Nobel Prize in Physics 2020

Roger Penrose

Predrag Cvitanović

Georgia Institute of Technology

11 November 2020

Understanding the 2020 Nobel Prize in Physics

Georgia Tech

From the pioneering theoretical work on black holes, to observing the galactic center of our Milky Way.

Predrag Cvitanović
(and Roger Penrose)
School of Physics, Georgia Tech

Erin Wells Bonning
Director of Planetarium, Emory University

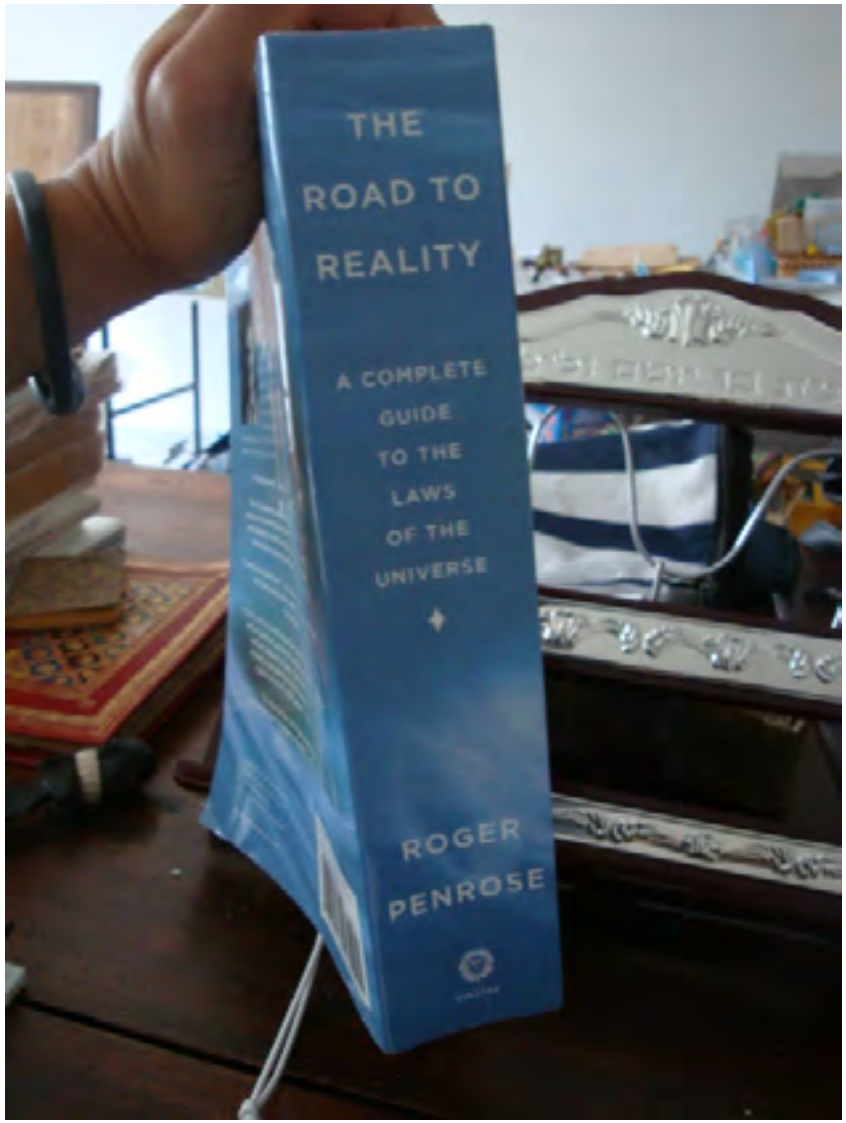
Join us virtually, as experts from Georgia Tech and Emory University explain the 2020 Nobel Prize in physics. After the presentation, the speakers will answer questions from the audience so come curious!

Wednesday Nov 11th
7pm EST

the morning of the Nobel Prize : wow, Penrose !!!

"The Road to Reality" should always be by your side

The Road to Reality



weighs in[1] at 3 lb and 1,099 pages :)

[1] R. Penrose, "Applications of negative dimensional tensors", in *Combinatorial mathematics and its applications*, edited by D. J.A. Welsh (Academic, New York, 1971), pp. 221–244.

this evening : the world through Roger Penrose's eyes

> There is only one thing which interests me vitally now, and that is the recording of all that which is omitted in books. Nobody, as far as I can see, is making use of those elements in the air which give direction and motivation to our lives.
>
> — Henry Miller, *Tropic of Cancer*

- Asked on Oct 9, 2020, upon receiving Nobel prize: What is your advice to young people?
- Penrose: advice to young people? Giving it is not a good idea. But do what you find exciting, do what you find beautiful.

age 10 - a boy flummoxed by problems of mathematics

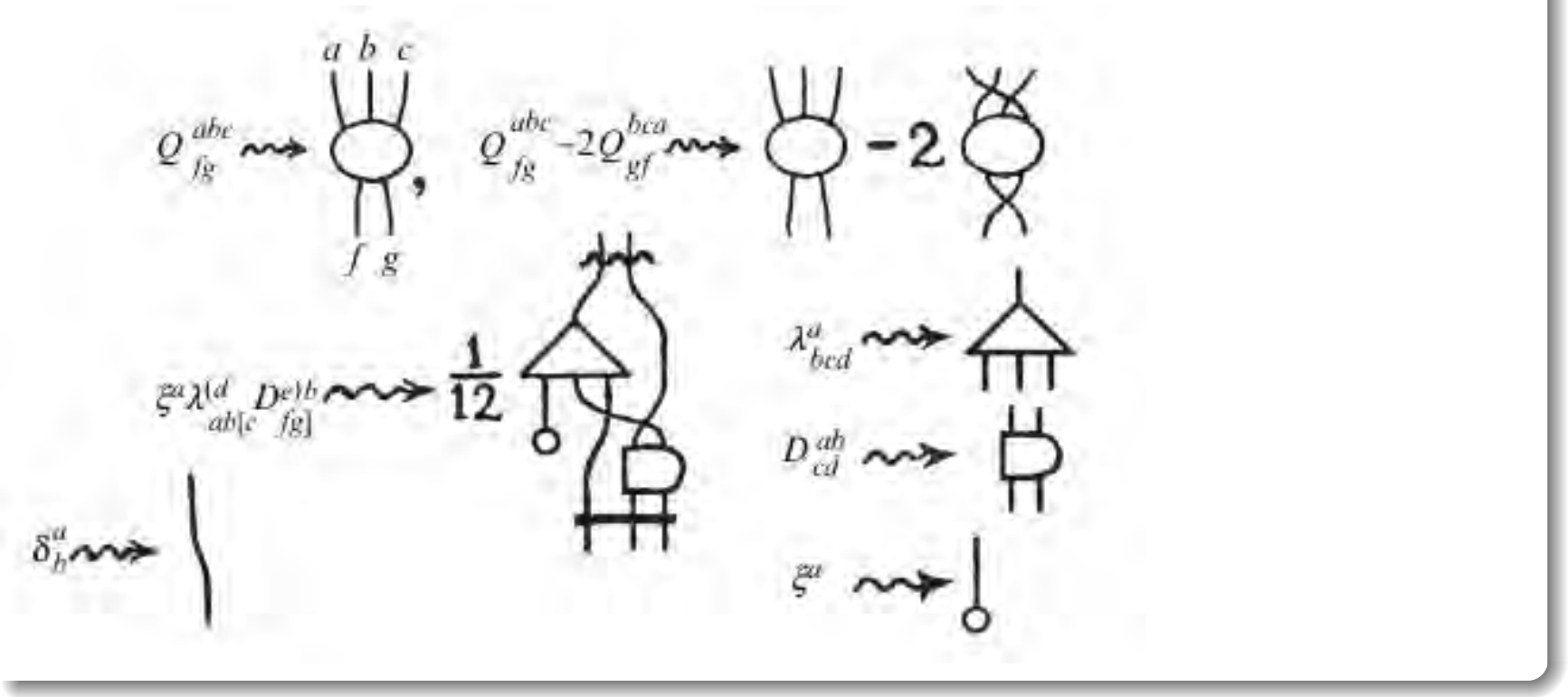
Teachers: His problem-solving skills too leisurely for school

Penrose: ‘I was moved down a class’

age 21 - math for those who don't 'get' equations

invents

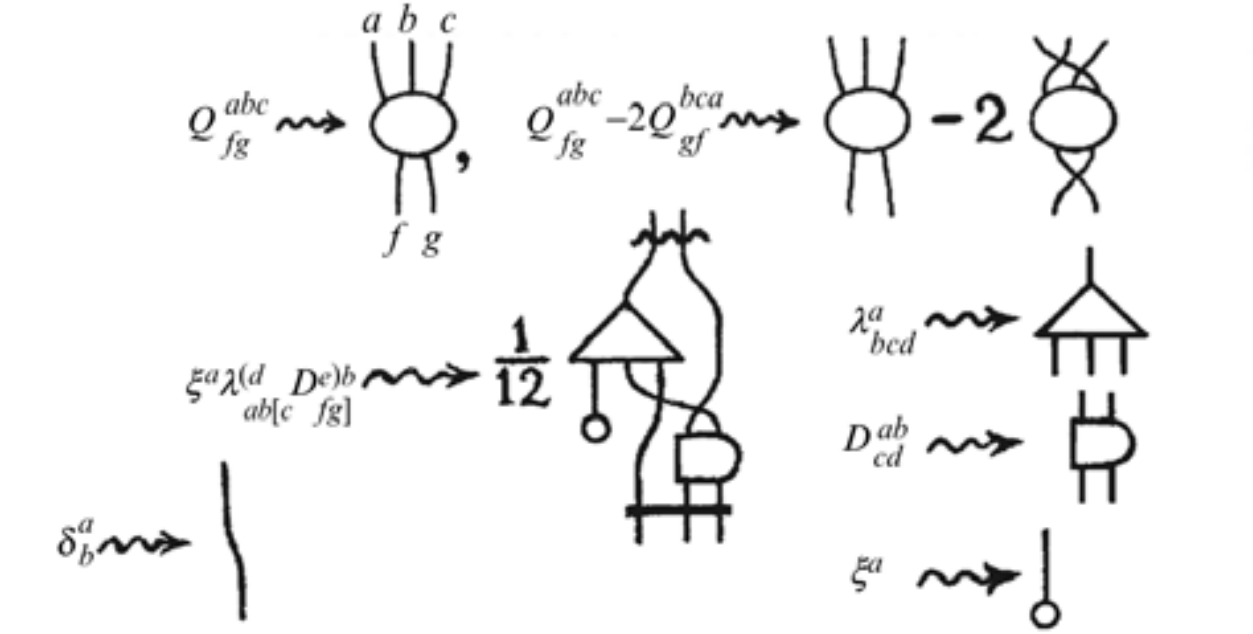
diagrammatic calculations

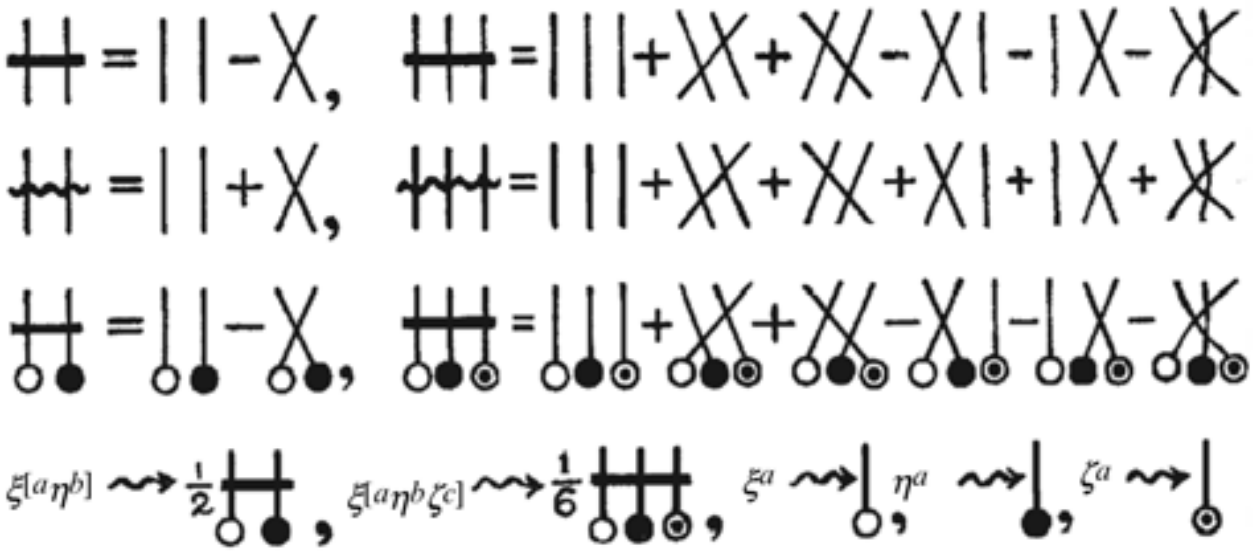


first shows it in a publication 17 years later[2]

[2] R. Penrose, "Applications of negative dimensional tensors", in *Combinatorial mathematics and its applications*, edited by D. J.A. Welsh (Academic, New York, 1971), pp. 221–244.

