

AGUJEROS

NEGROS

esos monstruos sutiles . . .

José L. Fernández Barbón IFT UAM/CSIC

BANDE ORIGINALE DE LA MUSIQUE DU FILM
ORIGINAL MOTION PICTURE SOUNDTRACK



VS-9603 F

LE TROU NOIR

THE BLACK HOLE

MUSIQUE DE
JOHN BARRY

Adès

© 1979 Walt Disney Records

BANDE ORIGINALE DE LA MUSIQUE DU FILM
ORIGINAL MOTION PICTURE SOUNDTRACK

Disneyland
RECORDED

VS-9603 F

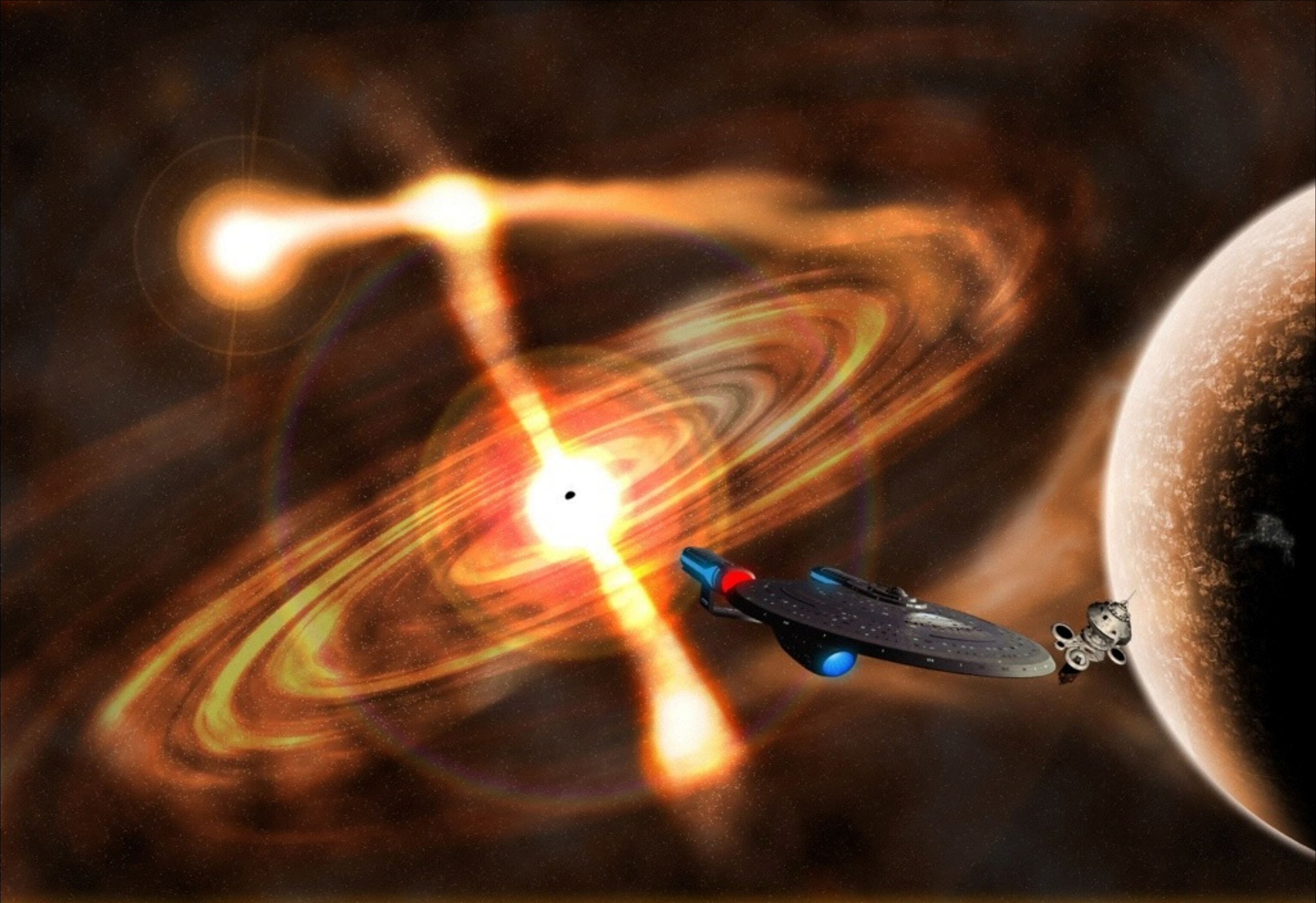
LE TROU NOIR

