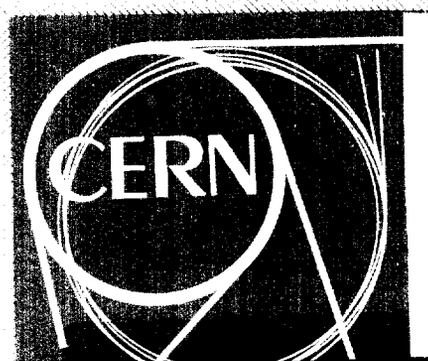


Cours/Lecture Series

1997–1998 ACADEMIC TRAINING PROGRAMME

LECTURE SERIES

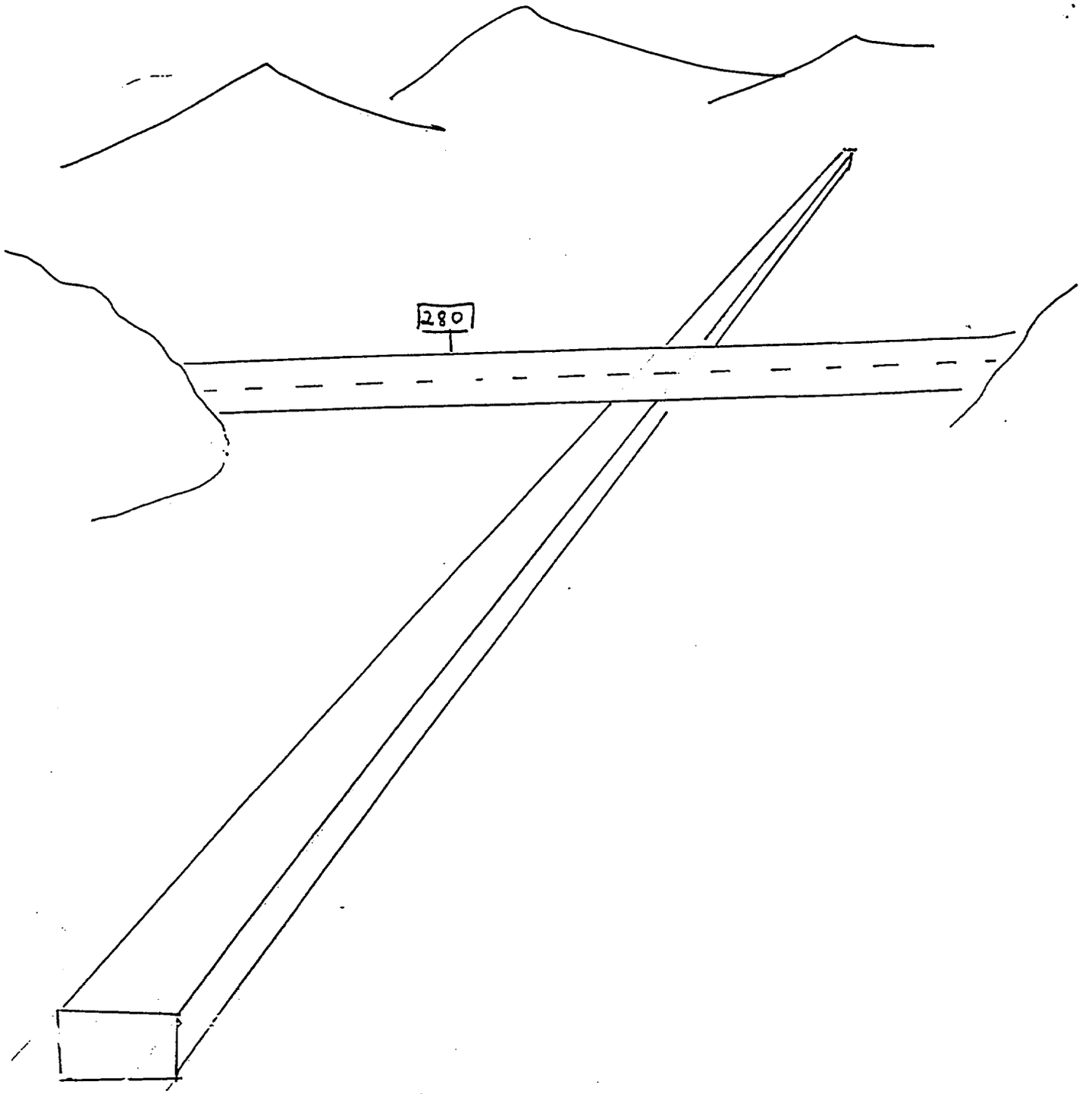
Acad. Train

SPEAKER	:	L. SUSSKIND / Stanford University, USA
TITLE	:	The Physics of Black Holes
TIME	:	15 & 16 December from 10.30 to 12.00hrs
PLACE	:	Auditorium

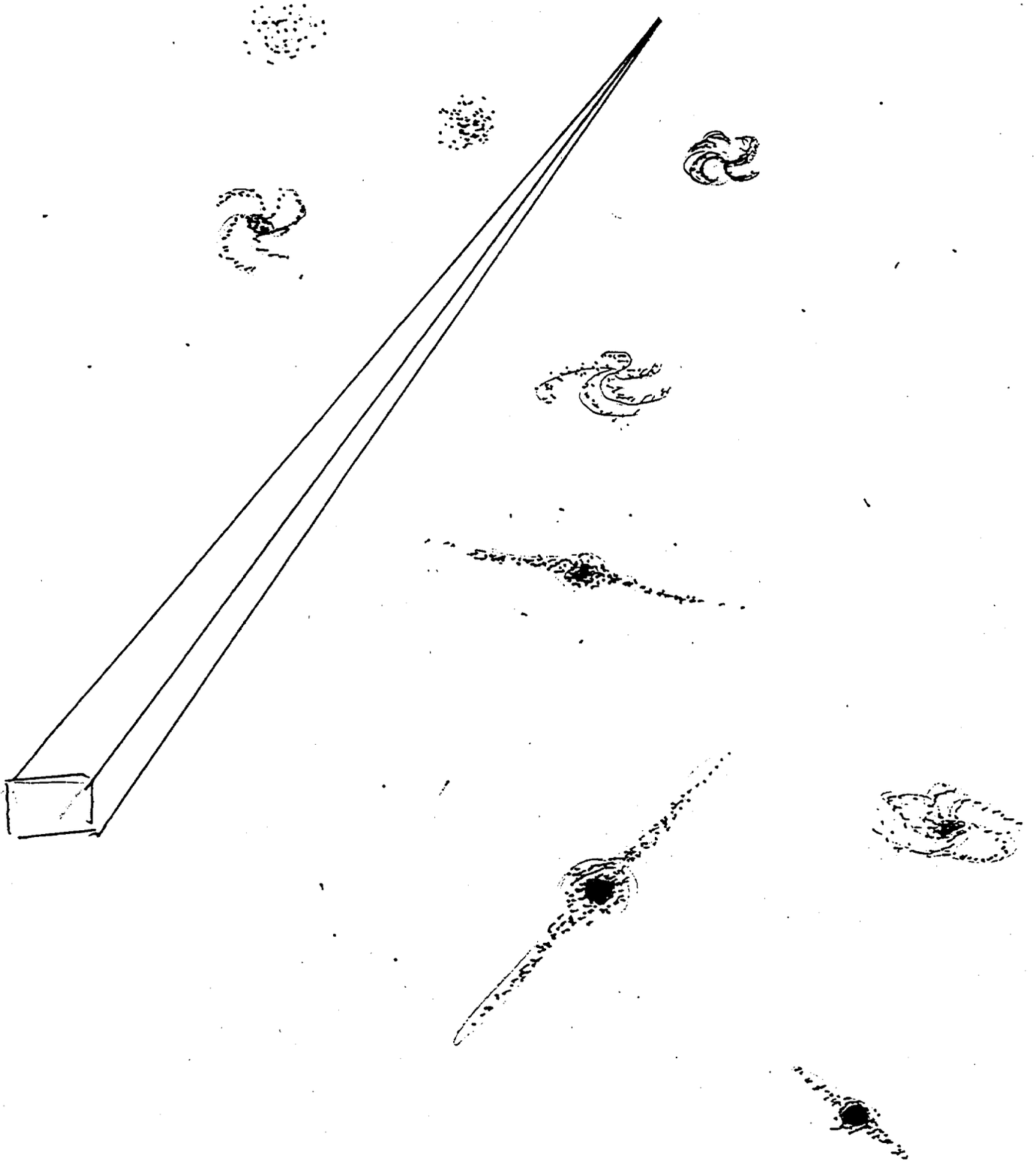
ABSTRACT

I will describe the profound revolution in our understanding of black holes and their relation to Quantum Mechanics that has occured over the last few years as a result of a deeper understanding of string theory.

1997/DSU-CP-MP
Distr. int. & ext.