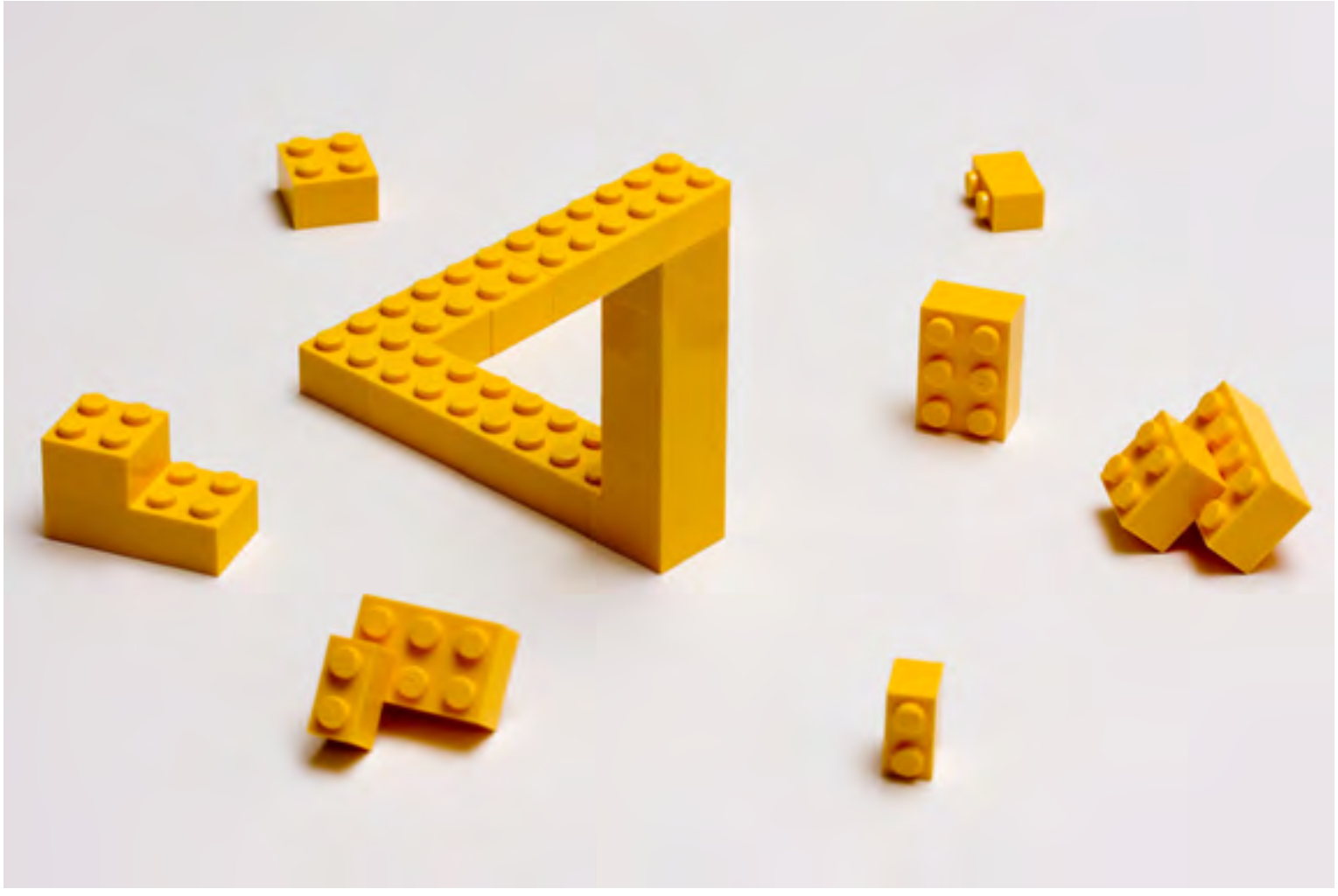
calculations for those who “see” math





age 23 in Amsterdam for a math conference

sees Escher's work, so



Penrose son and father construct the impossible tribar

Escher draws it

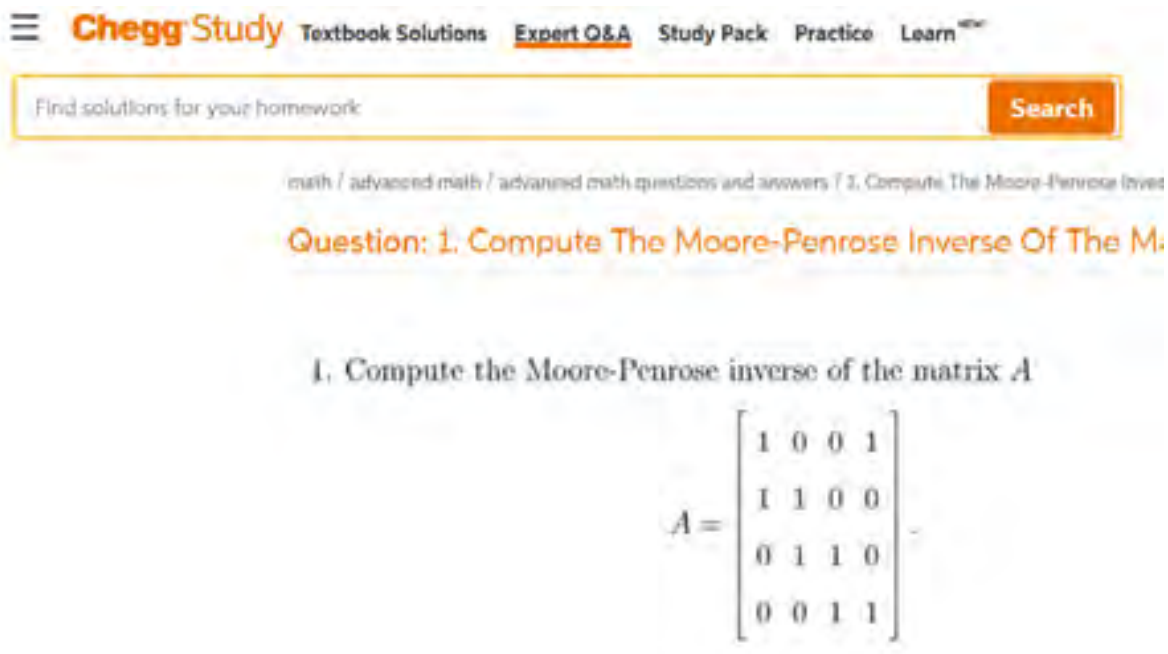
impossible waterfall

age 24 : ‘division by 0’ for matrices

(re)invents Moore-Penrose inverse of a matrix[3]

that “has no inverse”

our undergrads pay cool $$ for it :



today we use it all the time (neuroscience, big data, . . .)

[3] R. Penrose, Math. Proc. Cambridge Philos. Soc. **51**, 406–413 (1955).

age 27 : a math PhD who knows no physics

Penrose:

“I had decided I was going to start learning some physics, in a serious way. I had had to learn it myself because I’d never taken a proper physics course.”

age 27 : PhD & a fateful encounter

pure maths PhD
on tensors

meets 29-old
David Ritz Finkelstein

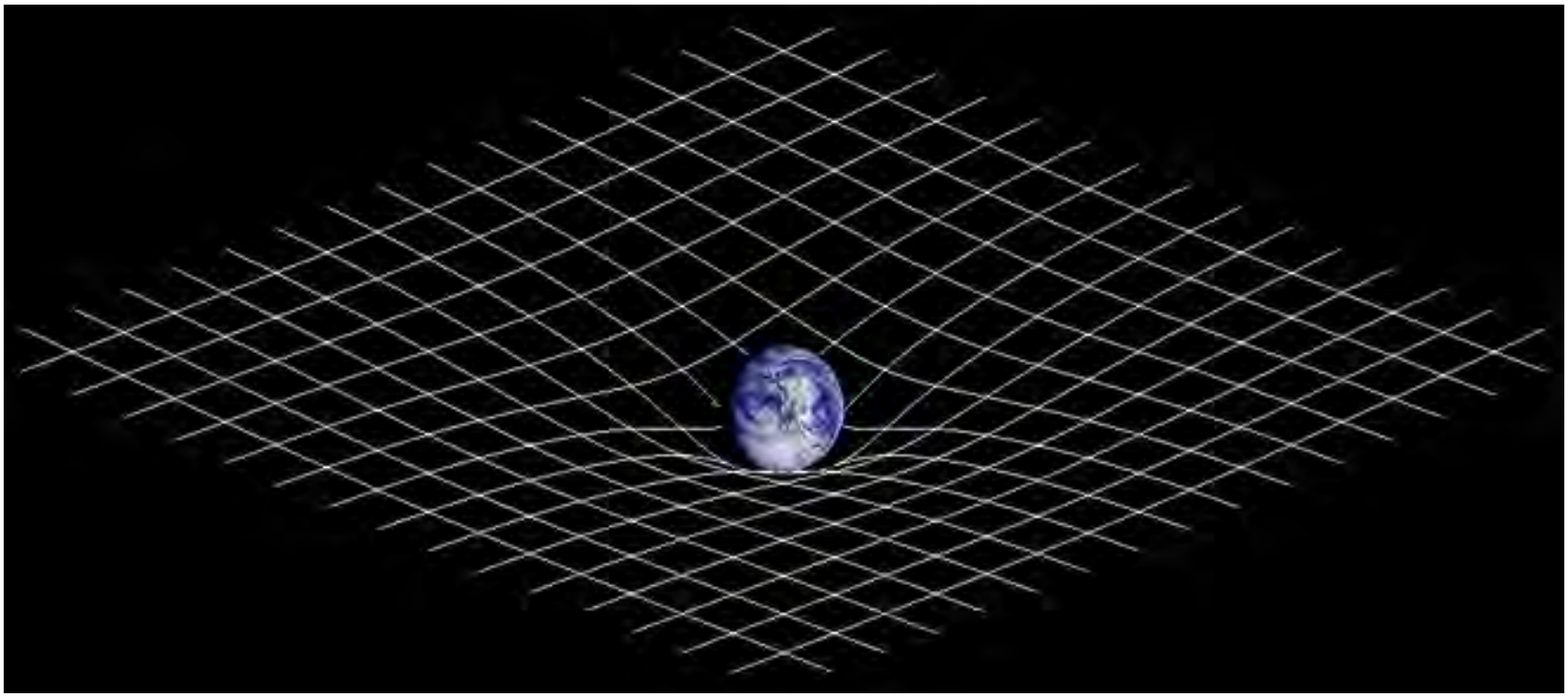
a fateful meeting that changes both men's lives forever

hear Penrose tell it

general relativity

Penrose: “... not difficult to comprehend, compared to quantum mechanics. Equations make complete sense - they are geometry”

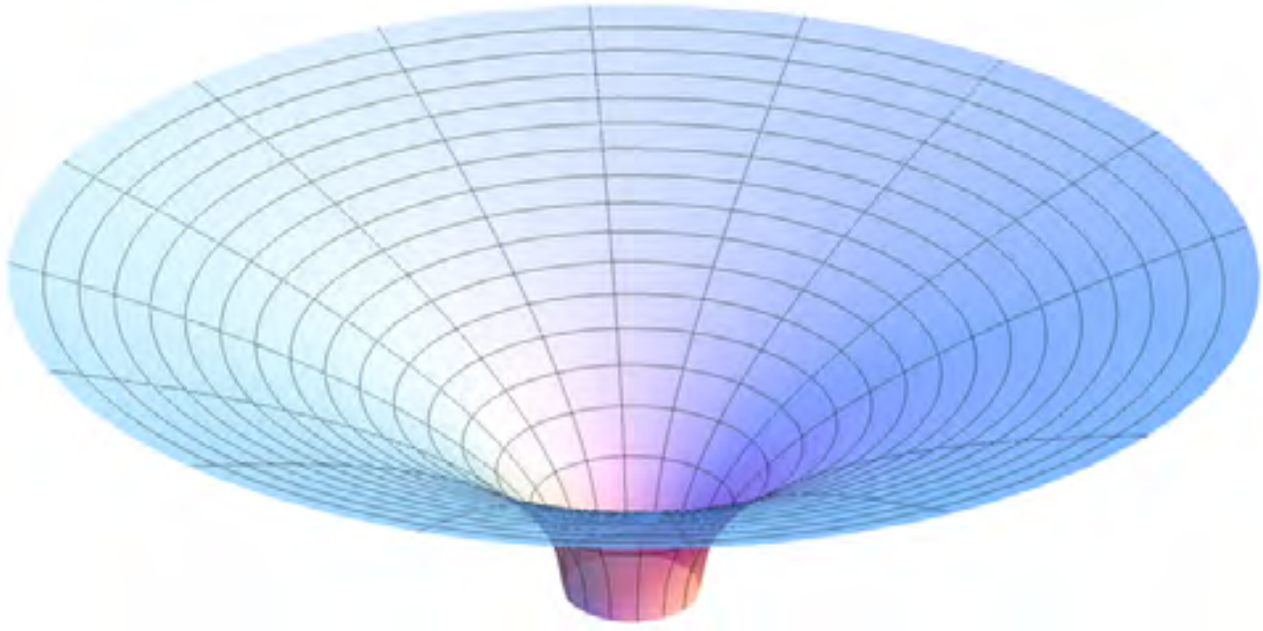
mass = spacetime curvature



too much mass $\Rightarrow$ fall into a hole ?

figure Wikipedia

extending Schwarzschild's metric



beyond the black hole horizon —a basic ingredient of the current understanding of black holes — was a revelation to Penrose.

figure Wikipedia / Flamm

the switch

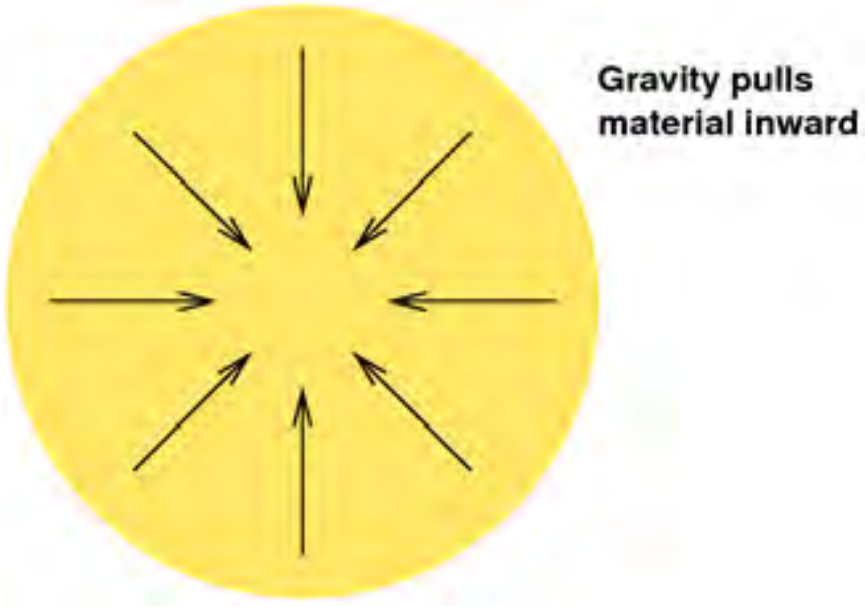
after the seminar Penrose explains to Finkelstein his spin-networks, and the two men exchange their research subjects, forever after.

Finkelstein picks up on the combinatorial aspects of quantum spin as a possible route to delving more deeply into the quantum nature of reality and, says Penrose, “took such ideas to greater lengths than anyone else.”

what was ? with early black hole solutions ?

Finkelstein's extension of the Schwarzschild metric provided Penrose with an opening into general relativity, as

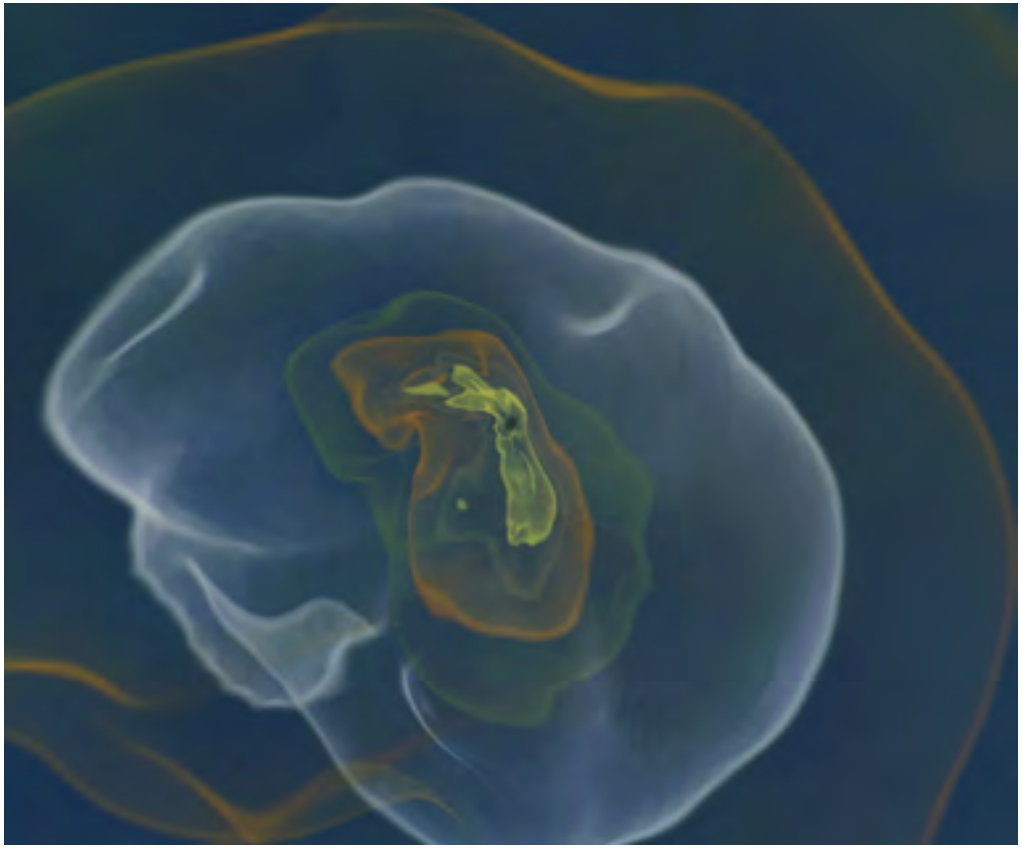
too much symmetry was assumed



how could this not lead to a singularity?

age 27 : what if matter sloshes around ?

gaseous collapse into a 10^5 solar mass black hole



Penrose: “Until then, symmetrical singularity collapsed, but asymmetrical could collapse and swirl out.”