THE BLACK HOLE

JOHN WILLIAMS

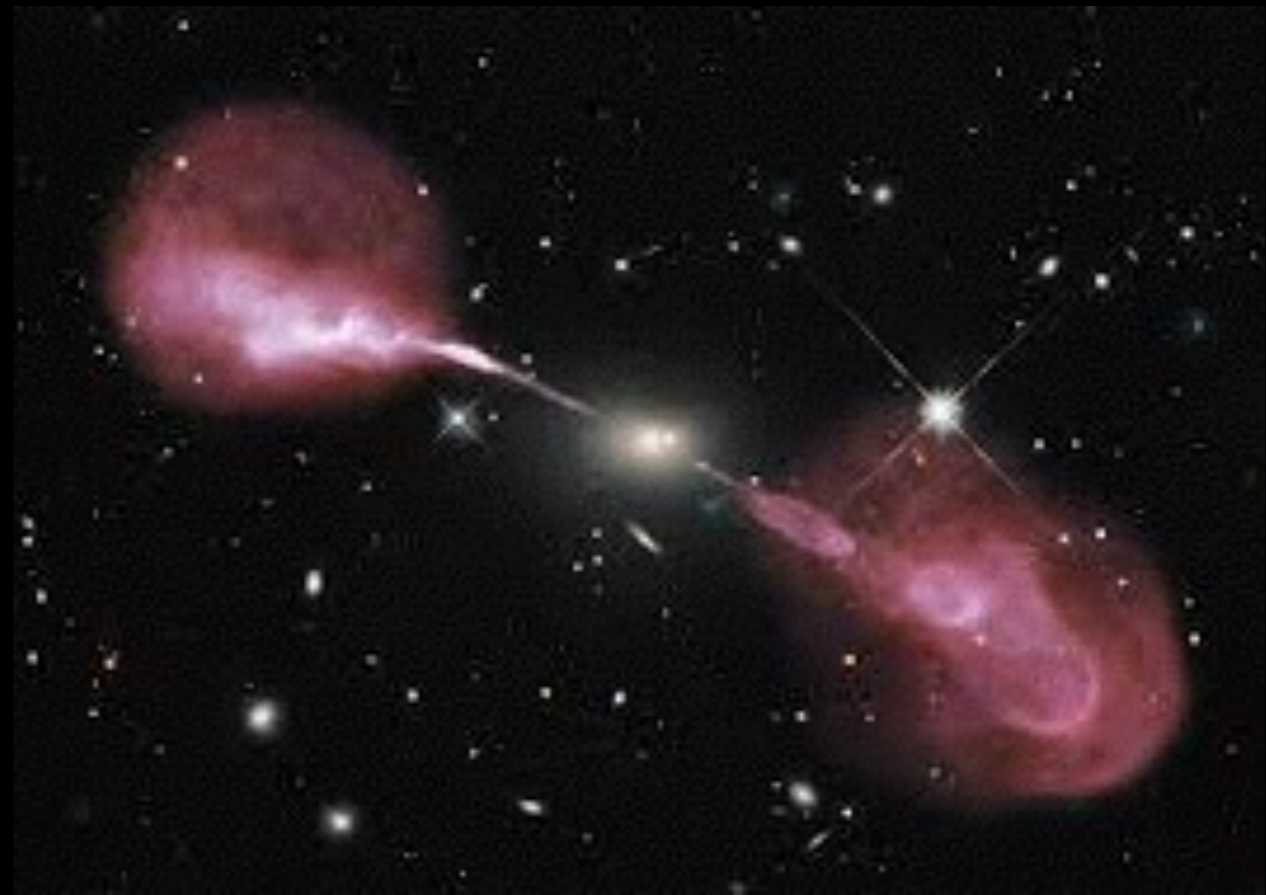
Adès

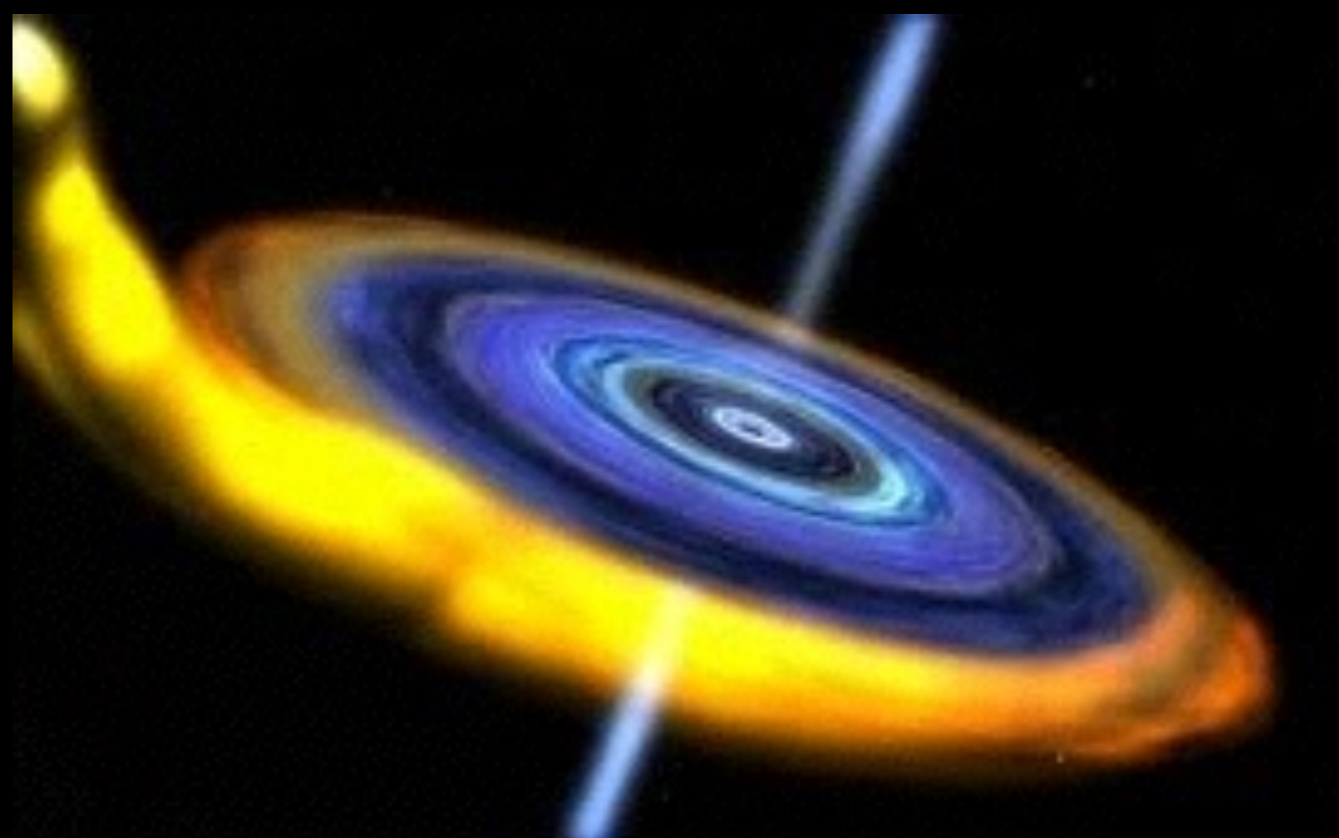
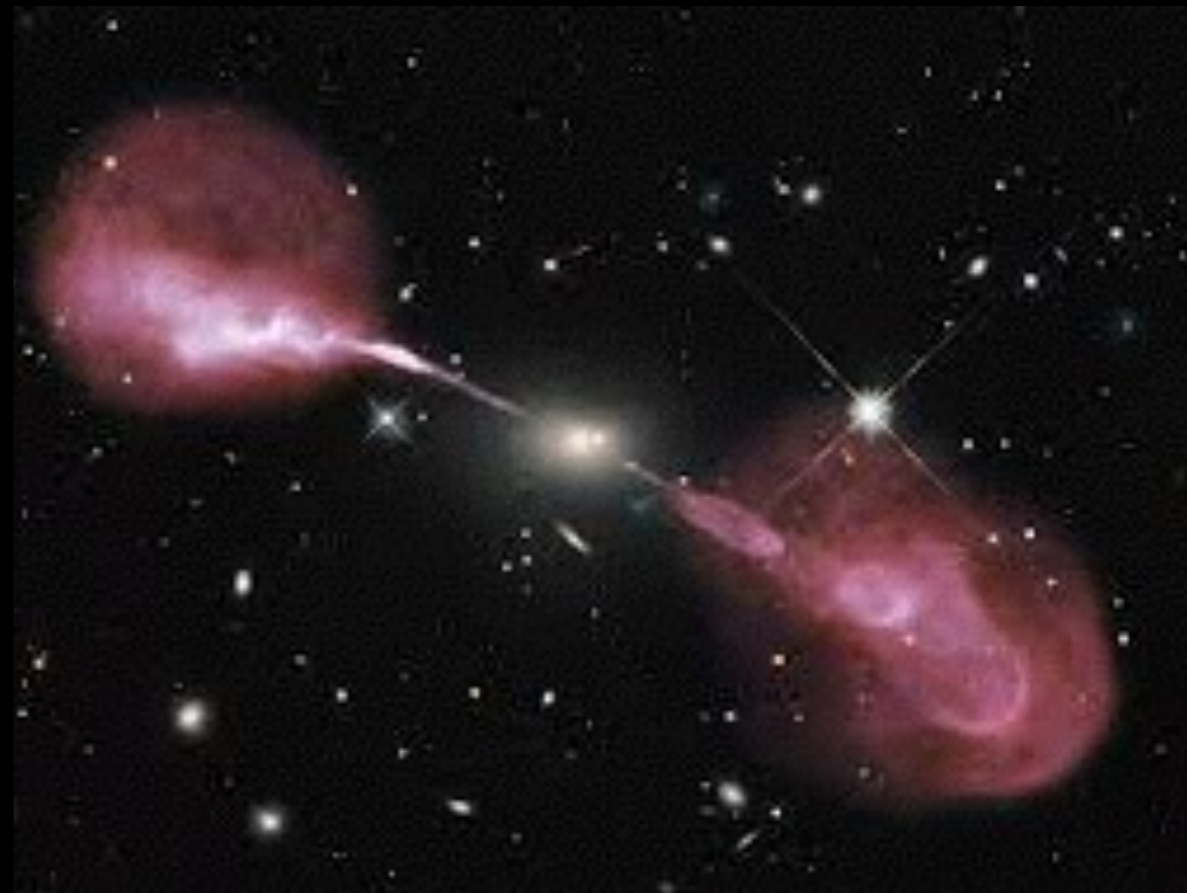
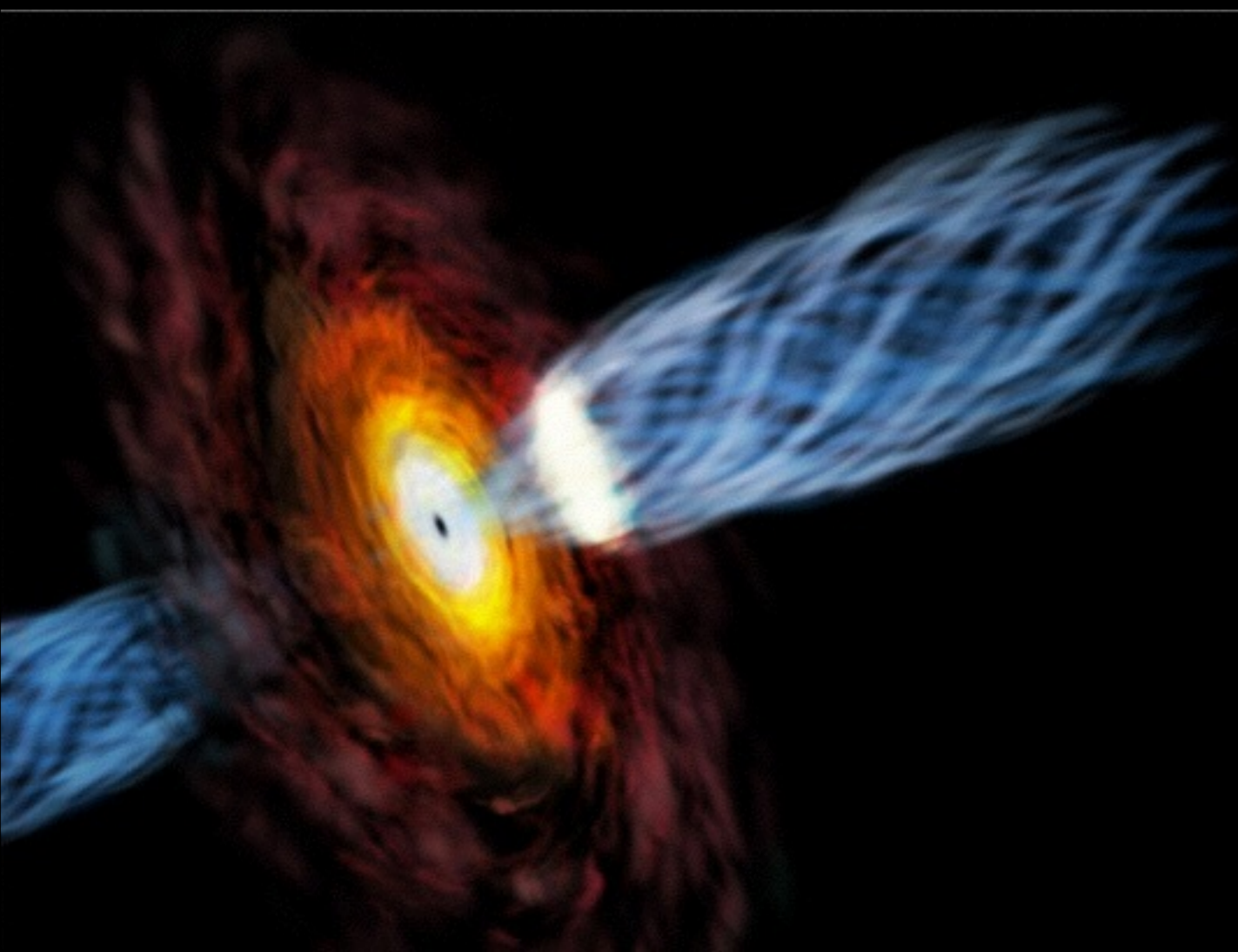