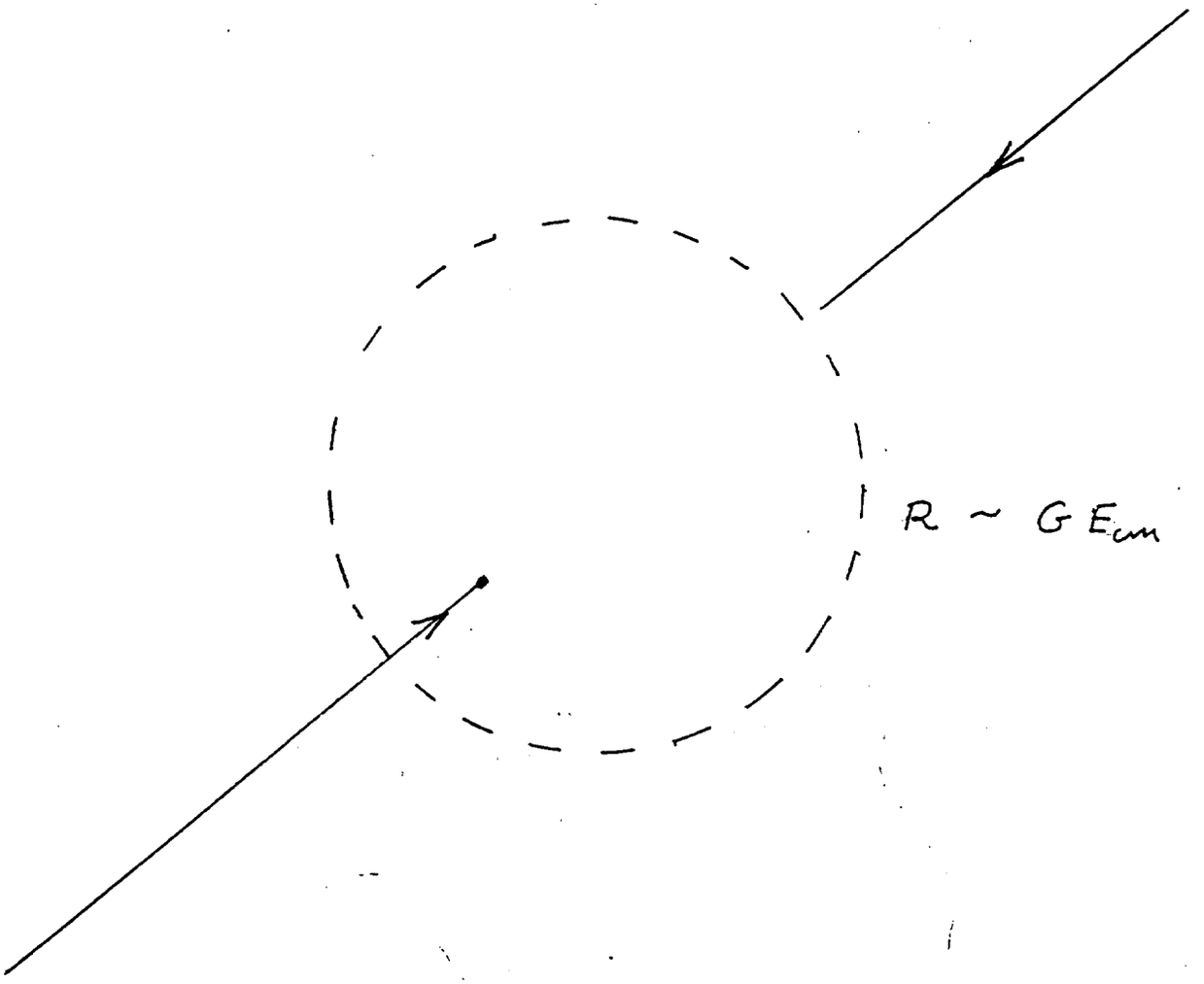


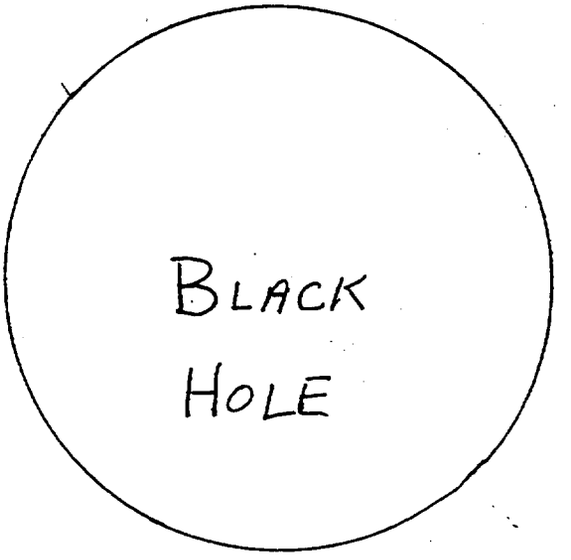
(1) SLAC 10^2 GEV $M_{PLANCK} = 10^{19}$ GeV