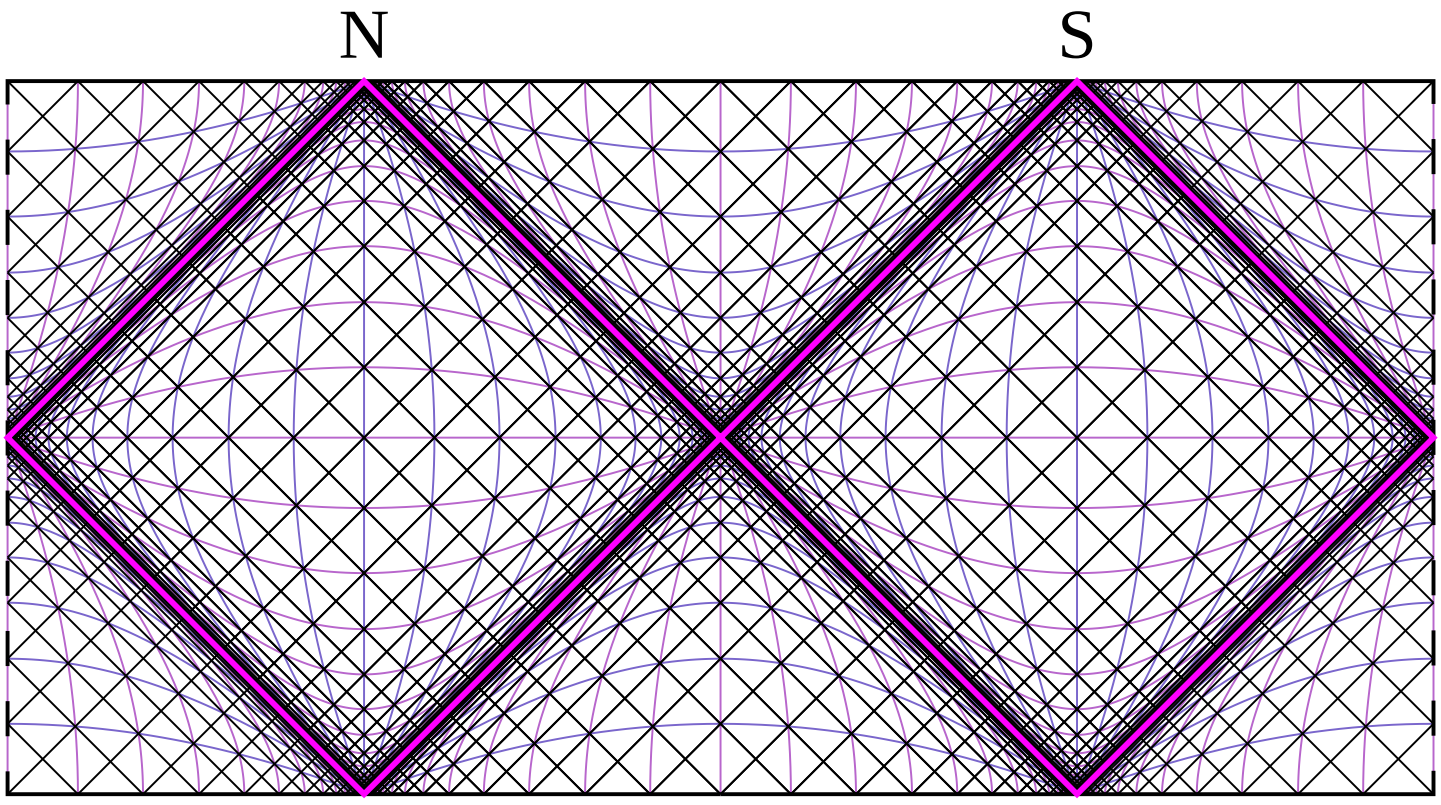
simulation : John Wise, Georgia Tech

age 31

Got a rocket in your pocket? Keep cooly cool, boy!

photo Joan Penrose

regions at infinity placed in a finite position on the causal diagram, so that the entire spacetime can be seen at once



Penrose (conformal) diagram of de Sitter space

age 33 : proves black holes are everywhere using topology

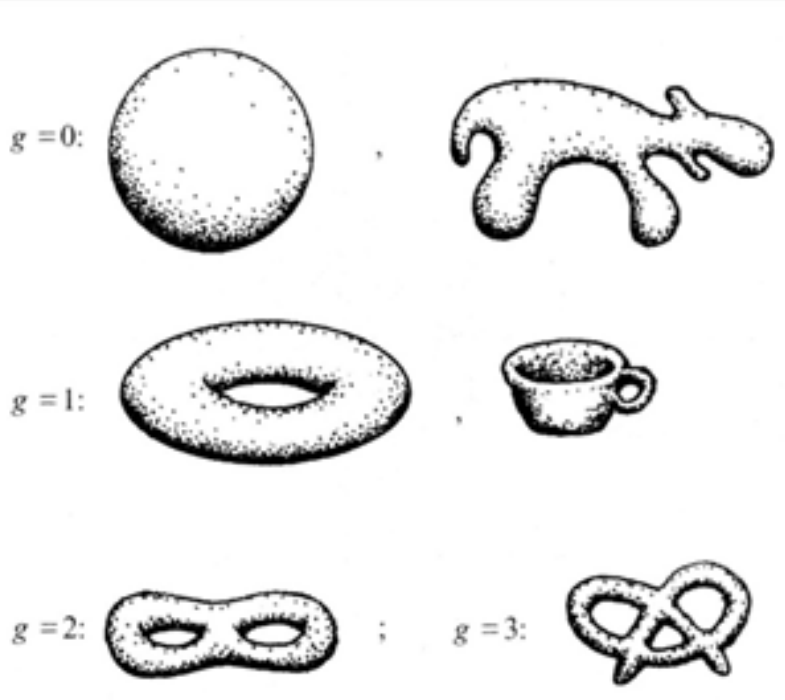
topology is a rubber sheet geometry that deals with

properties of objects when stretched

gravitation robustly leads to black hole singularities

new : no need to solve equations

“trapped surface of any shape” argument is too subtle for tonight’s story...



Nobel prize paper

VOLUME 14, NUMBER 3 PHYSICAL REVIEW LETTERS 18 JANUARY 1965

GRAVITATIONAL COLLAPSE AND SPACE-TIME SINGULARITIES

Roger Penrose
Department of Mathematics, Birkbeck College, London, England
(Received 18 December 1964)

The discovery of the quasistellar radio sources has stimulated renewed interest in the question of gravitational collapse. It has been suggested by some authors[1] that the enormous amounts of energy that these objects apparently emit may result from the collapse of a mass of the order of $(10^6 - 10^8)M_{\odot}$ to the neighborhood of its Schwarzschild radius, accompanied by a violent release of energy, possibly in the form of gravitational radiation. The detailed math-

measured by local comoving observers, the body passes within its Schwarzschild radius $r = 2m$. (The densities at which this happens need not be enormously high if the total mass is large enough.) To an outside observer the contraction to $r = 2m$ appears to take an infinite time. Nevertheless, the existence of a singularity presents a serious problem for any complete discussion of the physics of the interior region.

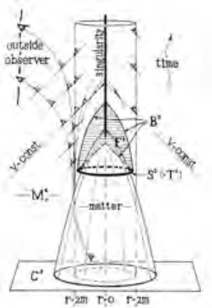


FIG. 1. Spherically symmetrical collapse (one space dimension suppressed). The diagram essentially also serves for the discussion of the asymmetrical case.

Done![4]

can we go home now ?

---

[4] R. Penrose, Phys. Rev. Lett. **14**, 57–59 (1965).

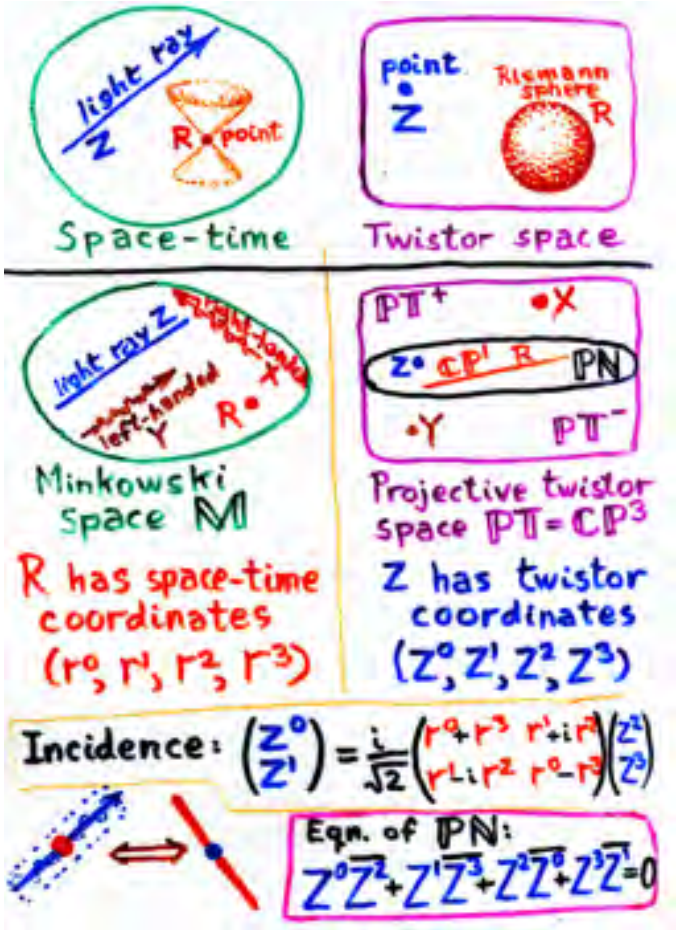
not so fast

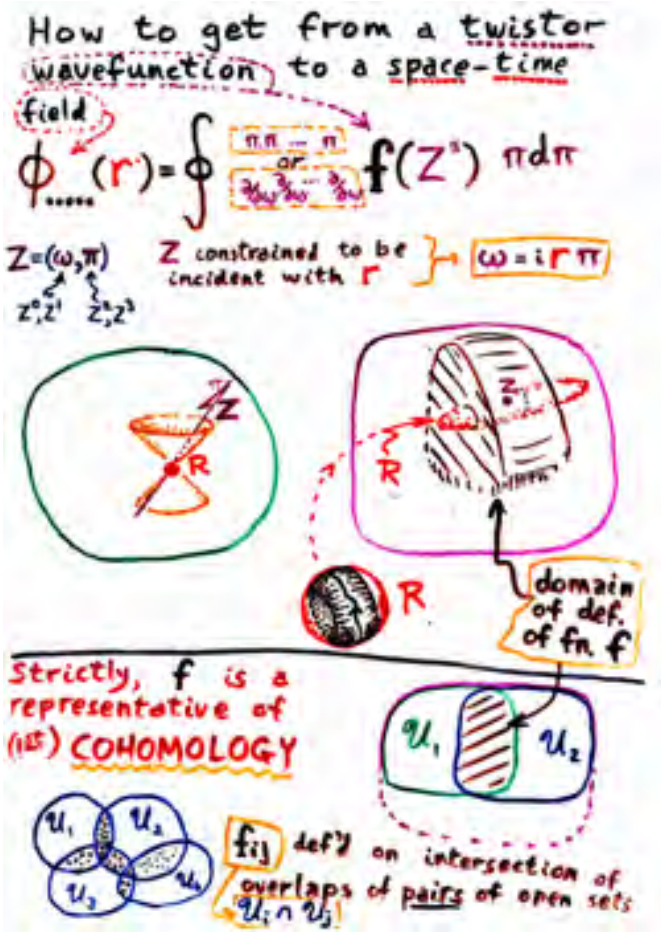
took many years for astronomers to become less skeptical

now they are on all board

age 36 invents twistors

why do we live in 3 space dimensions ?

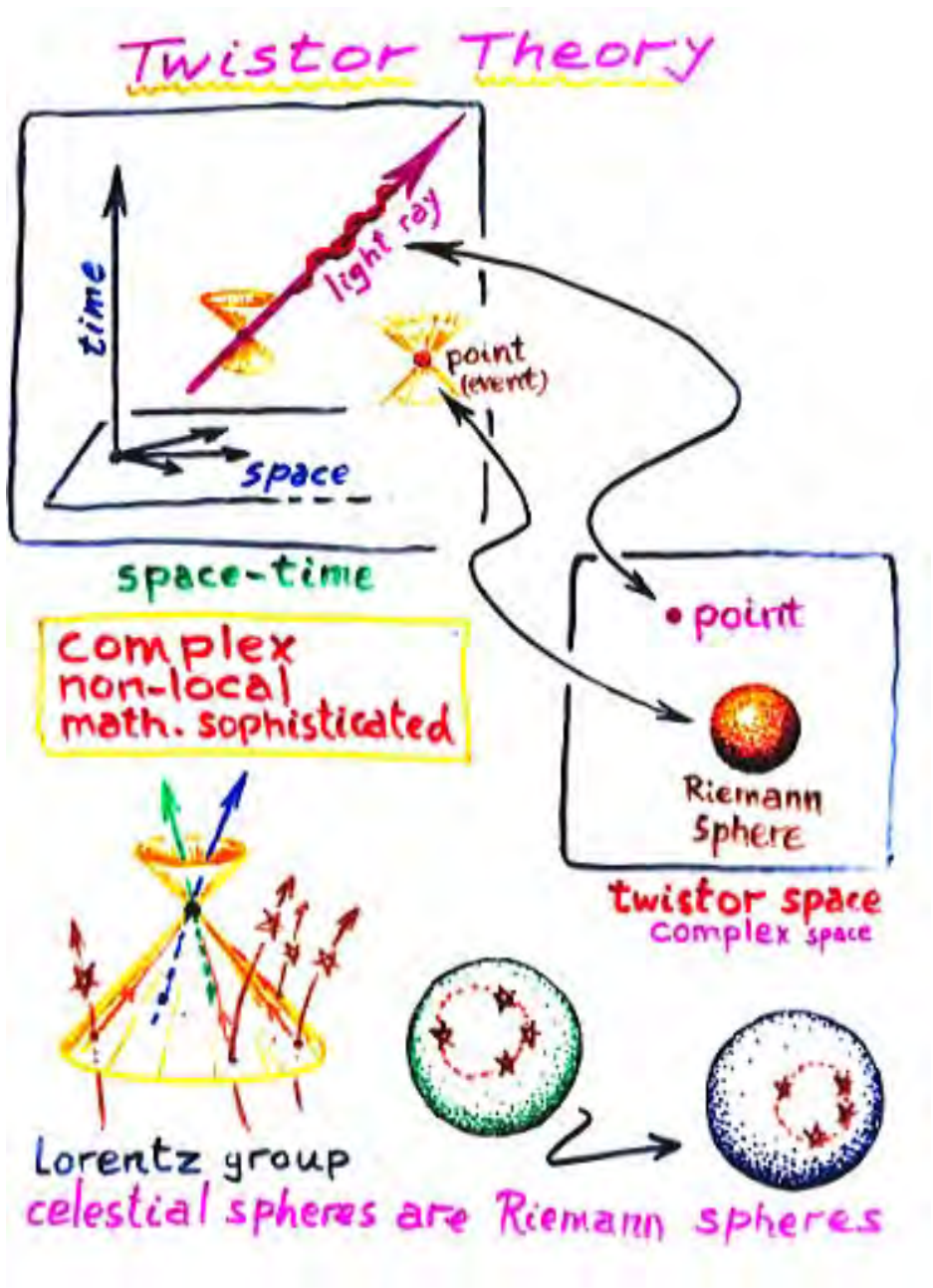




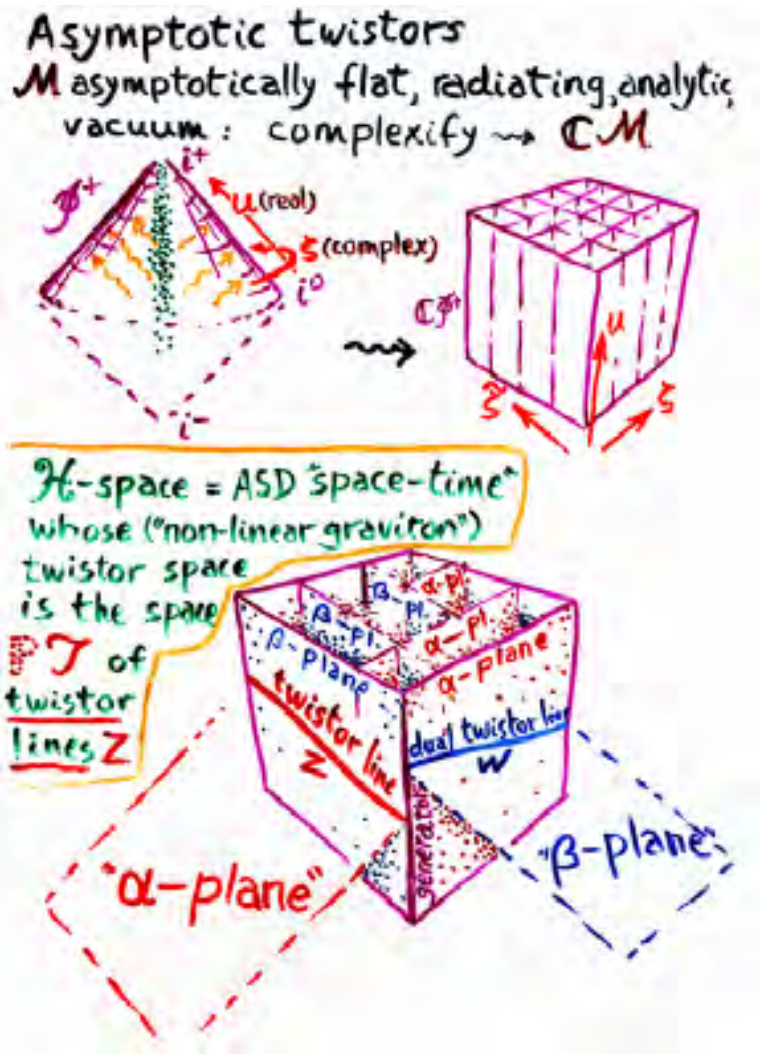
our 4-dimensional spacetime is a mirror of a 4-dimensional complex space[5]

