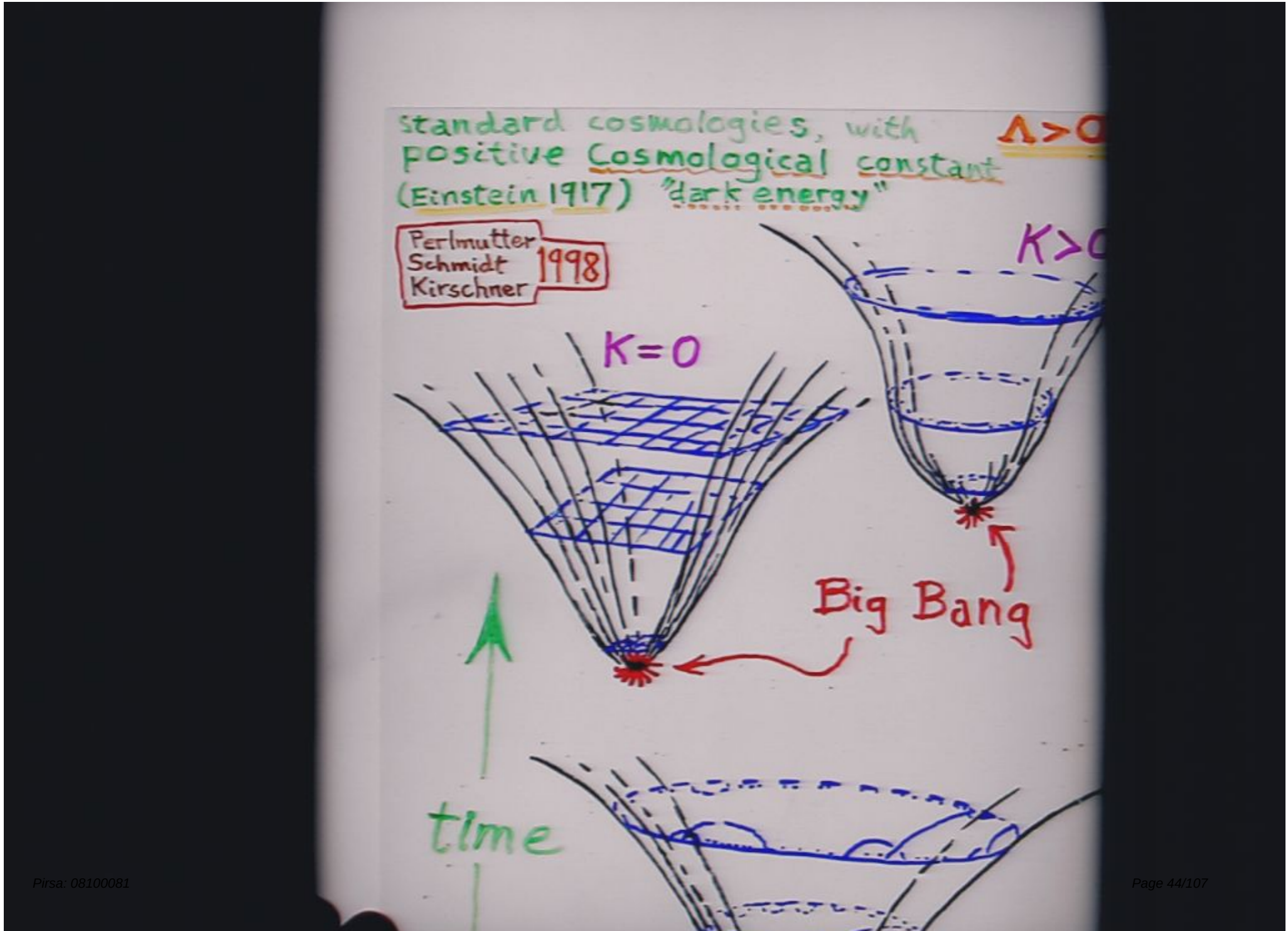
General Relativity

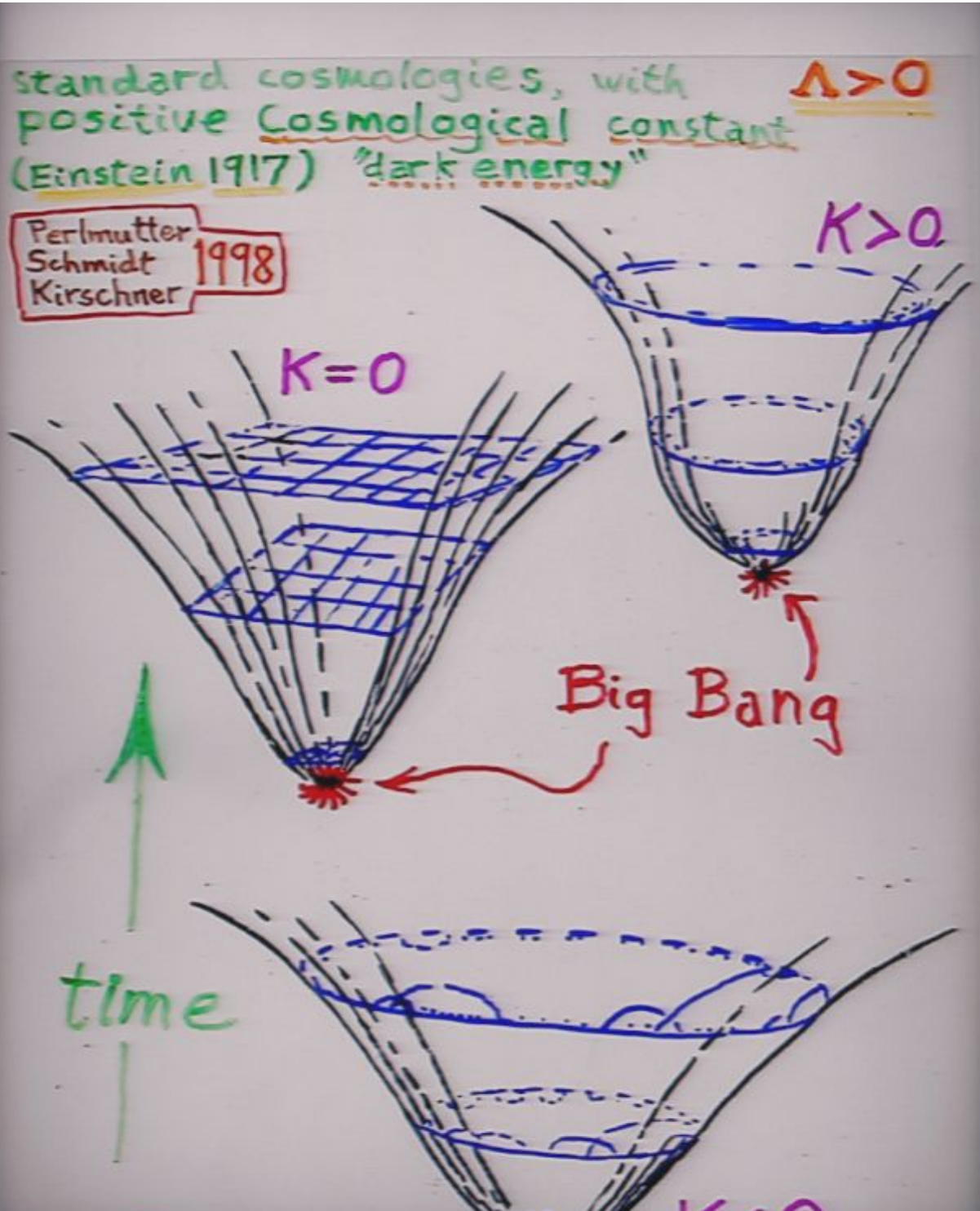

Singularity
Event Horizon
time
observer
Collapse
to a
BLACK HOLE


Standard (Friedmann) cosmologies Λ=0
1922
Big Crunch
K=0
K>0
Big Bang
time
Big Bang
K<0


Big Crunch
very messy!
K=0
K>0
Black-
hole
singularities
Big Bang
time
Black-hole singularities
Big Bang
K<0


tandard (Friedmann) cosmologies Λ=0
with perturbations
1922
Big Crunch
very messy!
K=0
K>0
Black-
hole
singularities
Big Bang
time
Black-hole singularities
K<0


standard cosmologies, with
positive Cosmological constant
(Einstein 1917) "dark energy"
Λ>0
Perlmutter
Schmidt
Kirschner
1998
K>0
K=0
Big Bang
time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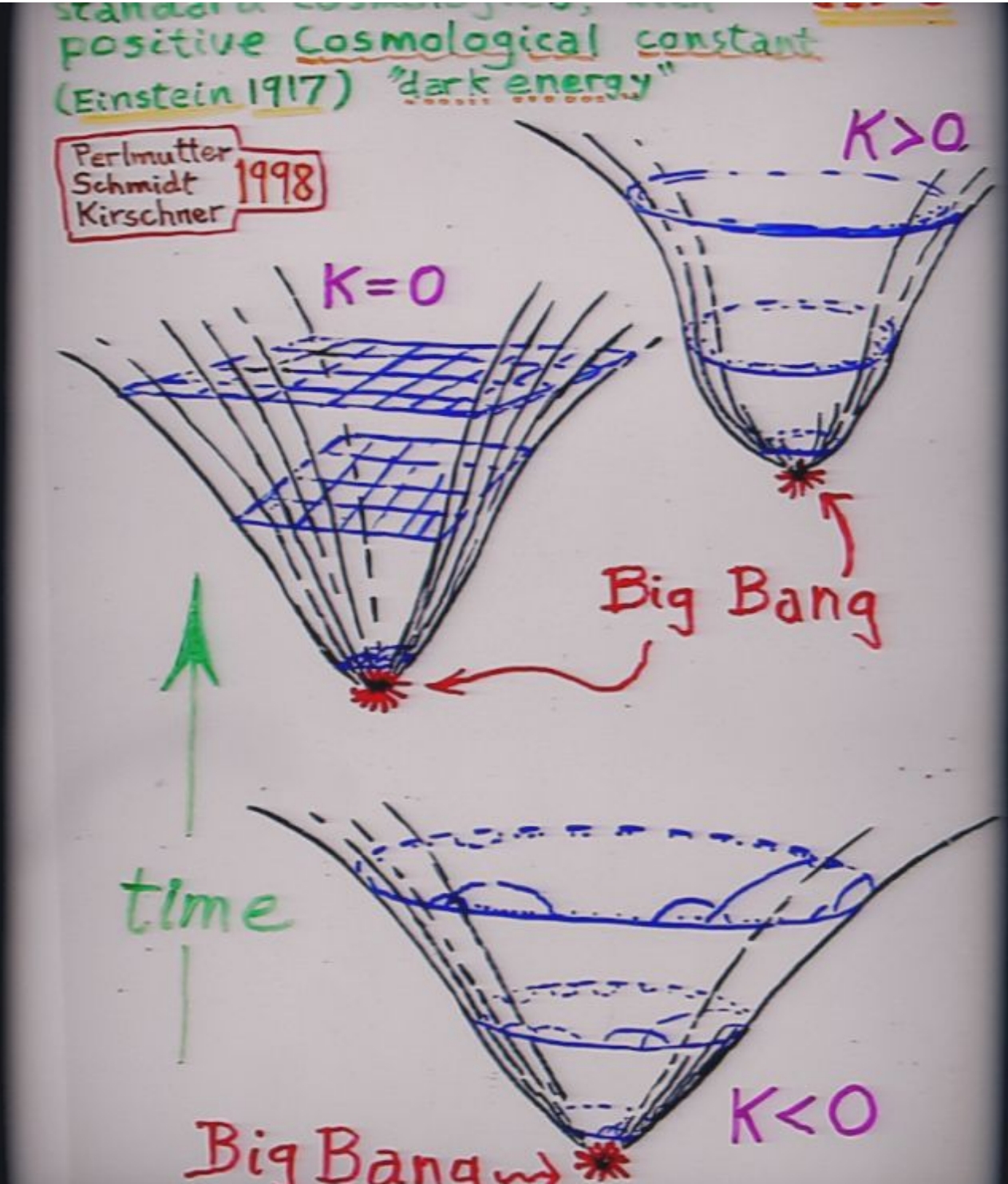
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Big Bang
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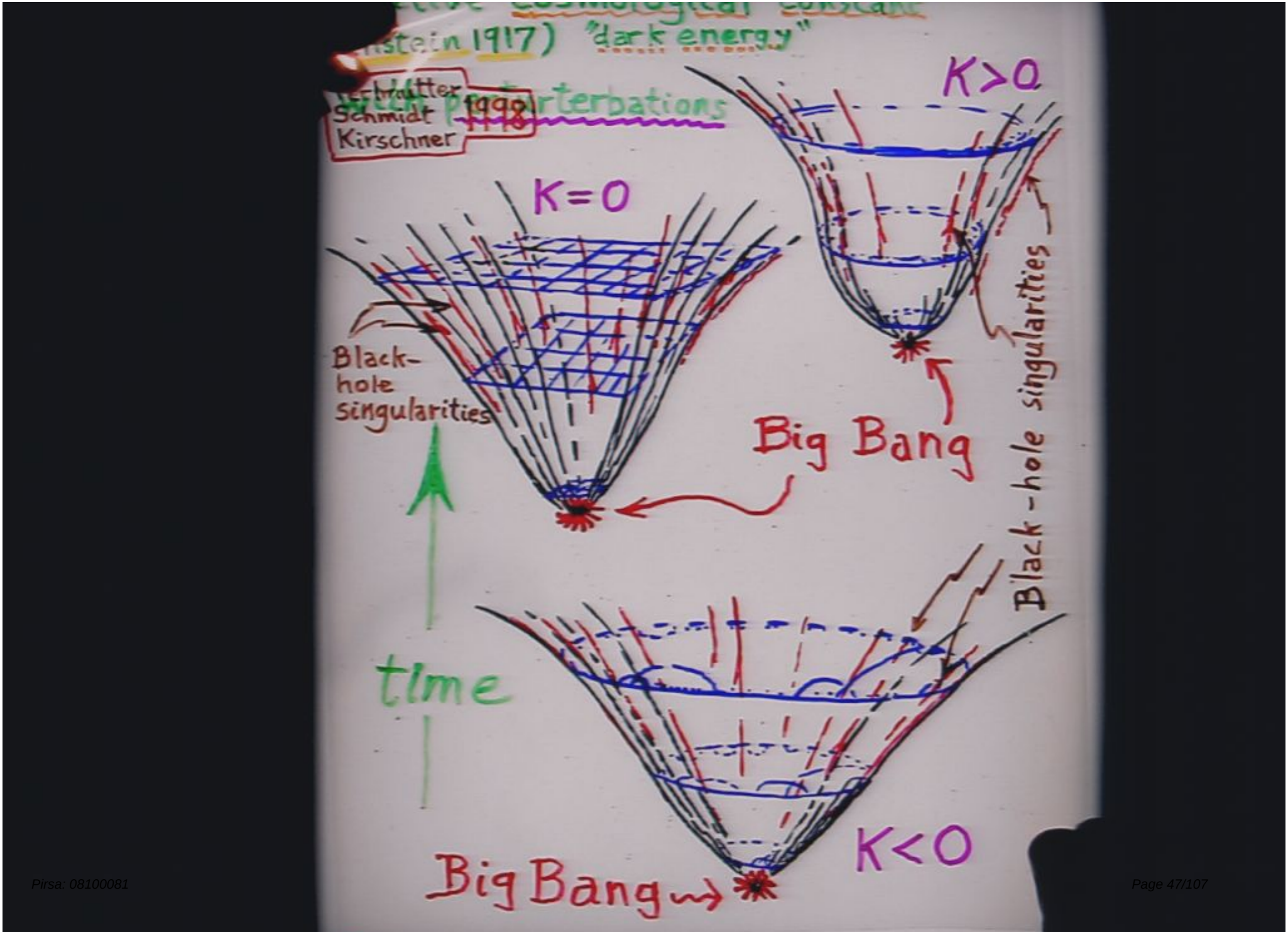
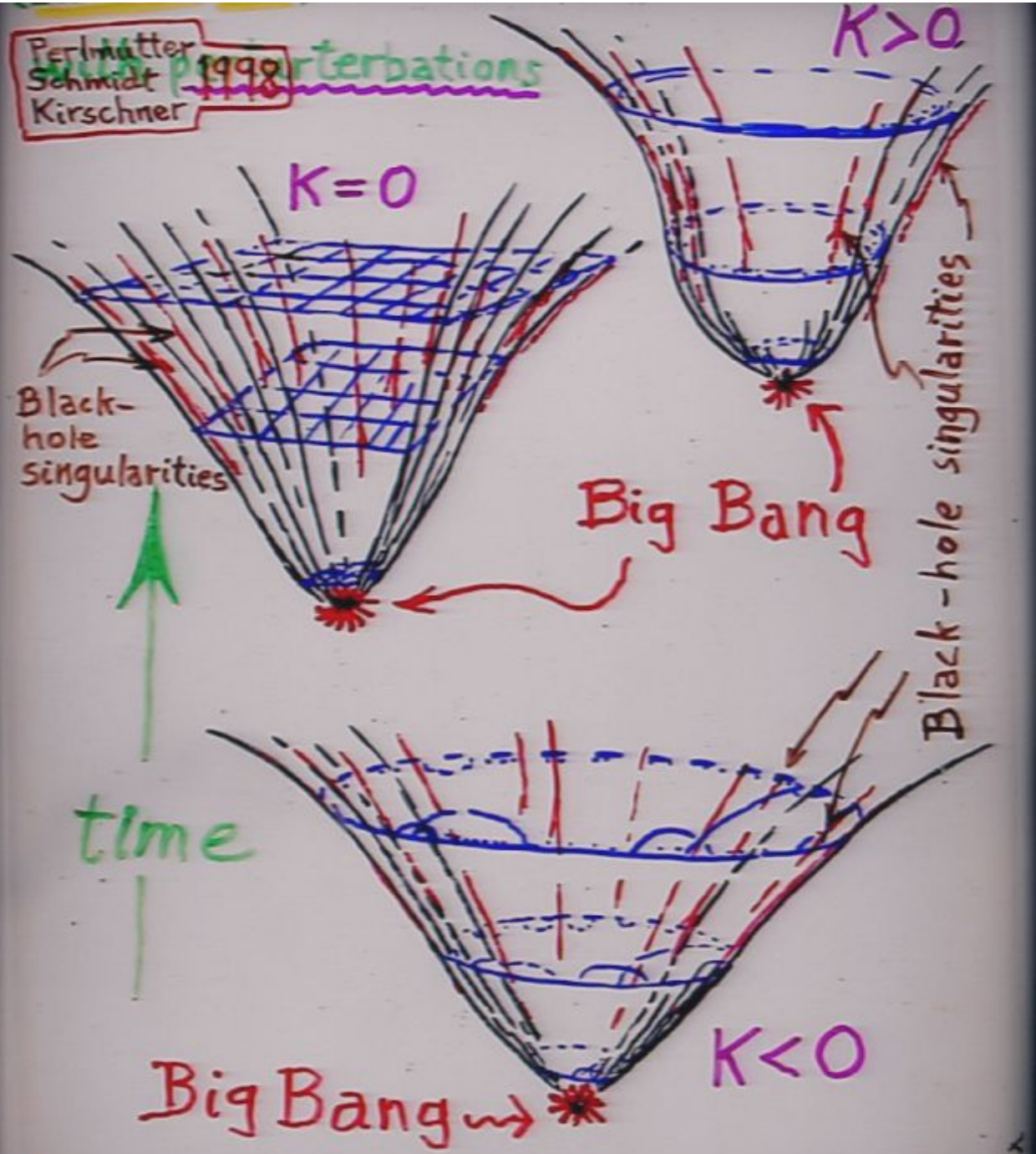
Big Bang


"dark energy"
Hofter
Schmidt 1990
Kirschner
K>0
K=0
Black-hole singularities
Big Bang
Black-hole singularities
time
K<0
Big Bang