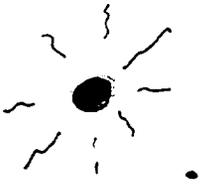


SUPER PLANCKETRON

10^{19} GEV


$R \sim G E_{cm}$


BLACK
HOLE

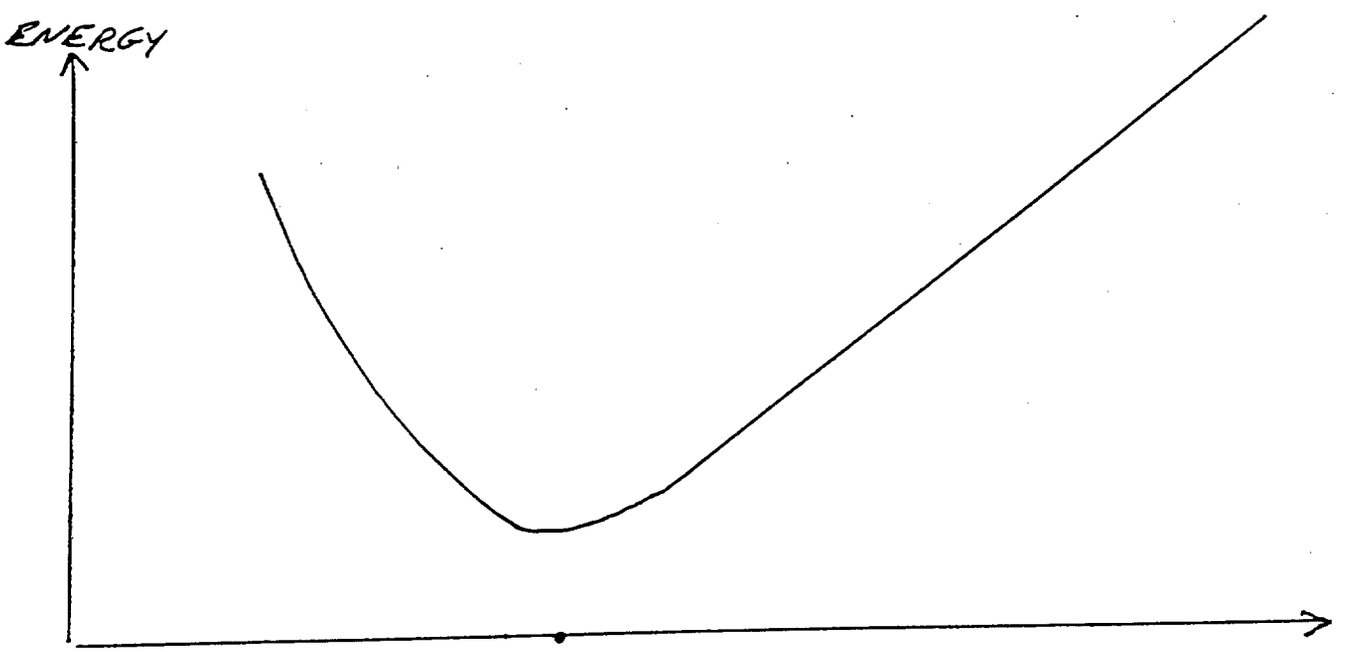


TOTAL CROSS SECTION : $\sim E_{c.M}^{2} / M_p^4$

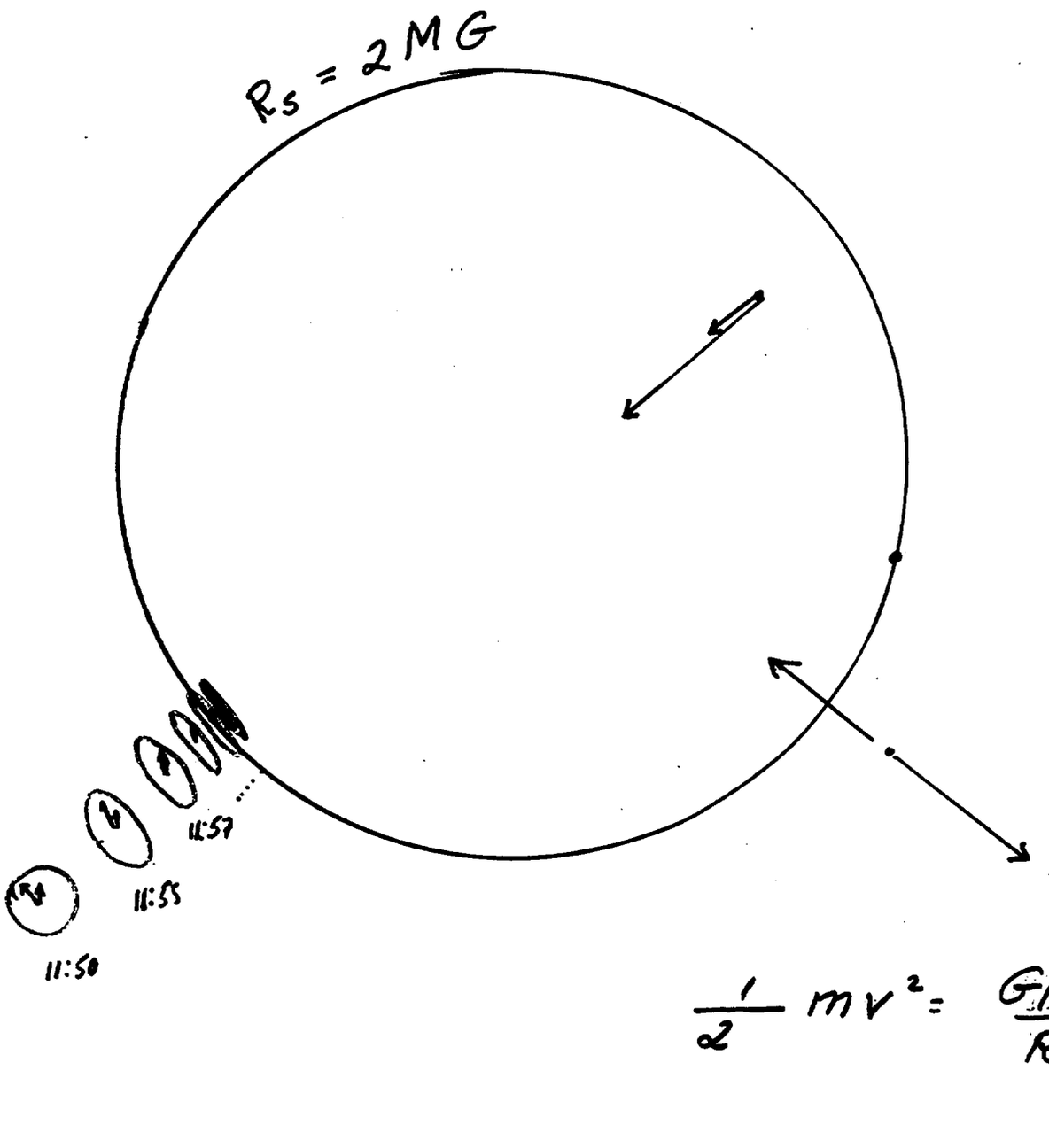
PARTICLE MULTIPLICITY : $\sim E_{c.M.}^{2} / M_p^2$

SECONDARY PARTICLE ENERGY $\sim M_p^2 / E_{CM}$

ASYMPTOTIC INCLUSIVE SPECTRUM $\quad CXP - \left\{ \frac{P E_{cm}}{M_p^2} \right\}$

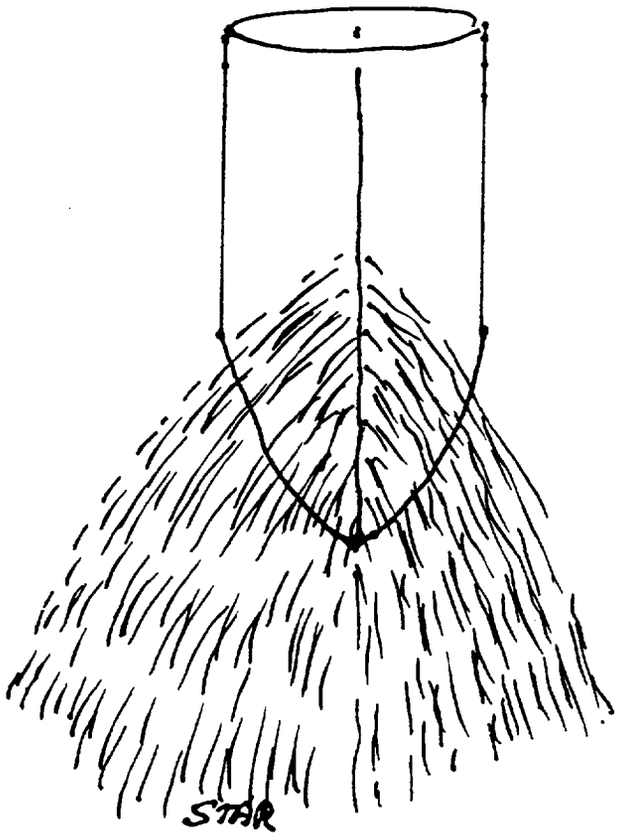


THE BLACK HOLE HORIZON



$$\frac{1}{2} mv^2 = \frac{GMm}{R}$$

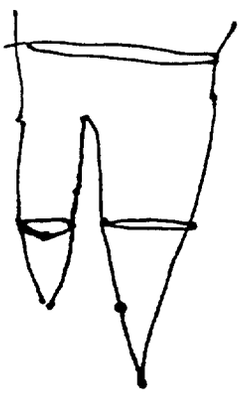
Formation of a Black Hole



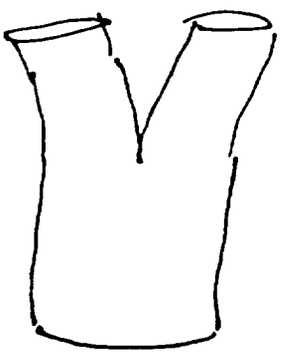
Area Theorem

$$\frac{dA}{dt} > 0$$

Black holes can not split



OK



Forbidden

$$M \longrightarrow \frac{M}{2} + \frac{M}{2}$$

$$\text{Area} \longrightarrow 2 \times \frac{\text{Area}}{4} = \frac{\text{Area}}{2}$$

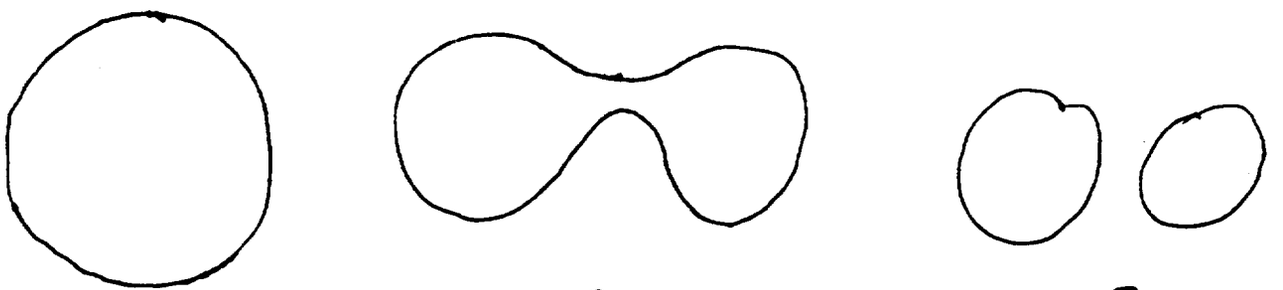
BHs are Eternal

A PATICLE PHYSICISTS' "CONFUSION"

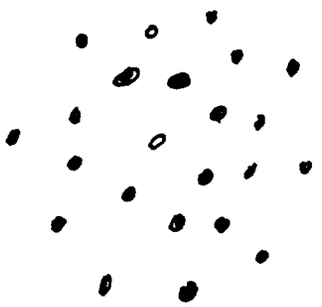
FORM A BLACK HOLE OUT ON NEUTRAL MATTER.

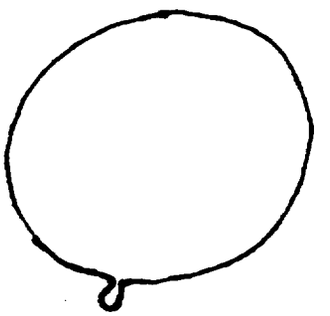
HOW CAN A NEUTRAL OBJECT BE STABLE AGAINST DECAY ?

IT IS ONLY FORBIDDEN TO DECAY BY CLASSICAL EQUATIONS OF MOTION



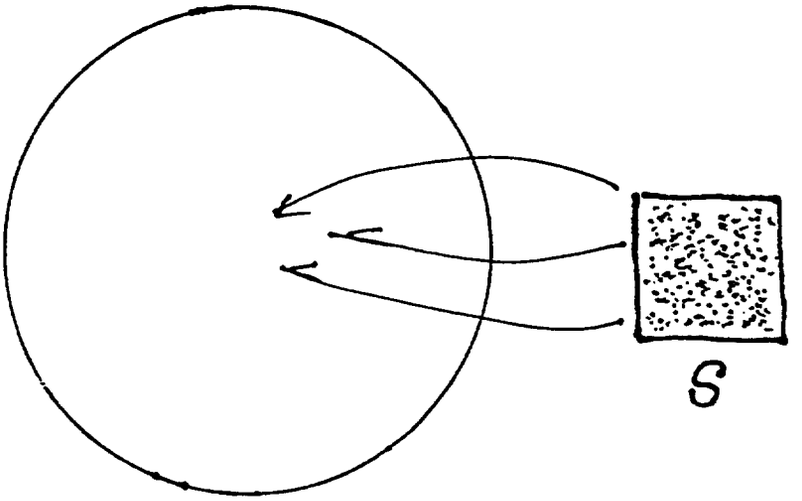
FISSION VIA TUNNELING ?





FEYNMAN

BEKENSTEIN and HAWKING



S decreases !!!

UNLESS

THE BLACK HOLE HAS ENTROPY

$S \sim \text{AREA}$?