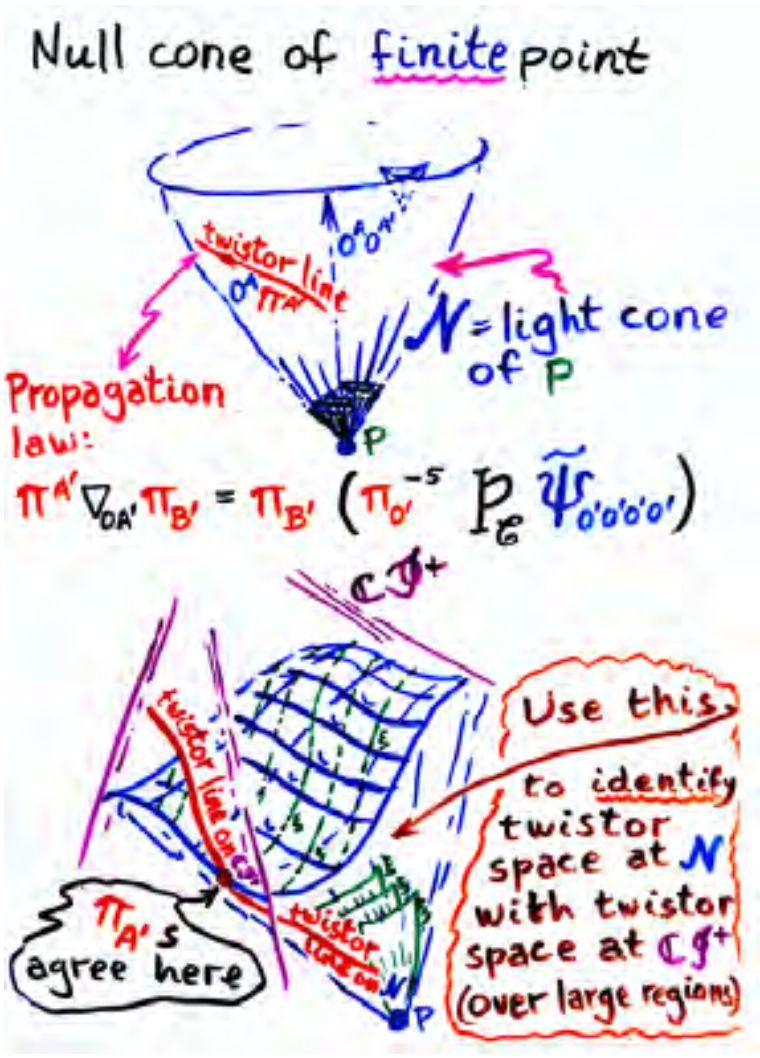
[5] R. Penrose, Journal of Mathematical Physics **8**, 345–366 (1967).

twistors


Twistor Theory
time
light ray
point
(event)
space
space-time
complex
non-local
math. sophisticated
• point
Riemann
Sphere
twistor space
complex space
Lorentz group
celestial spheres are Riemann spheres

let's twist again





gravitational collapse cosmic censorship conjecture

black hole singularities are confined to an event horizon

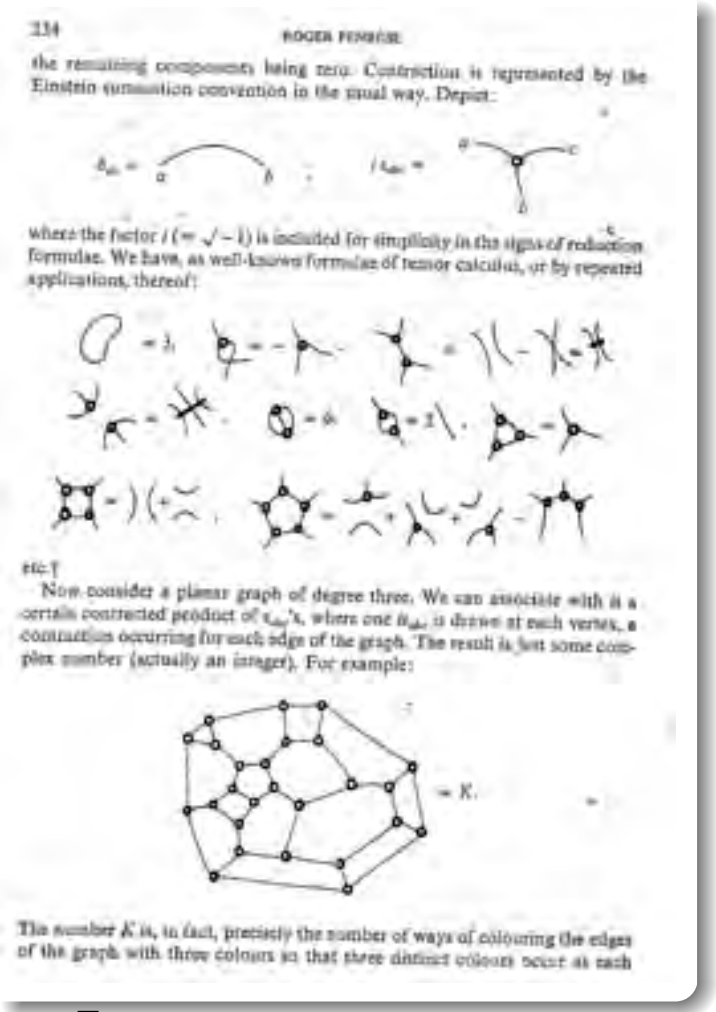
–a “body bag”–

NASA Chandra & NuSTAR satellite telescopes (2019)

surrounding a hidden space-time region from which a civilization could harvest energy[6]

[6] R. Penrose, Riv. Nuovo Cimento **Num. Spez. I**, 257 (1969).

age 38 invents negative dimensions



234 ROGER PENROSE

the remaining components being zero. Contraction is represented by the Einstein summation convention in the usual way. Depict:

where the factor i ($= \sqrt{-1}$) is included for simplicity in the signs of reduction formulae. We have, as well-known formulae of tensor calculus, or by repeated applications, thereof:

etc.†

Now consider a planar graph of degree three. We can associate with it a certain contracted product of $\varepsilon_{\alpha\beta\gamma}$'s, where one $\varepsilon_{\alpha\beta\gamma}$ is drawn at each vertex, a contraction occurring for each edge of the graph. The result is just some complex number (actually an integer). For example:

$= K.$

The number K is, in fact, precisely the number of ways of colouring the edges of the graph with three colours so that three distinct colours occur at each

*7

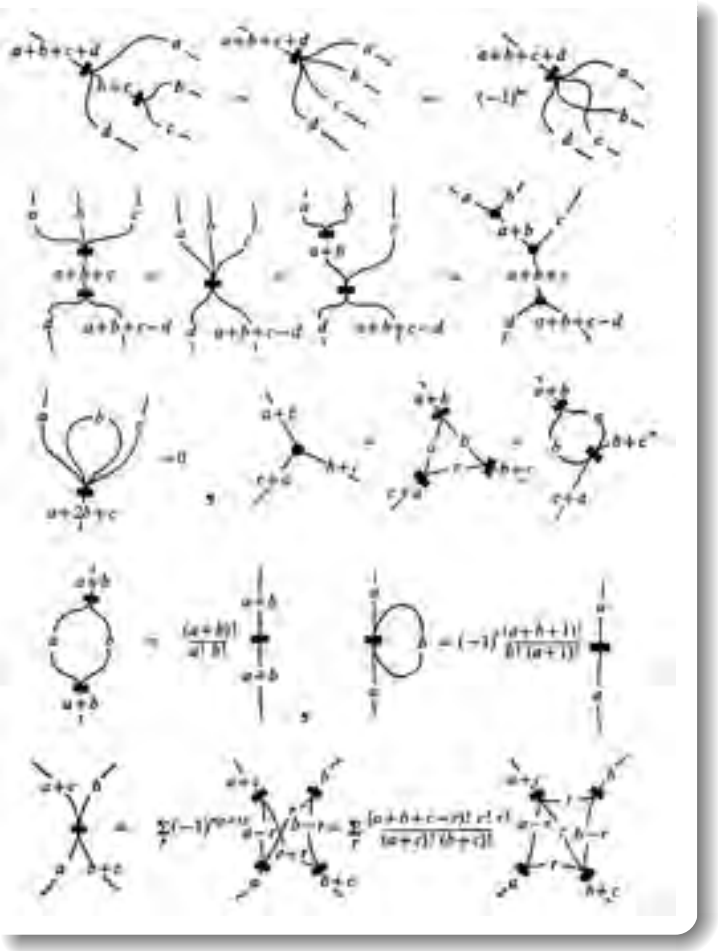
life in -2 dimensions

negative two dimensional world is elegant and pretty
(and all calculated by drawings)

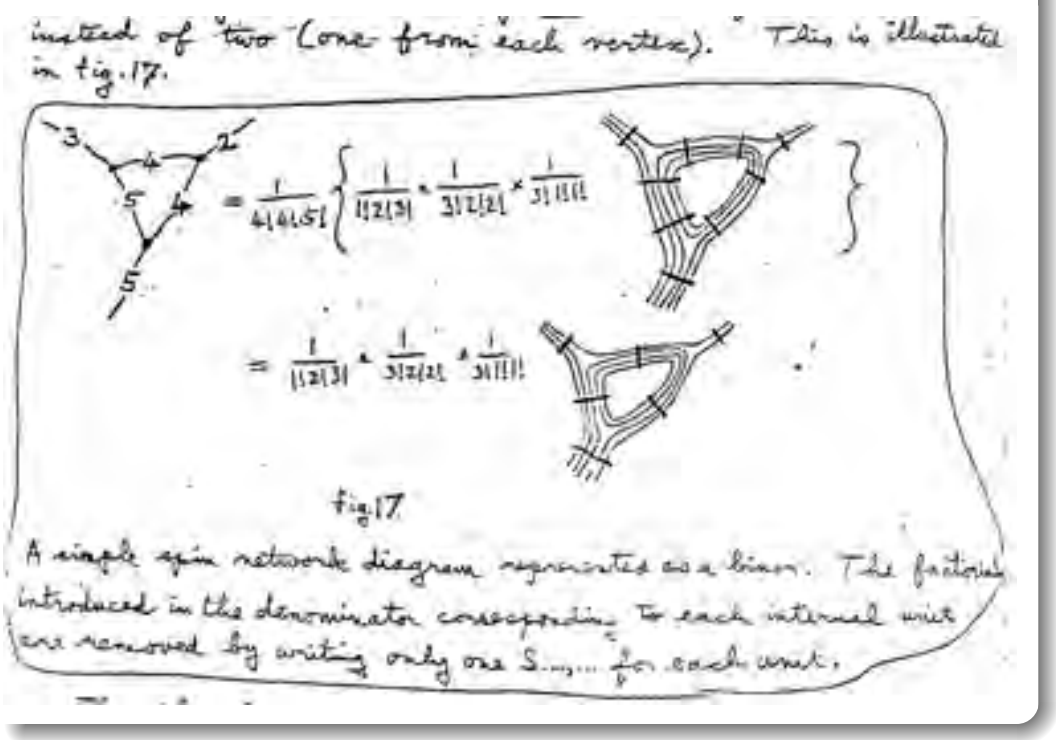
[7] R. Penrose, "Applications of negative dimensional tensors", in *Combinatorial mathematics and its applications*, edited by D. J.A. Welsh (Academic, New York, 1971), pp. 221–244.

age 40 invents spin networks

students ask me : is space continuous or discrete ?



quantum geometry

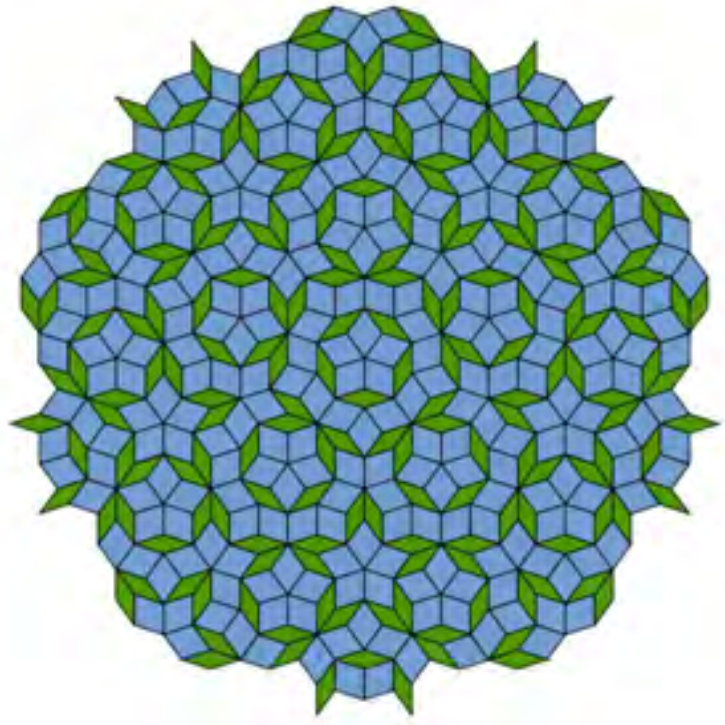


attempt to build our spacetime from quantum spins[8]

[8] R. Penrose, "Angular momentum: An approach to combinatorical space-time", in *Quantum Theory and Beyond*, edited by T. Bastin (Cambridge Univ. Press, Cambridge, 1971).

age 43 invents Penrose tiling

two tiles that tile the plane nonperiodically



with pentagons everywhere[9]

Google the beautiful Veritasium video :