Perlmutter
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K>0
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Black-
hole
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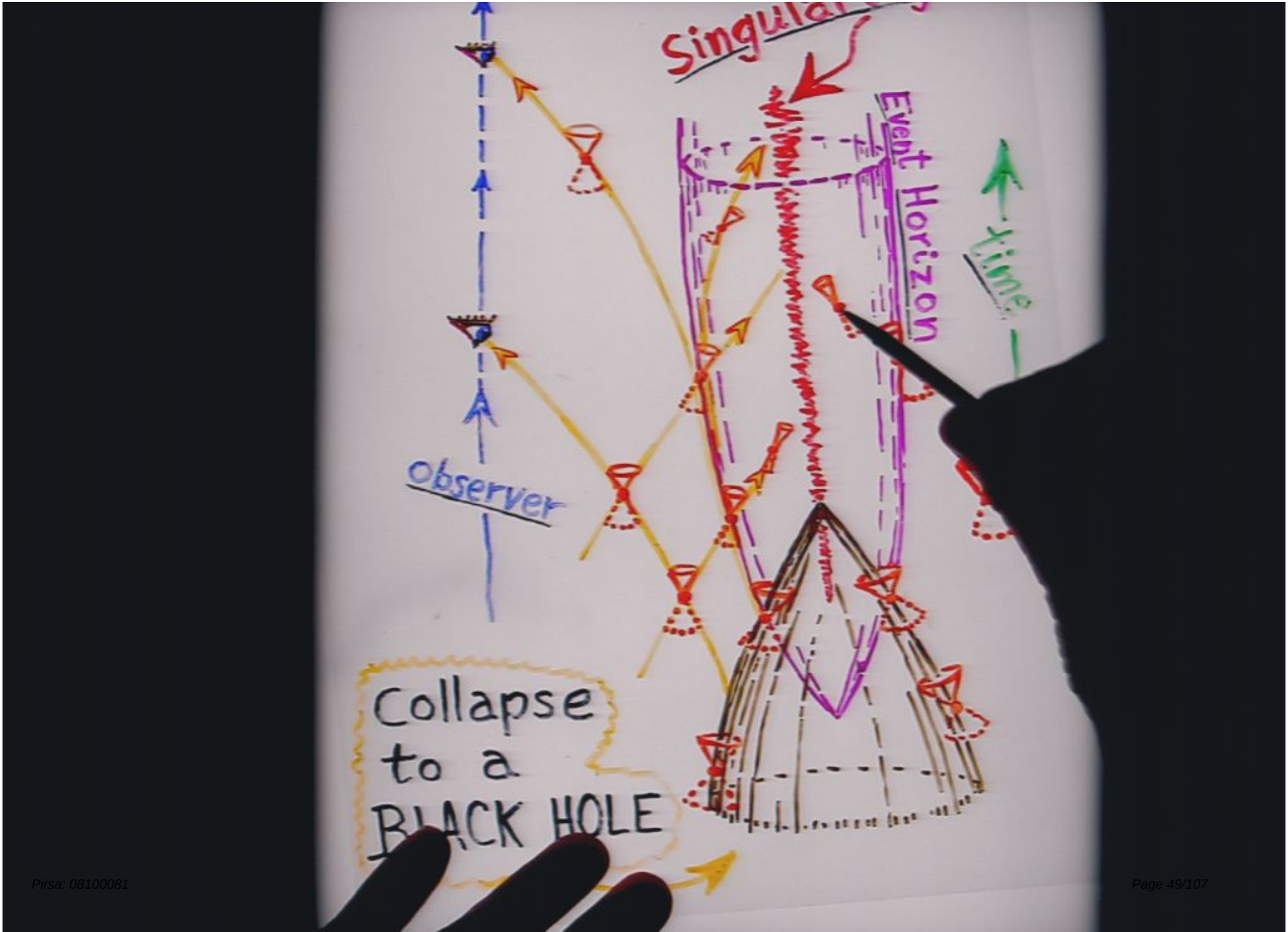
Big Bang
K<0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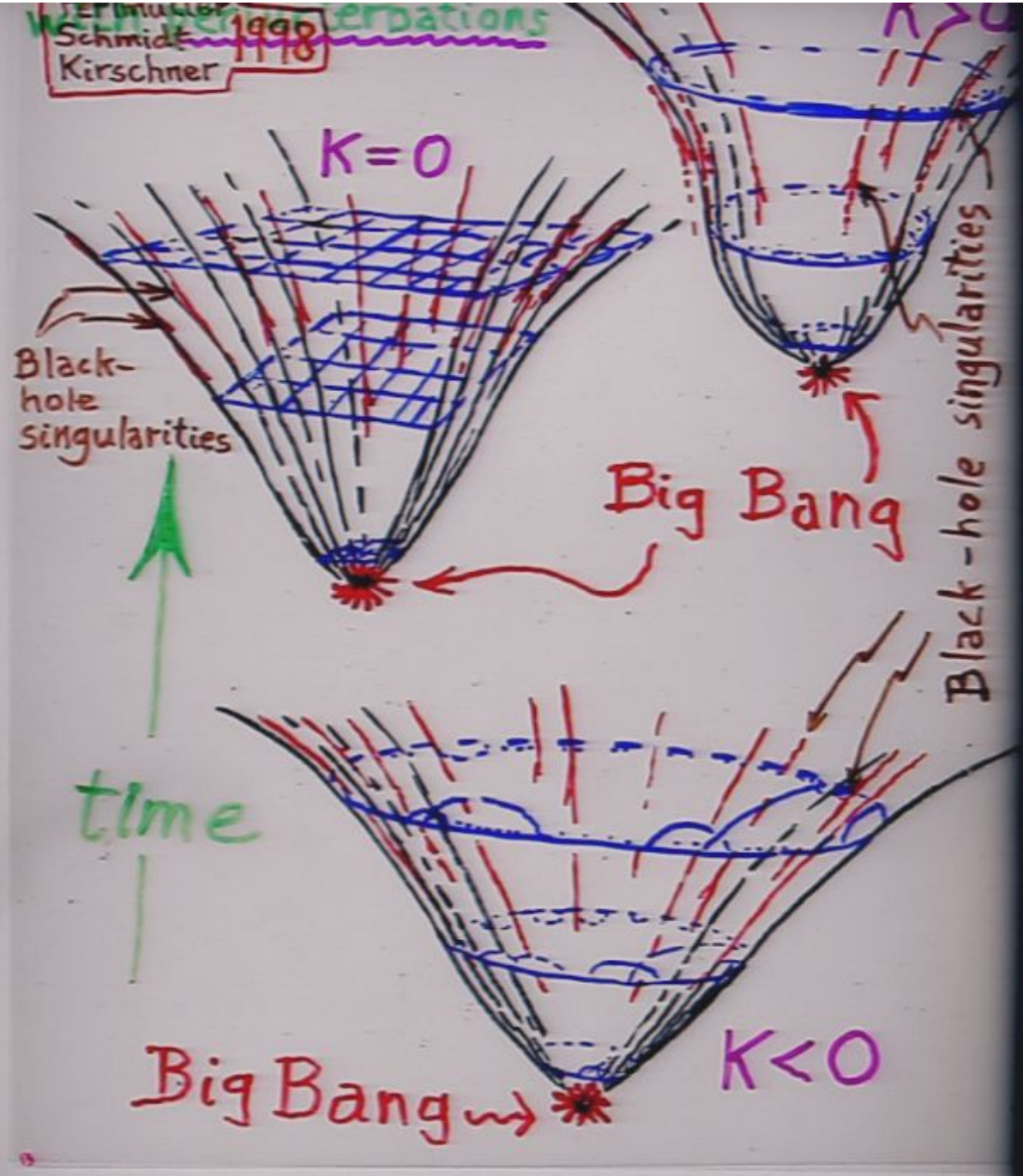
Ehlers
Schmidt
Kirschner
1990
K=0
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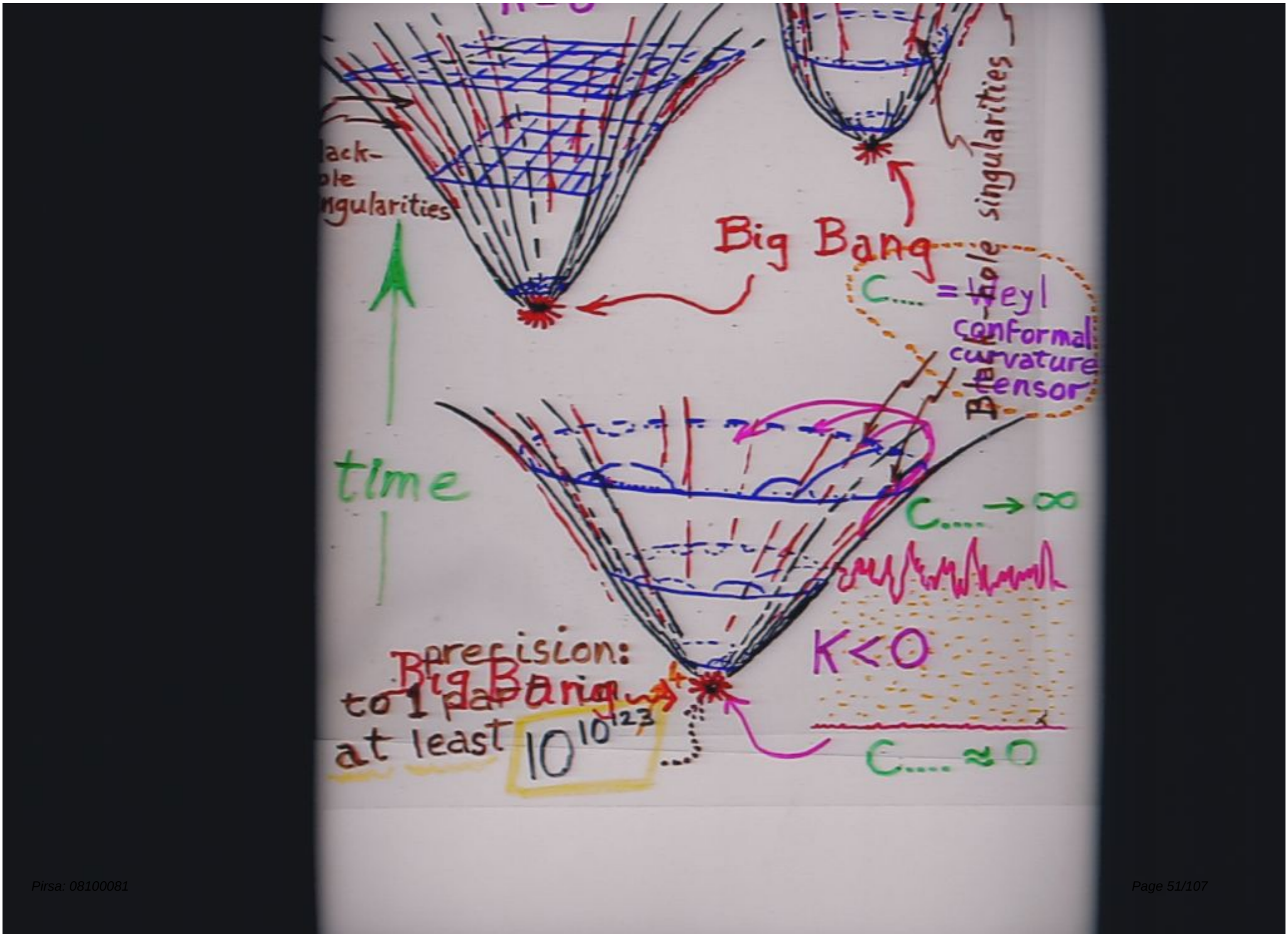
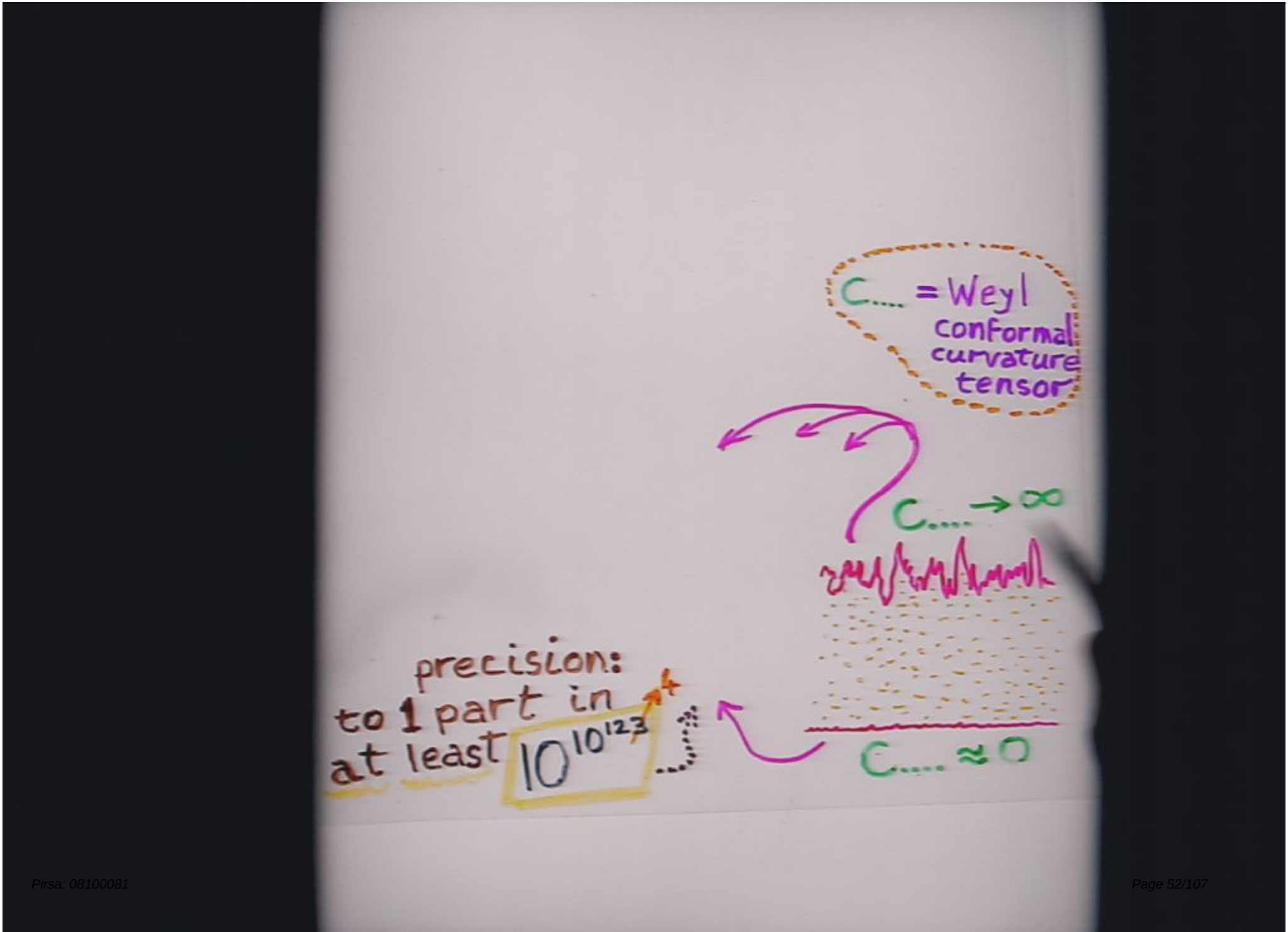
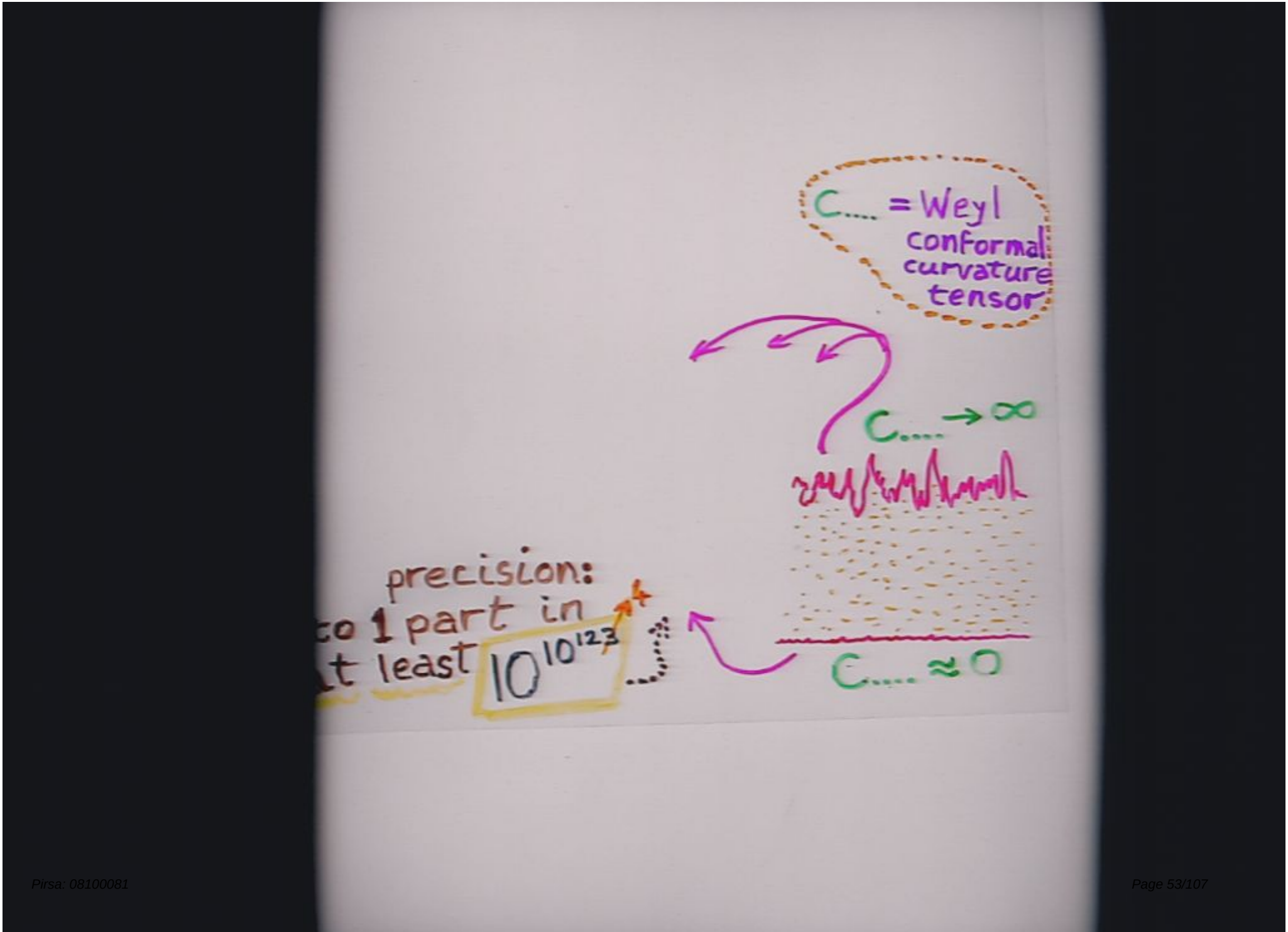
Big Bang
K<0


singularities
Big Bang
Weyl
conformal
curvature
tensor
time
precision:
Big Bang
to 1 part in
at least
$10^{10^{123}}$
K<0


C.... = Weyl conformal curvature tensor
C.... → ∞
C.... ≈ 0
precision:
to 1 part in
at least
$10^{10^{123}}$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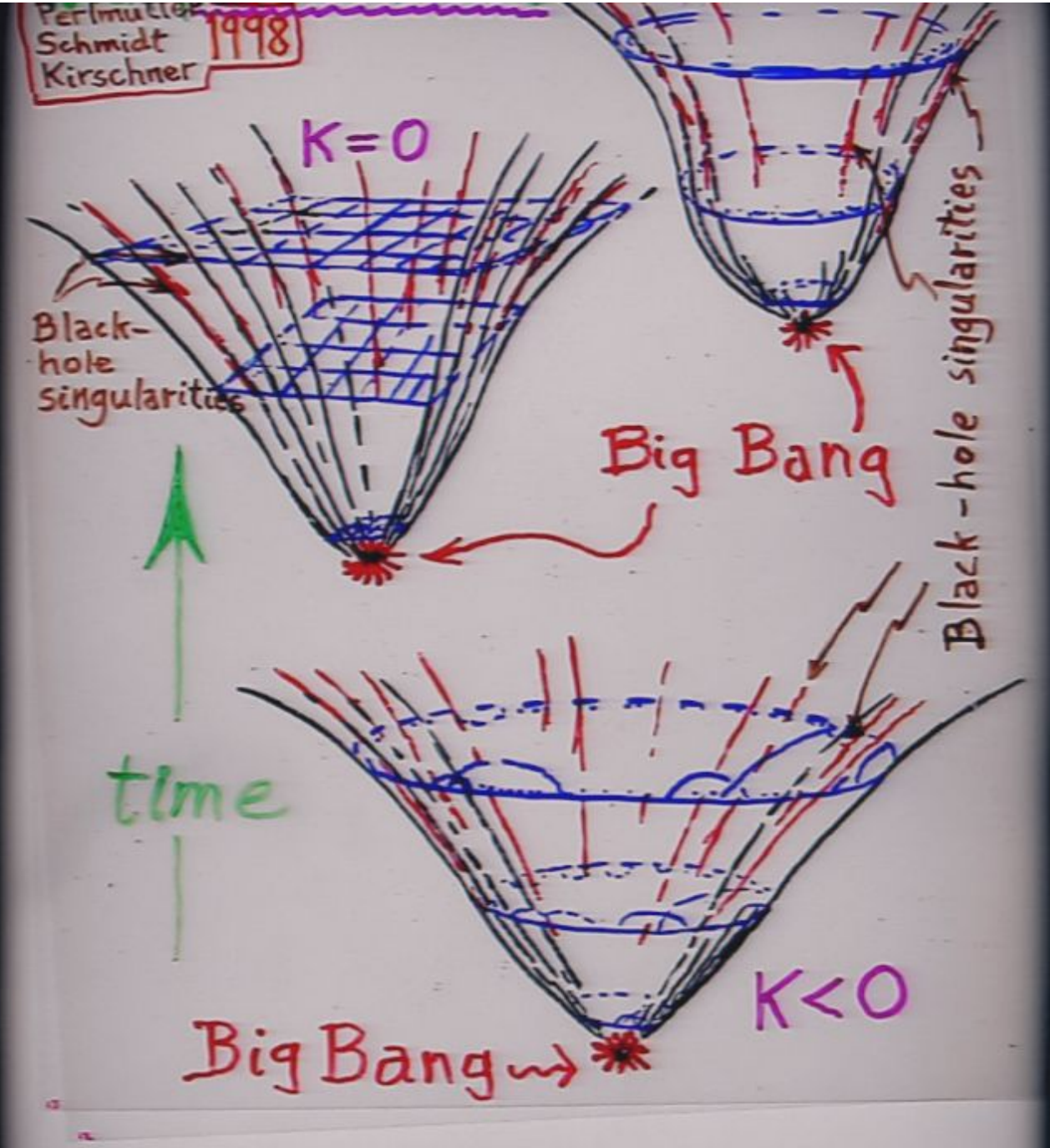
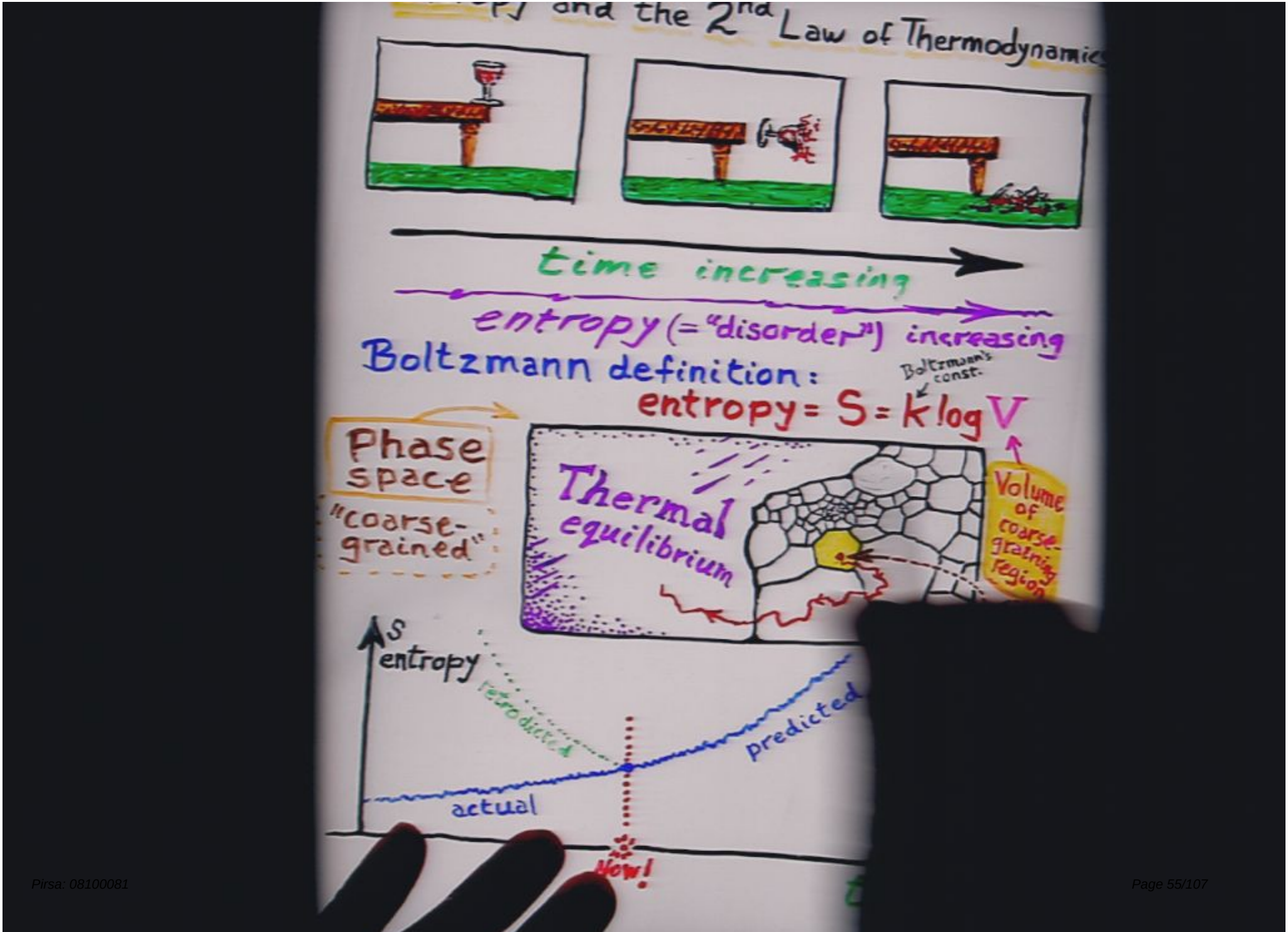
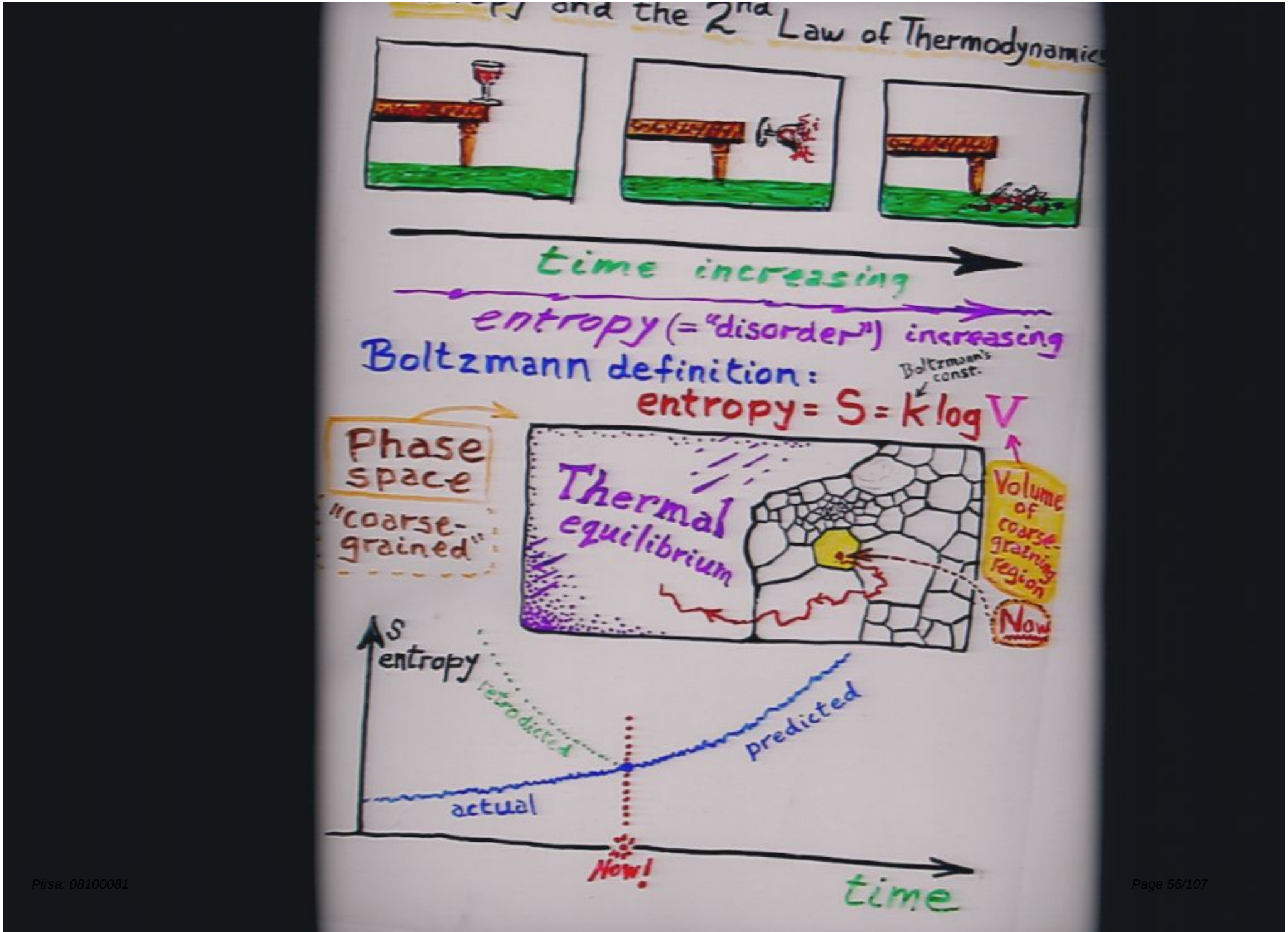
to 1 part in
t least $10^{10^{123}}$