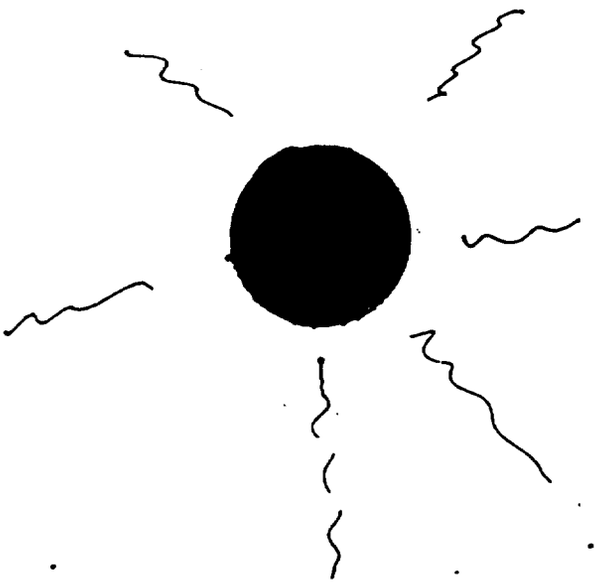
BEKENSTEIN

$$S \sim \frac{\text{AREA}}{4G\hbar}$$

$$= \frac{4M^2 G\pi}{\hbar}$$

THERMODYNAMICS: $dE = T\,dS$

$$T = \frac{dM}{dS} = \frac{\hbar}{8\pi M G}$$



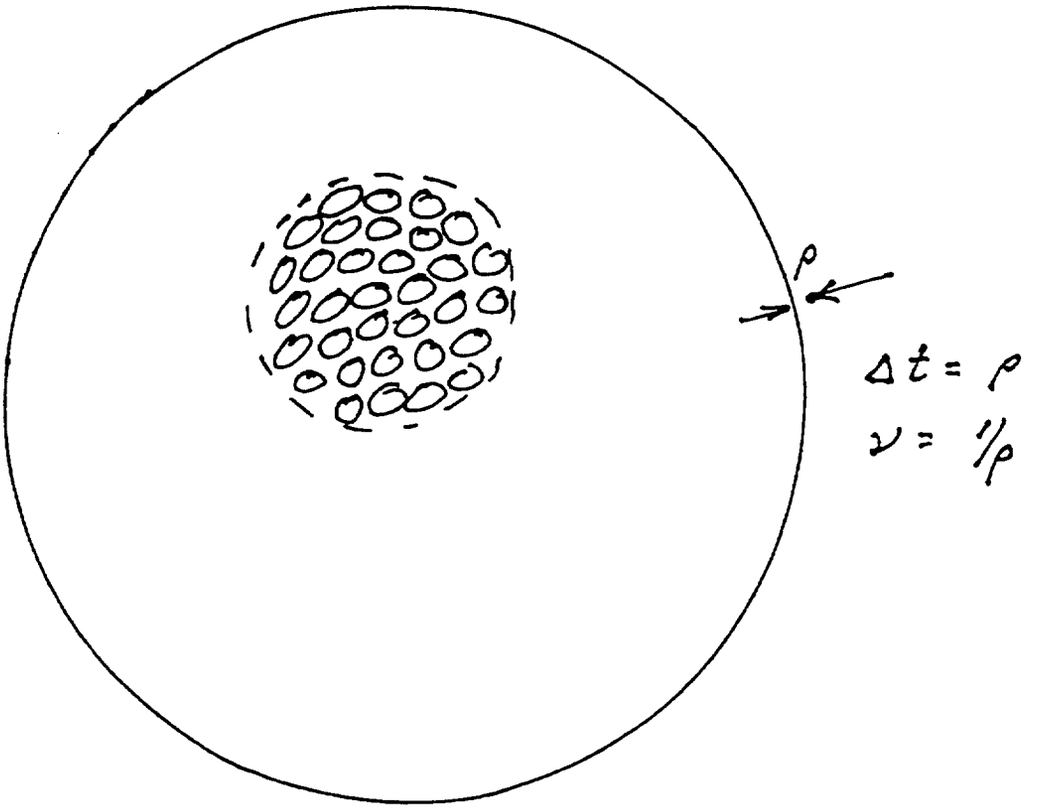
BLACK HOLE
=
BLACK BODY

$$L \approx \text{AREA}\; T^4 \sim \frac{\hbar}{(MG)^2}$$

$\boxed{c=1}$

$$L \times \text{TIME} = M$$

$$\text{TIME} \approx \frac{M^3 G^2}{\hbar}$$



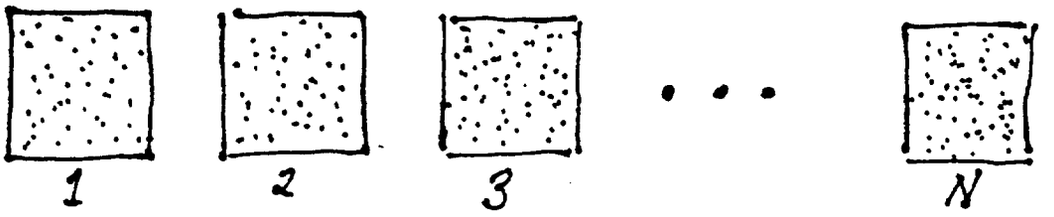
BLACK HOLE COMPLEMENTARITY

1) TO AN EXTERNAL OBSERVER THE HORIZON OF A BLACK HOLE IS EQUIPPED WITH PLANCKIAN DEGREES OF FREEDOM WHICH ABSORB, THERMALIZE AND ULTIMATELY REEMIT ALL INFORMATION

2) AN OBSERVER IN FREE FALL DETECTS NOTHING OUT OF THE ORDINARY AT THE HORIZON. HOWEVER ANY ATTEMPT TO COMMUNICATE THIS FACT IS FRUSTRATED BY THE EXTREME "RED SHIFT."

NO CONTRADICTION !!

The Mystery of Entropy



$$S = \text{Log } N$$

What are the microstates which are counted by $S_{B.H.}$?

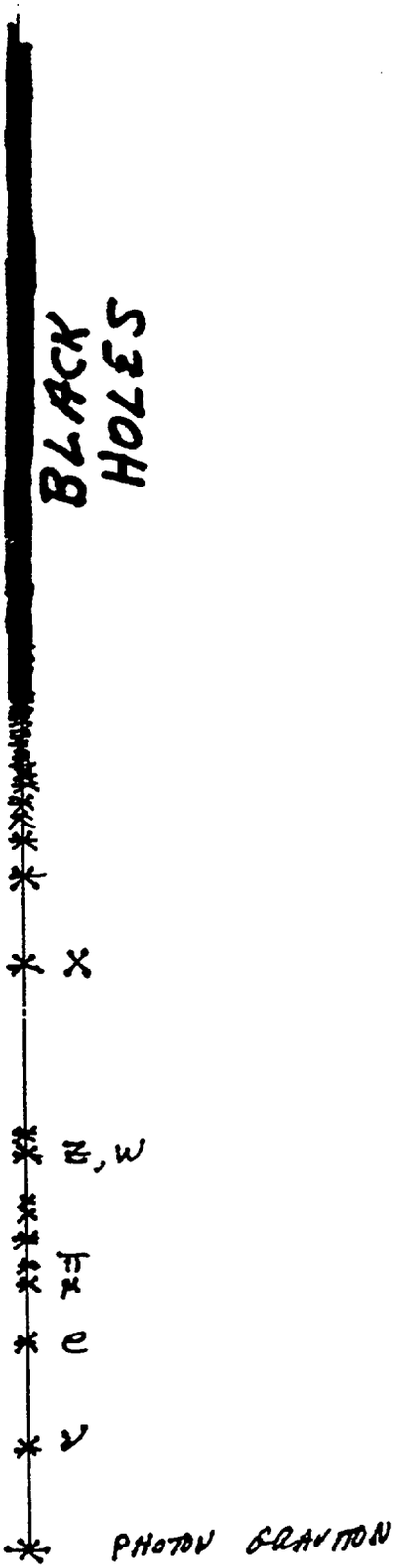
Is the Black Hole really bald ?

Is the usual gravitational field some sort of "coarse graining" ?

Are there microscopic degrees of freedom that "cover" the horizon, one per Planck area ?

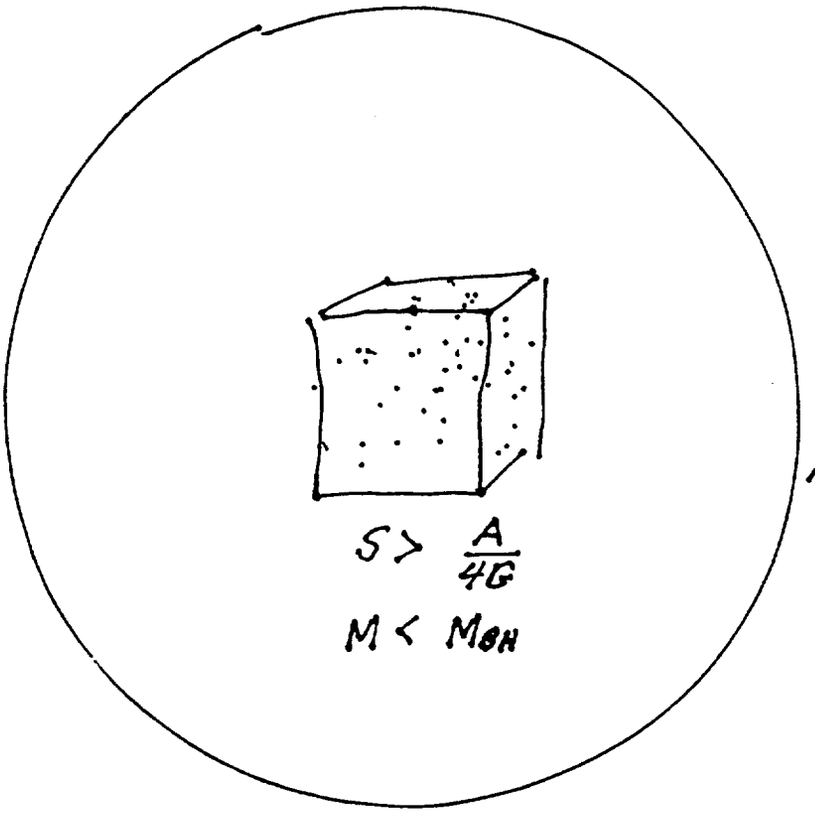
Why doesn't someone falling into the black hole "feel" them ?