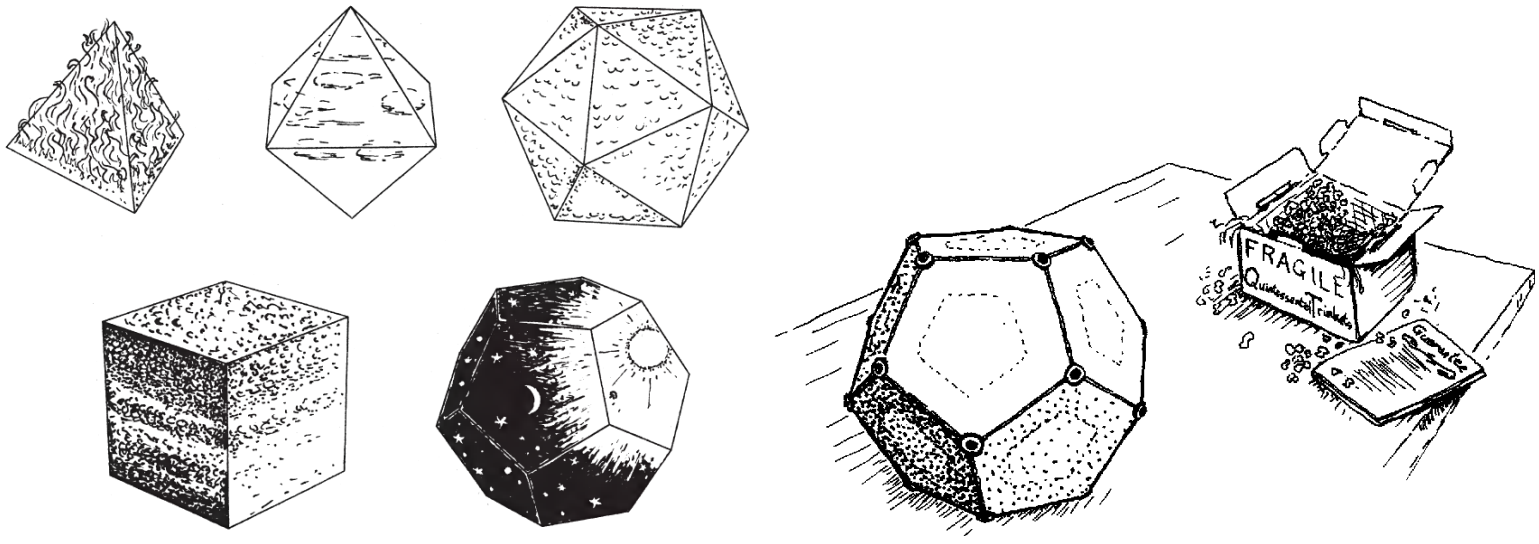
"The Infinite Pattern That Never Repeats"

figure Wikipedia

[9] R. Penrose, Bull. Inst. Math. Appl. **10**, 266–271 (1974).

Penrose tiling disposes of centuries of hitherto

“forbidden” pentagonal symmetry crystals



completes Kepler’s search for pentagonal “snow flakes”
nets a much abused experimentalist a Nobel Prize in chemistry

age any : always contrarian

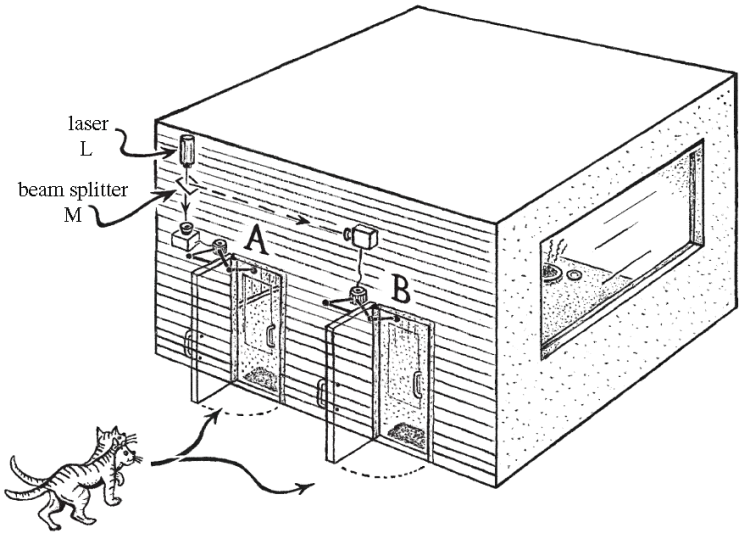
always needle and irritate fellow physicists

quantum mechanics is wrong!

What is missing is gravity :
“gravitization of quantum mechanics” is needed

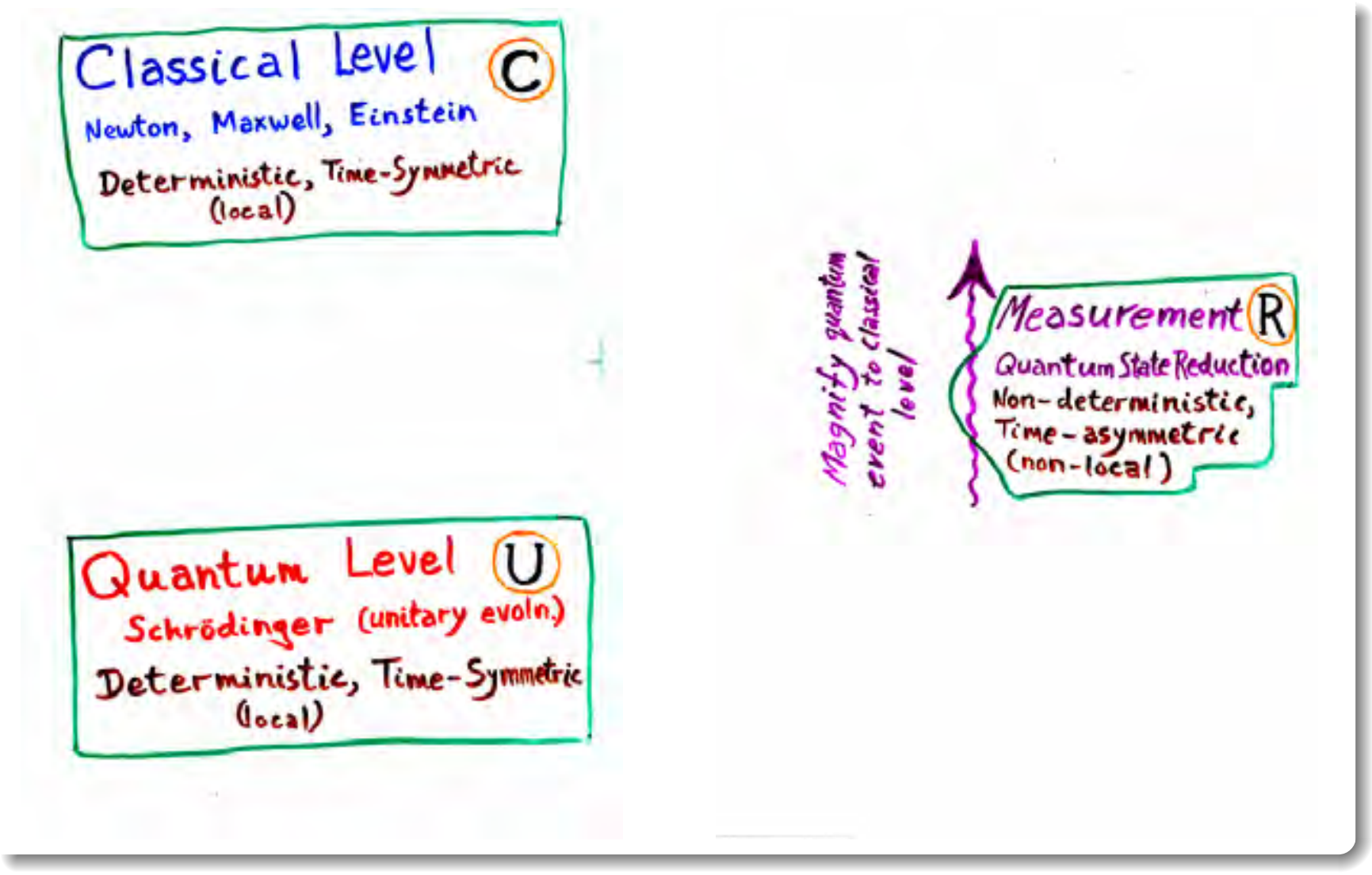
age any : quantum mechanics is not right

Schrödinger's cat



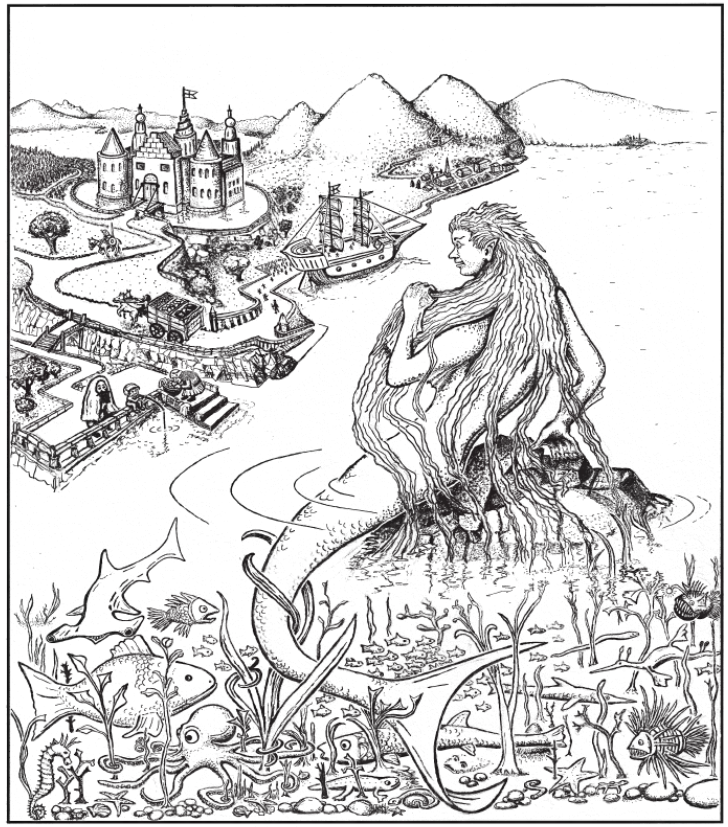
classical and/or quantum ?

age any : quantum mechanics' gotta go



age 58 little Mermaid

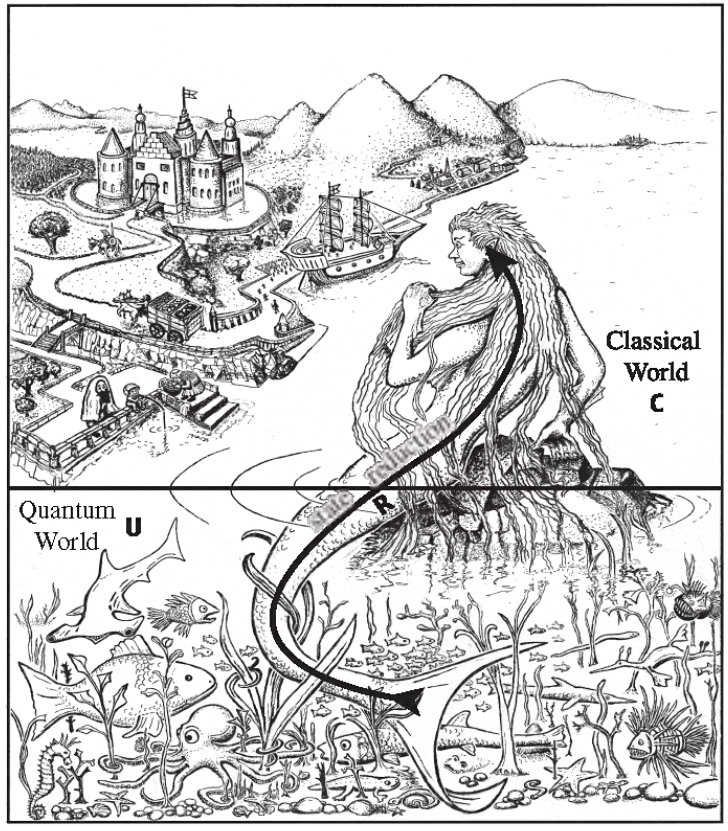
quantum mechanics



classical and quantum

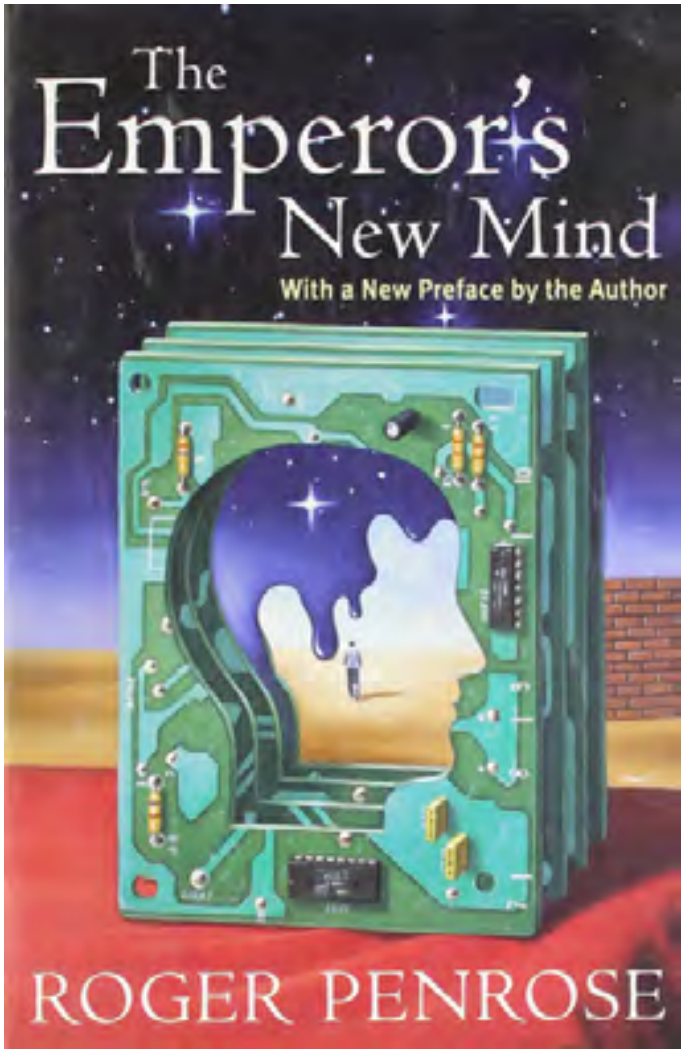
age 58 little Mermaid

quantum mechanics is wrong



classical and quantum miss-joined at hip

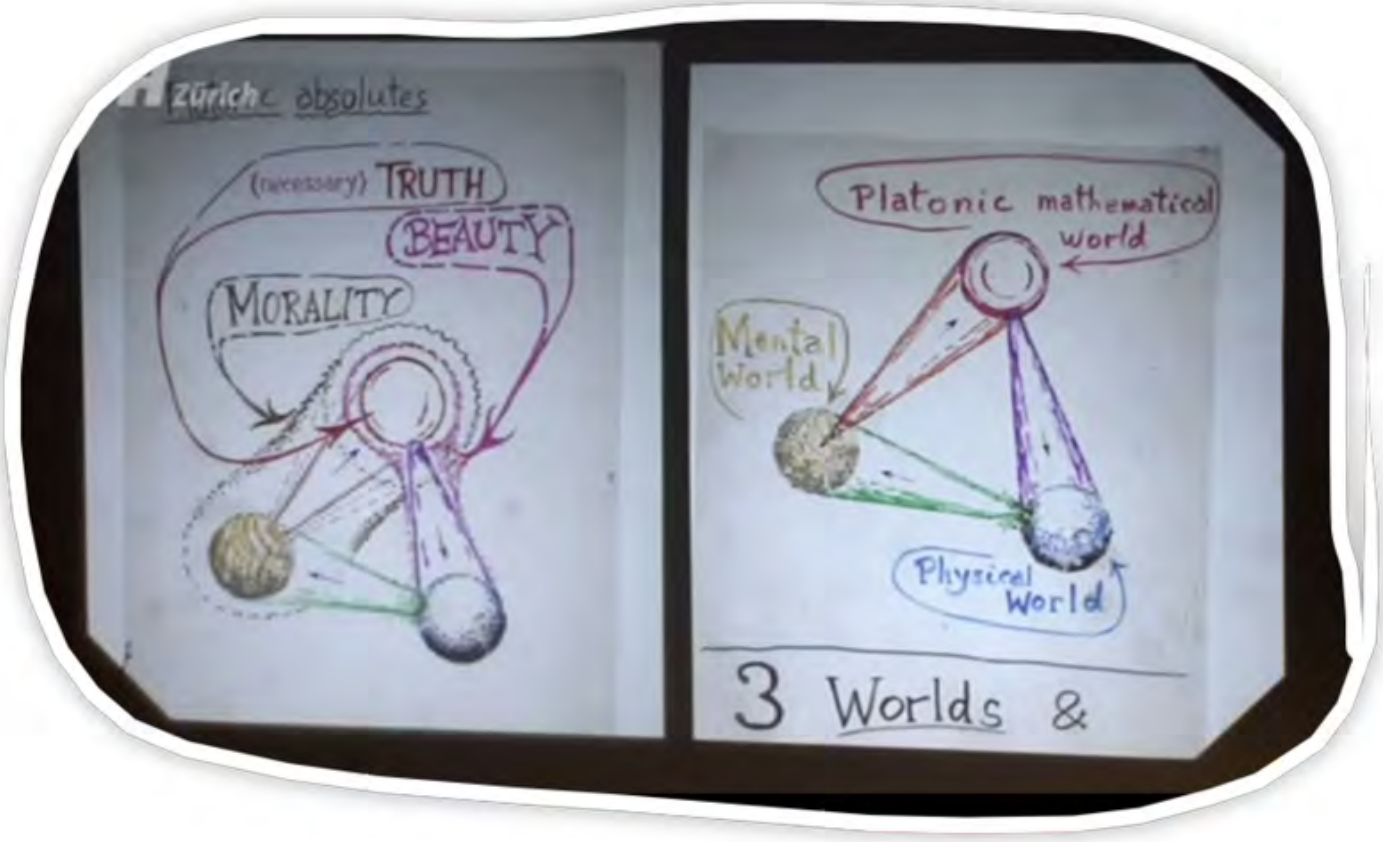
age 58 book The Emperor's New Mind



I didn't know much about neuroscience, ...[10]