Perlmutter
Schmidt
Kirschner
1998
K=0
Black-
hole
singularities
Big Bang
Black-hole singularities
time
K<0
Big Bang


and the 2nd Law of Thermodynamics
time increasing
entropy (="disorder") increasing
Boltzmann definition:
Boltzmann's const.
entropy = S = k log V
Phase space
"coarse-grained"
Thermal equilibrium
Volume of coarse-graining region
S entropy
retrodicted
predicted
actual
Now!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actual
Now!
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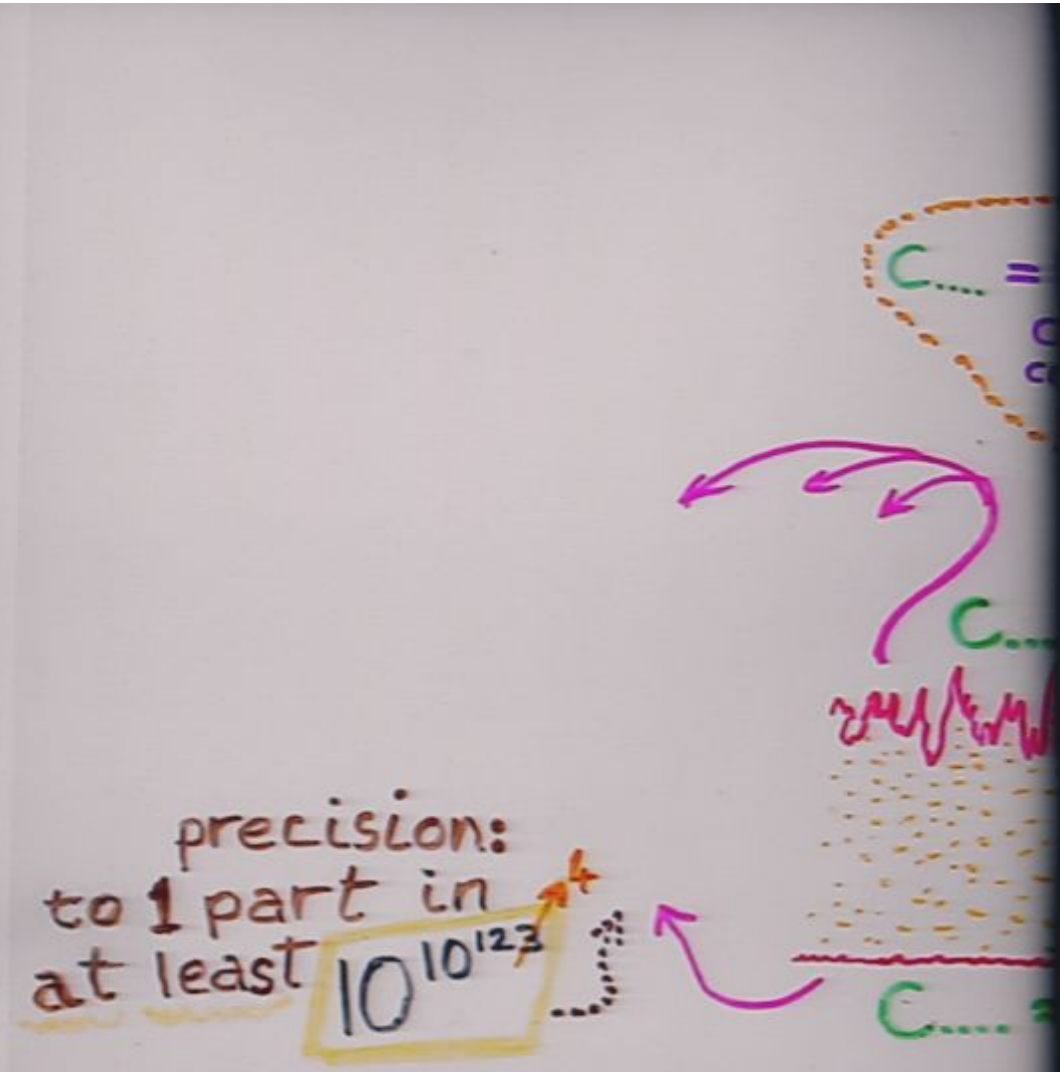
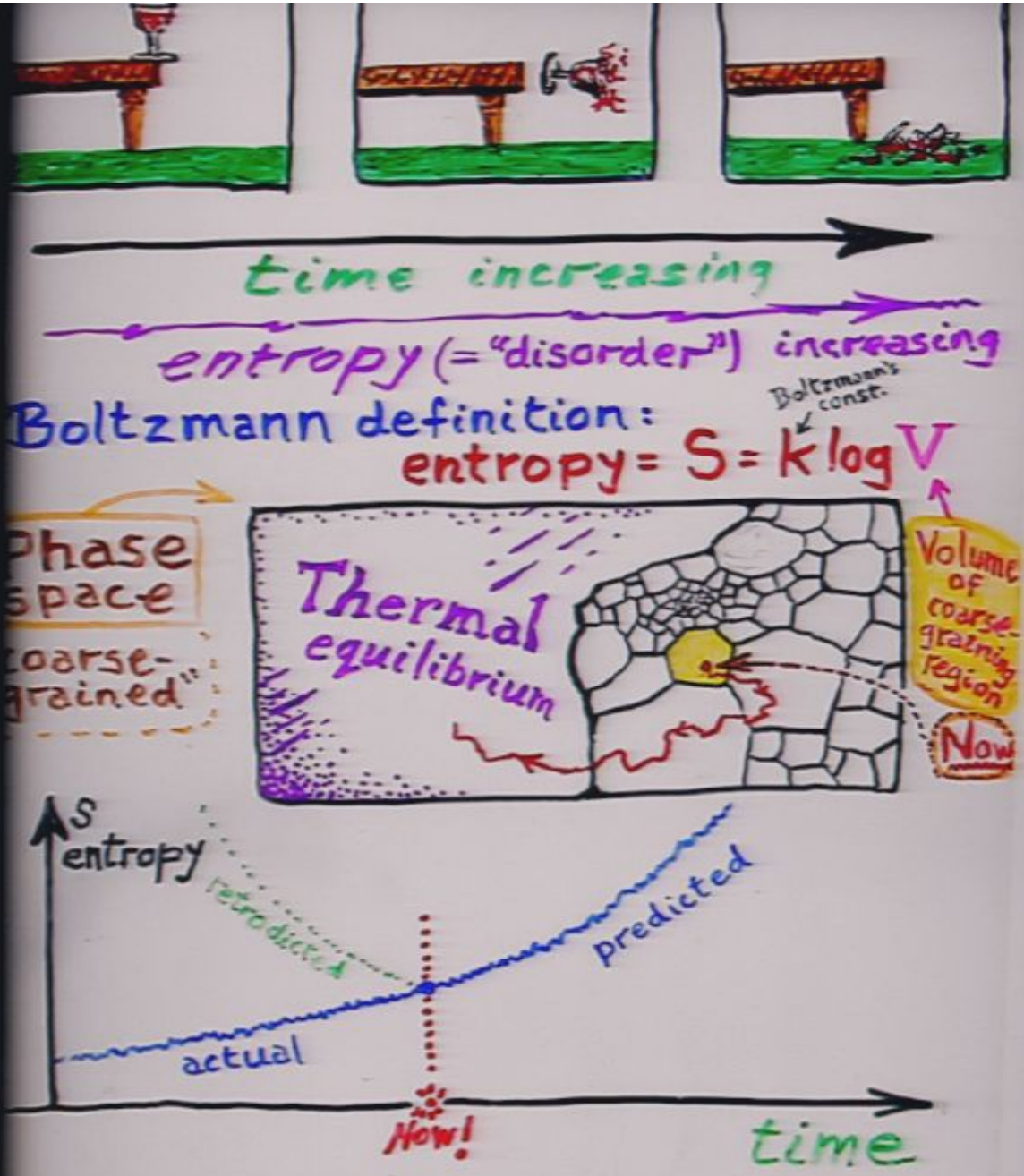

precision:
to 1 part in
at least
$10^{10^{123}}$


time increasing
entropy (="disorder") increasing
Boltzmann definition:
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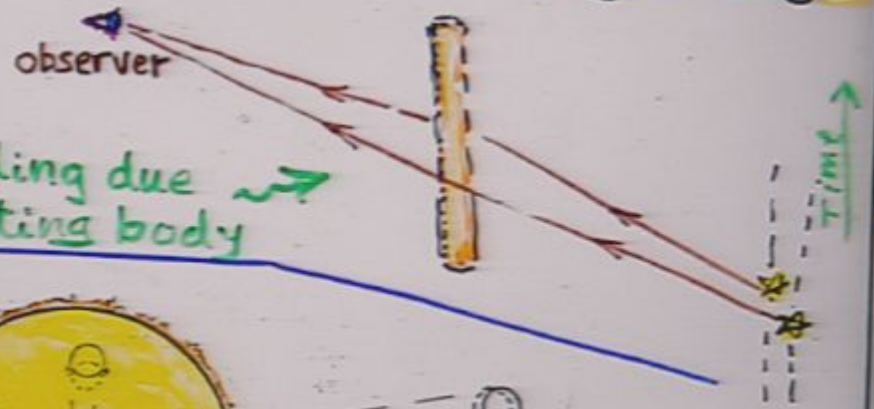
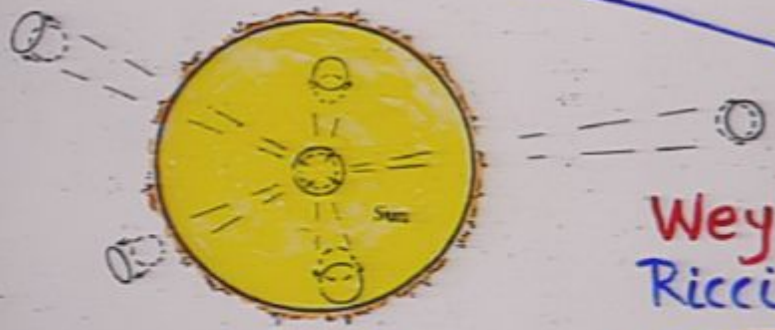
entropy = S = k log V
Phase space
coarse-grained"
Thermal equilibrium
Volume of coarse-graining region
Now
S entropy
retrodicted
predicted
actual
Now!
time

Effects of Weyl & Ricci (trace-free) space-time curvature on light rays



light bending due to gravitating body



spatial picture

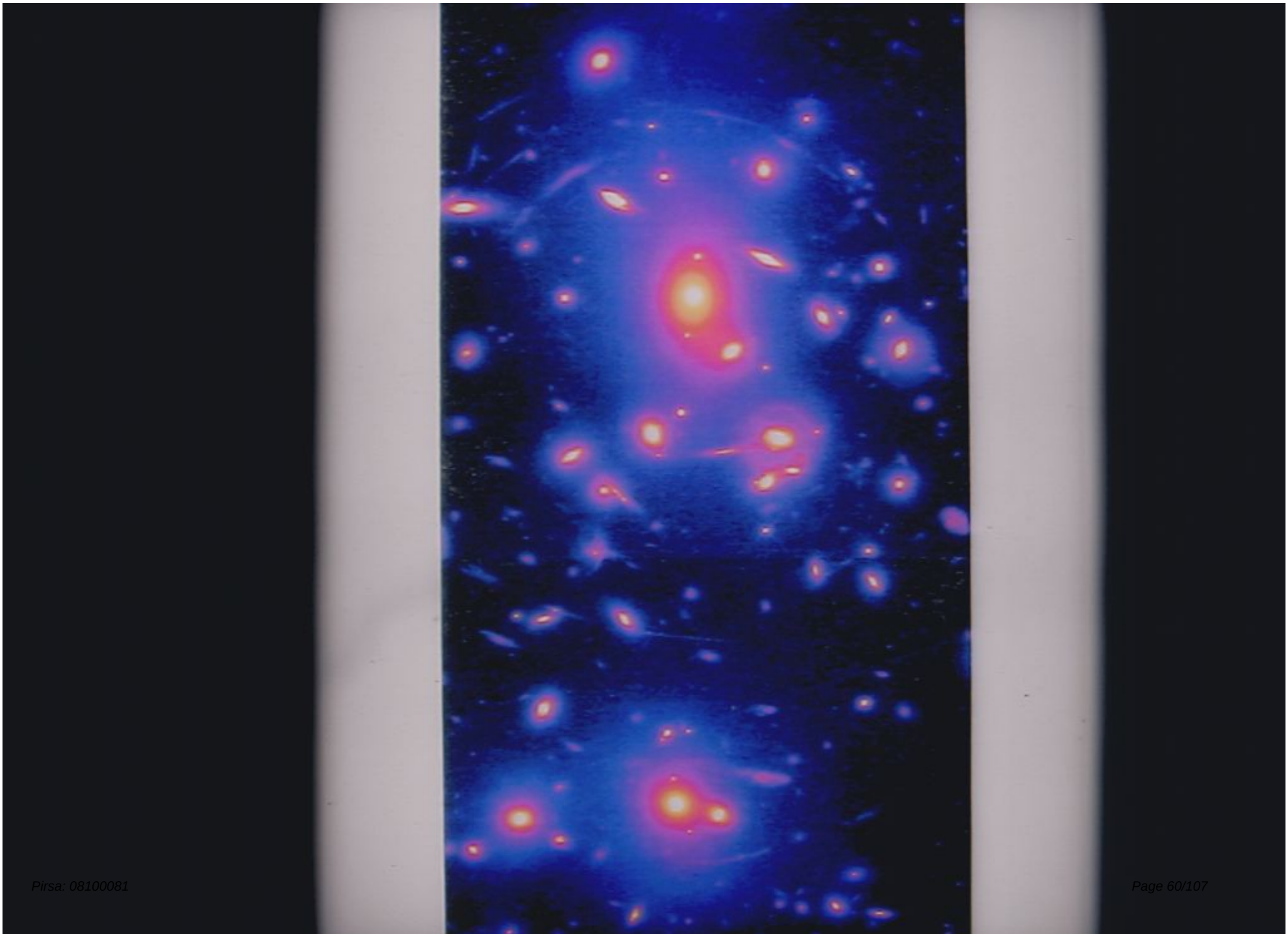
Weyl: distortion
Ricci: magnification

$$\overset{20}{\text{Riemann}} = \overset{10}{\text{Weyl}} + \overset{9+1}{\text{Ricci}}$$

geodesic deviation of light rays

Ricci from matter

Weyl curvature = conformal curvature

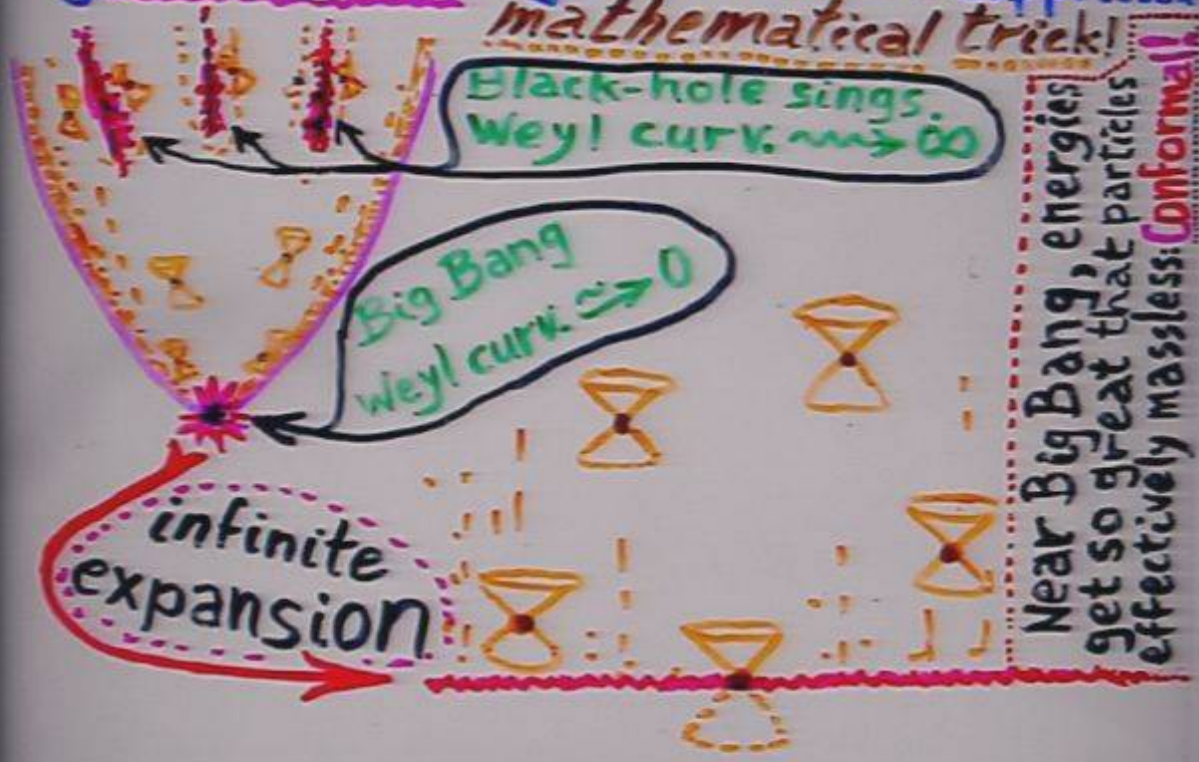


Tod's conformal formulation

Constraint on Big Bang: 1 part in $10^{10^{124}}$

- from Bekenstein-Hawking black-hole entropy for hole from 10^{80} baryons + some dark matter [protons, neutrons?]

⇒ 2nd Law – in the form we know it, with great spatial uniformity, so gravitational degrees of freedom suppressed mathematical trick!



12. CIRCLE LIMIT IV (*Heaven and Hell*), woodcut printed from two blocks, diam. 42 cm., 1960.

Starting from the six central figures — three white angels and three black devils — the circle can be divided into six sectors in which alternately the white and the black figures function as "background" and as "object" (see captions of prints 1 and 2). In three sectors the white angels prevail, in three others the black devils. The notions of "heaven" and "hell" constantly alternate, via stages in which angels and [illegible] figures are equivalent.

K<0

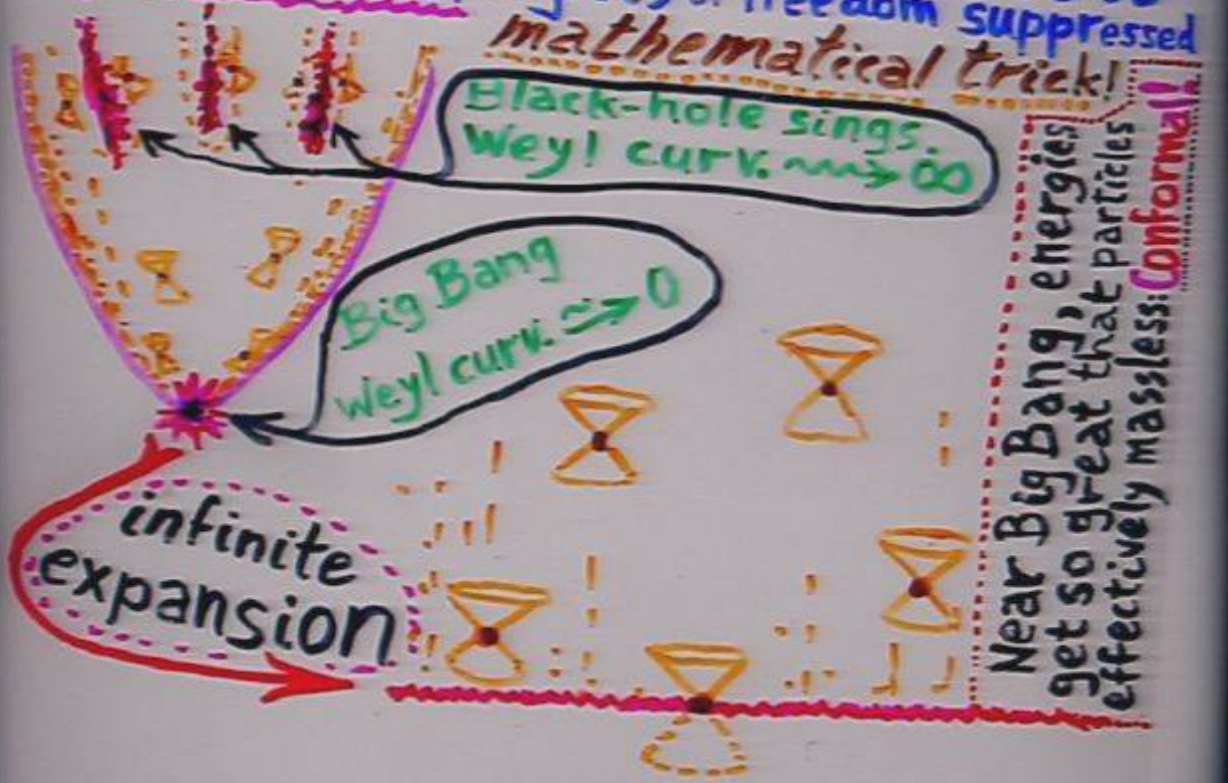
formulation

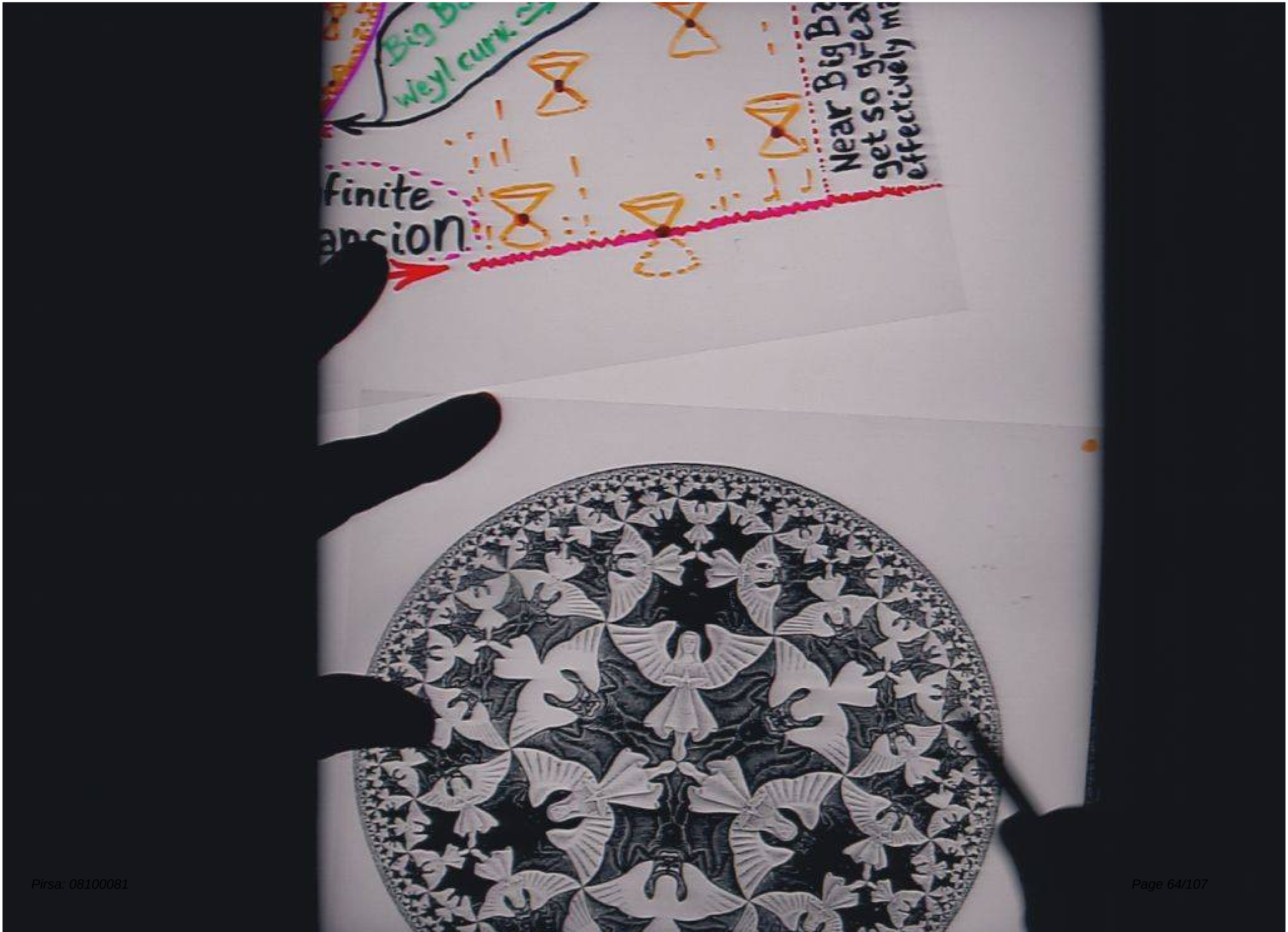
Constraint on Big Bang: 1 part in $10^{10^{124}}$

-from Bekenstein-Hawking black-hole entropy for hole from 10^{80} baryons + some dark matter [protons, neutrons?]

$\Rightarrow$ 2nd Law – in the form we know it, with great spatial uniformity, so gravitational degrees of freedom suppressed

mathematical trick!