THE SPECTRUM



THE HOLOGRAPHIC PRINCIPLE

't Hooft
Susskind



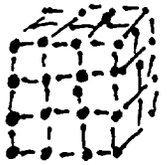
NOW DROP IN ENOUGH MATTER TO MAKE A BLACK HOLE OF AREA A AND $S = \frac{A}{4G}$

2nd LAW VIOLATED

$$S_{max} = \frac{A}{4G}$$

NUMBER OF QUANTUM STATES $\leq \exp \frac{A}{4G}$

MAXIMUM ENTROPY ?

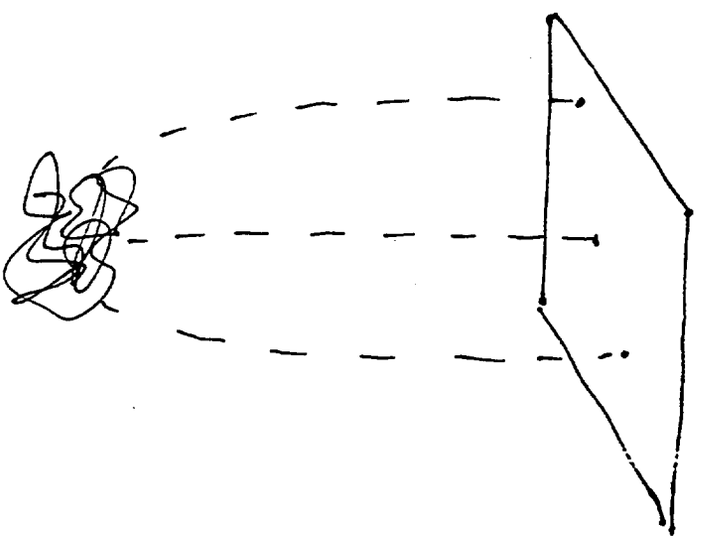


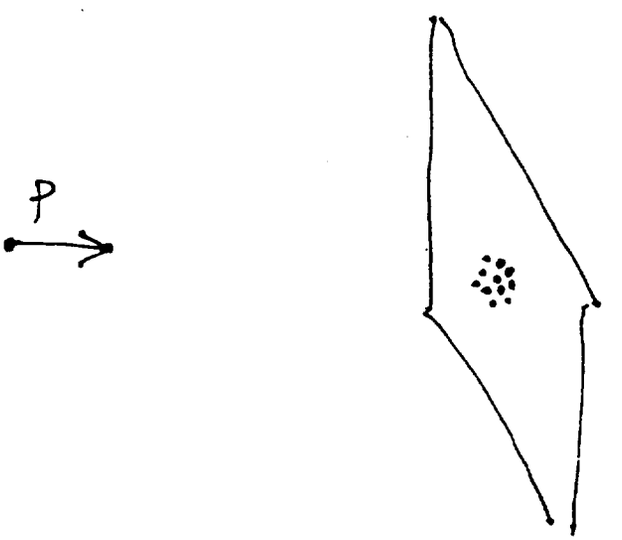
NUMBER OF STATES $= 2^n = 2^{V/V_0}$

$S_{max} = \log N \propto V/V_0$

HOLOGRAPHIC PRINCIPLE

THE DEGREES OF FREEDOM OF A REGION OF SPACE RESIDE ON THE SURFACE WITH NO MORE THAN ONE PER PLANCK AREA.