Ambassador by Andrew J Hodges - SciFart.com
Spacelab by Rick Snider

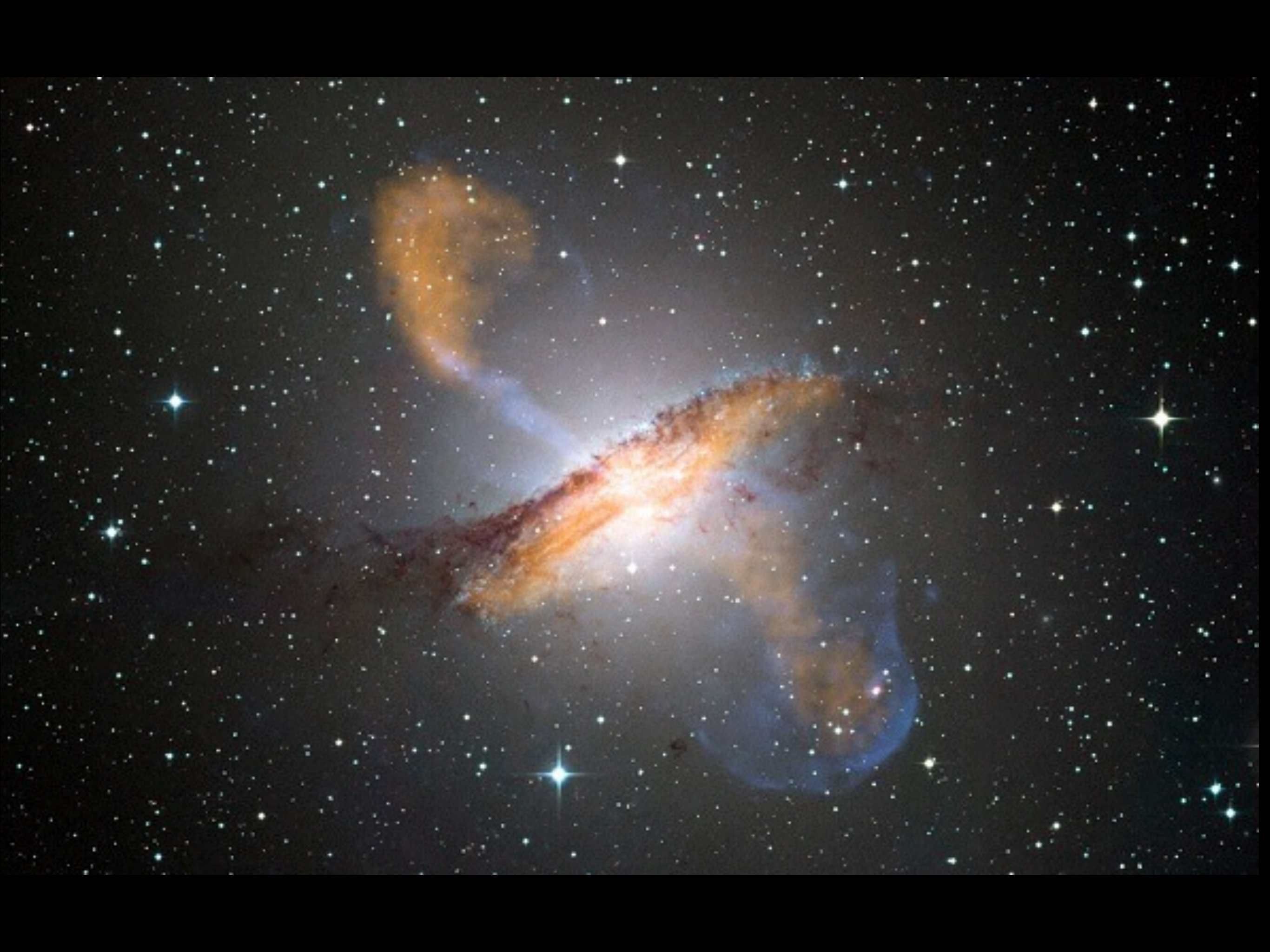
Singularity
www.ufplanets.com