Big B
weyl curv
finite
ansion
Near Big B
get so grea
effectively

Weyl curvature hypothesis

Tod's conformal formulation

Constraint on Big Bang: 1 part in $10^{10^{123}}$

- from Bekenstein-Hawking black-hole entropy for hole from 10^{80} baryons + some dark matter [protons, neutrons]

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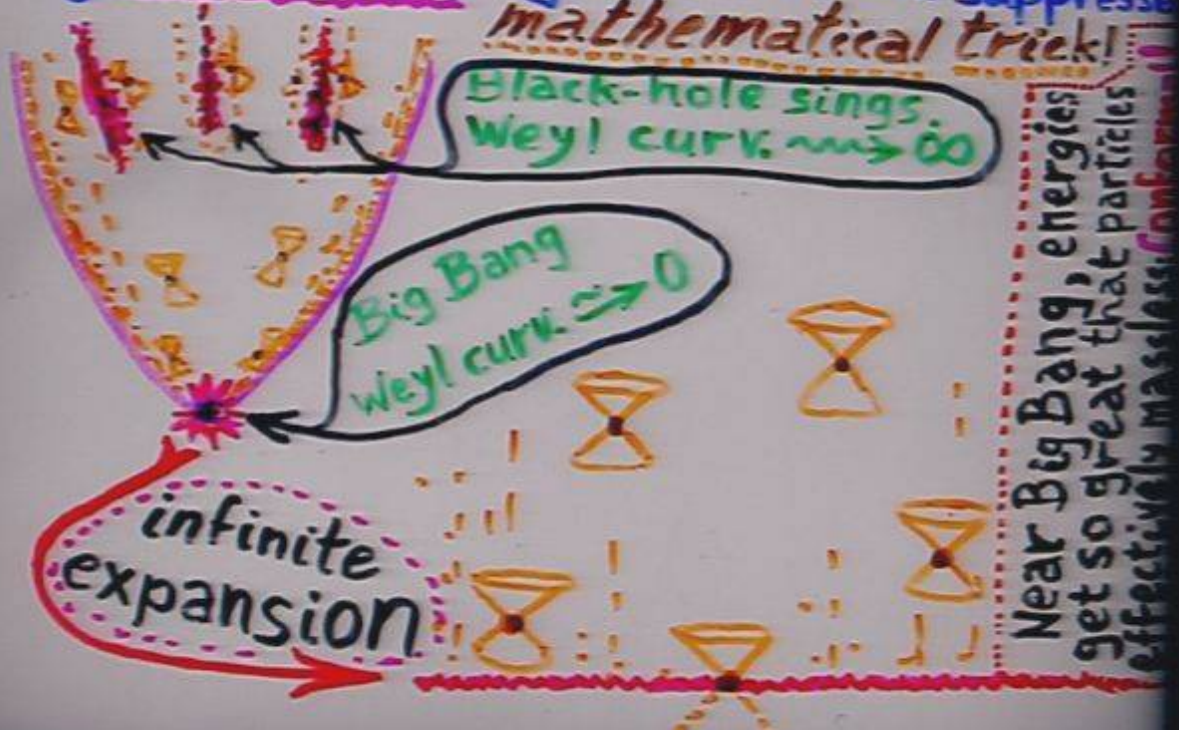
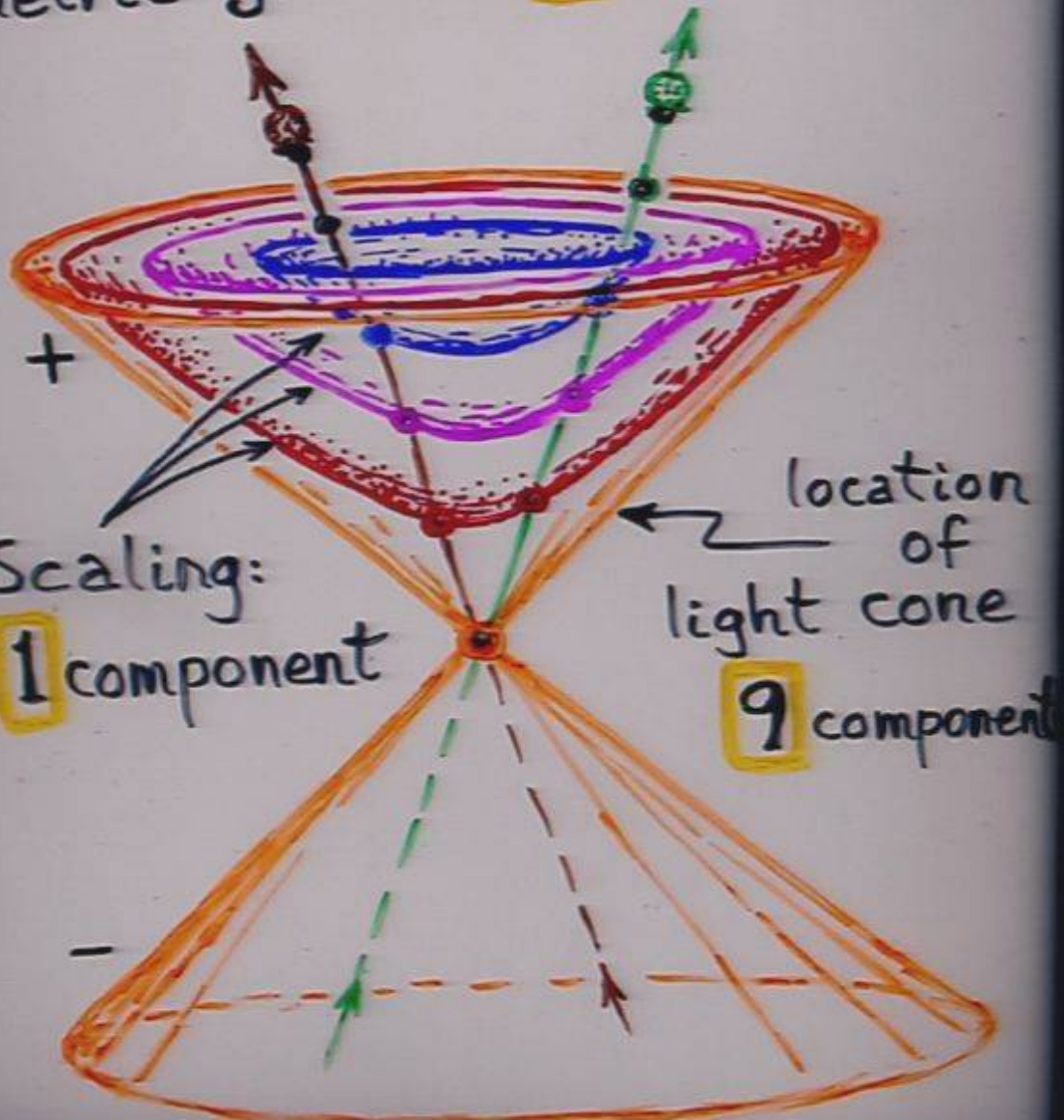
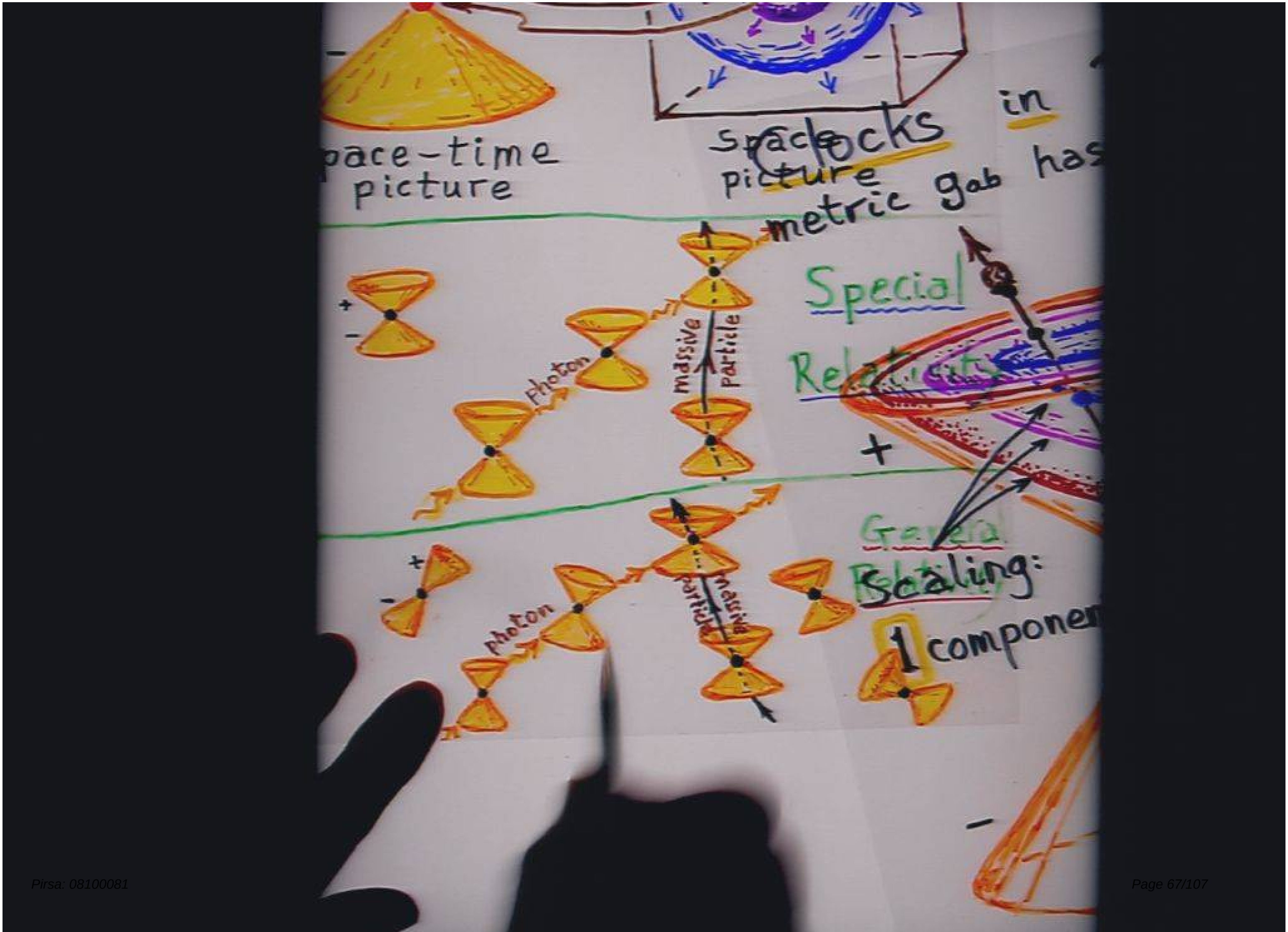
mathematical trick!



Clocks in Relativity

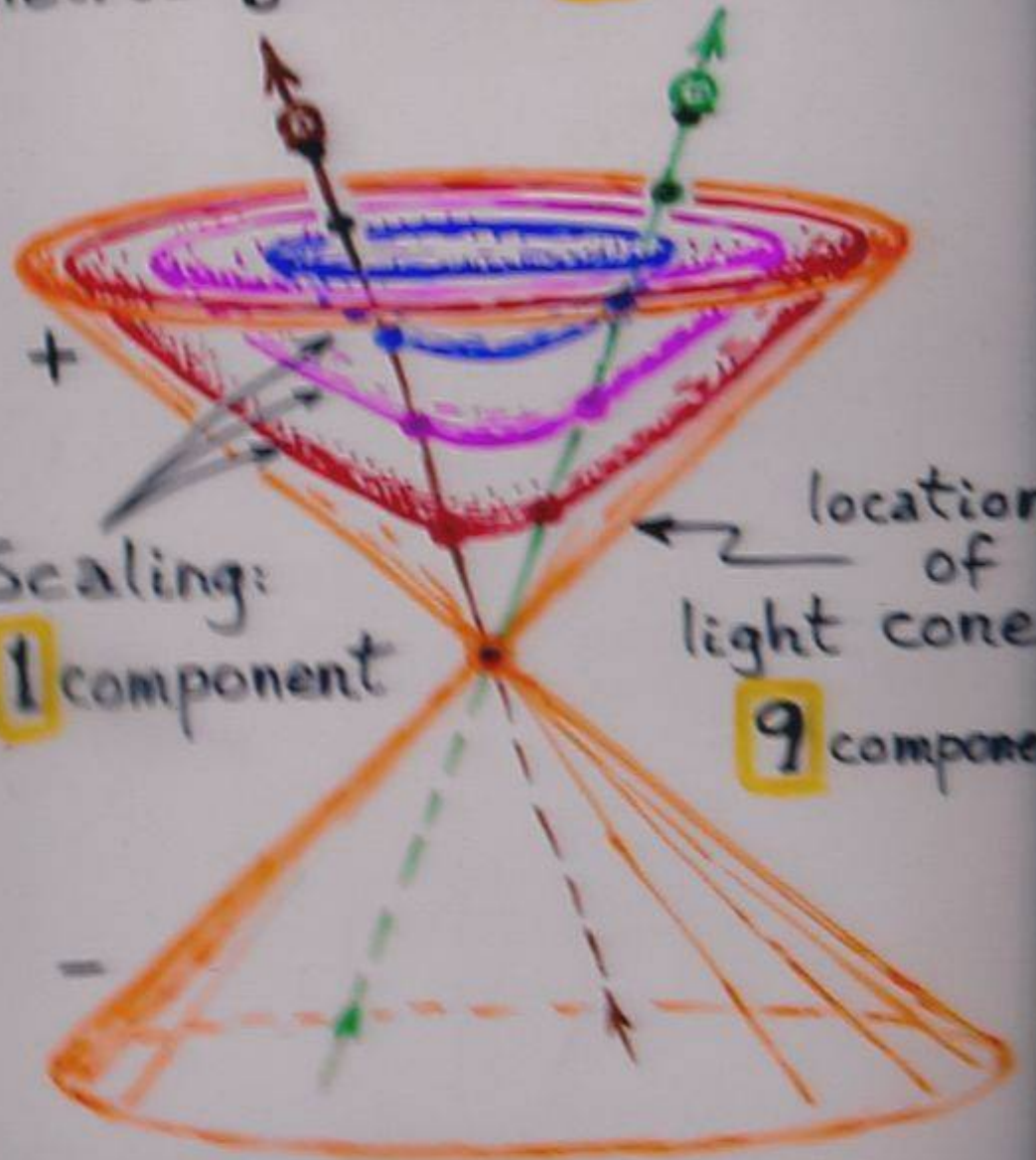
metric g_{ab} has 10 components

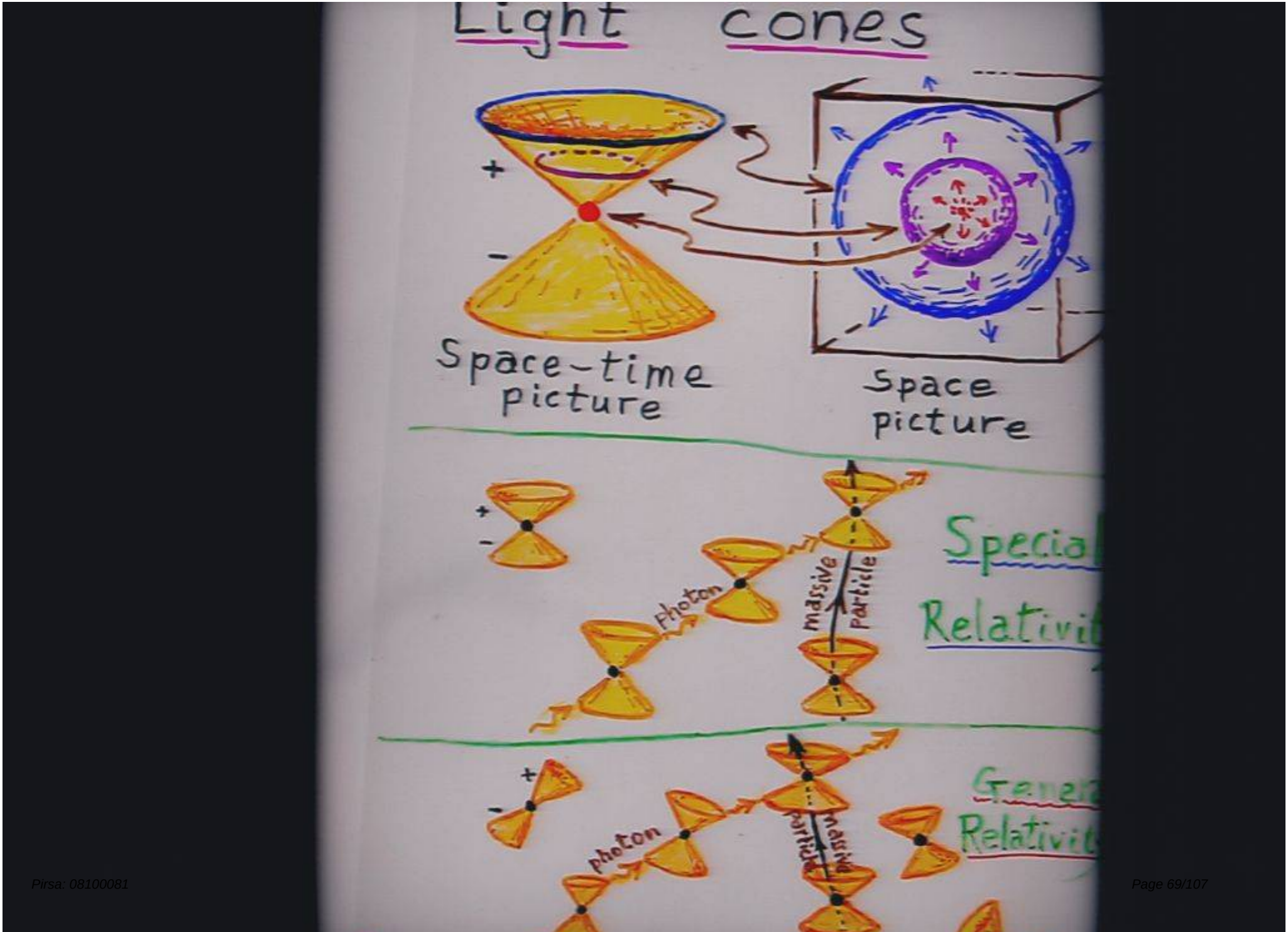


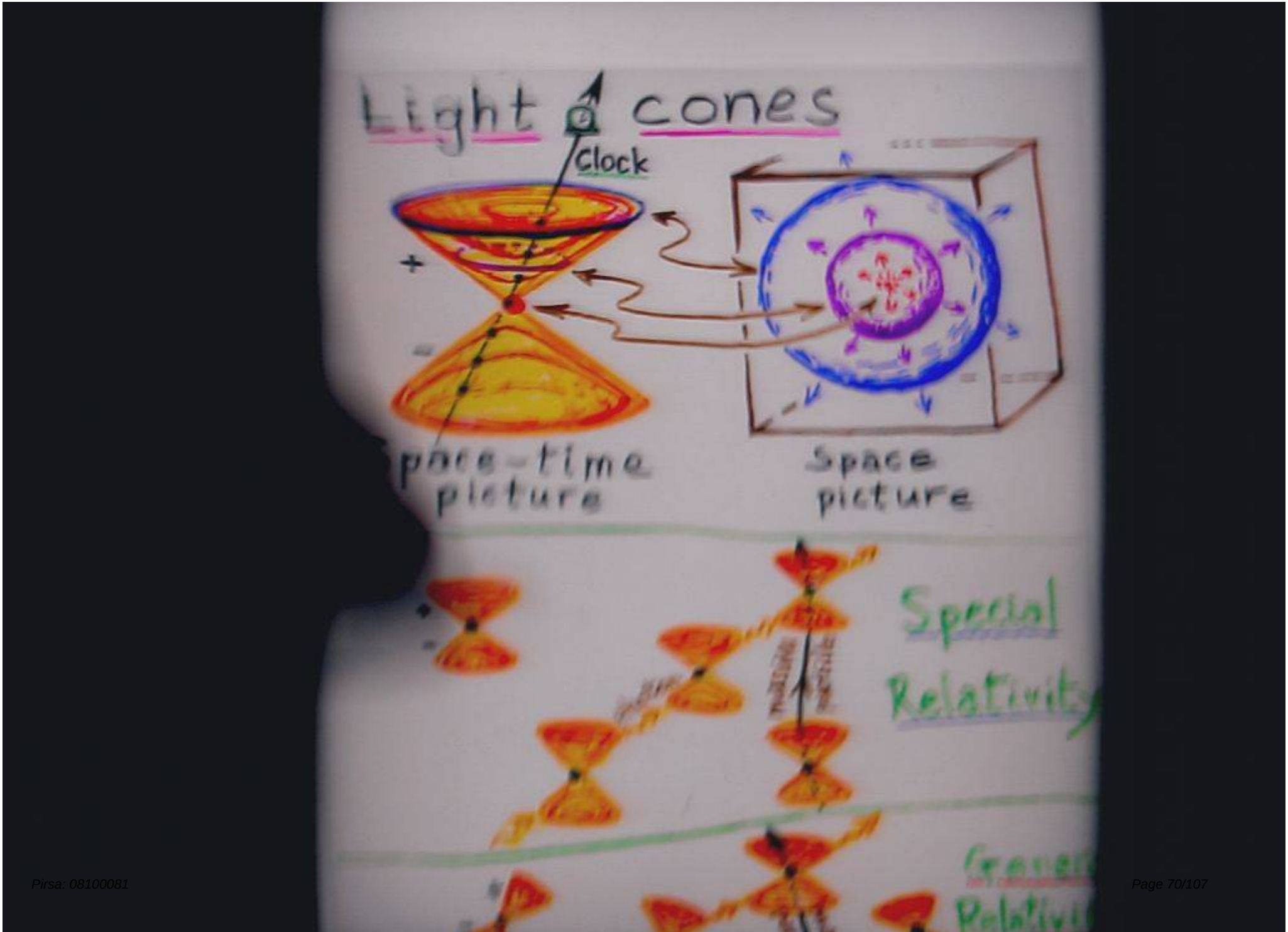

pace-time
picture
Space
picture
Clocks in
metric gab has
Special
photon
massive
particle
Scaling:
1 componen

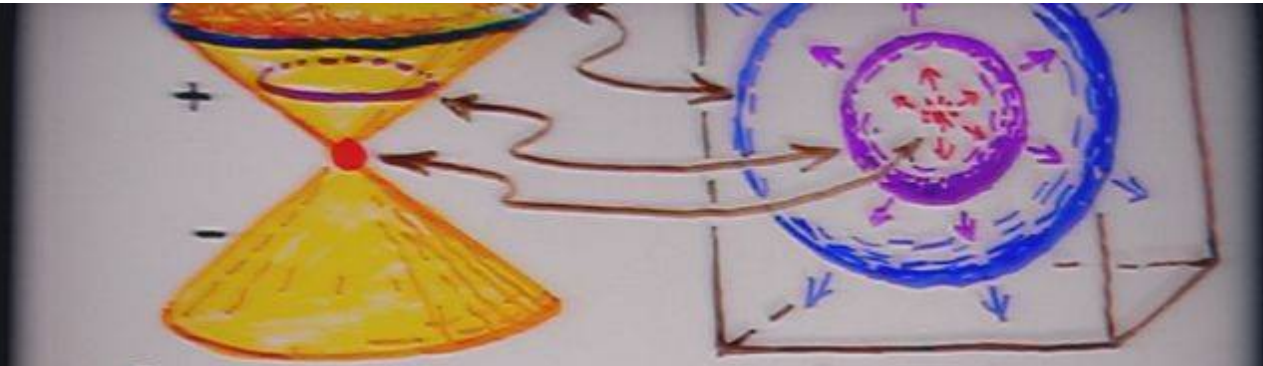
Clocks in Relativity

metric g_{ab} has 10 components



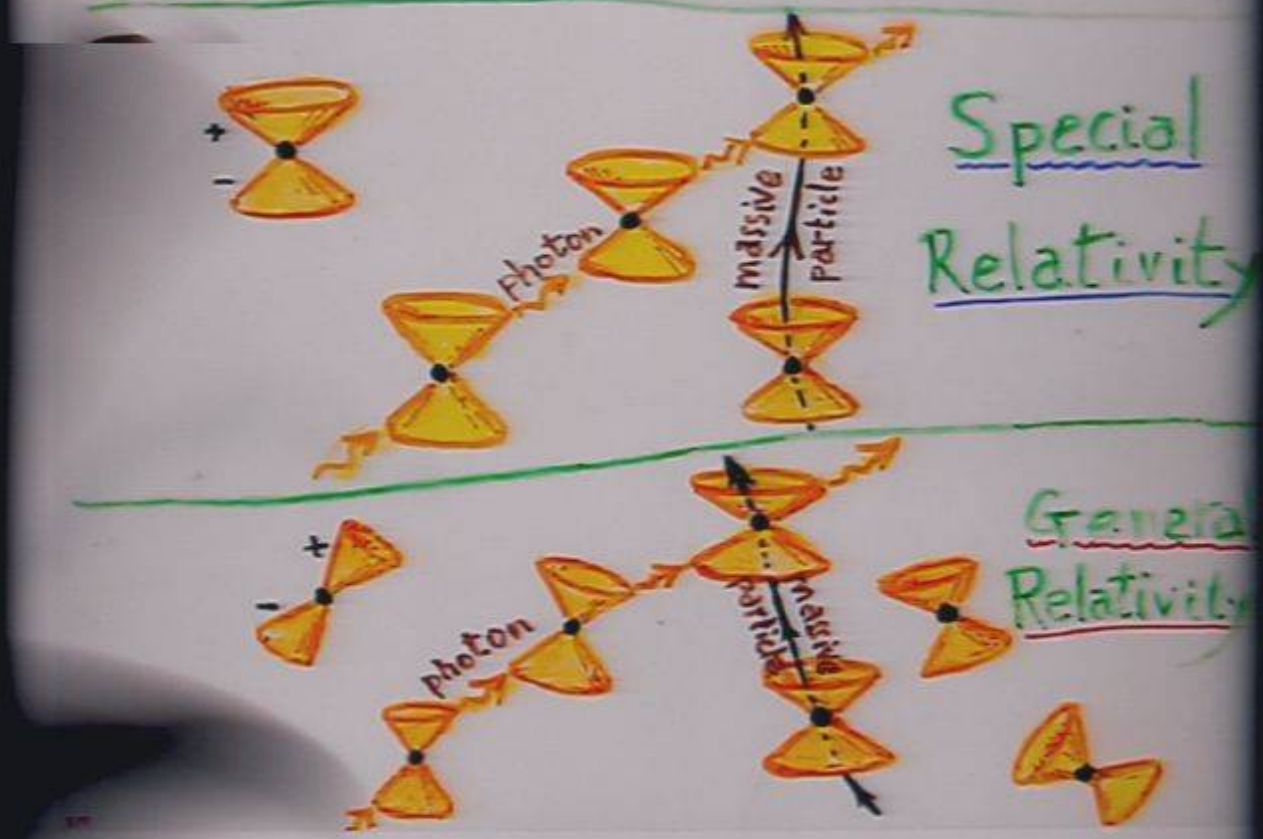

Light cones
+
-
Space-time picture
Space picture
+
-
Photon
massive particle
Special
Relativity
+
-
photon
massive particle
General
Relativity