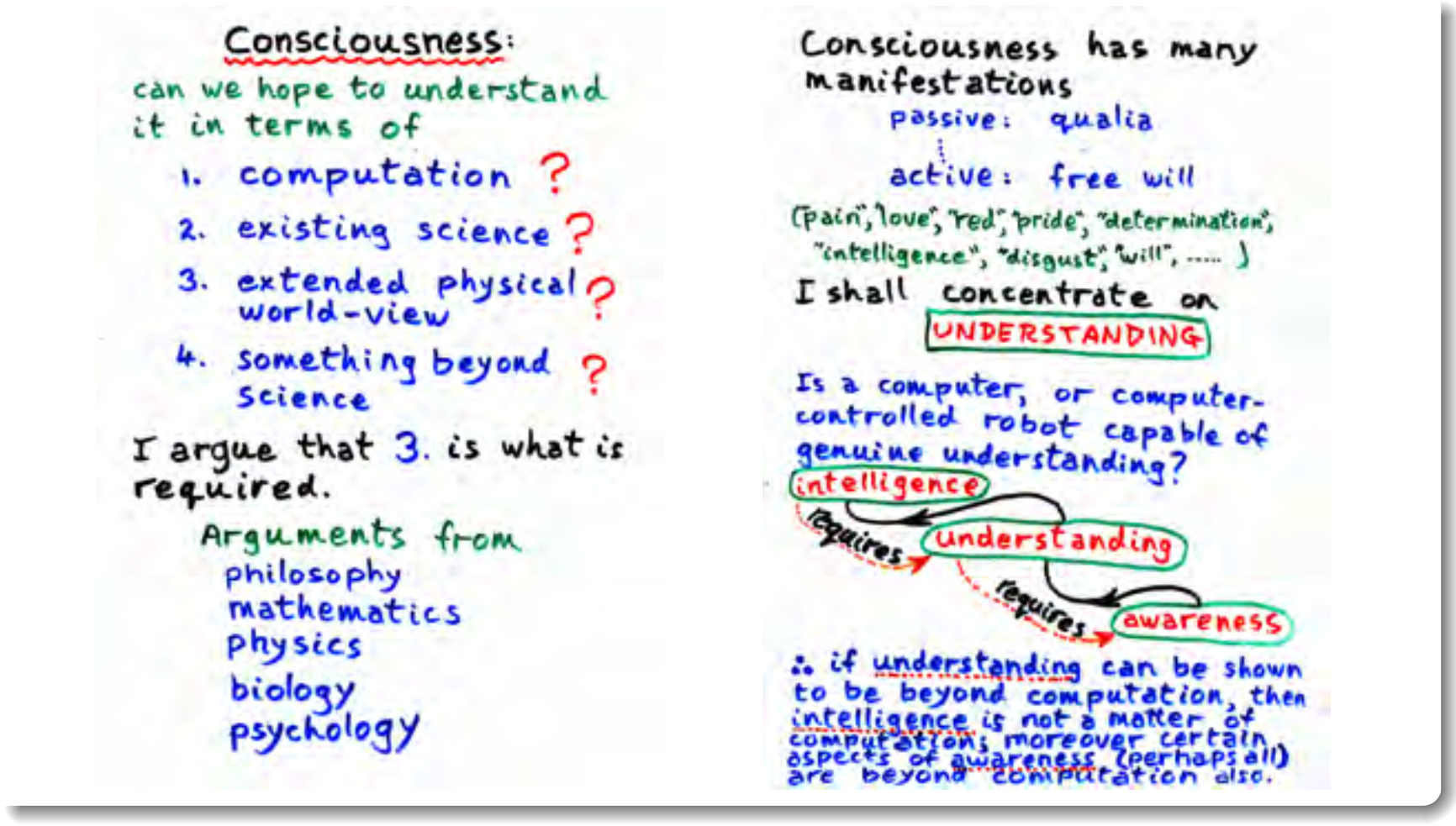
[10] R. Penrose, *The Emperor's New Mind, Concerning computers, minds, and the laws of physics*, (Oxford Univ. Press, Oxford UK, 1989).

age 58 Penrose goes New Age on us



argues that quantum mechanics is a fundamental component of consciousness

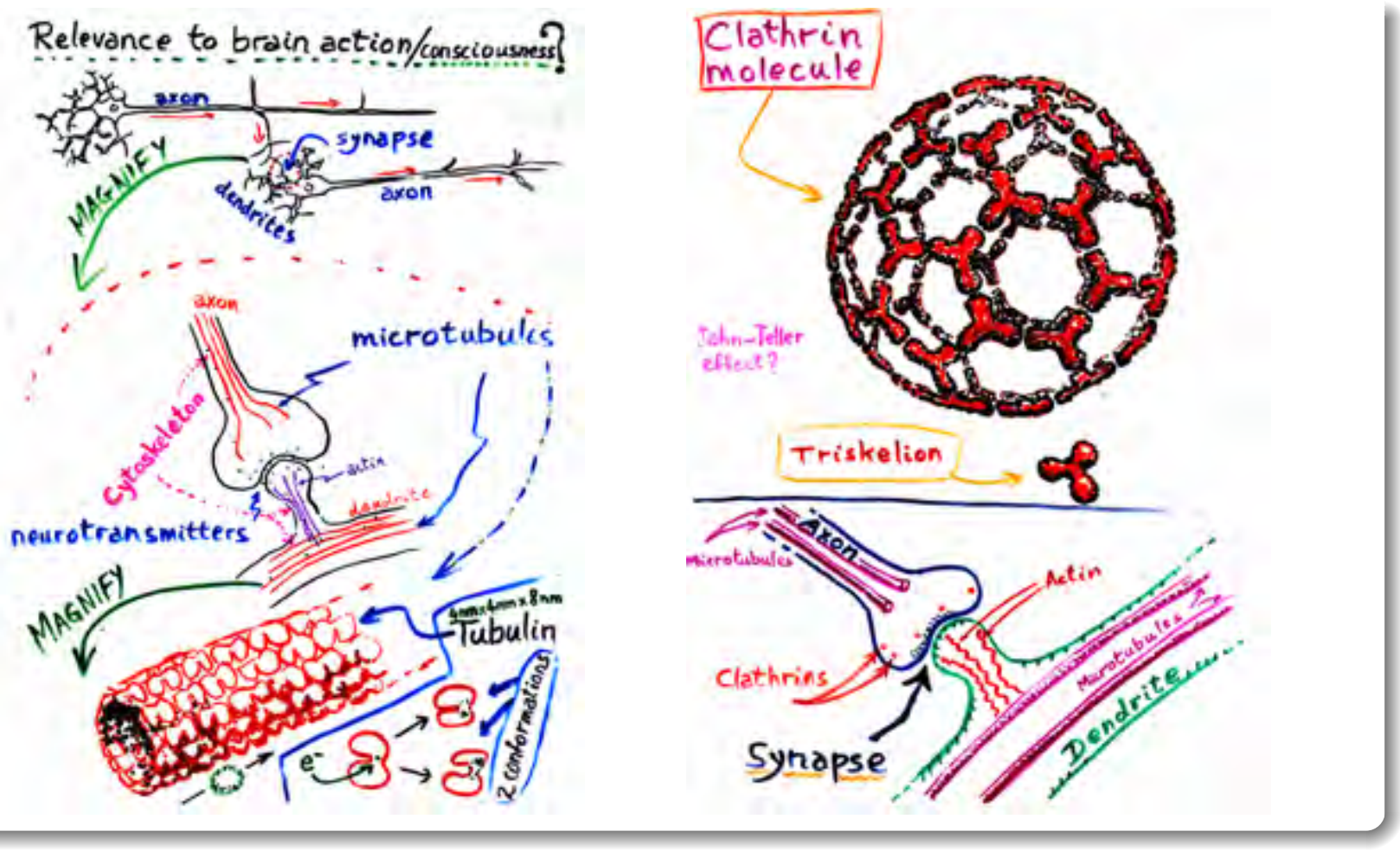
age 58 New Age full monty



"arouses the fury of evolutionary biologists for debunking their ideas about human consciousness"

age 63 book Shadows of the Mind

a search for the missing science of consciousness[11]



with the anaesthesiologist Stuart Hamenoff

[11] R. Penrose, *Shadows of the Mind: A Search for the Missing Science of Consciousness*, (Oxford Univ. Press, Oxford UK, 1996).

age 66 sues Kleenex quilted loo paper

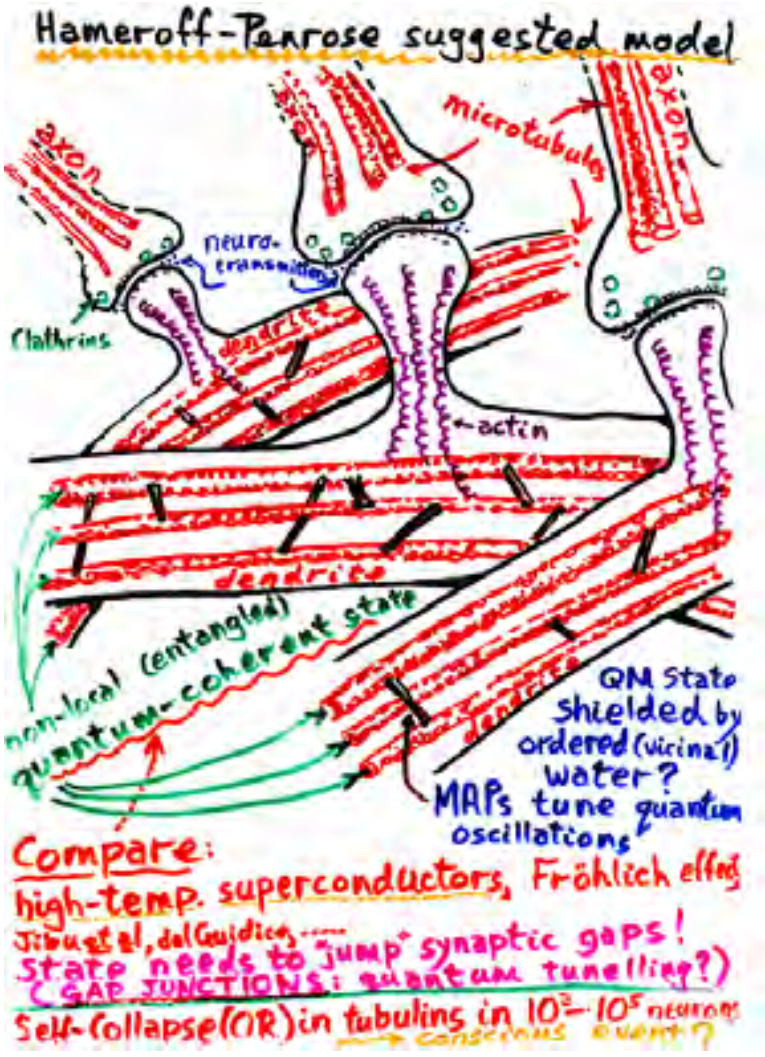
for copyrighted "Penrose Pattern"

'I should explain the loo-roll business except I cannot as there was an out-of-court settlement, a condition of which is that I am not allowed to talk about it,' says Penrose, though his smile suggests there was a happy outcome.

Science Museum Group Collection

age 68 talk Science and the Mind

quantum mechanics of neurophysiology



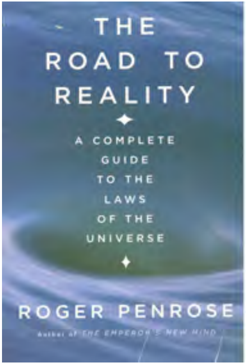
KITP.ucsb.edu/online/plecture/penrose

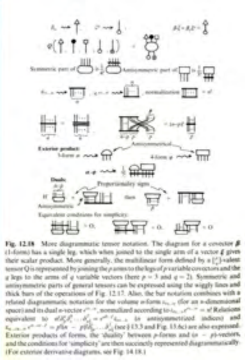
age 69 collaborative effort with Vanessa Penrose

son Maxwell Penrose

age 73 book The Road to Reality

A Complete Guide to the Laws of the Universe[12]





'Colleagues liked my equations but not the contentious stuff about the mind and urged me to write a straightforward book on physics. I thought it would be a simple scissors job but it didn't work out that way.'