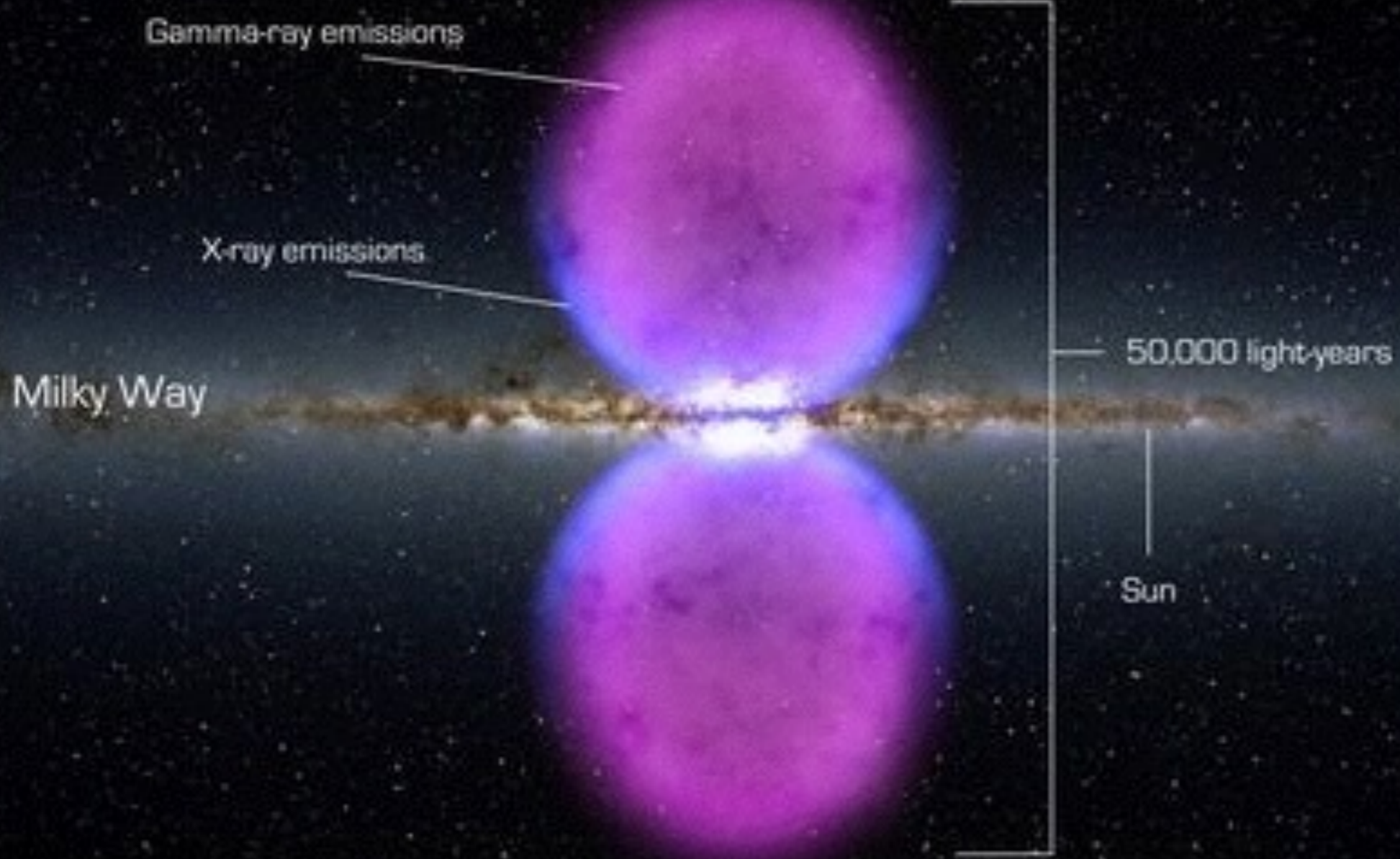


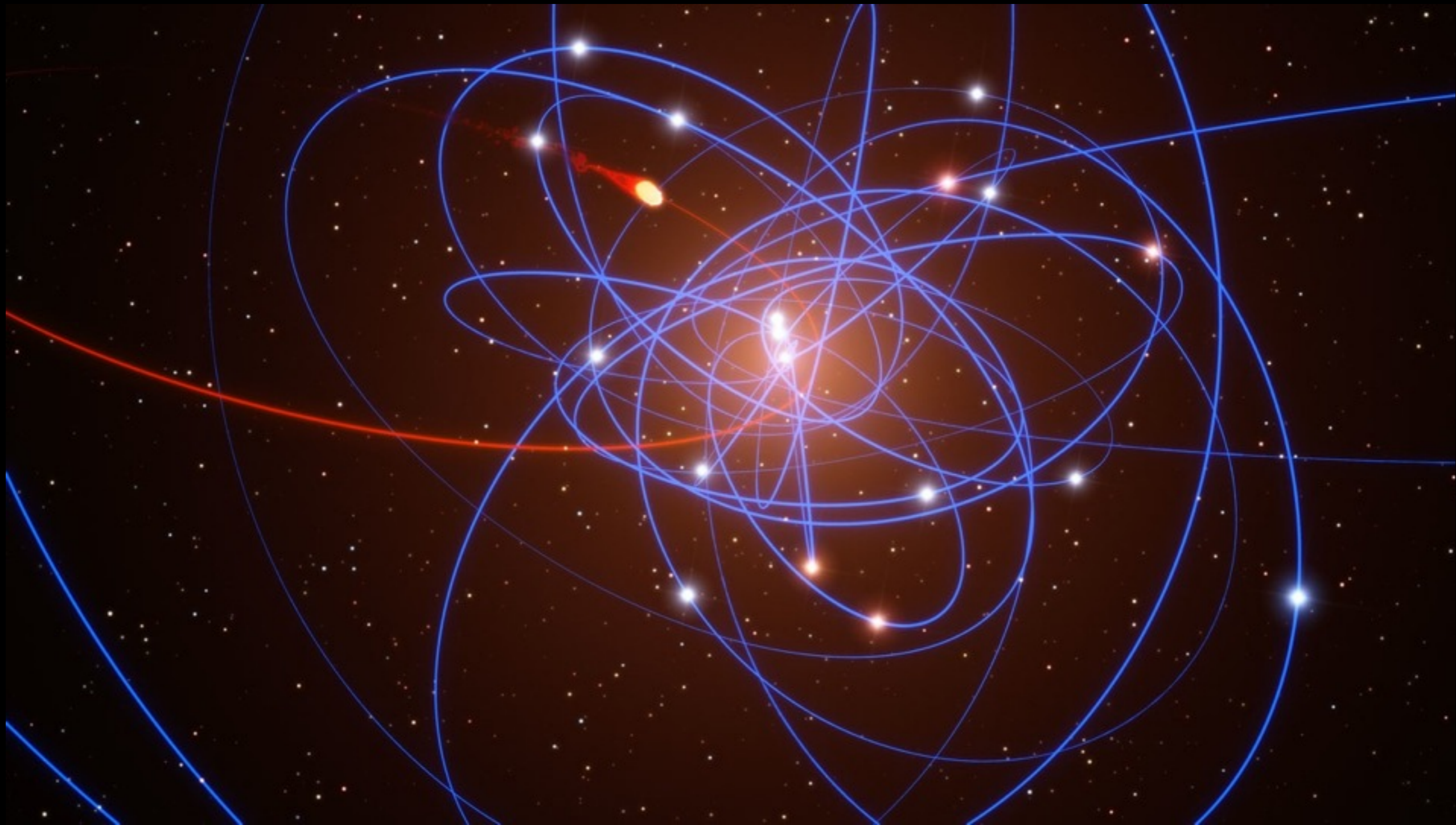


10 M_{Sol}









$70^6 M_{\text{Sol}}$