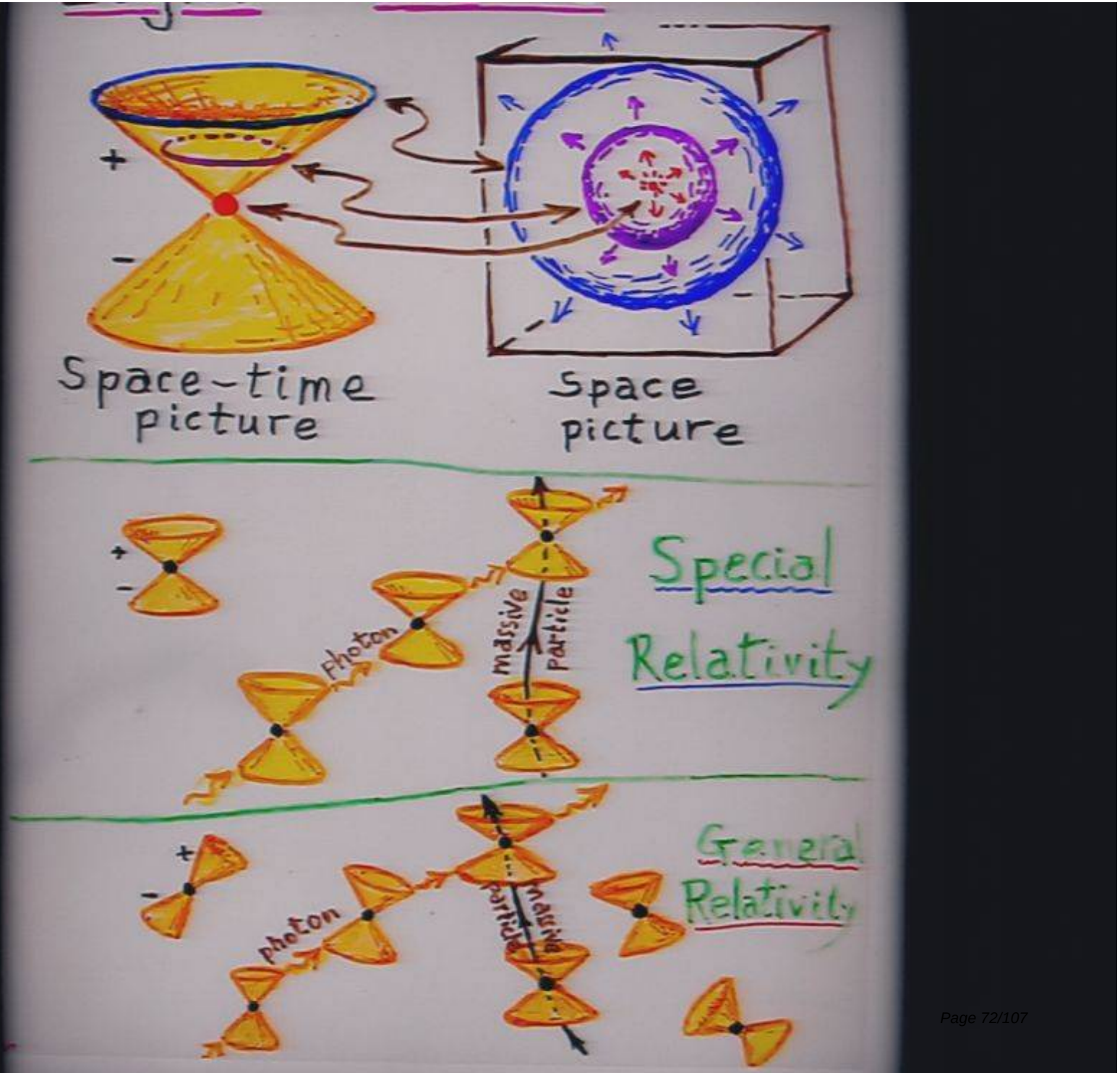

Light cones
Clock
+
-
pace-time
picture
Space
picture
Special
Relativity

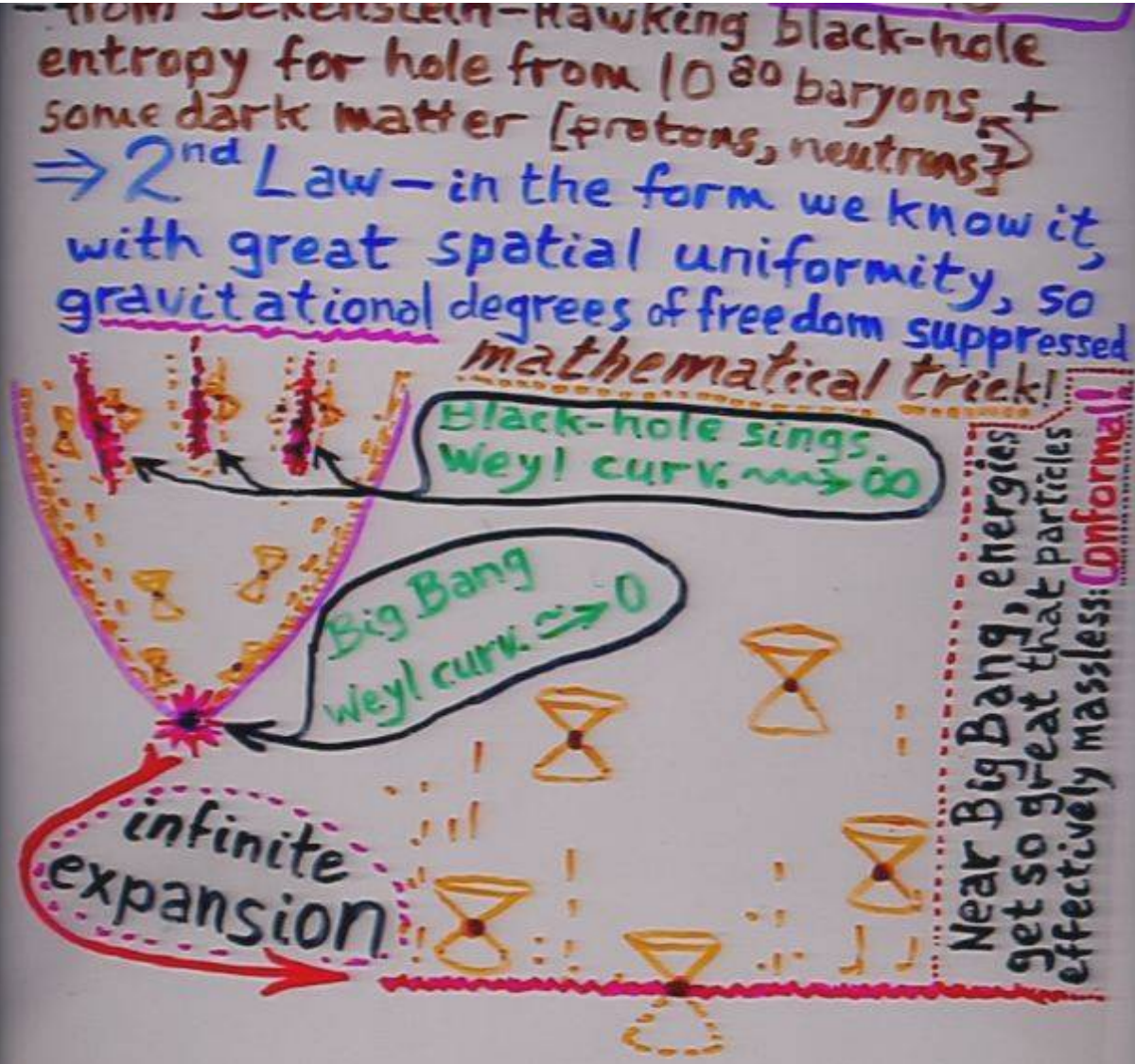


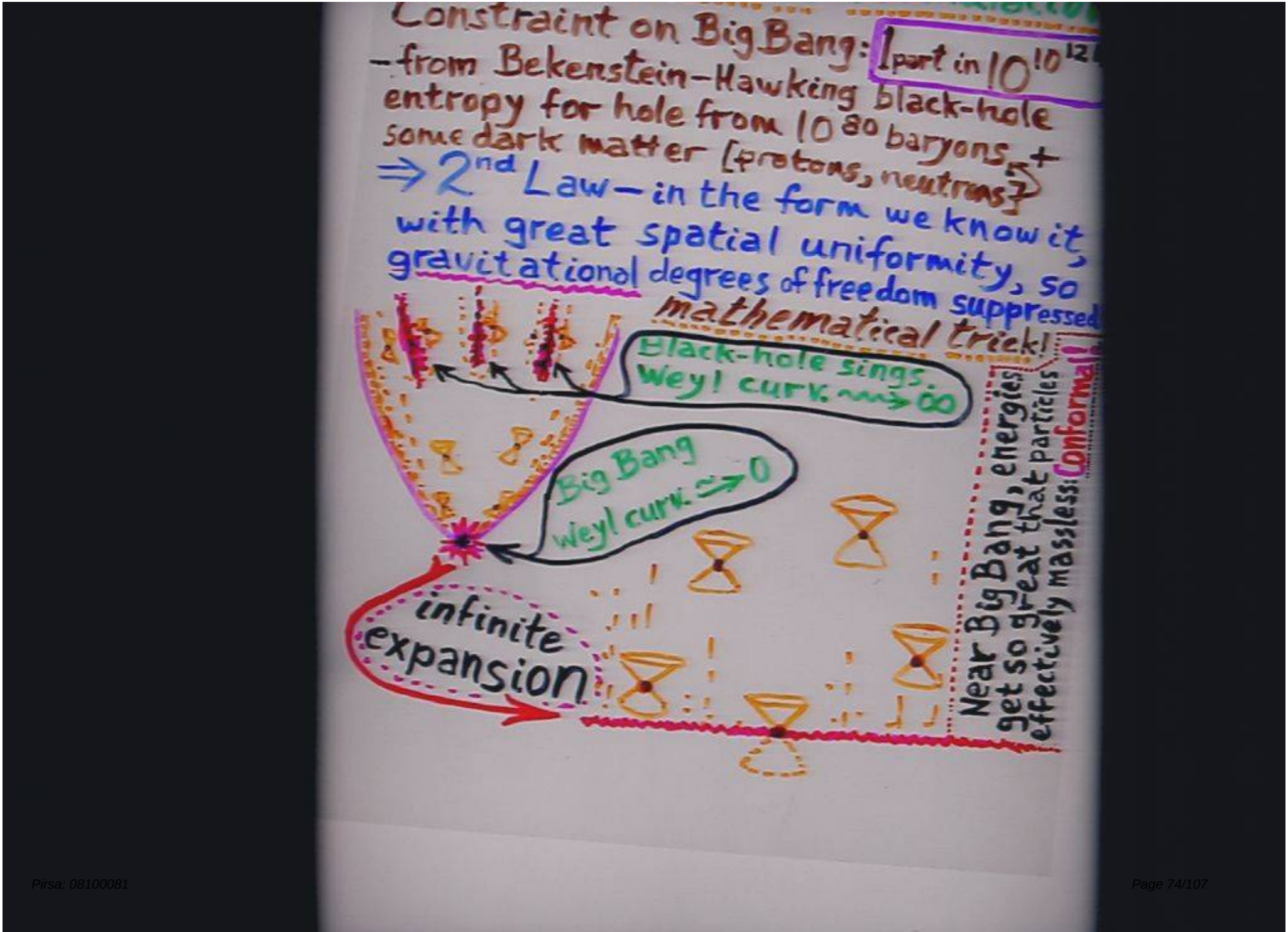
Space-time picture

Space picture




+
−
Space-time picture
Space picture
Special Relativity
Photon
massive particle
General Relativity
photon
massive particle


-Hawking black-hole
entropy for hole from 10^{80} baryons +
some dark matter [protons, neutrons]
⇒ 2nd Law – in the form we know it,
with great spatial uniformity, so
gravitational degrees of freedom suppressed
mathematical trick!
Black-hole sings.
Weyl curv. → ∞
Big Bang
Weyl curv. → 0
infinite
expansion
Near Big Bang, energies
get so great that particles
effectively massless: Conformal!!


Constraint on Big Bang: 1 part in $10^{10^{12}}$
-from Bekenstein-Hawking black-hole entropy for hole from 10^{80} baryons + some dark matter [protons, neutrons]
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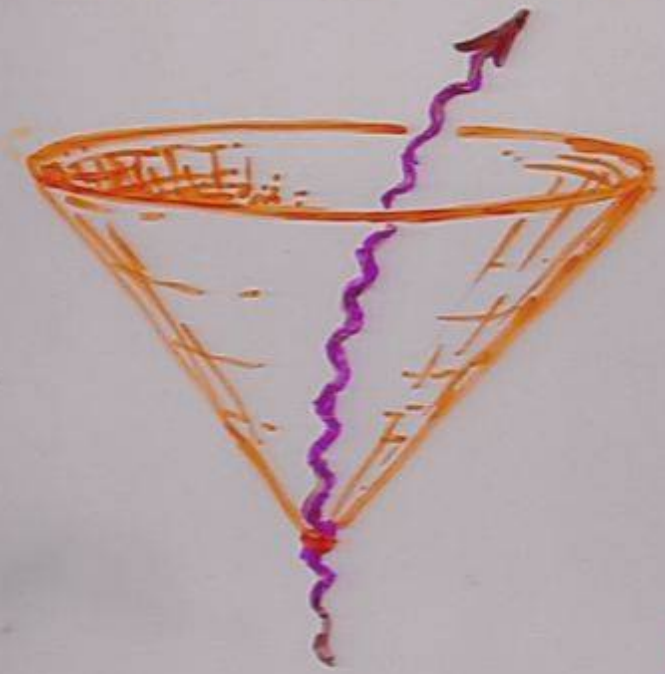
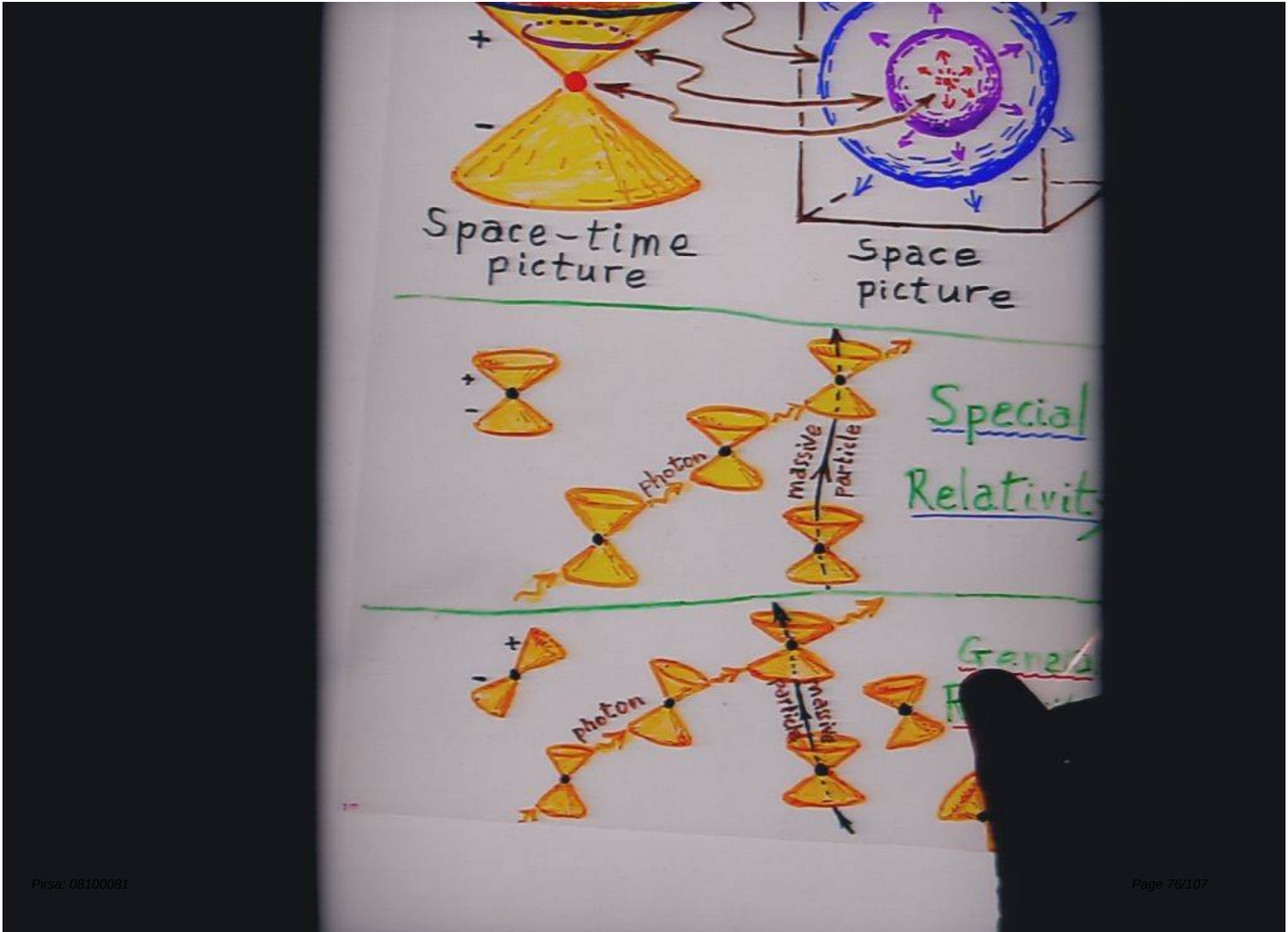
mathematical trick!
Black-hole sings Weyl curv. → ∞
Big Bang Weyl curv. → 0
infinite expansion
Near Big Bang, energies get so great that particles effectively massless: Conformal!

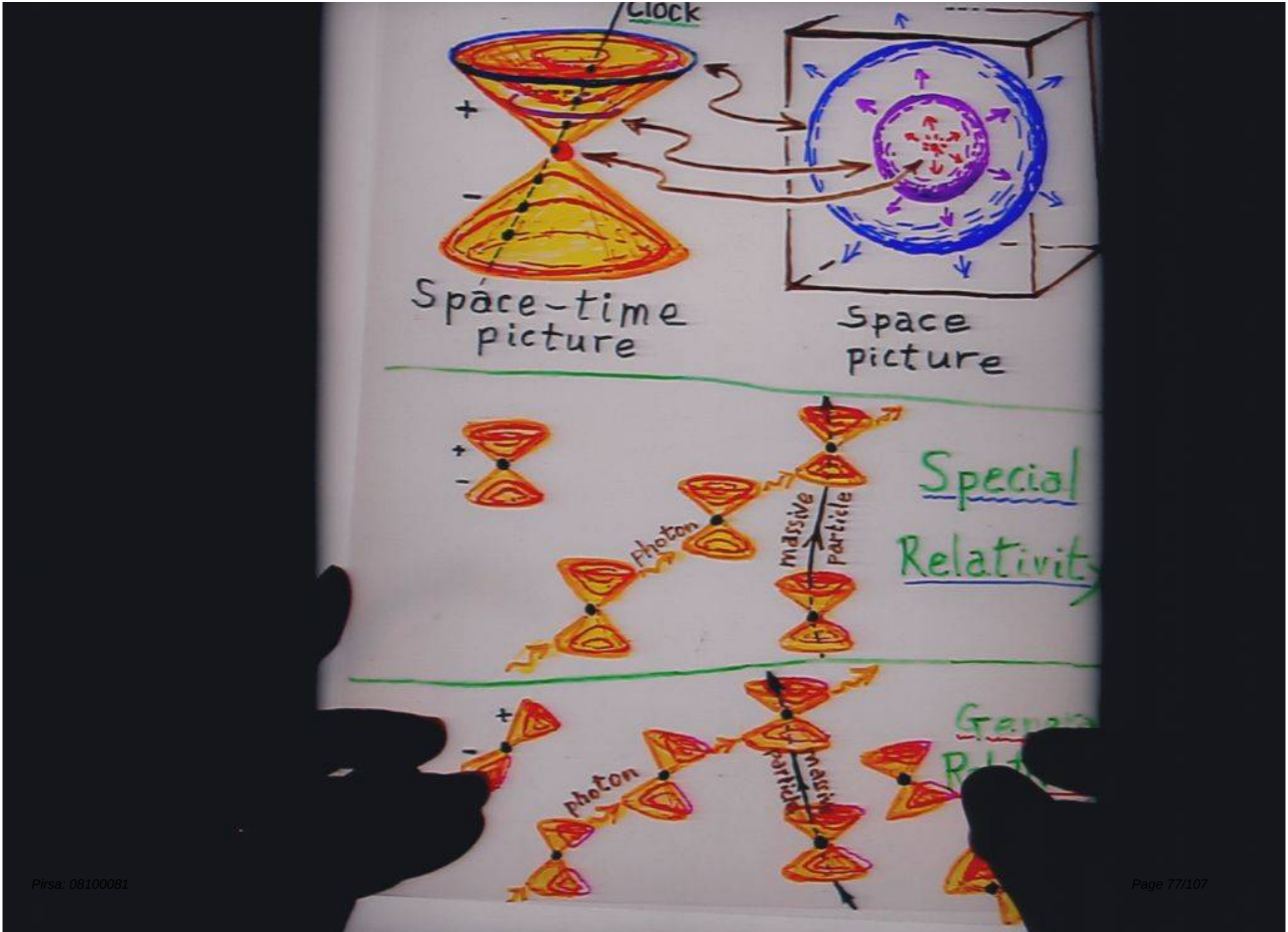
It's MASS (rest-mass) that determines clock rates



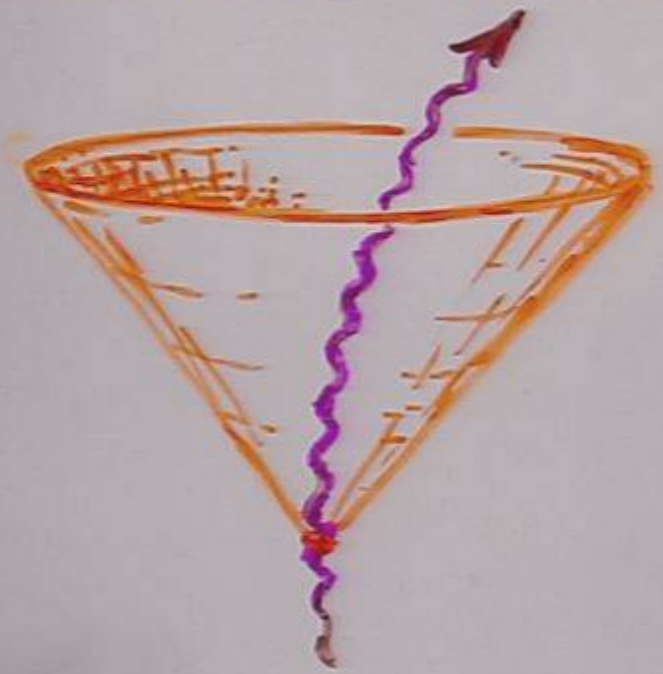
Planck: $E = h\nu$

Einstein: $E = mc^2$ } $\nu = m\left(\frac{c^2}{h}\right)$


+
-
Space-time picture
Space picture
+
-
photon
massive particle
Special
Relativit
+
-
photon
massive particle
Genera


Clock
+
-
Spáce-time picture
Space picture
+
-
Photon
massive particle
Special
Relativity
+
-
photon
massive particle