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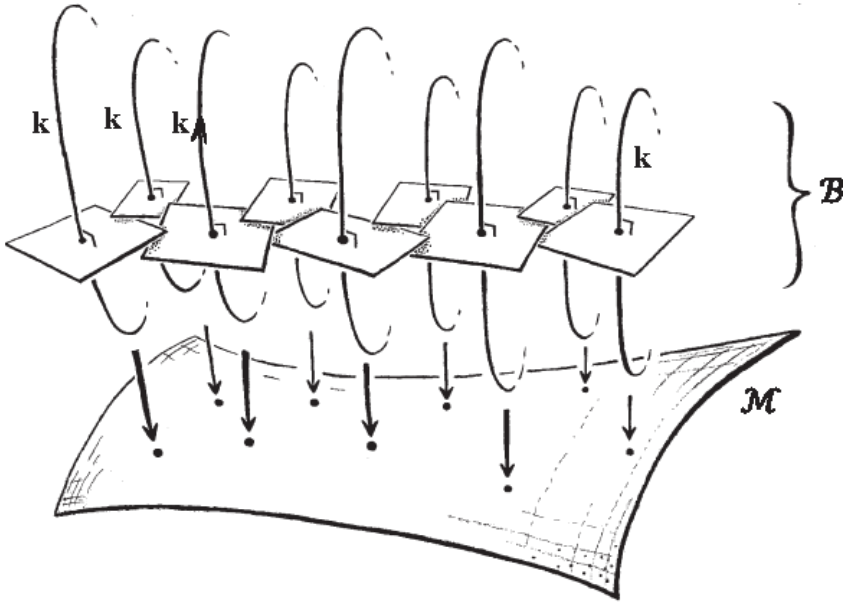
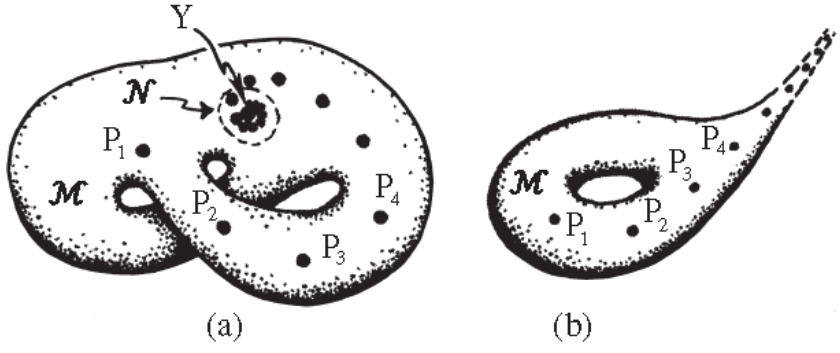
[12] R. Penrose, "Applications of negative dimensional tensors", in *Combinatorial mathematics and its applications*, edited by D. J.A. Welsh (Academic, New York, 1971), pp. 221–244.


k
k
k
k
B
M


Y
N
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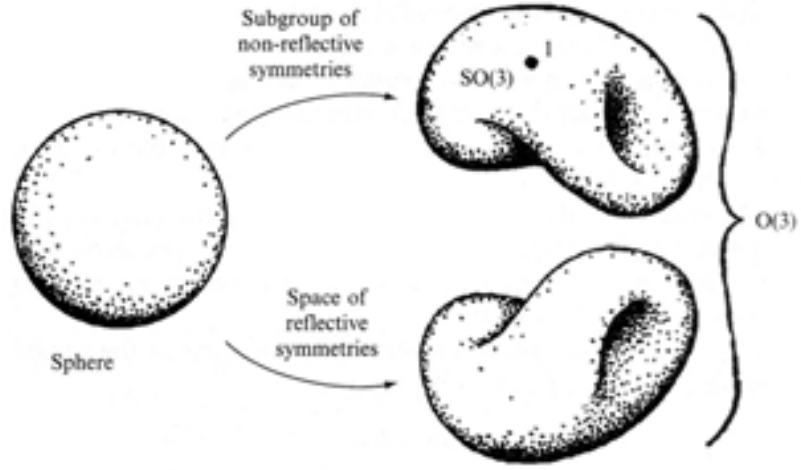
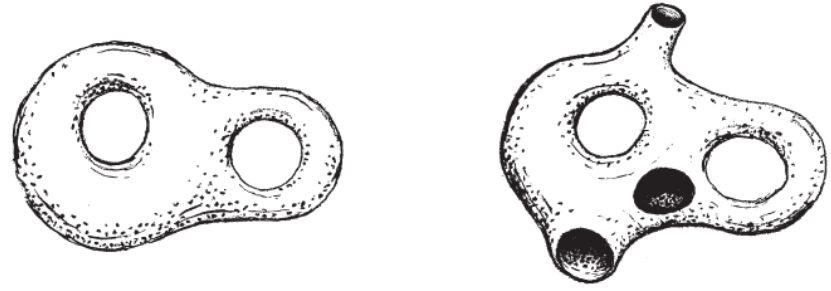
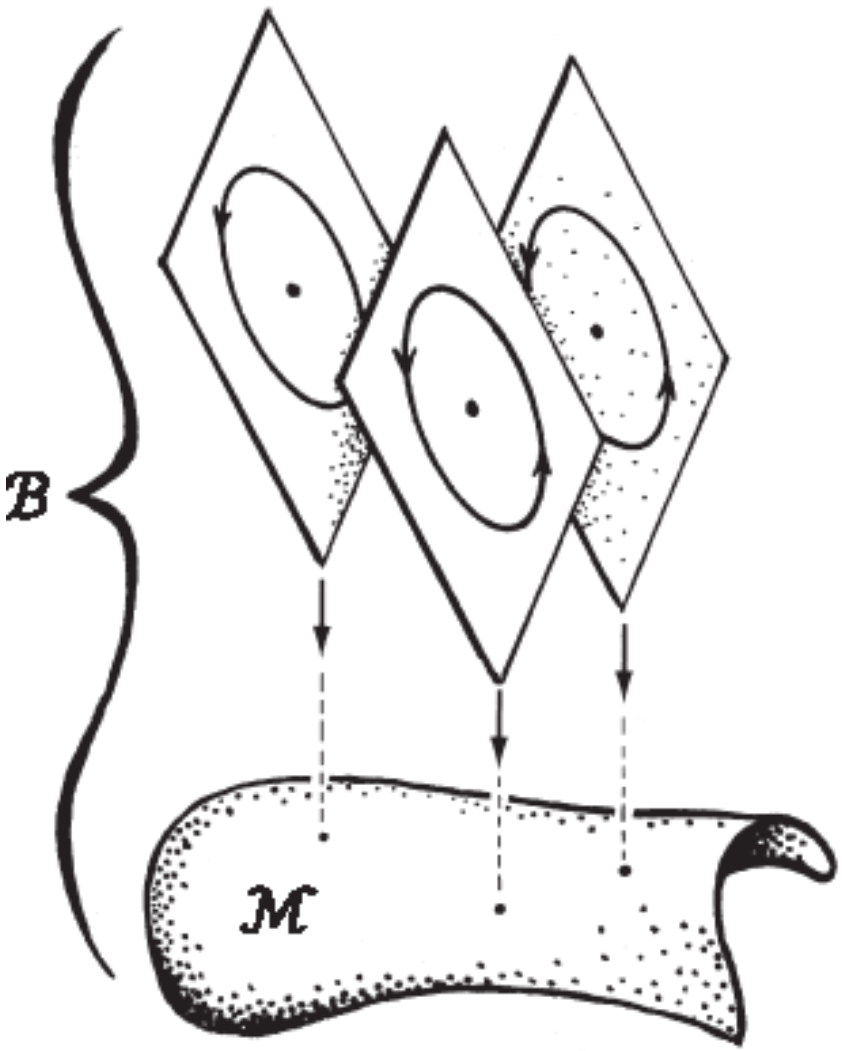
P3
M
P4
P3
P1
P2

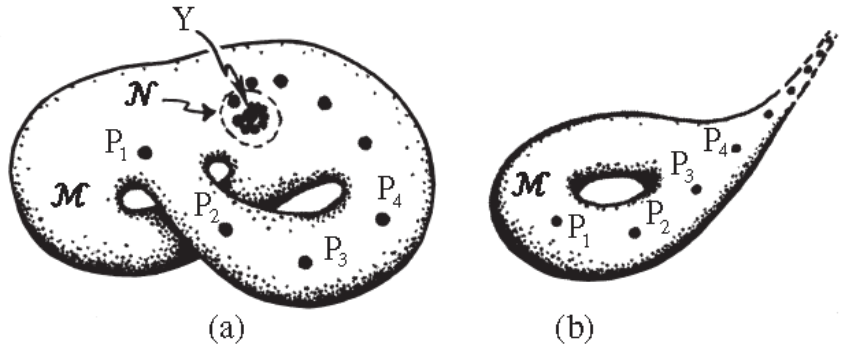
(a) (b)

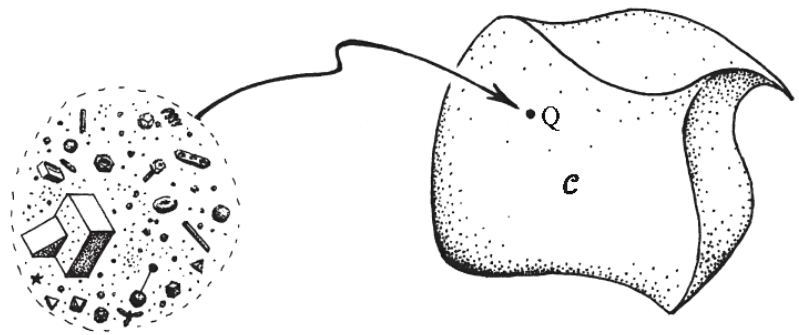

Subgroup of
non-reflective
symmetries
SO(3)
1
O(3)
Sphere
Space of
reflective
symmetries

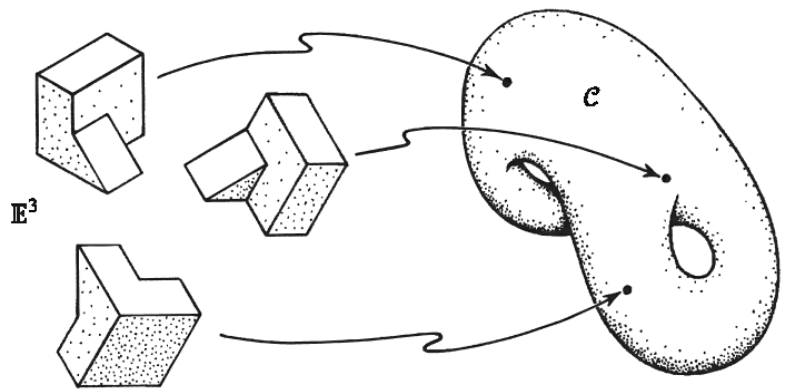


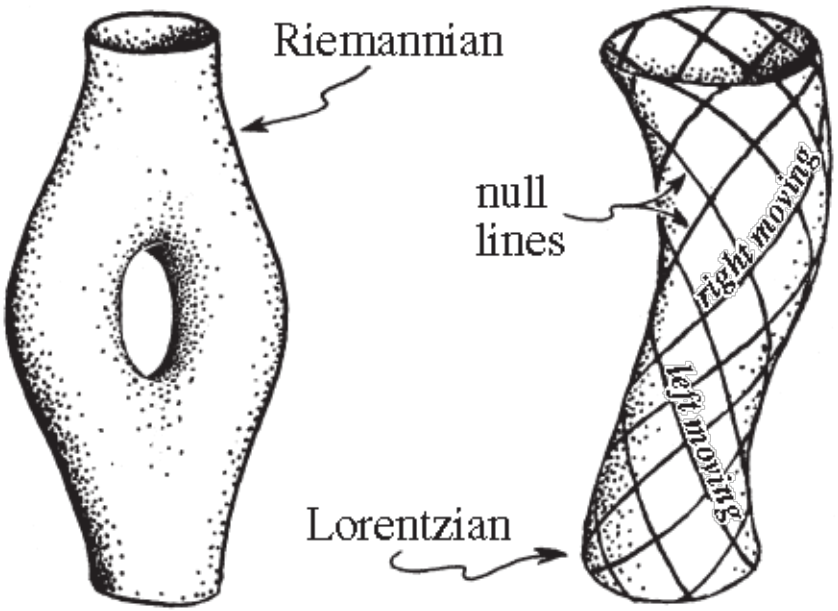
(a) (b)

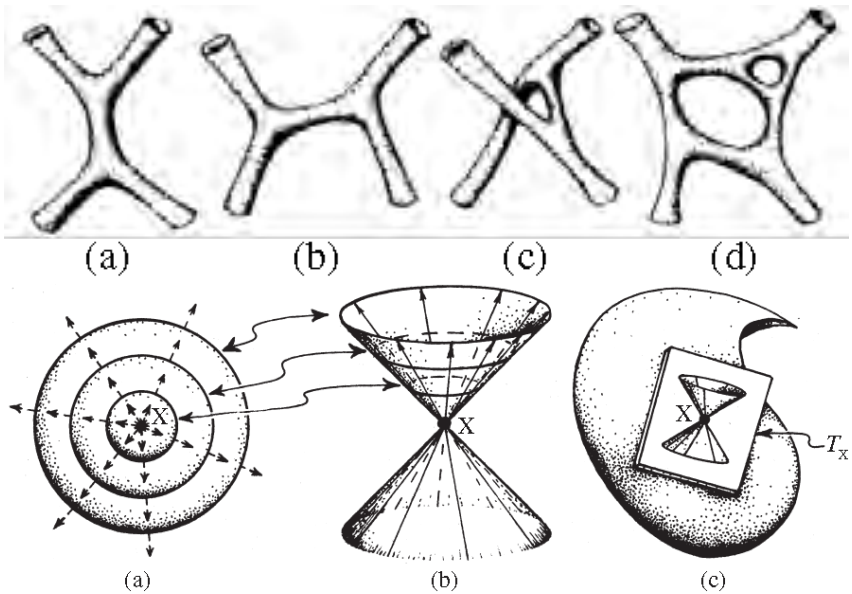

B
M


Y
N
P1
P2
P3
P4
M
(a)
P4
P3
M
P1
P2
(b)


Q
c


E3
c

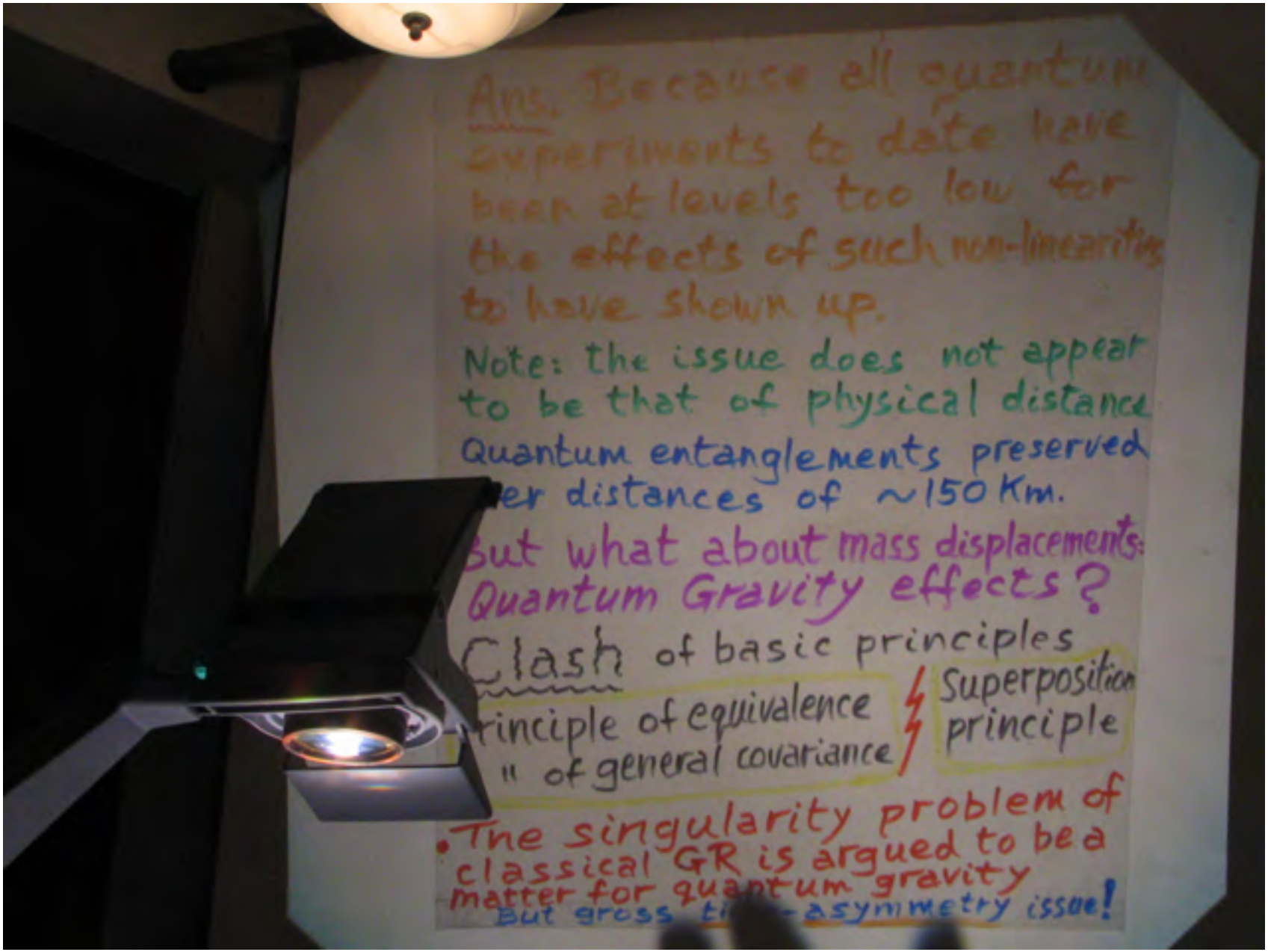

Riemannian
null
lines
right moving
left moving
Lorentzian


(a)
(b)
(c)
(d)
X
X
X
T_X
(a)
(b)
(c)