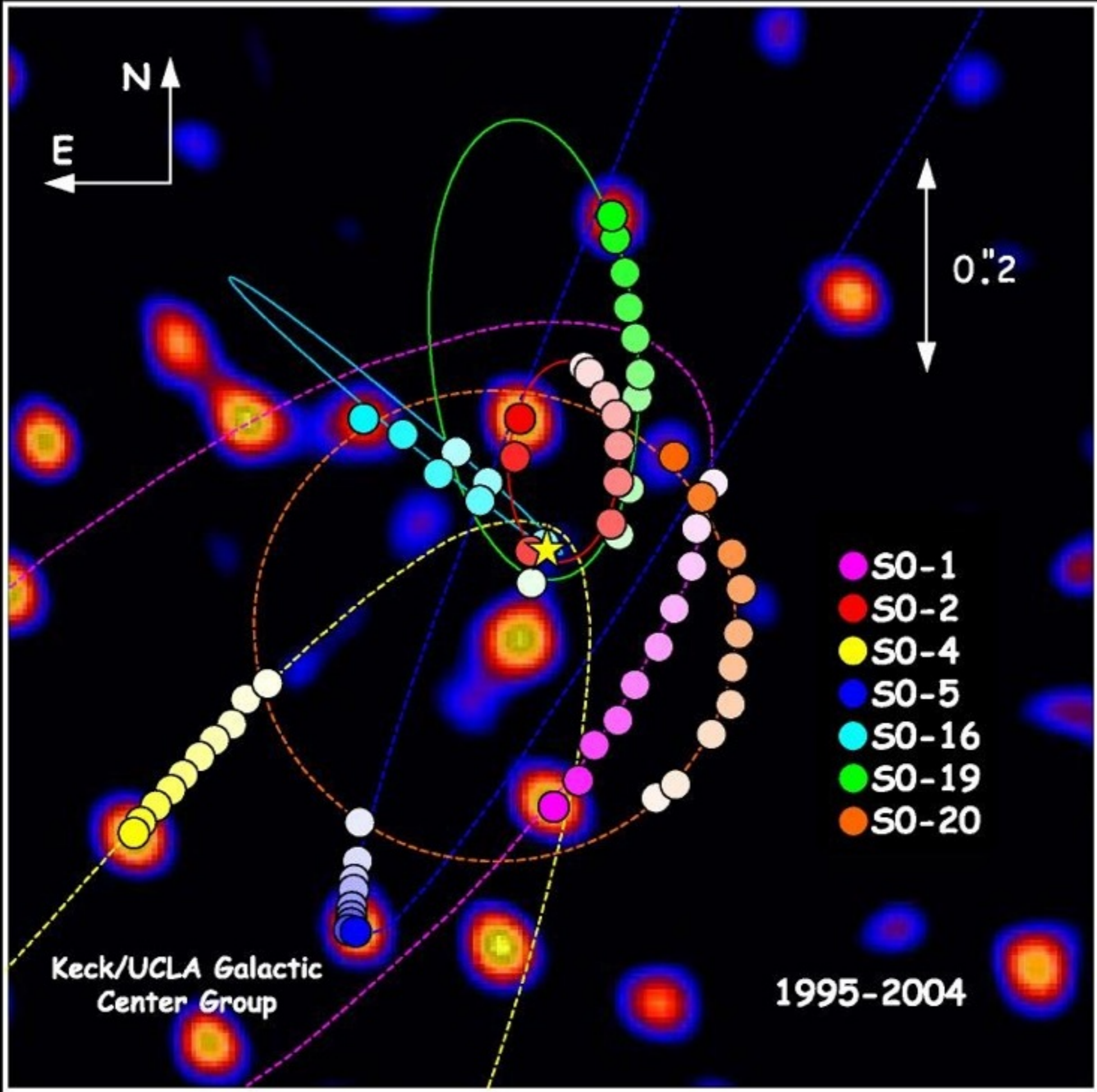


0".2

- S0-1
- S0-2
- S0-4
- S0-5
- S0-16
- S0-19
- S0-20

Keck/UCLA Galactic
Center Group

1995-2004