It's MASS (rest-mass) that determines clock rates



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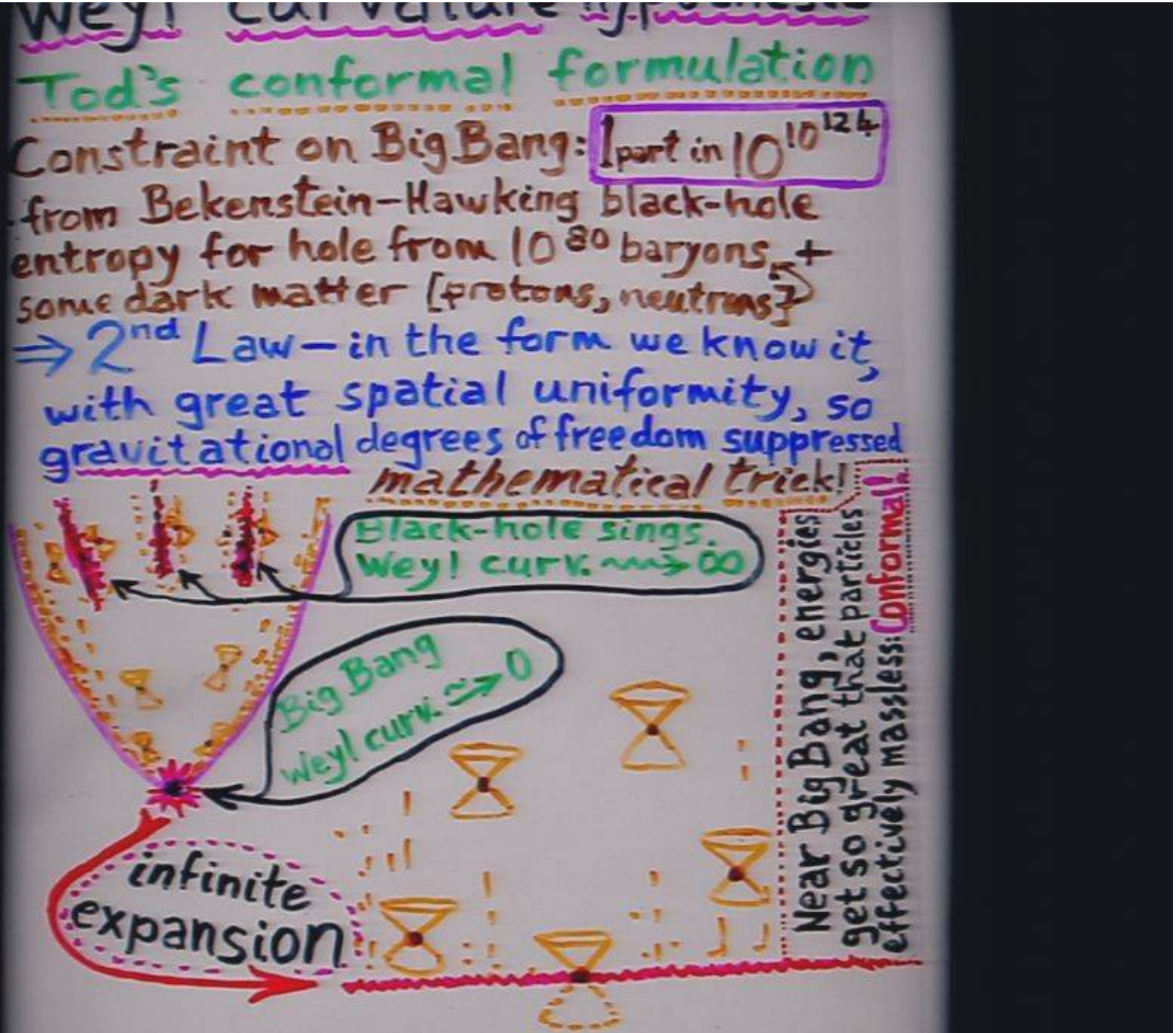
Weyl curvature hypothesis
Tod's conformal formulation
Constraint on Big Bang: 1 part in $10^{10^{124}}$
from Bekenstein-Hawking black-hole entropy for hole from 10^{80} baryons + some dark matter [protons, neutrons]
⇒ 2nd Law – in the form we know it, with great spatial uniformity, so gravitational degrees of freedom suppressed
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infinite expansion
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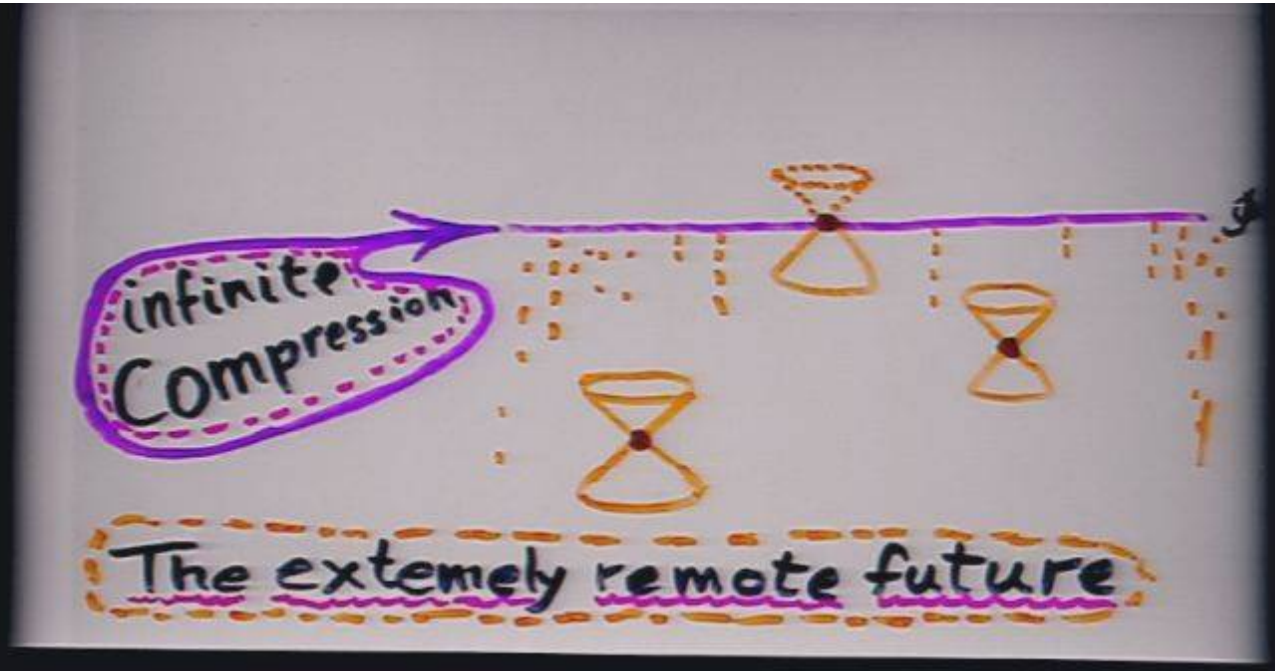
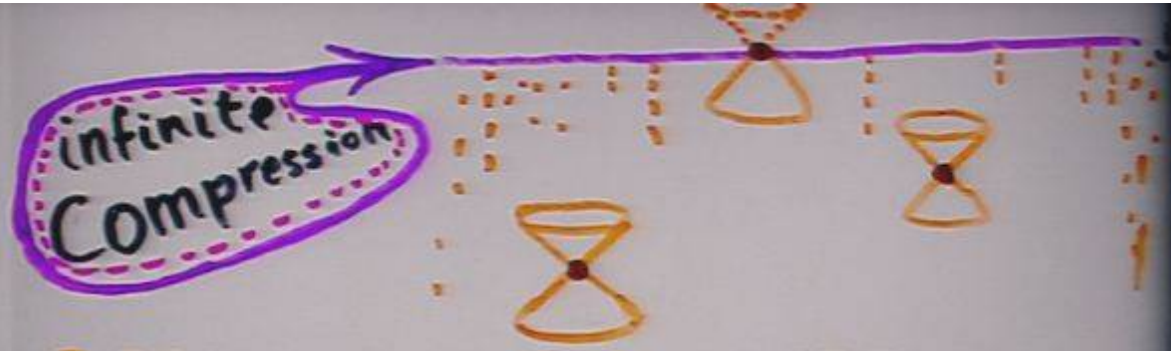

infinite
Compression
The extemely remote future



The extemely remote future

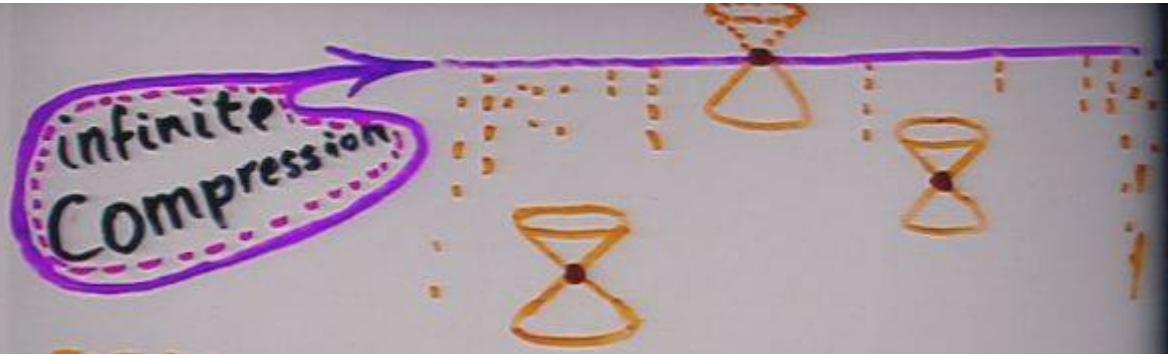
Much matter collapses to black holes. Eventu
expanding universe cools to lower than bla
holes' Hawking temperature. Then, the ho
gradually evaporates away, very slowly
$\sim 10^{64}$ yrs for $M_\odot$, $\sim 10^{90}$ yrs. for galactic
until pop! it disappears. With only
massless ingredients left, the universe
loses track of time. No way to
build a clock!

Eternity is no time
at all, for a photon!

Conformal geometry

Conformal $\infty(\mathcal{F})$ is spacelike
if $\Lambda > 0$. Mathematical trick!

rogue electrons?



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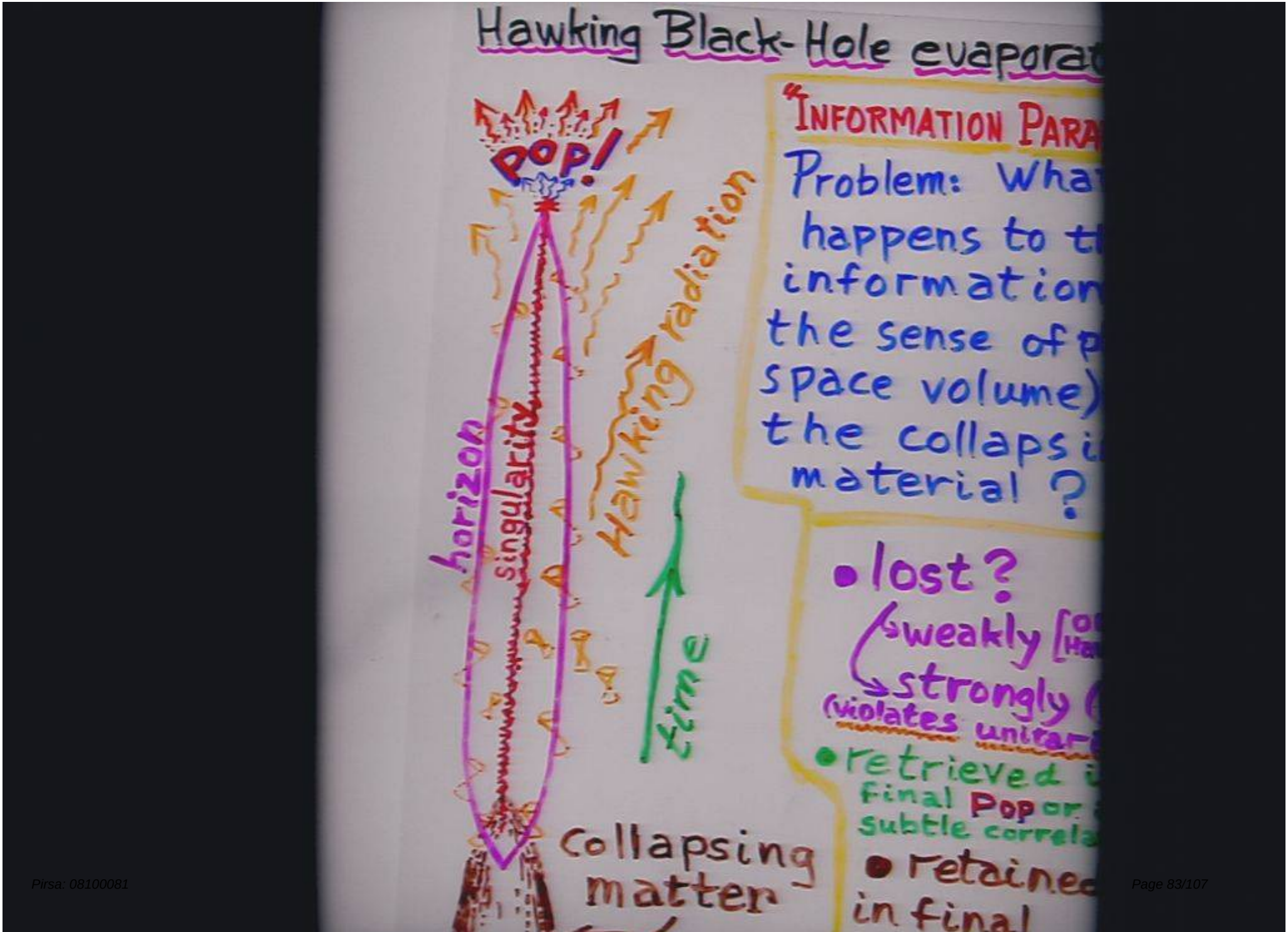
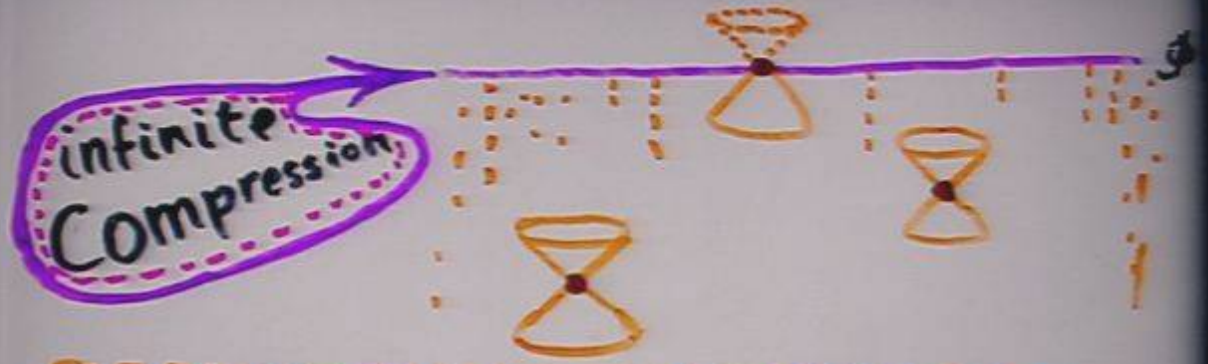

Hawking Black-Hole evaporat
POP!
horizon
singularity
Hawking radiation
time
Collapsing matter
"INFORMATION PARA
Problem: Wha
happens to t
information
the sense of p
space volume)
the collapsi
material ?
• lost ?
weakly
strongly
(violates unitar
• retrieved
final Pop or
subtle correla
• retained
in final



The extemely remote future

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rogue electrons?
mass evaporation?

xtemely remote future

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formal geometry
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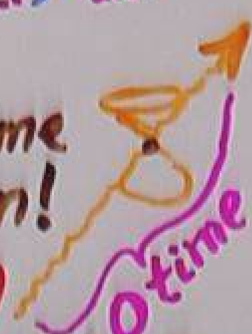

rogue electrons?
mass evaporation?

infinite Compression

The extemely remote future

Much matter collapses to black holes. Eventually expanding universe cools to lower than black-holes' Hawking temperature. Then, the hole gradually evaporates away, very slowly $\sim 10^{64}$ yrs. for $M_\odot$, $\sim 10^{90}$ yrs. for galactic until pop! it disappears. With only massless ingredients left, the universe loses track of time. No way to build a clock!

rogue electrons? mass evaporation?

Eternity is no time at all, for a photon!

Conformal geometry

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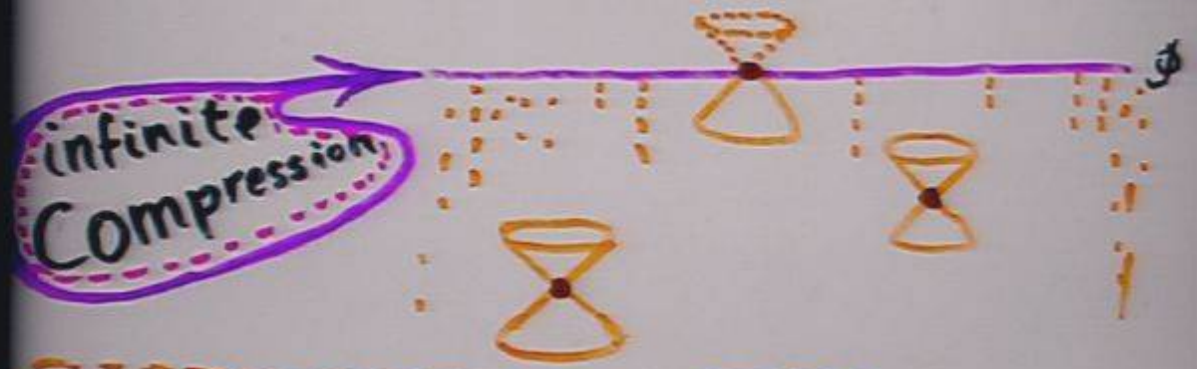

The extemely remote future

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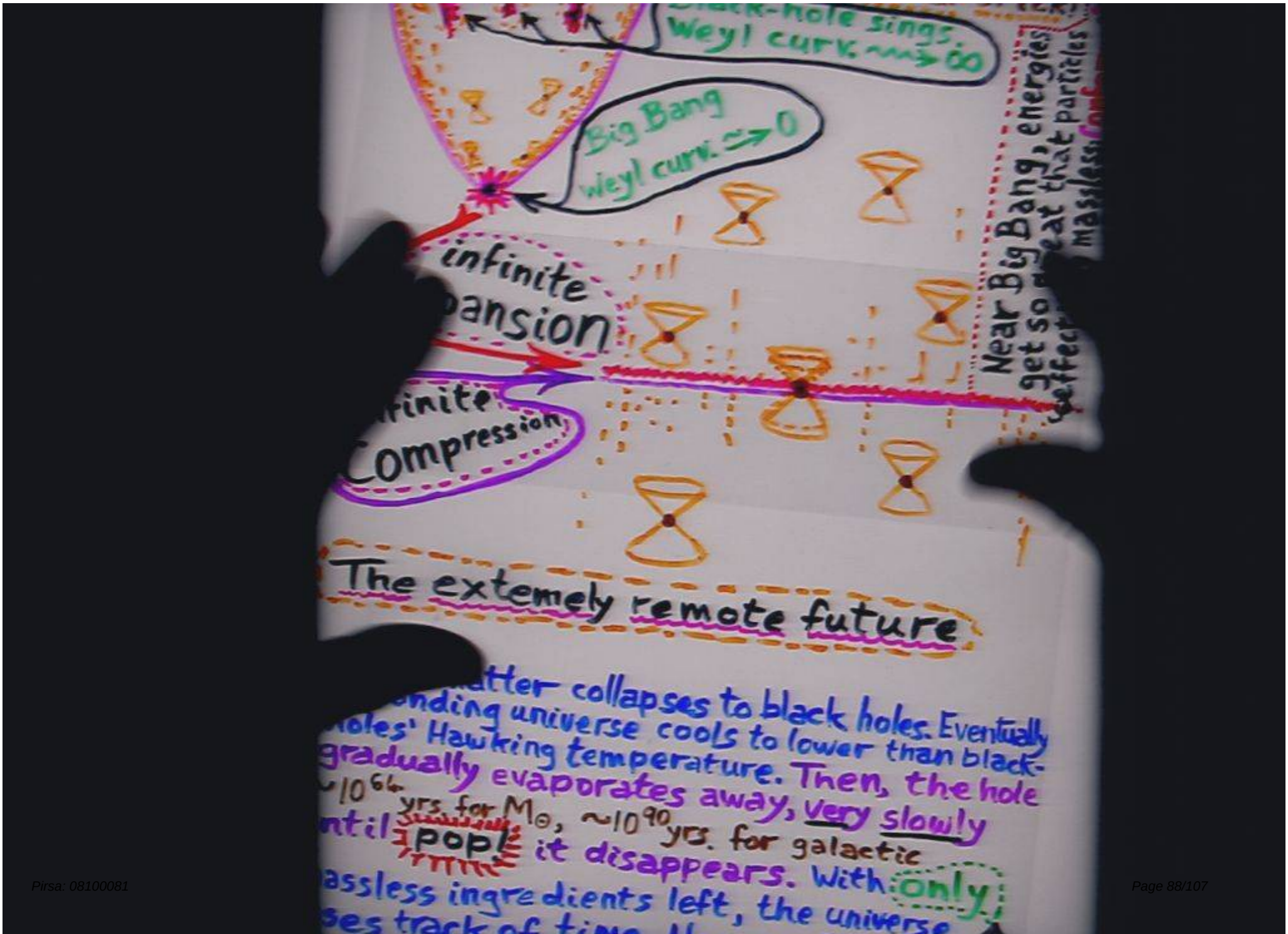
Eternity is no time at all, for a photon!


Big Bang
weyl curv. ⇒ 0
infinite
pansion
Compression
Near Big Bang, energies
massless
The extemely remote future
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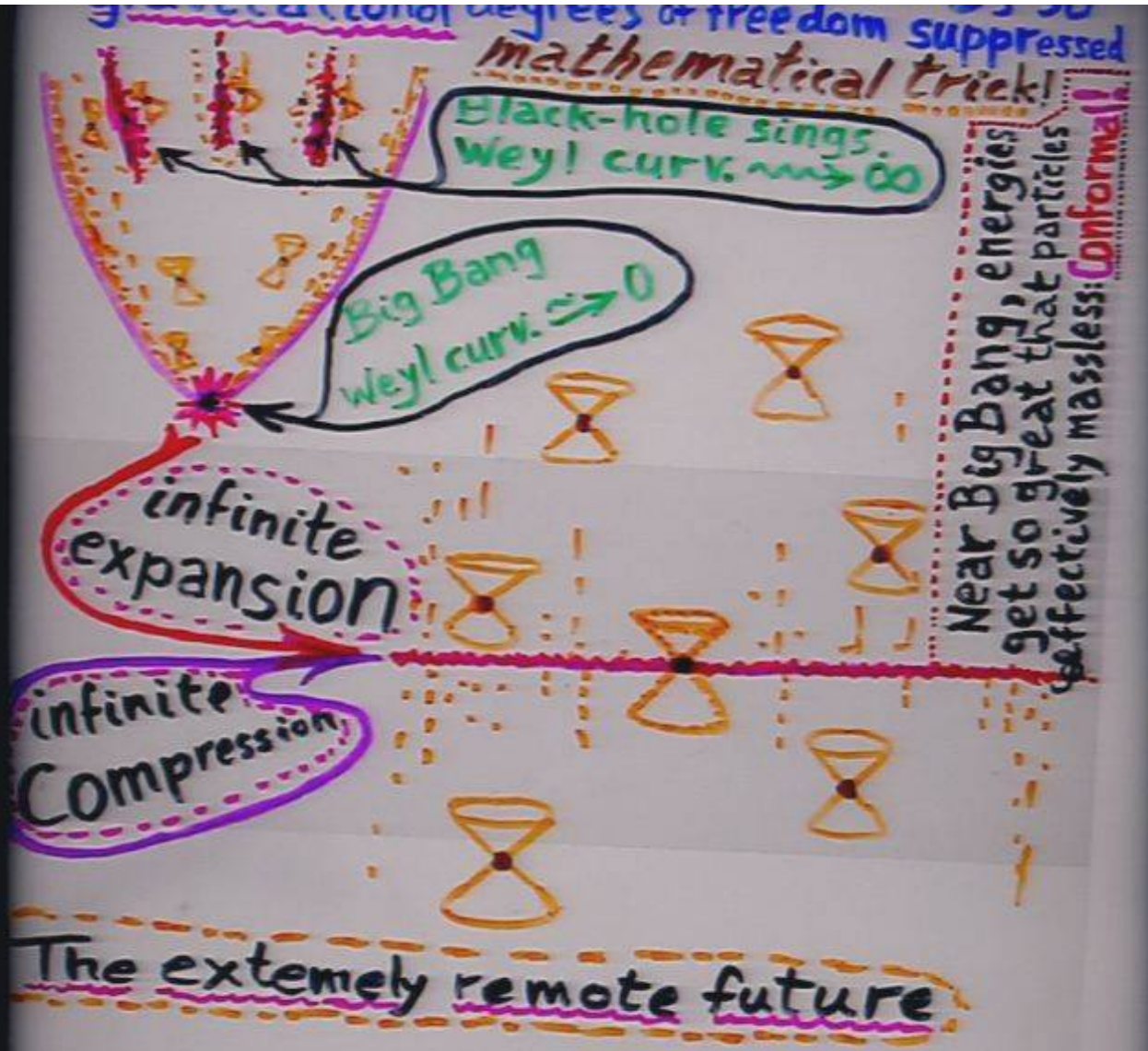
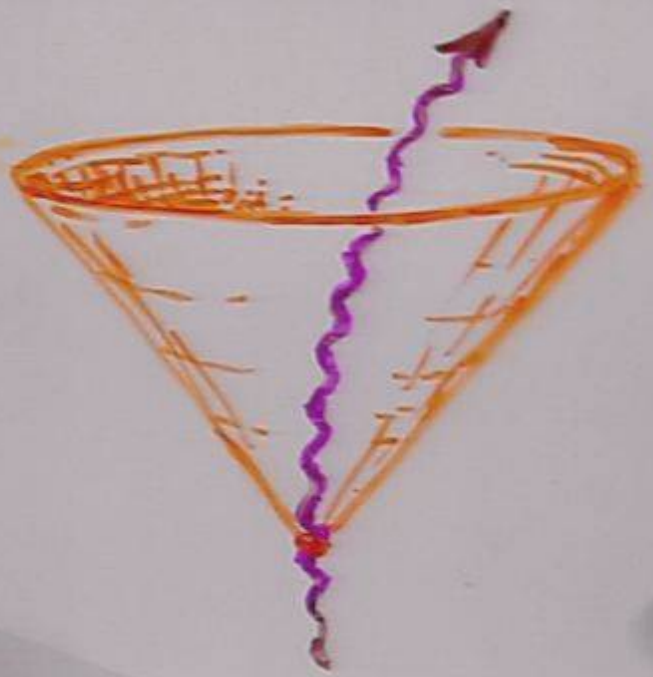
assless ingredients left, the universe
es track of time.