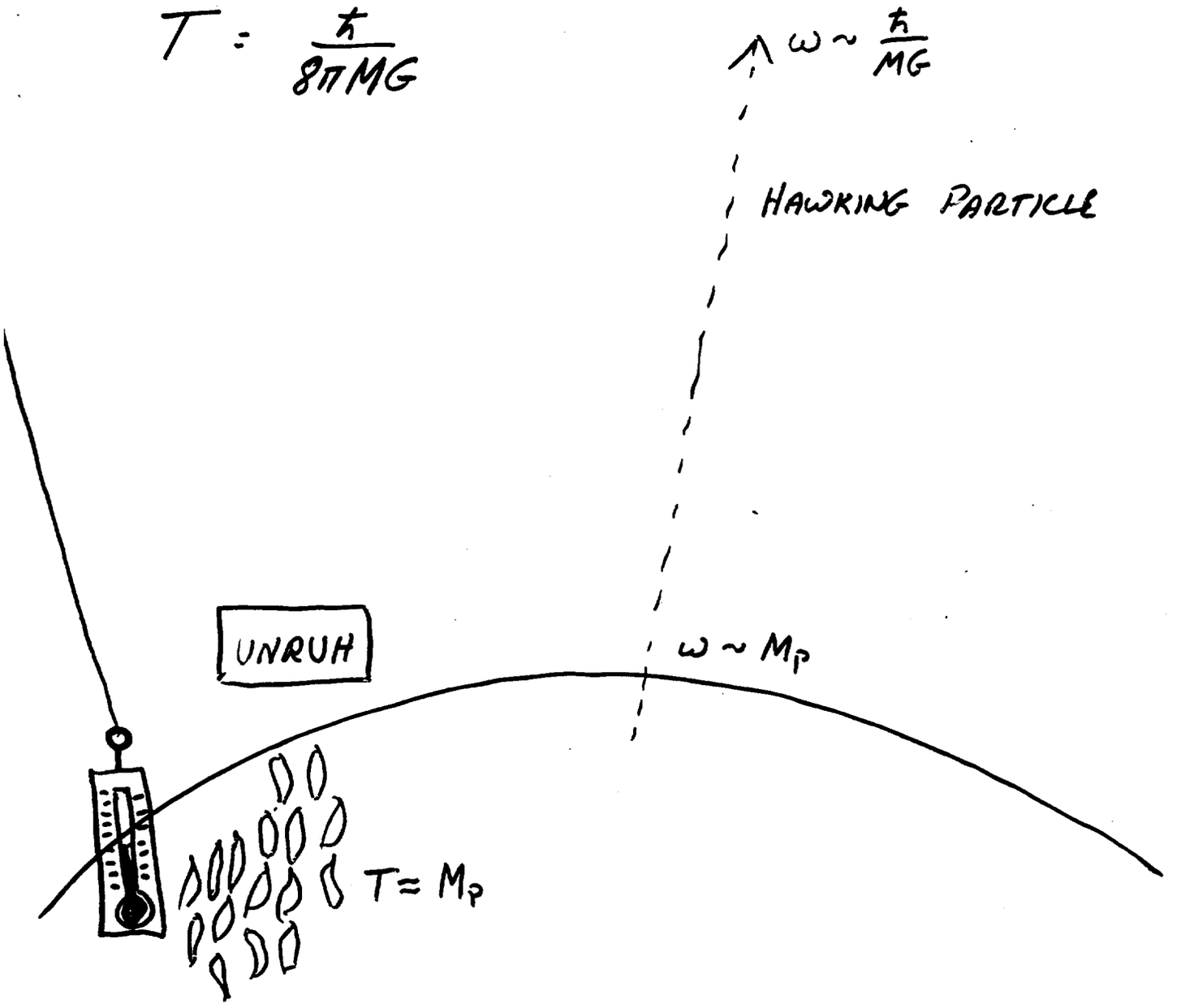
$P = N\epsilon$

$r = N^{1/2} l_p$

BLACK HOLES ARE THERMAL

$$S = \frac{A}{4G\hbar}$$

$$T = \frac{\hbar}{8\pi MG}$$



BLACK HOLE COMPLEMENTARITY

STRING THEORY

$M = \text{LENGTH} \cdot T$

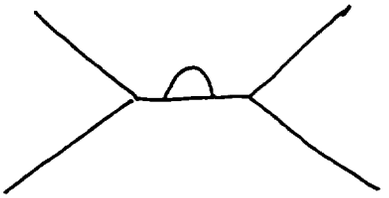
•

POINT PARTICLE

O

STRING LOOP

OF SIZE $l_s \sim 10^{-32}$ cm

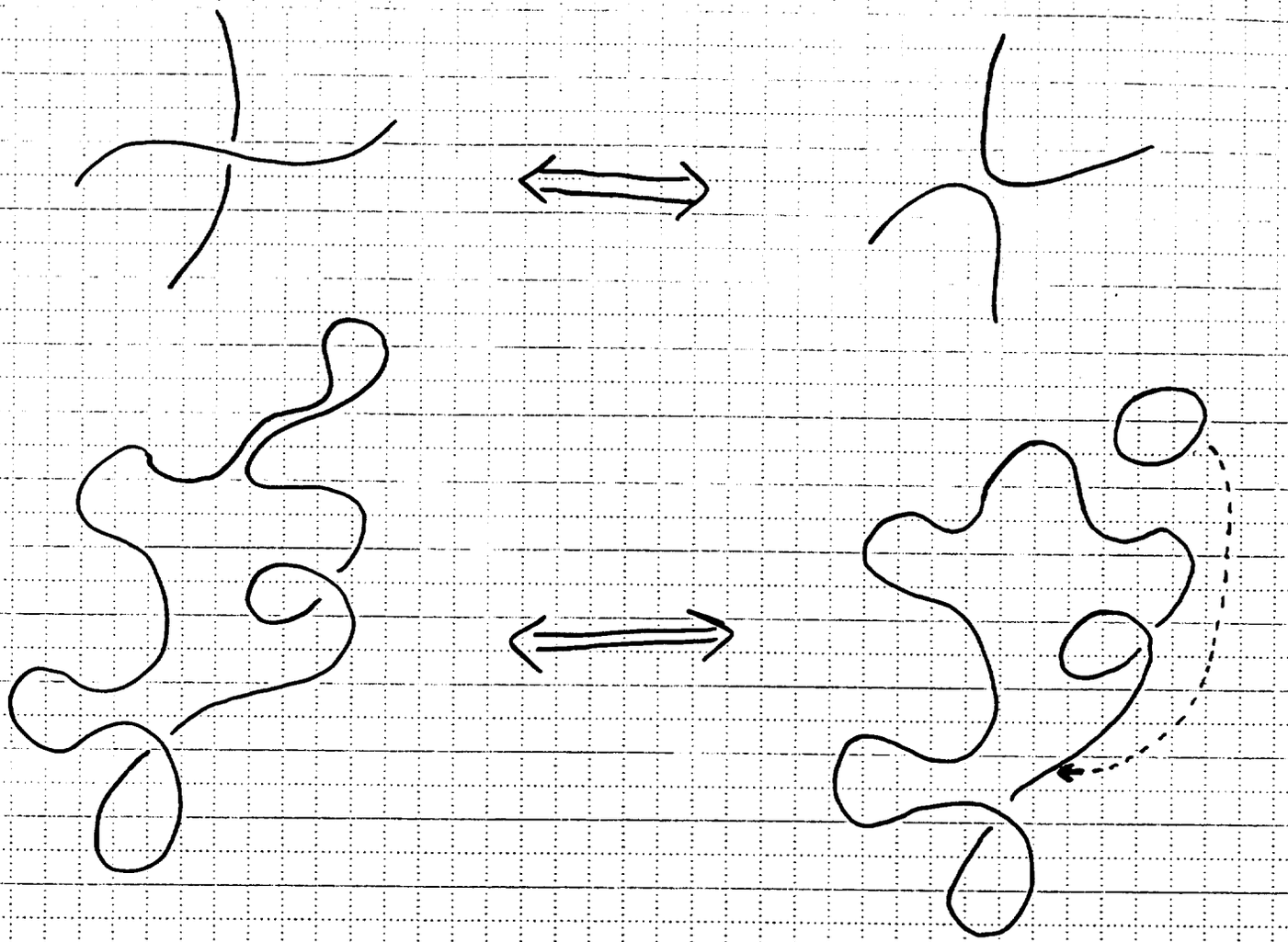


FEYNMAN DIAGRAM

EXCITED STRINGS !

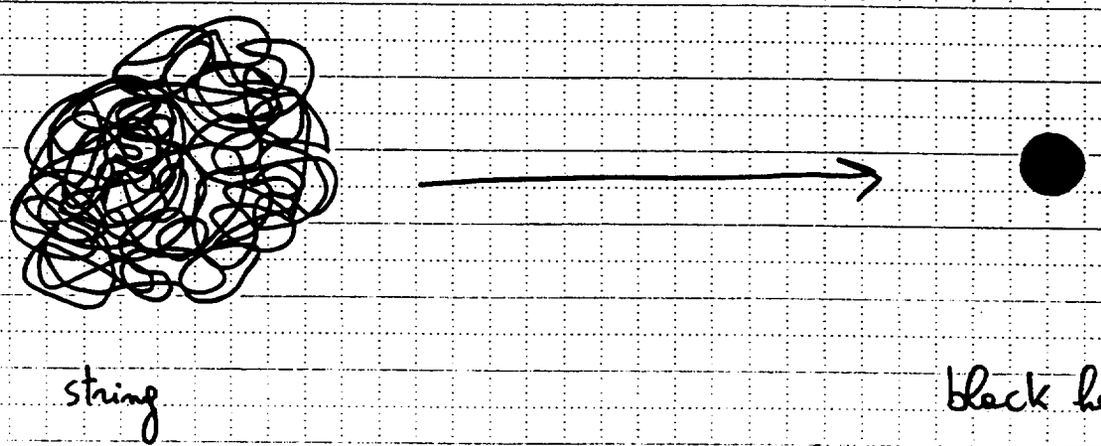
8 $M \sim 10^{-6}$ gr

EFFECTS OF INTERACTION

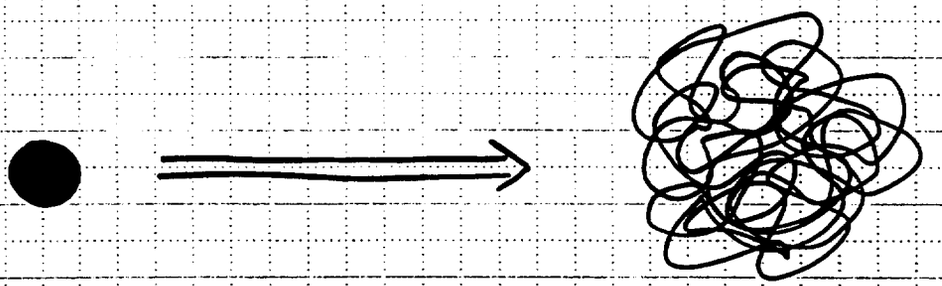


GRAVITY $G_N = g^2 l_s^2$

As g is increased, a highly excited string will evolve into a black hole



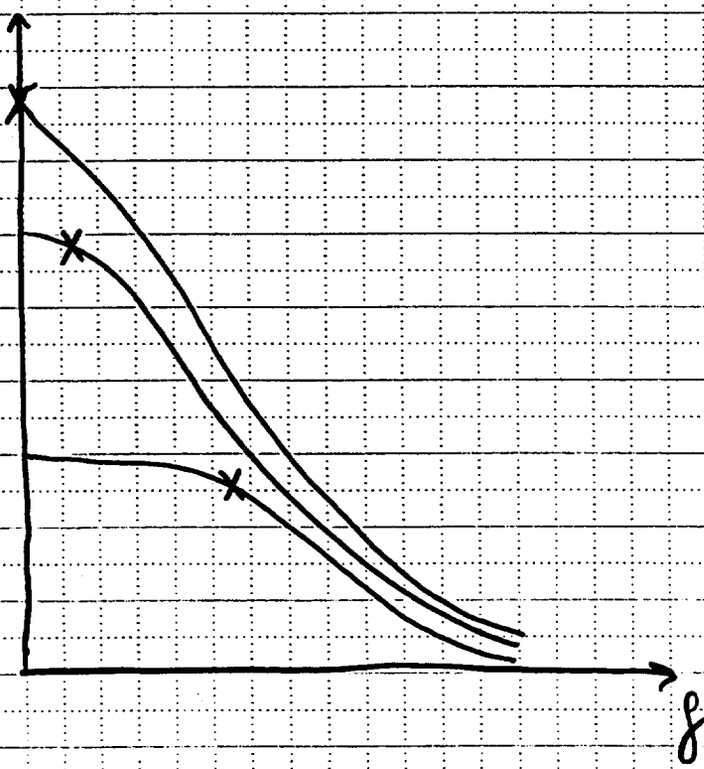
WHAT HAPPENS TO A BLACK HOLE AS g DECREASES