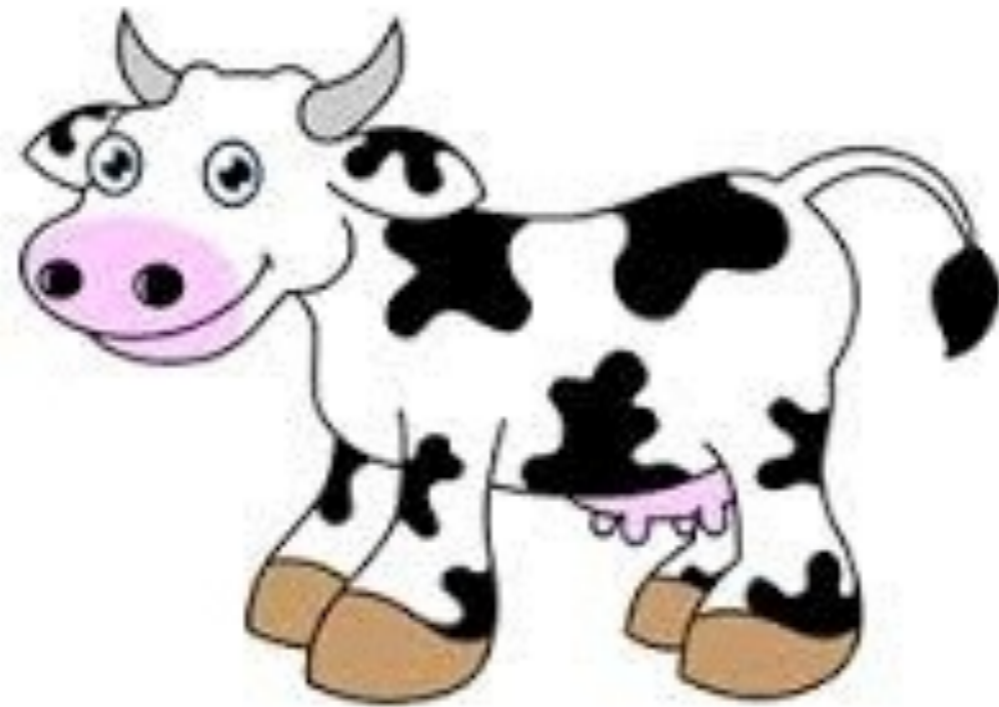




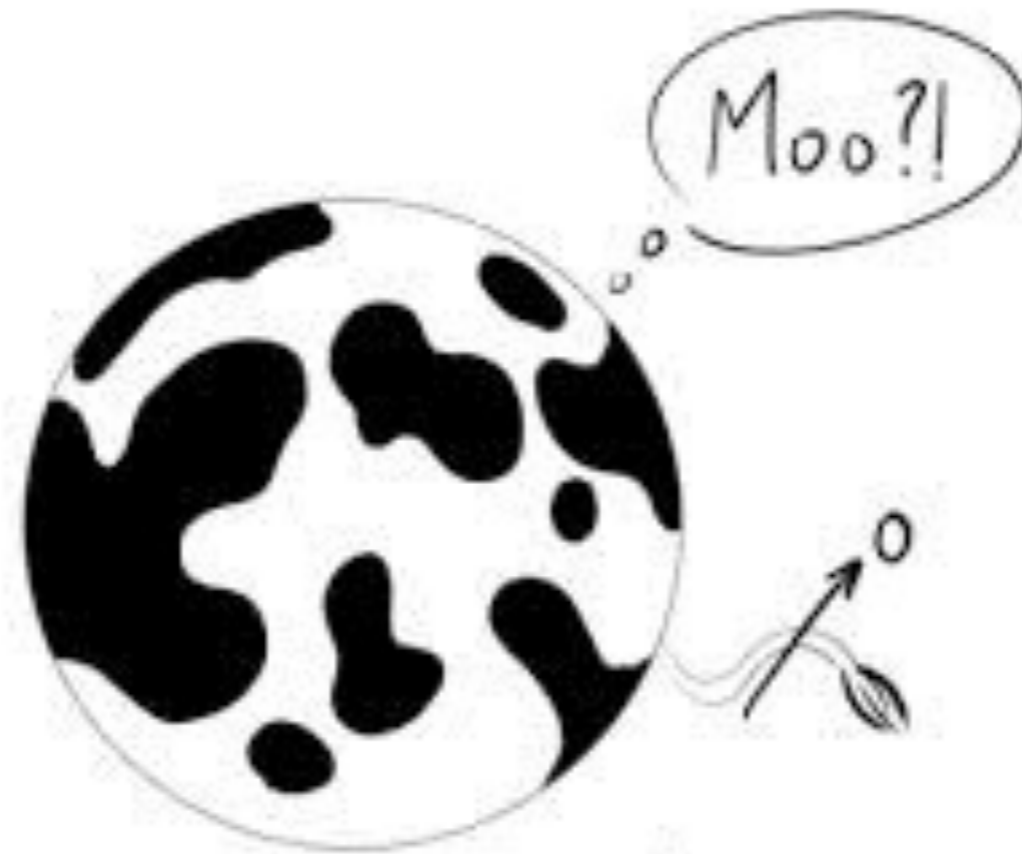
$10^9 M_{\text{sol}}$



La física fundamental es una cuestión de estilo. . .