age 75 : Before the Big Bang

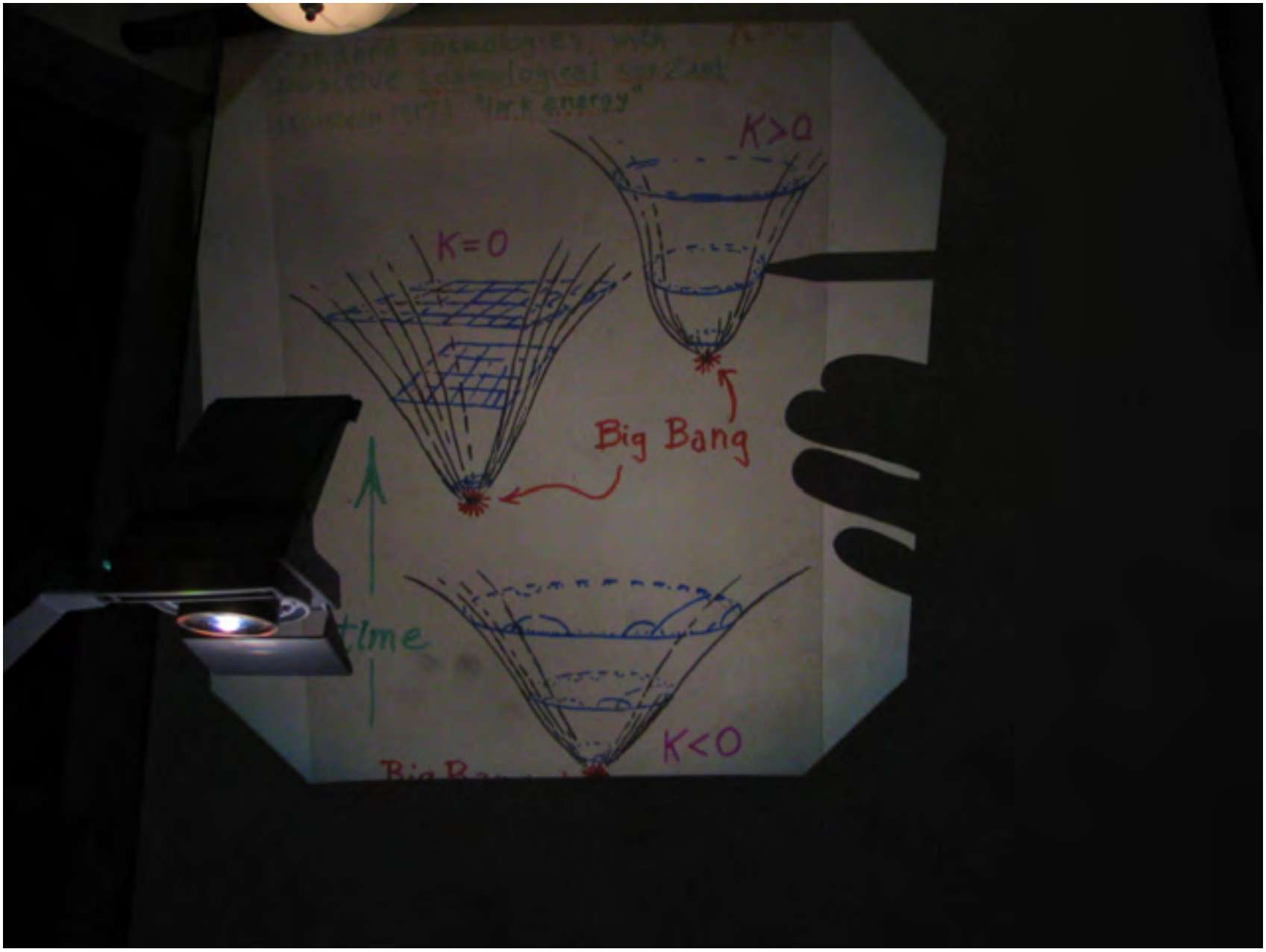
an Outrageous Solution to a Profound Cosmological Puzzle

age 75 : a birthday present



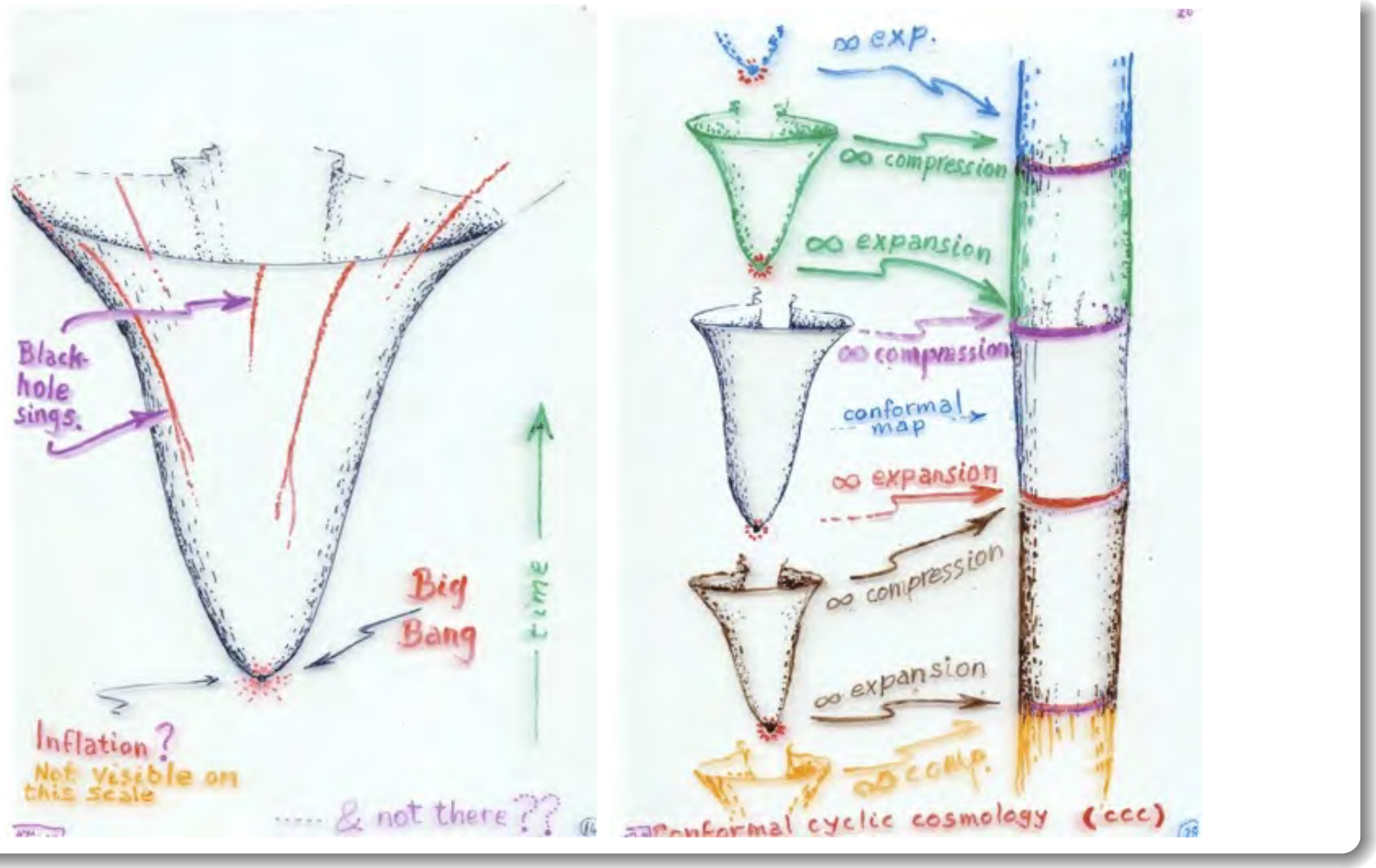
cosmology of eternal rebirth

age 75 : Niels Bohr Institute lecture



we barbarians did not ‘get’ it ...

age 75 book : Cycles of Time

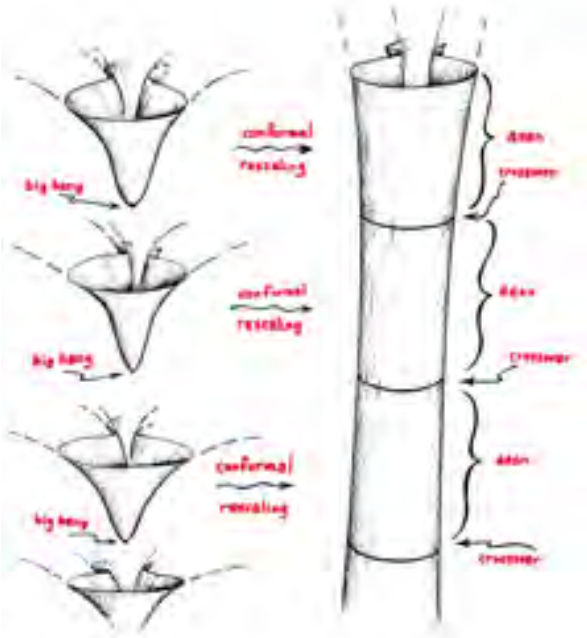


*13

[13] R. Penrose, *Cycles of Time : An Extraordinary New View of the Universe*, (VINTAGE, New York, 2011).

age 75 and the bang goes on

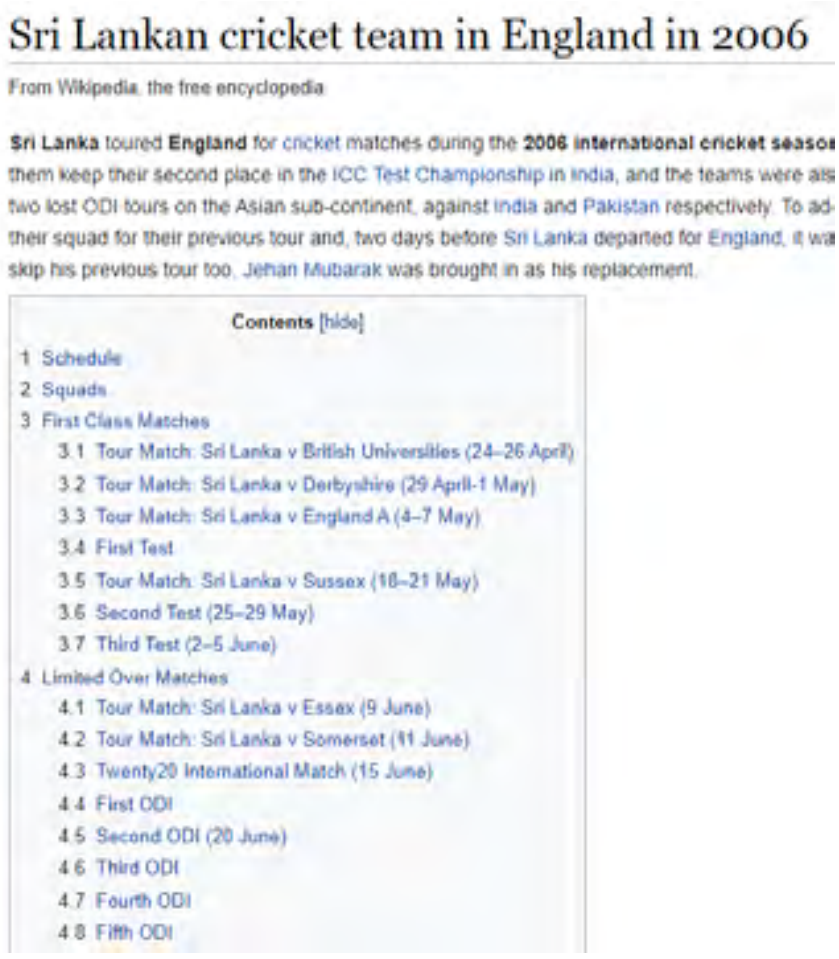
evidence of an earlier universe existing before the Big Bang of our own present universe.



The Big Bang is only an apparent singularity, similar to the apparent singularity at the event horizon of a black hole

age 75 : important things first

we barbarians still do not ‘get’ it ...



Sri Lankan cricket team in England in 2006

From Wikipedia, the free encyclopedia

Sri Lanka toured **England** for cricket matches during the **2006 international cricket seaso**
them keep their second place in the ICC Test Championship in India, and the teams were als
two lost ODI tours on the Asian sub-continent, against India and Pakistan respectively. To ad-
their squad for their previous tour and, two days before Sri Lanka departed for England, it wa
skip his previous tour too. Jehan Mubarak was brought in as his replacement.

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G. Gunaratne: “all he would talk about was ...”

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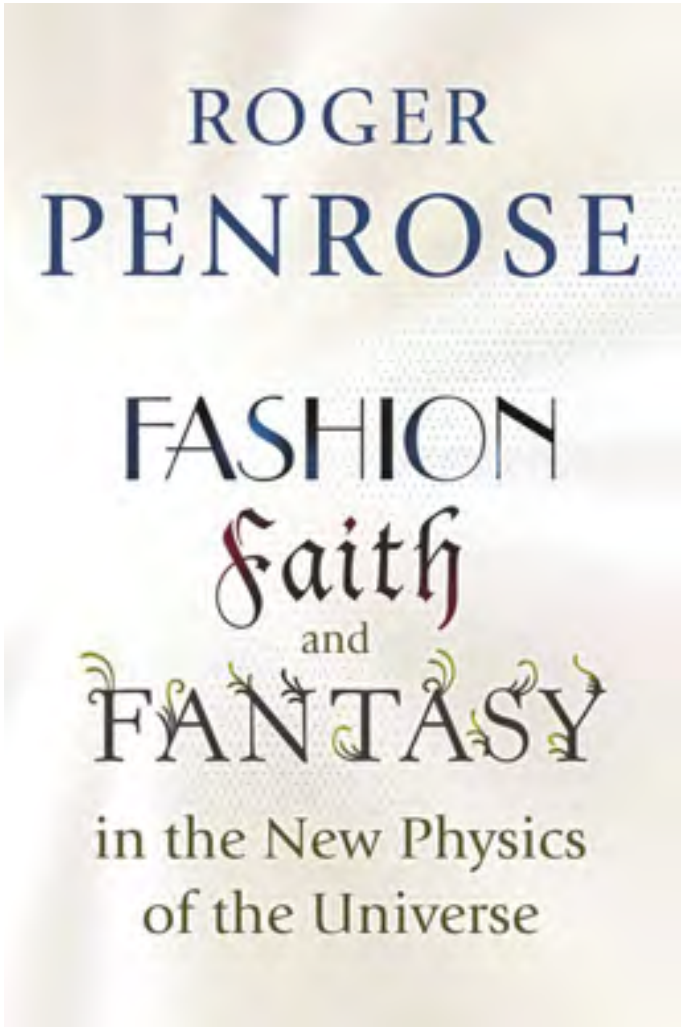
age 85 book Fashion, Faith, and Fantasy

in the New Physics of the Universe[14]



[14] R. Penrose, *Fashion, Faith, and Fantasy in the New Physics of the Universe*, (Princeton Univ. Press, 2016).

I - as do so many of your friends

love you

and so - back to dreams of reality

with “The Road to Reality" always by my side