Much matter collapses to black holes. Eventually expanding universe cools to lower than black-holes' Hawking temperature. Then, the hole gradually evaporates away, very slowly ~10^{64} yrs for $M_\odot$, ~10^{90} yrs. for galactic until pop! it disappears

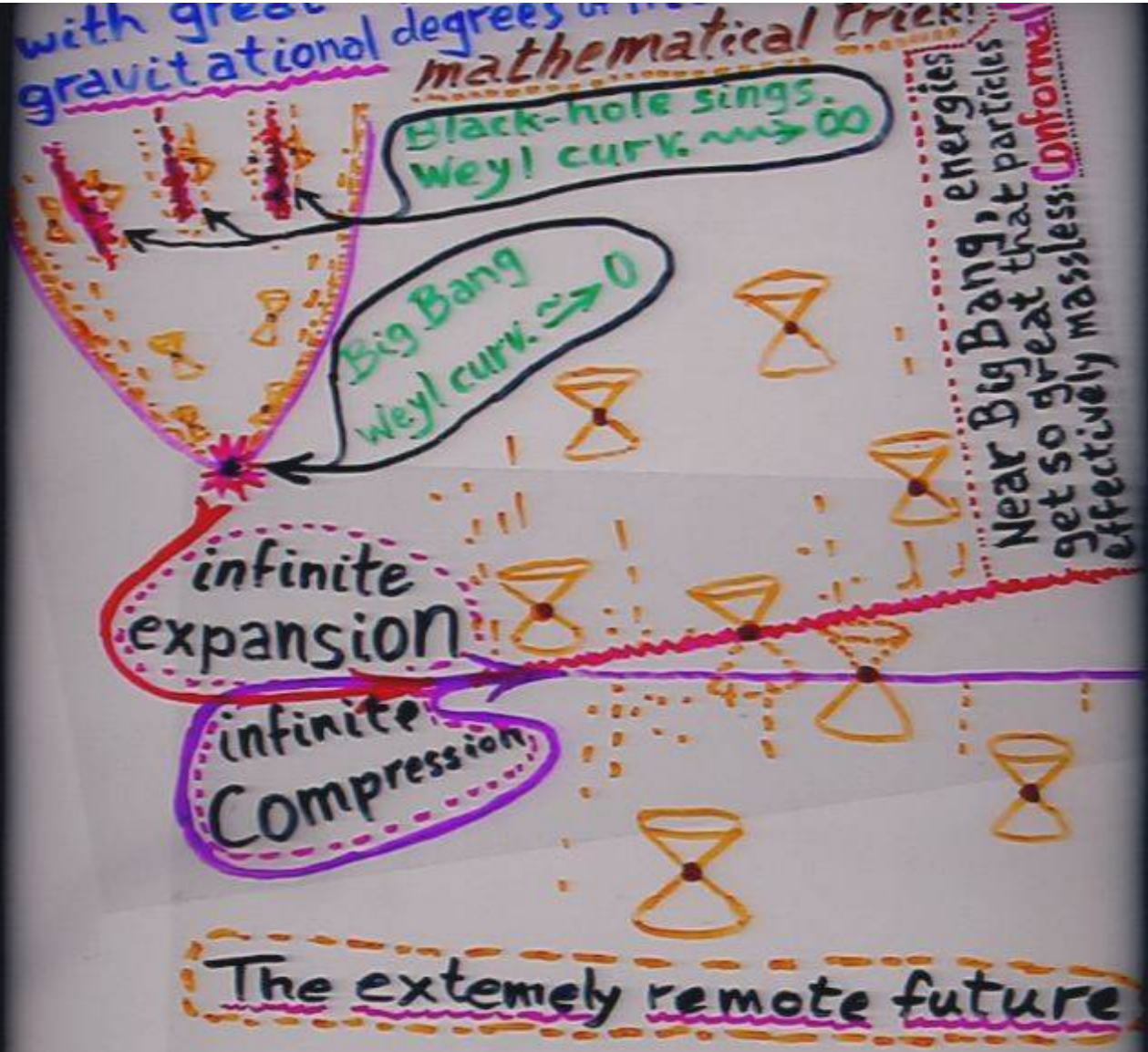
It's MASS (rest-mass) that determines clock rates



Planck: $E = h\nu$

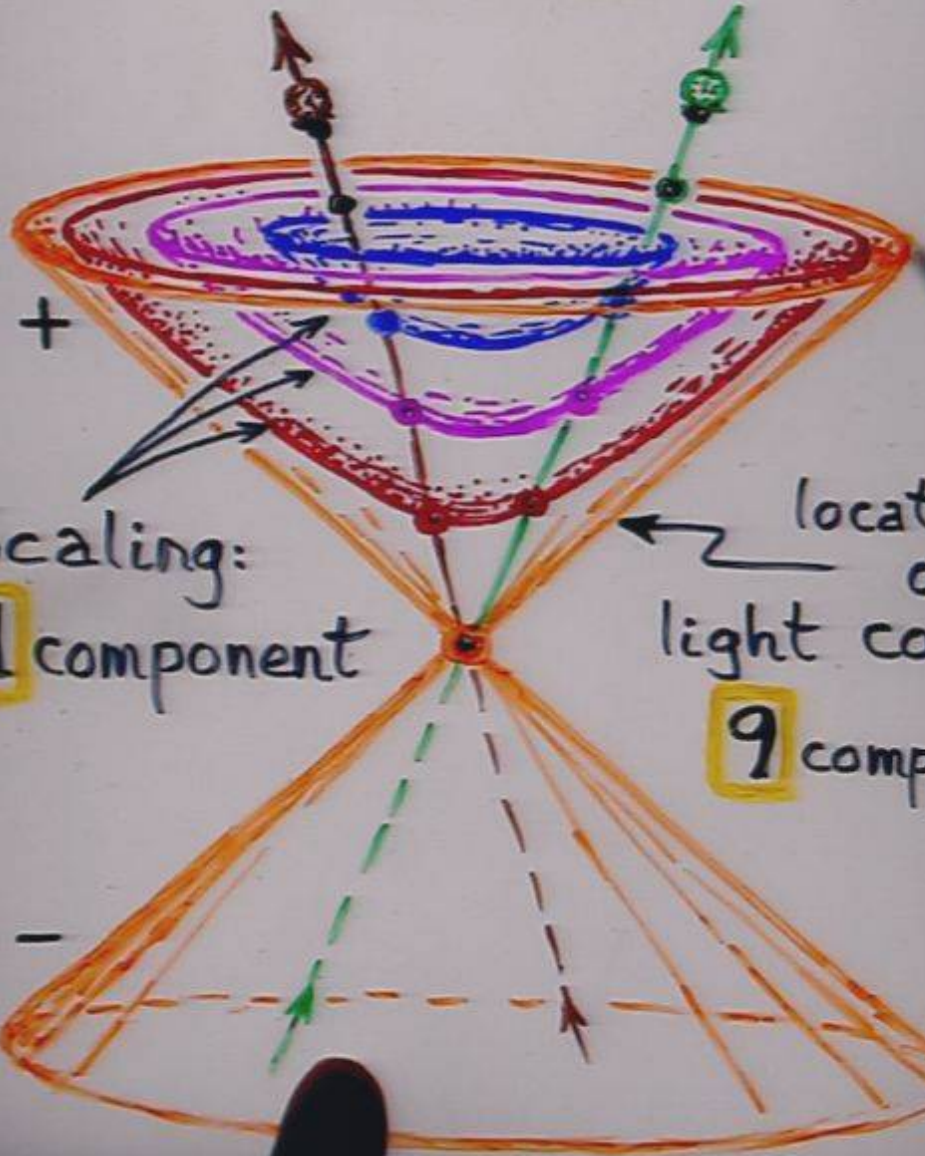
Einstein: $E = mc^2$

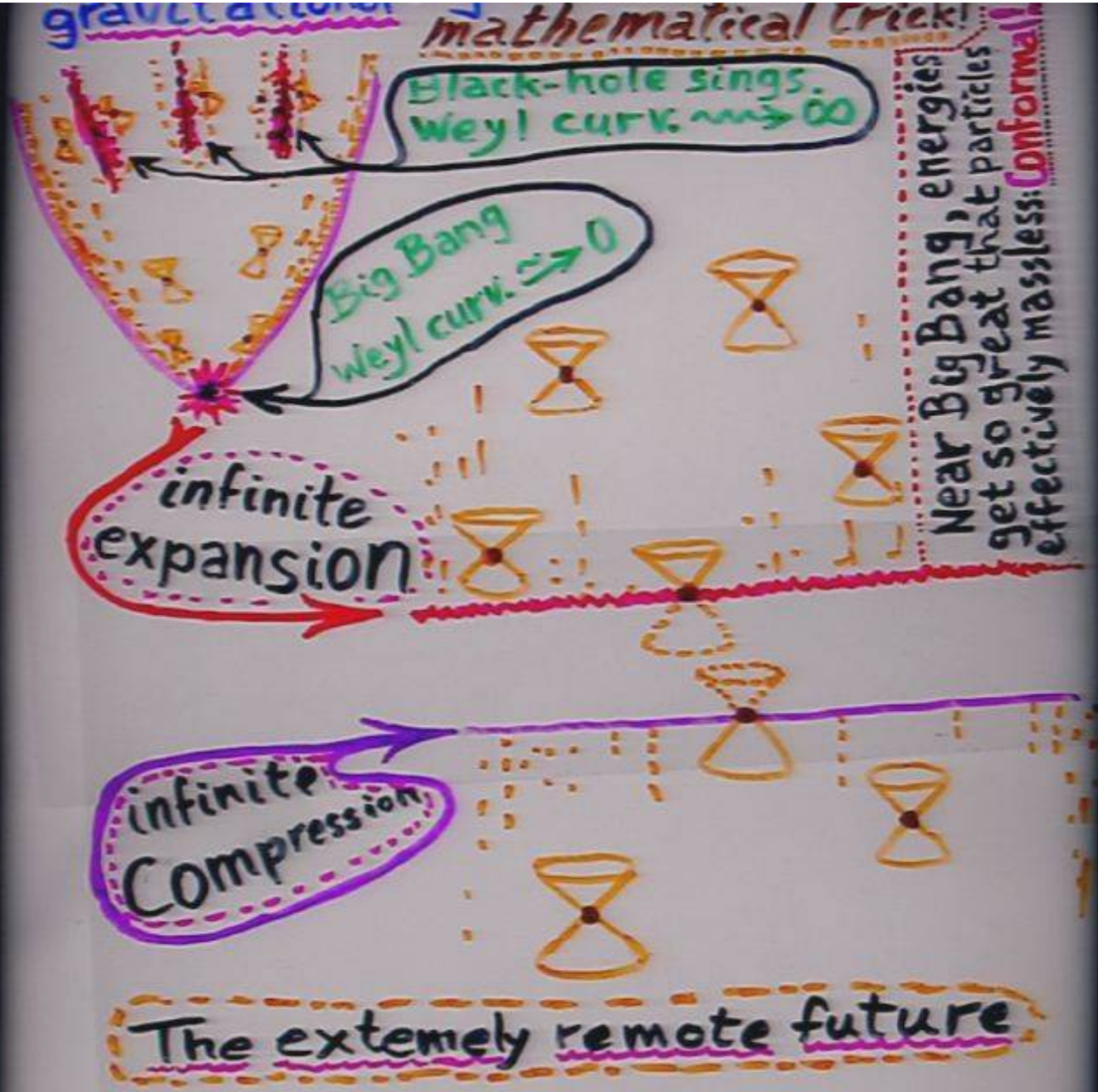
$\nu = \frac{1}{\lambda}$

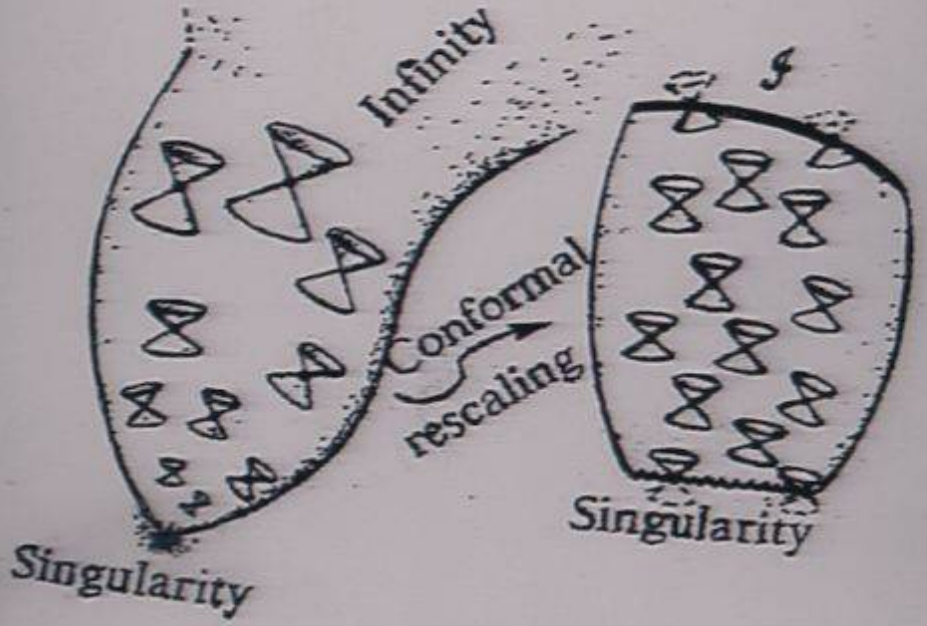

with great
gravitational degrees
mathematical trick!
Black-hole sings.
Weyl curv. ~→ ∞
Big Bang
Weyl curv. ~→ 0
Near Big Bang, energies
get so great that particles
effectively massless: Conformal
infinite
expansion
infinite
Compression
The extemely remote future
Much matter collapses to black holes. Ev
expanding universe cools to lower than
holes' Hawking temperature. Then, the
gradually evaporates away, very slow
~10^64 yrs for M⊙, ~10^90 yrs. for galactic
until

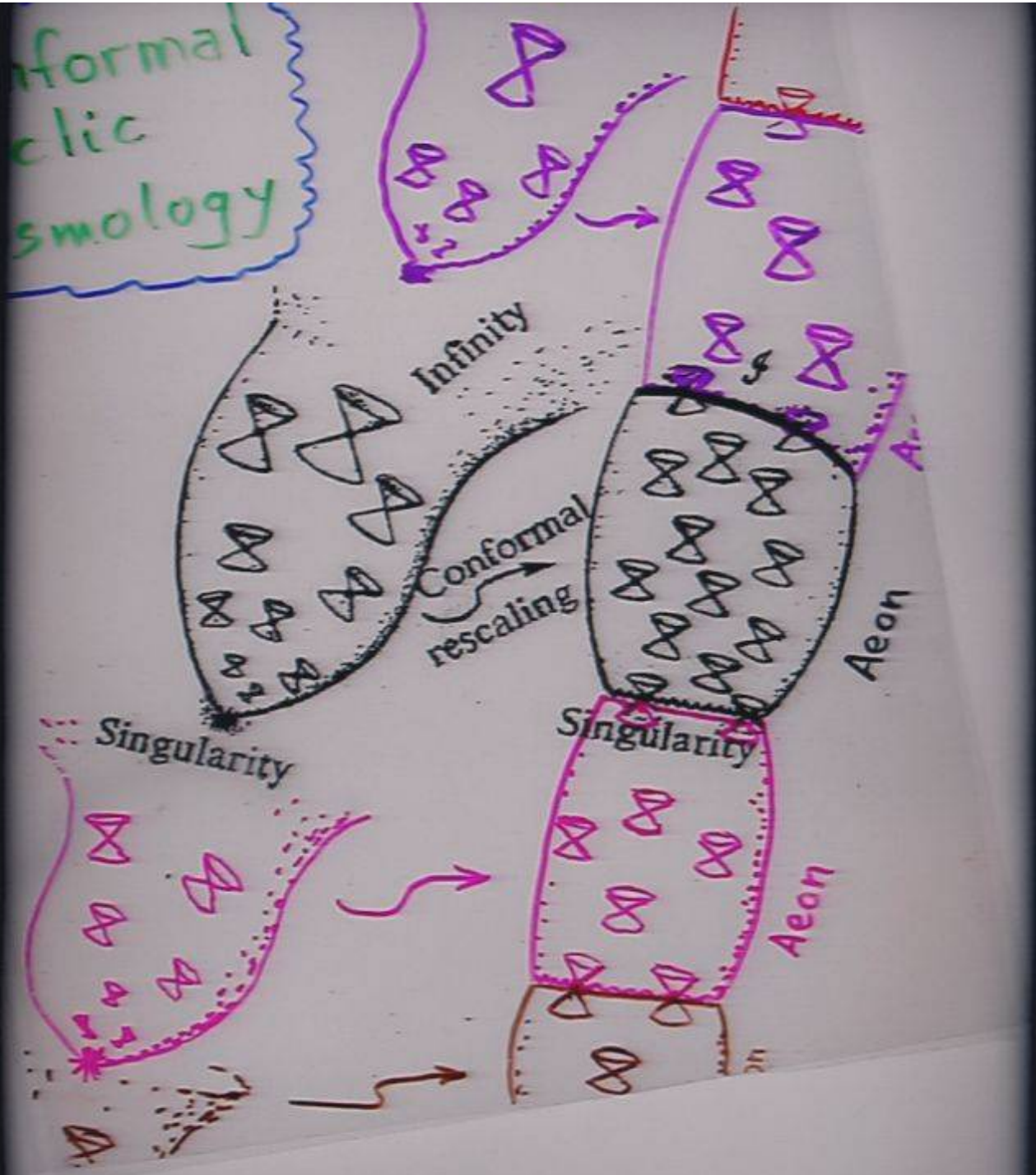
Clocks in Relativity

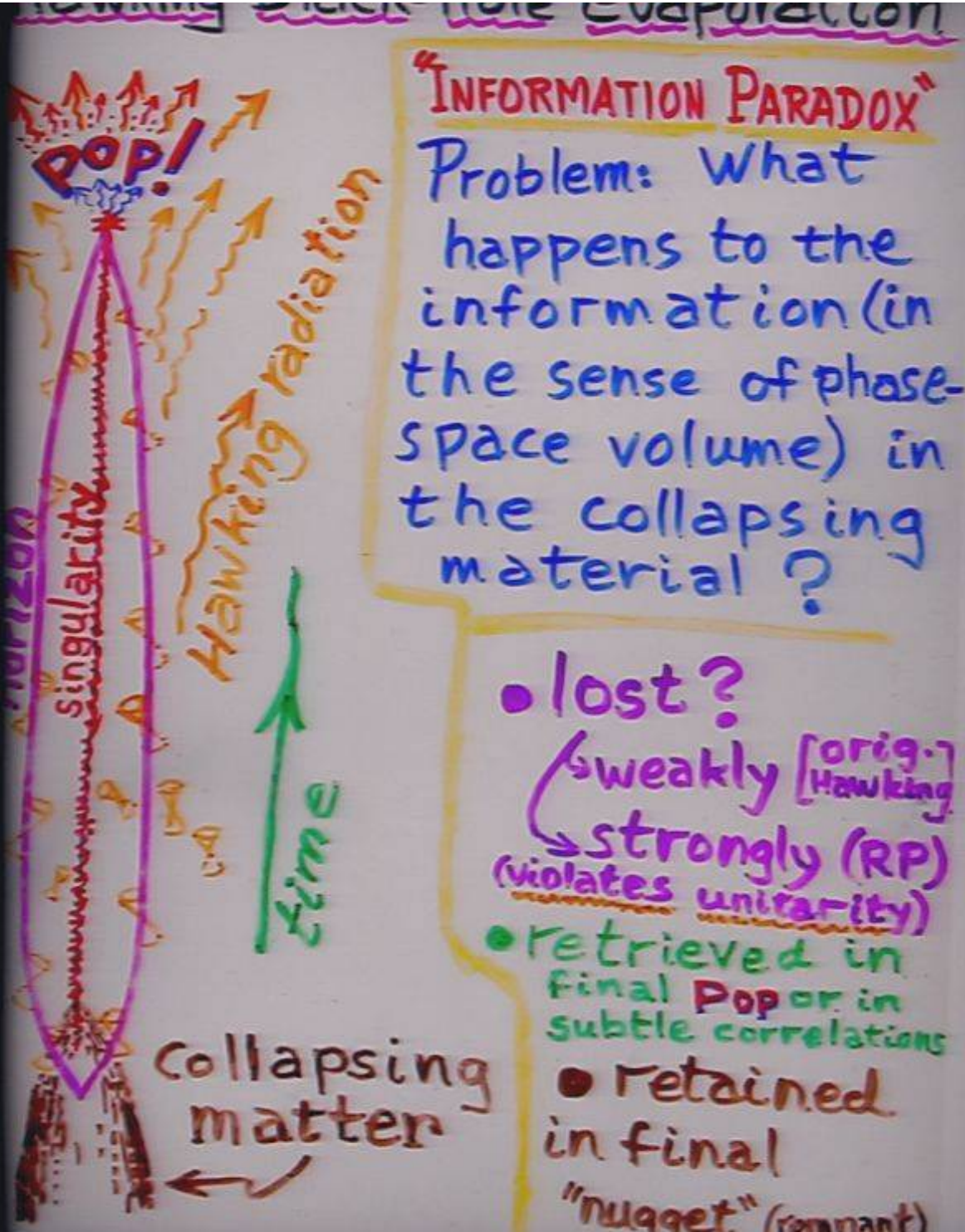
metric g_{ab} has 10 components

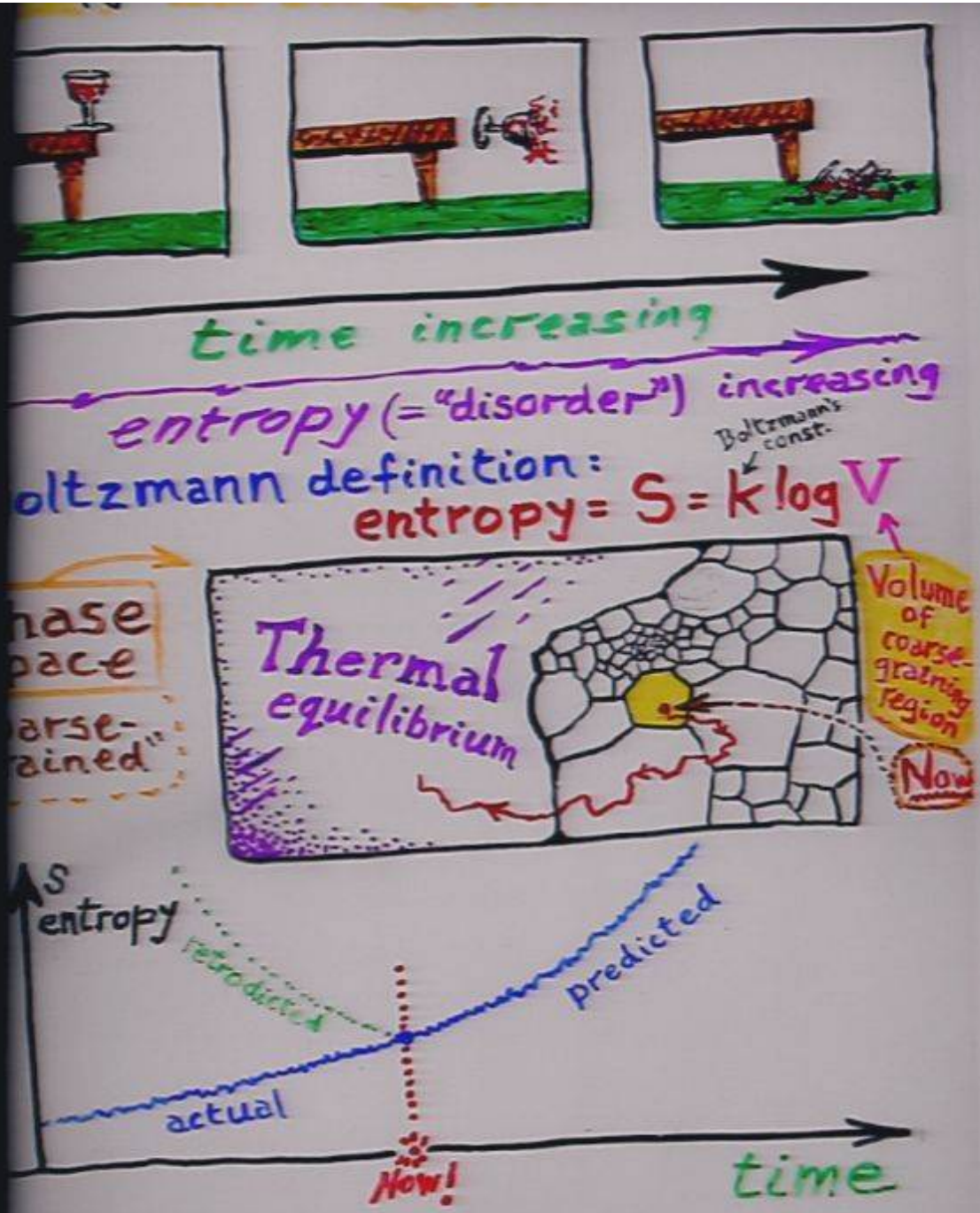



mathematical trick!
Black-hole sings.
Weyl curv. → ∞
Big Bang
Weyl curv. → 0
Near Big Bang, energies get so great that particles effectively massless: Conformal!
infinite expansion
infinite Compression
The extemely remote future
Much matter collapses to black holes. Even
expanding universe cools to lower than bl
holes' Hawking temperature. Then, the
gradually evaporates away, very slowly