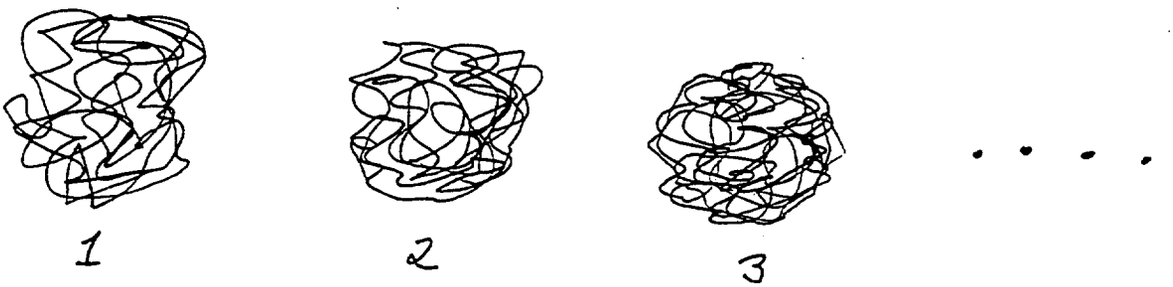
$$\boxed{R_s = \ell_s}$$

$$2MG = 2M g^2 \ell_s^2 = \ell_s$$

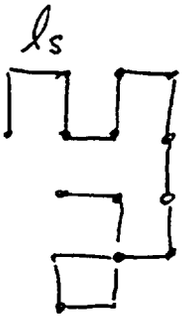
$$g \sim \frac{1}{M \ell_s}$$



STRINGS HAVE ENTROPY



$$\text{MASS} = \frac{\text{LENGTH}}{\ell_s^2}$$



NUMBER OF STATES

$$= 4^{L/\ell_s}$$

$$S \approx \frac{L}{\ell_s}$$

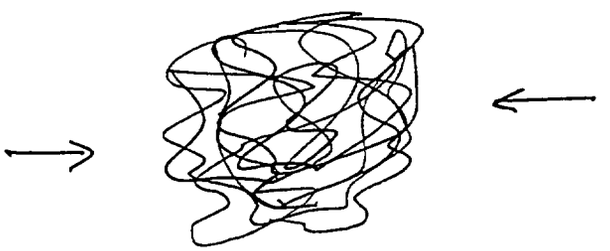
OR

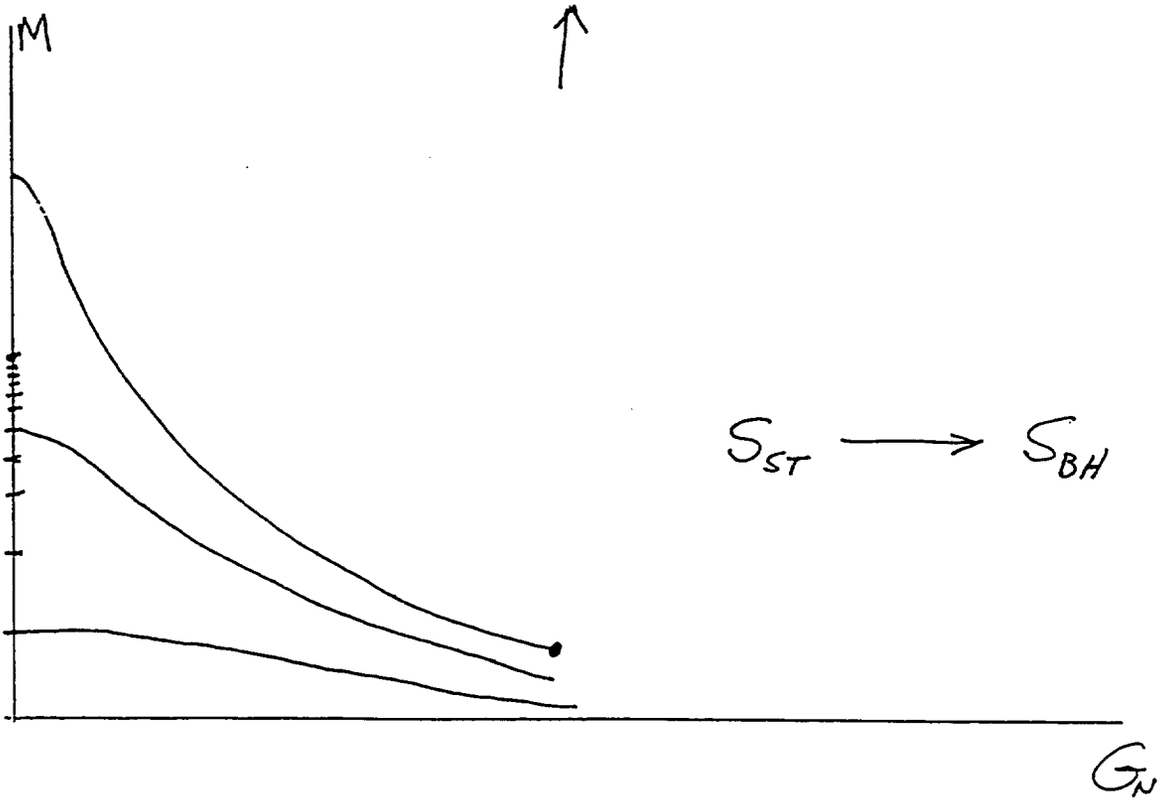
$$S = \text{MASS} \cdot \ell_s$$

Could Black Holes and Strings Be the same thing?

$$S_{STRING} = M l_s$$

$$S_{B.H.} = M^2 l_p^2$$

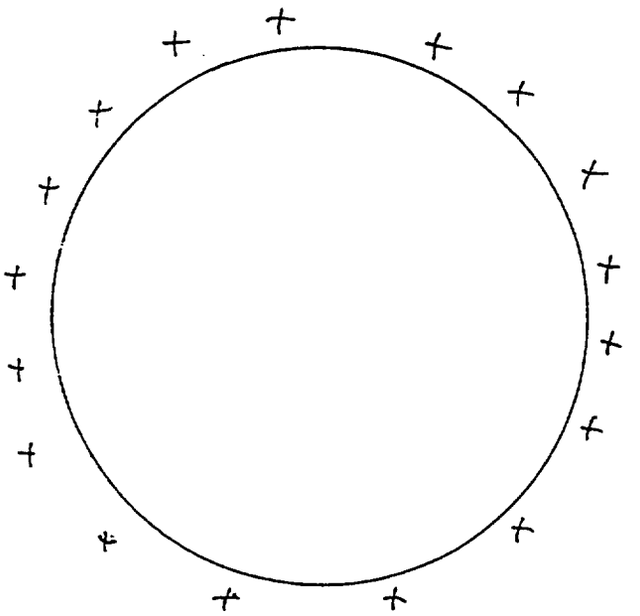




HAWKING RADIATION

EXTREMAL BLACK HOLES

CHARGED



M DECREASES UNTILL

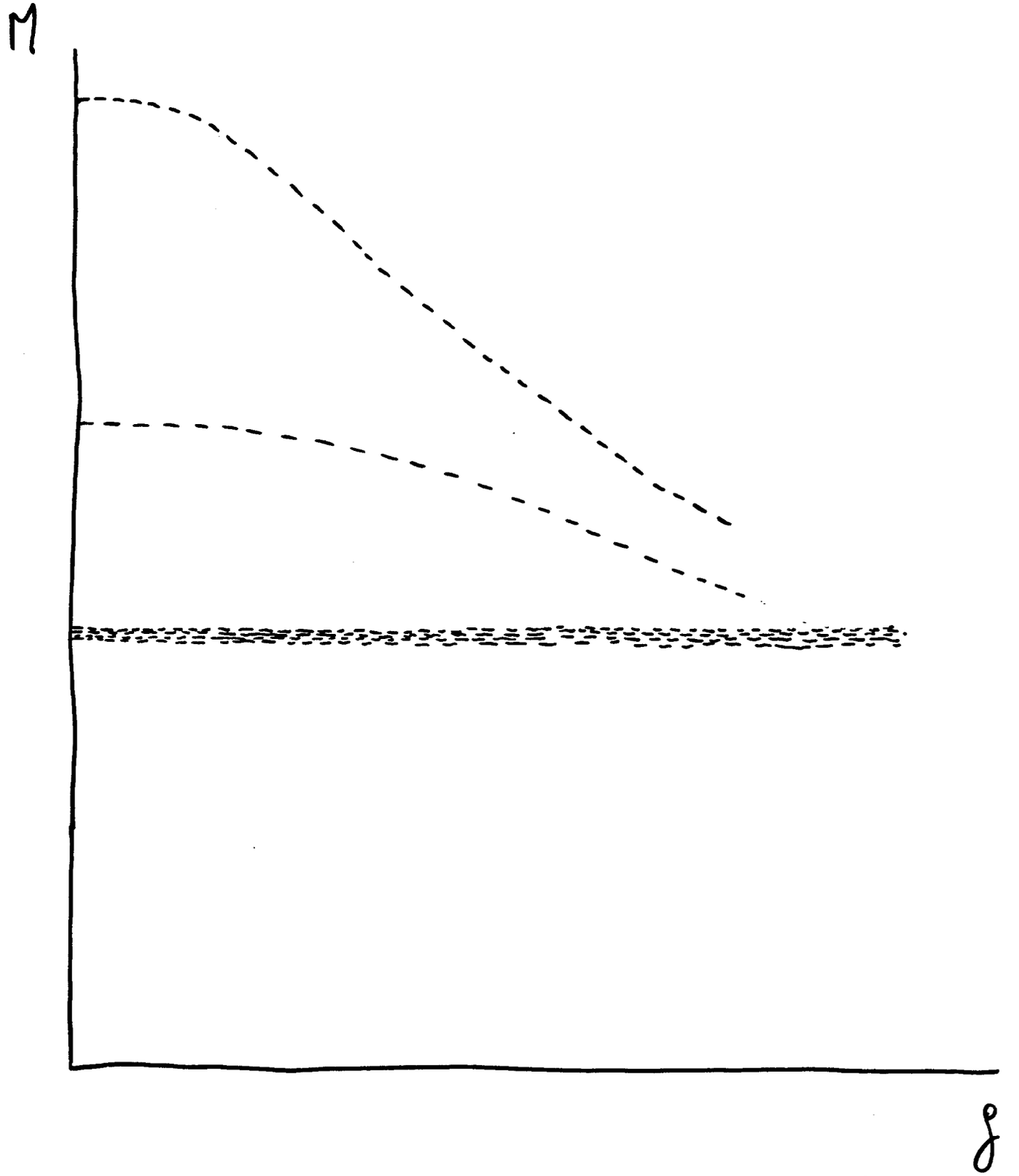
$$G\frac{M^2}{R^2} \approx \frac{Q^2e^2}{R^2} \quad \text{OR} \quad GM^2 = Q^2e^2$$

NOW WE HAVE AN EXTREMAL B.H.