Infinity
Conformal
rescaling
Singularity
Singularity

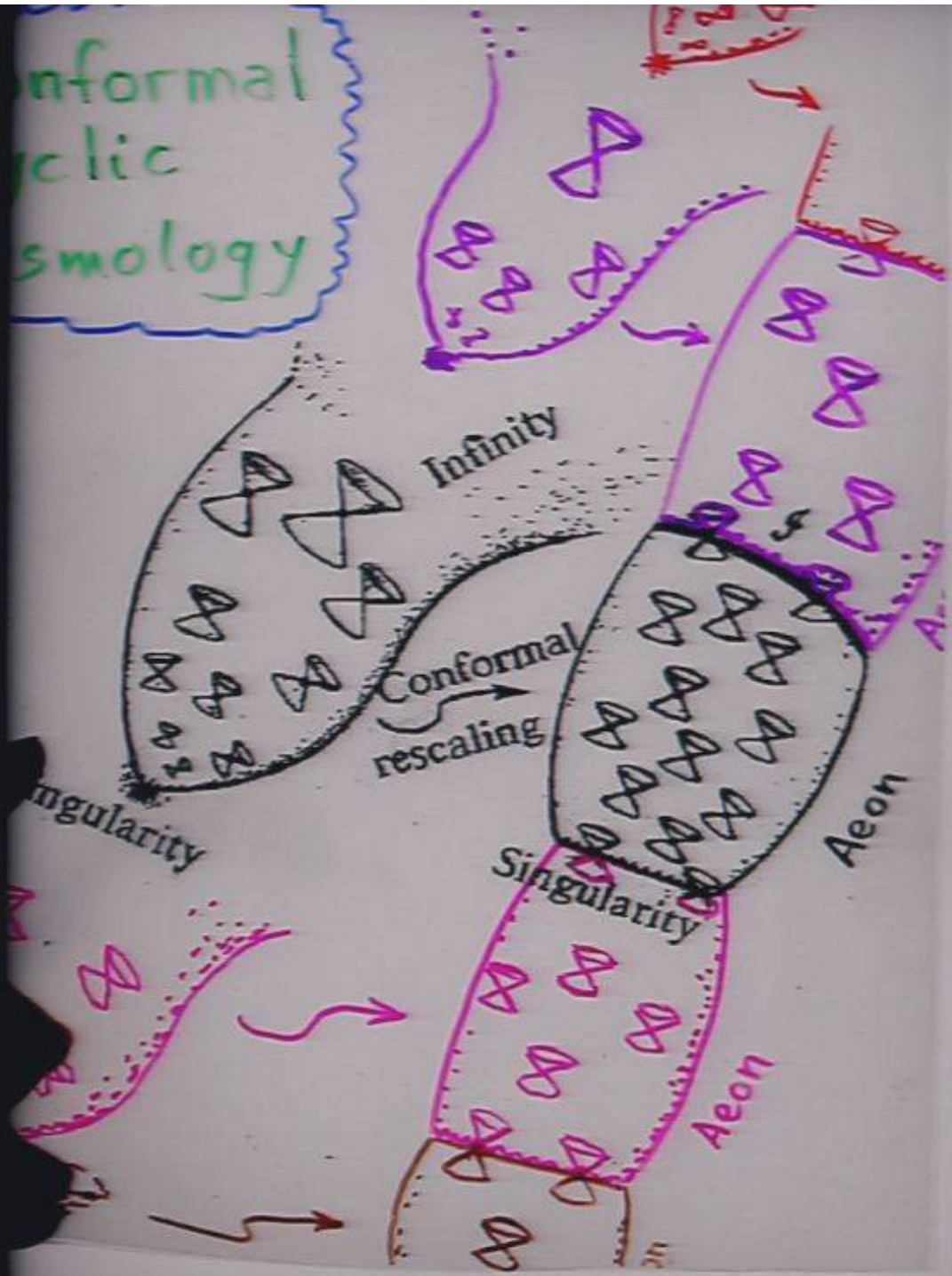

nformal
clic
smology
Infinity
Conformal
rescaling
Singularity
Singularity
Aeon
Aeon


Evaporation
"INFORMATION PARADOX"
Problem: What happens to the information (in the sense of phase-space volume) in the collapsing material?
POP!
singularity
Hawking radiation
Time
Collapsing matter
• lost?
weakly [orig. Hawking]
strongly (RP)
(violates unitarity)
• retrieved in final Pop or in subtle correlations
• retained in final
"nugget" (remnant)


time increasing
entropy (="disorder") increasing
Boltzmann's const.
oltzmann definition:
entropy = S = k log V
hase
pace
arse-
ained"
Thermal equilibrium
Volume of coarse-graining region
Now
S
entropy
retrodicted
predicted
actual
Now!
time

But, is it

TRUE?


nformal
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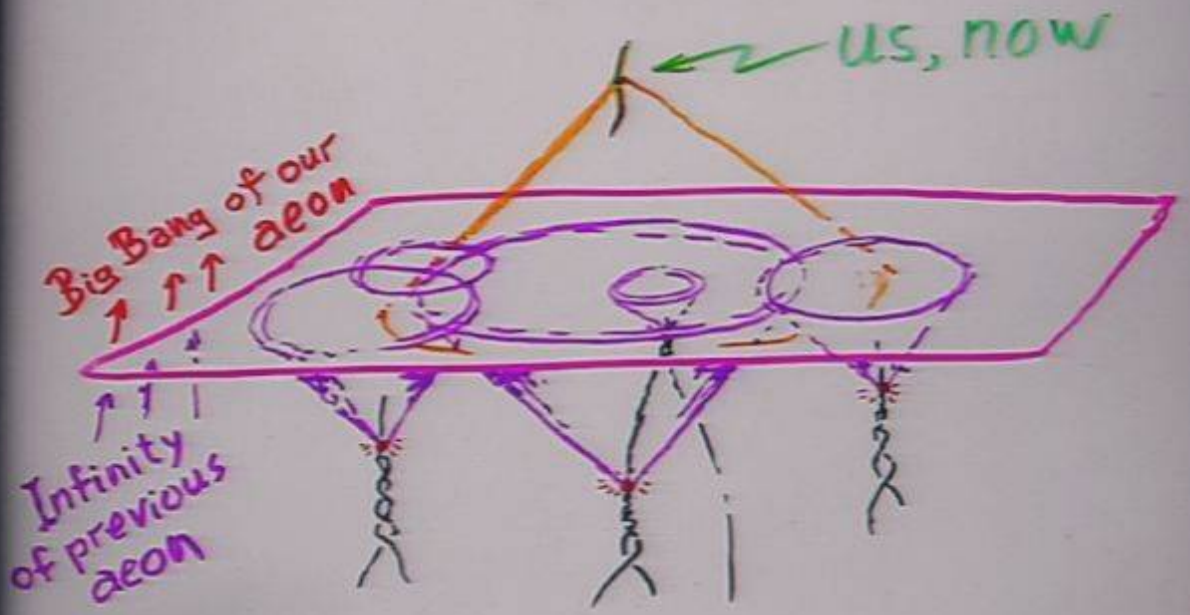
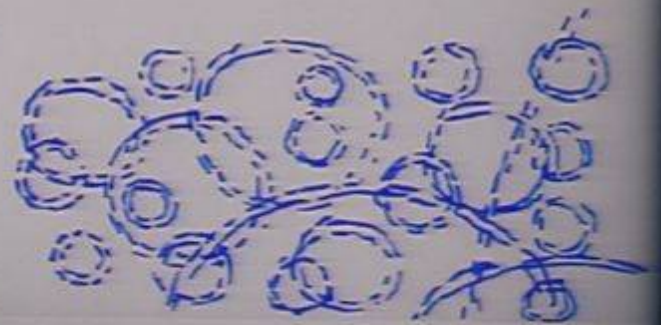
ngularity
Singularity
Aeon
Aeon

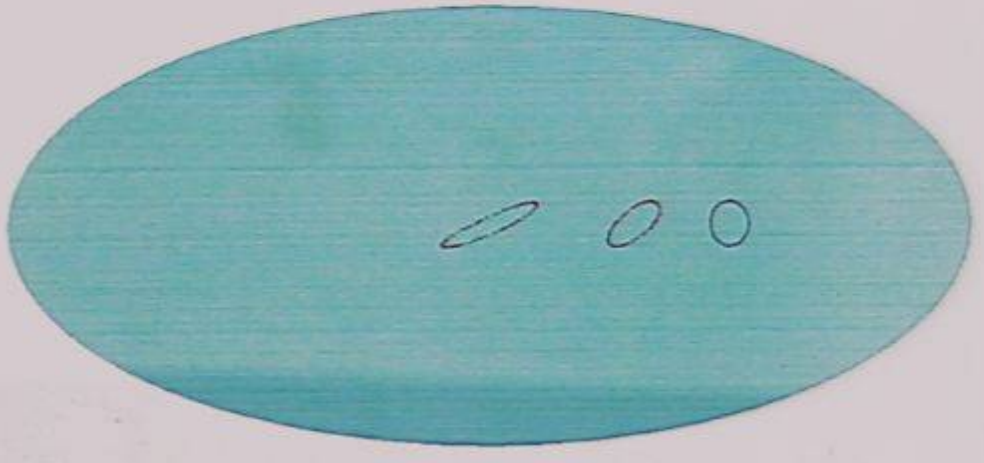
Observational consequence concerning temperature/density variations in Cosmic Microwave Background



Think of ripples on a pond, caused by raindrops which have recently stopped falling.

Pattern of ripples looks random at first, but can be analysed into circles by statistical analysis.





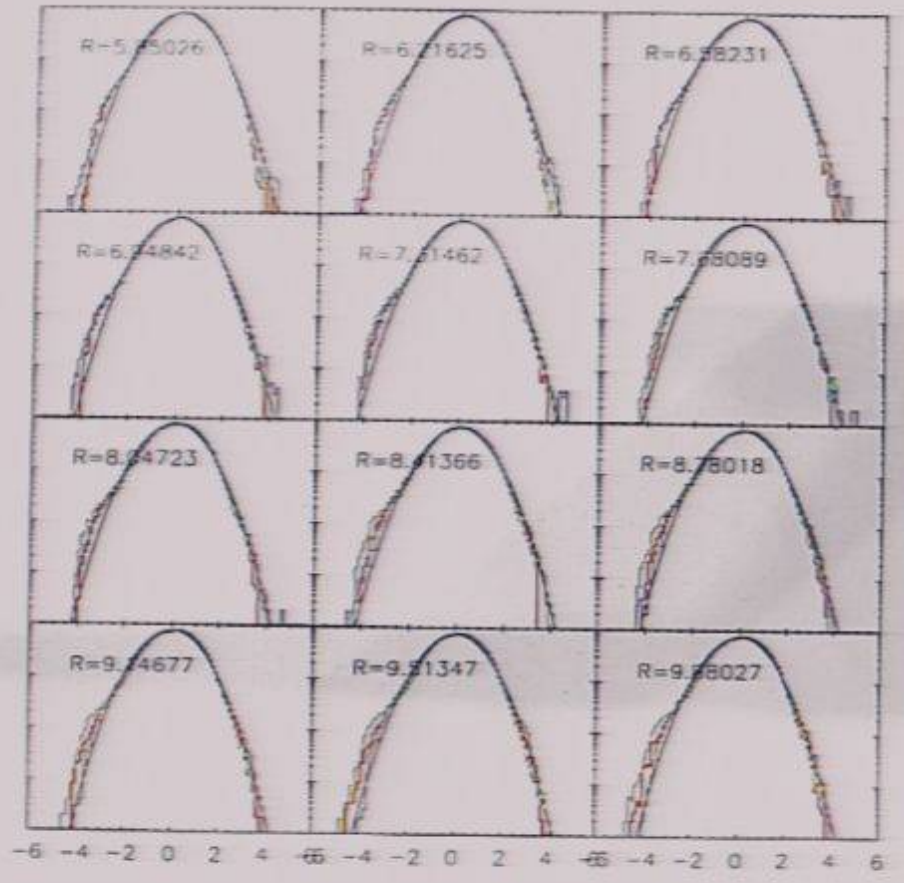
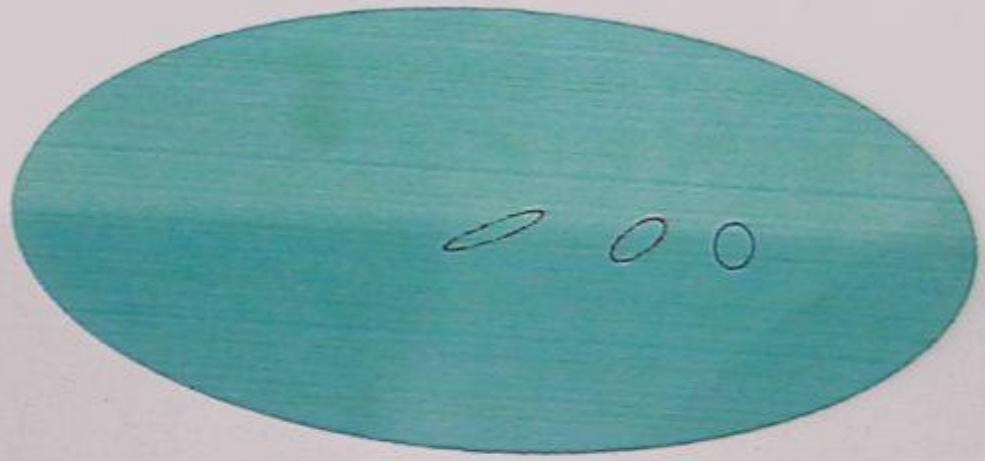


FIG. 3: Red: $\Lambda = 0$, Green: $\Lambda = 0.002$, Blue: $\Lambda = 0.005$, Black: Gaussian Curve



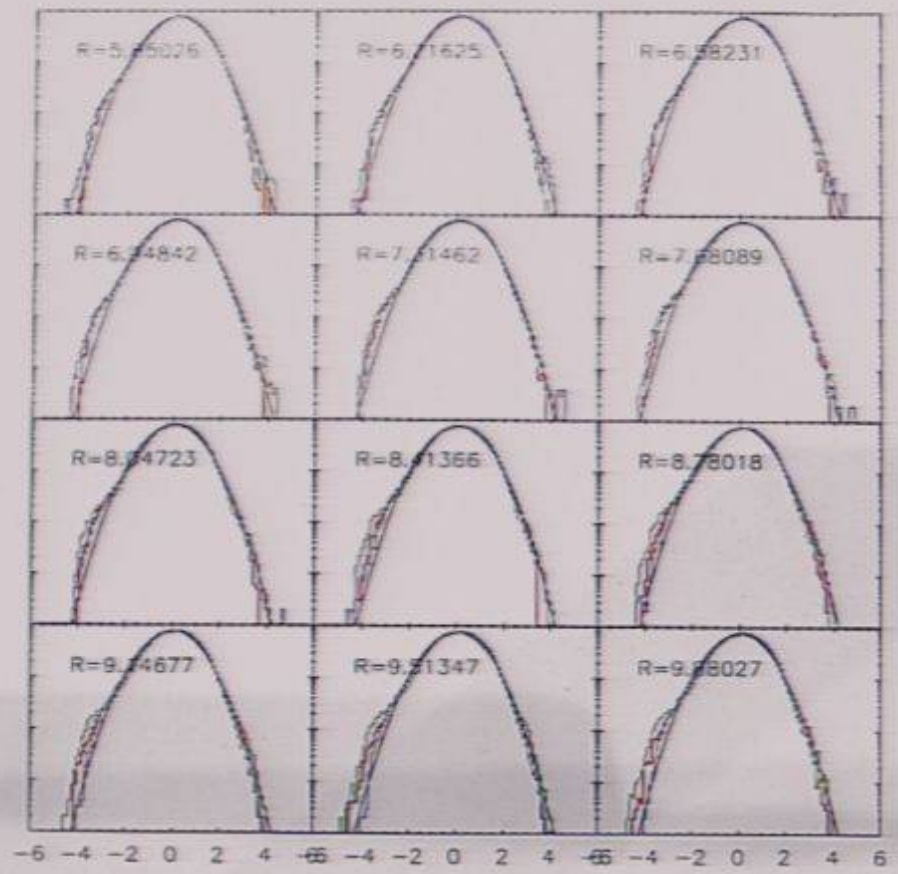


FIG. 33: Red: A = 0, Green: A= 0.02, Blue: A = 0.05, Black: Gaussian Curve.

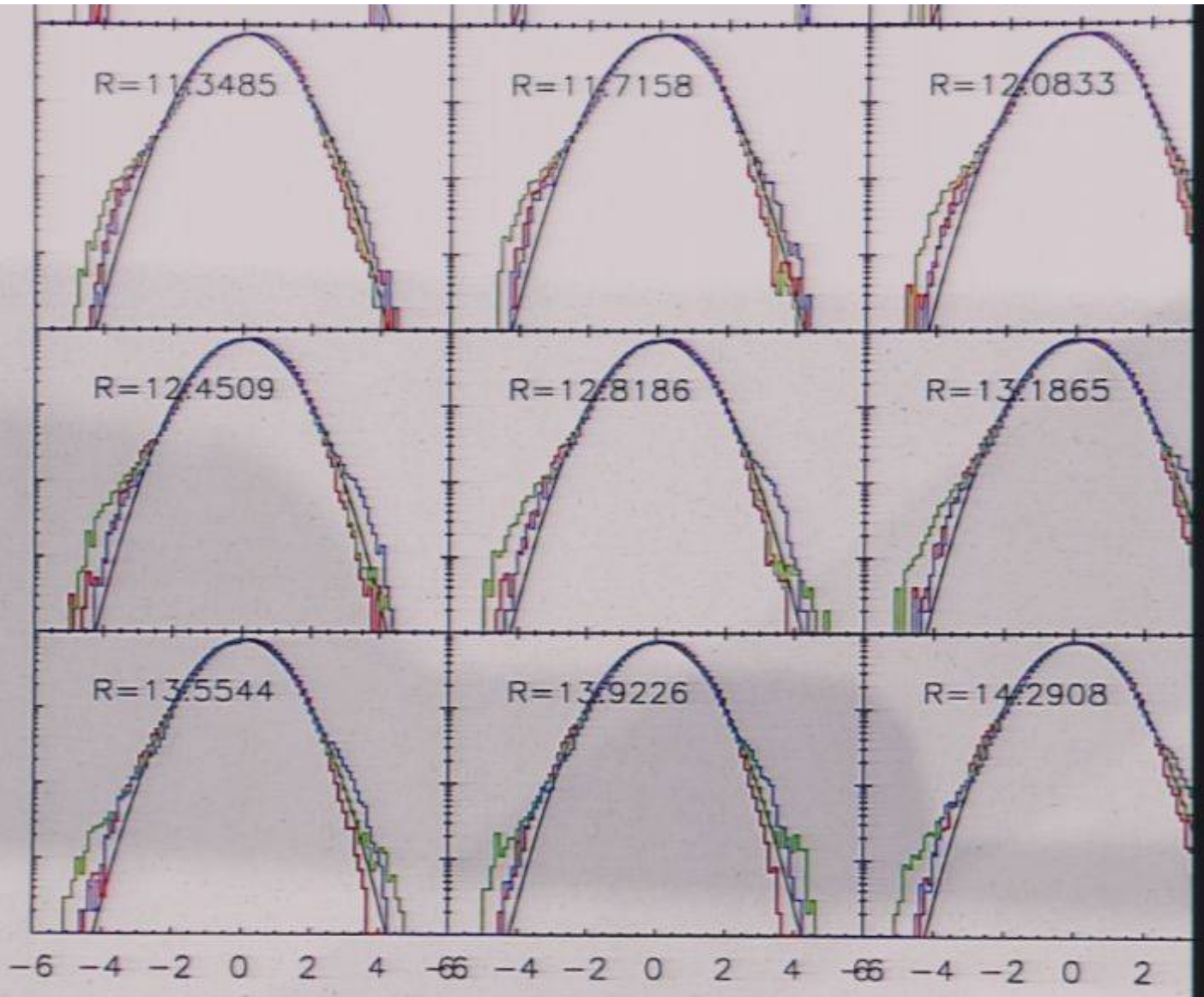
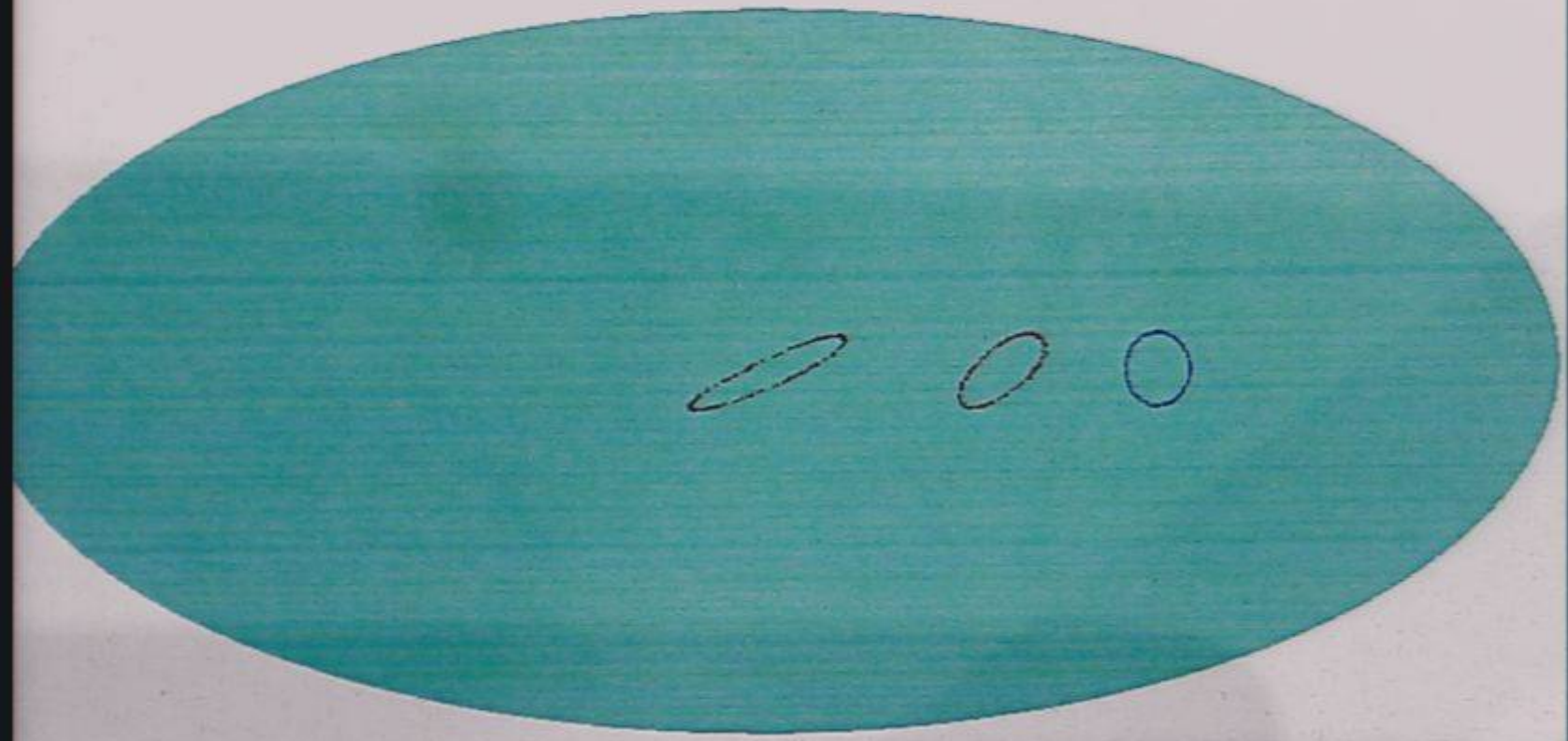


FIG. 34: Red: A = 0, Green: A= 0.02, Blue: A = 0.05, Black: Gaussian Curve.

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