ELECTRICAL FORCES BALANCE GRAVITATIONAL.

$$S \approx Q^2$$

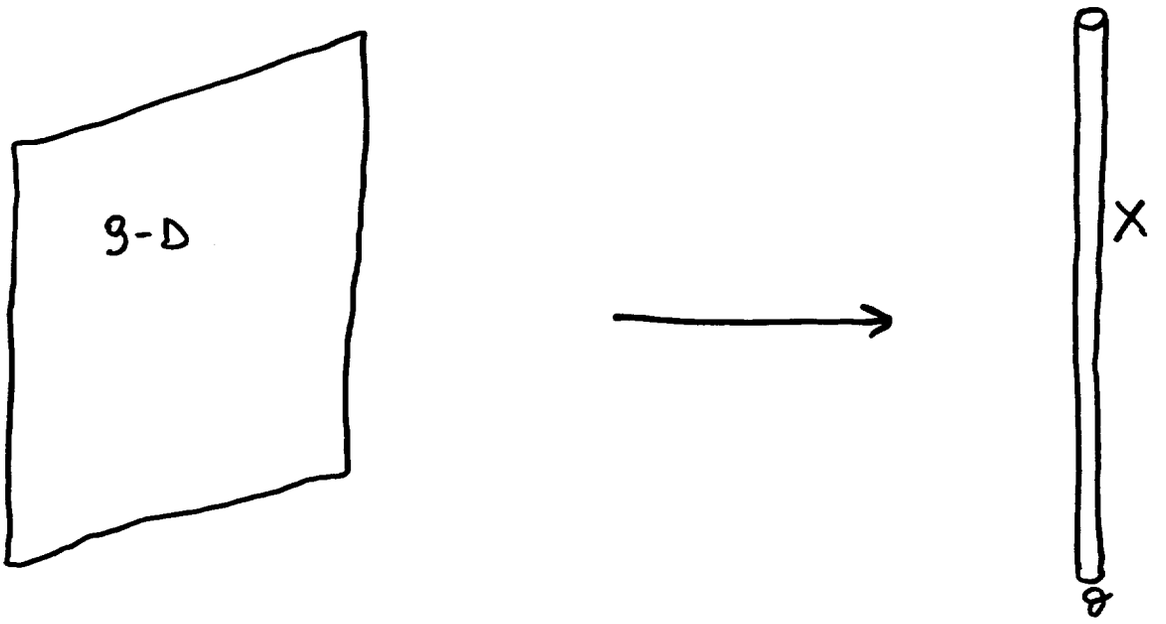
EXTREMAL BLACK HOLES



COMPACTIFICATION OF SPACE (KALUZA KLEIN)

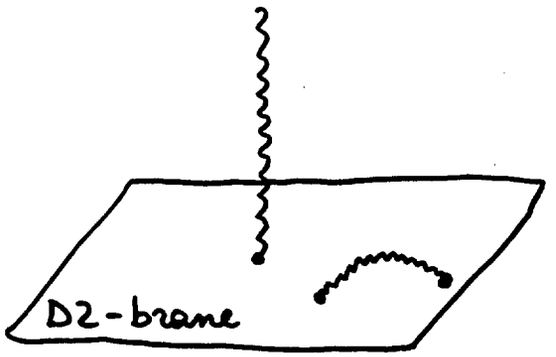
10 DIMENSIONS $\longrightarrow$ 4 DIMENSIONS

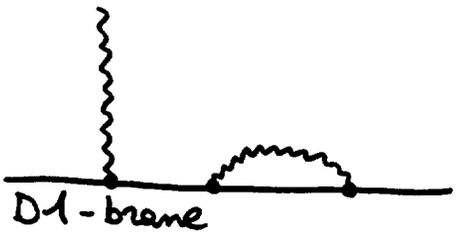
$X^1, \ldots X^9 \longrightarrow X^1, X^2, X^3, \theta^4, \ldots, \theta^9$



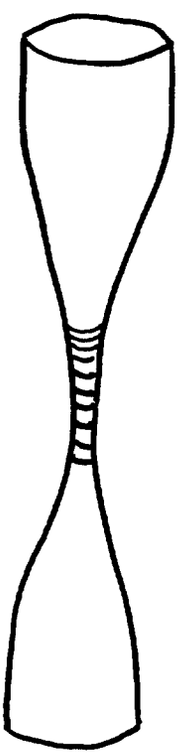
MOMENTUM IN θ DIRECTION = CHARGE

D-BRANES

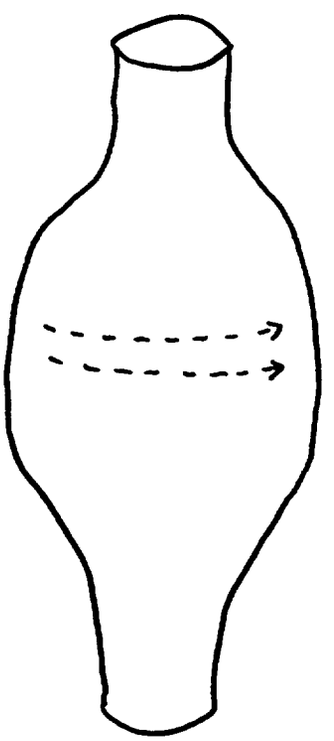




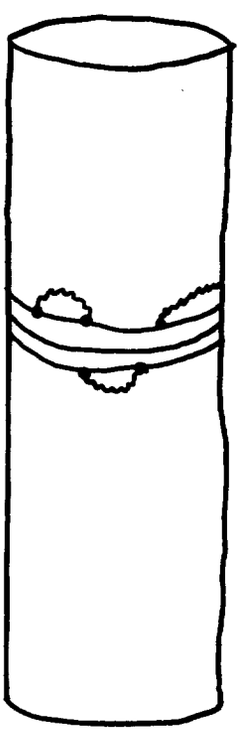
WRAPPING CHARGE + KK CHARGE



W



KK



W + KK

D-BRANE

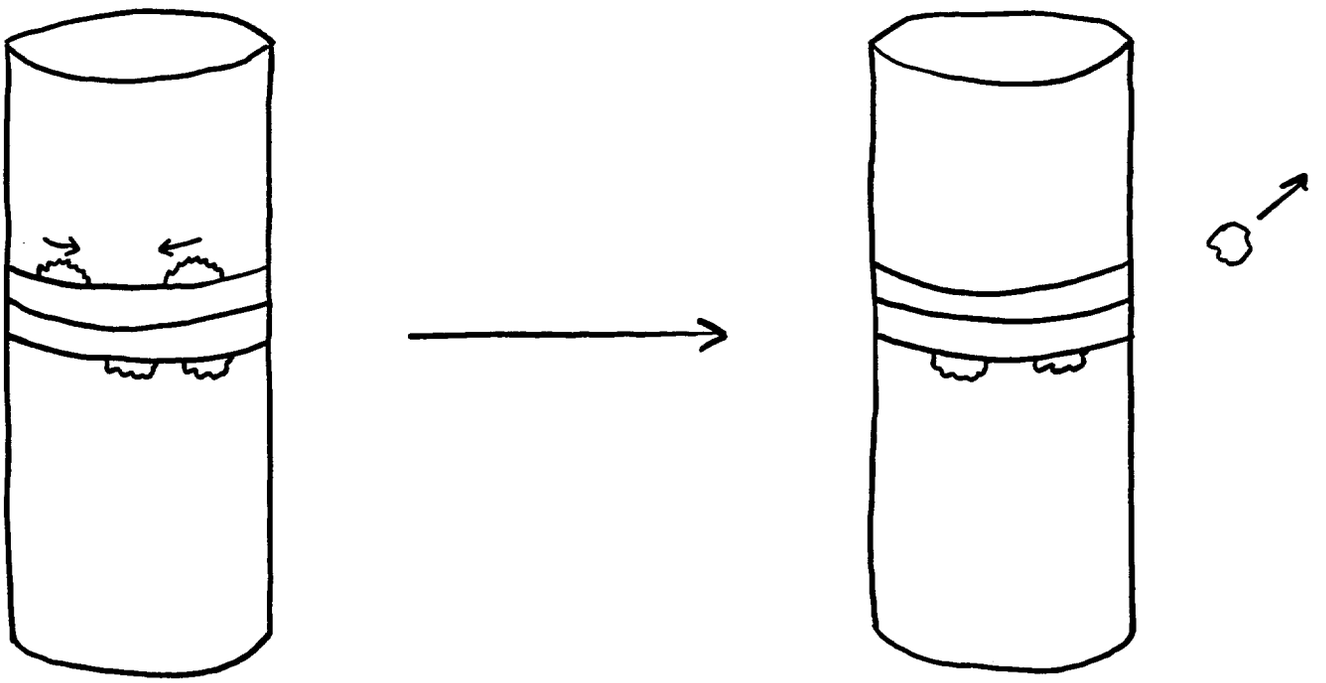
$$S = 2\pi\sqrt{NQ_1Q_5}$$

GRAVITY

$$S = \frac{A}{4G}$$

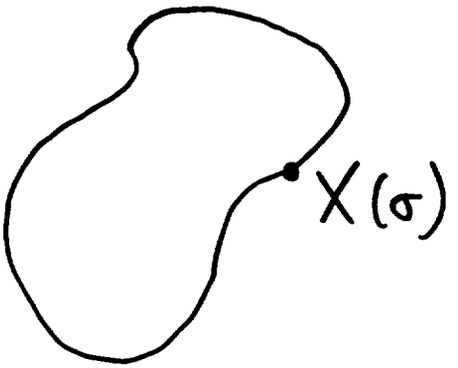
Einstein's equations

$$A = 8\pi G\sqrt{NQ_1Q_5}$$



HAWKING RADIATION

BLACK HOLE COMPLEMENTARITY ?



$$X(\sigma) = \sum \frac{a(n)\, e^{in\sigma}}{\sqrt{n}} + c.c.$$

ZERO POINT OSCILLATIONS

$$\langle X^2 \rangle = \sum_{n}^{n_{max}} \frac{1}{n} \sim \log n_{max}$$

$$n_{max} \sim \exp\left(\frac{4t}{MG}\right)$$