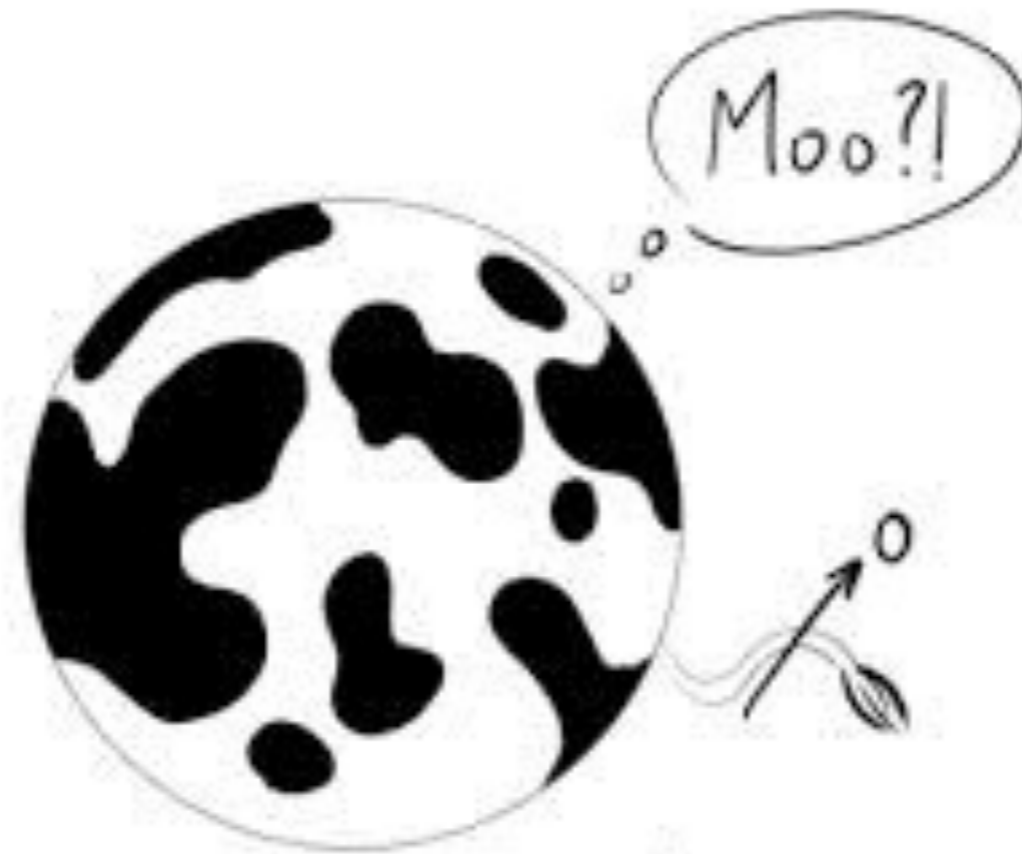


La física fundamental es una cuestión de estilo. . .



Consider a spherical cow
of radius R ... □

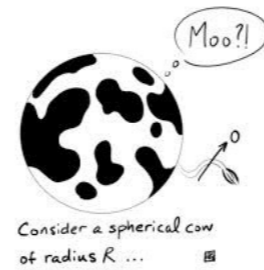
La física fundamental es una cuestión de estilo. . .



Consider a spherical cow
of radius R ... \square

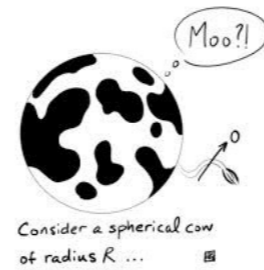
$$x^2 + y^2 + z^2 = R^2$$

UNIDADES DE LA VACA REDONDA



$$2 \sim 3 \sim e \sim \pi \sim 7$$

UNIDADES DE LA VACA REDONDA



$$2 \sim 3 \sim e \sim \pi \sim 7$$

$$h \text{ } \left[\begin{array}{c} \text{Moo?!} \\ \text{Consider a spherical cow} \\ \text{of radius } R \dots \end{array} \right] = c \text{ } \left[\begin{array}{c} \text{Moo?!} \\ \text{Consider a spherical cow} \\ \text{of radius } R \dots \end{array} \right] = 7$$

$$L_{\text{cow}} \approx \left(\sqrt{\frac{\alpha}{G m_p^2}} \right)^{2/3} L_{\text{atom}}$$

L

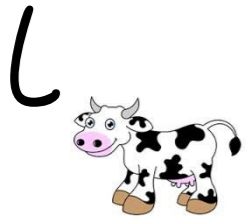


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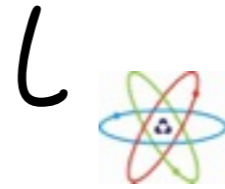
$$\left(\sqrt{\frac{\alpha}{G m_p^2}} \right)^{2/3}$$

L





$$\sim \left(\sqrt{\frac{\alpha}{G m_p^2}} \right)^{2/3}$$



$$\alpha = 1/137$$

$$L_{\text{atom}} = 1/\alpha m_e$$

$$L_{\text{cow}} \approx \left(\sqrt{\frac{\alpha}{G m_p^2}} \right)^{2/3} L_{\text{atom}}$$

$$L_{\text{Earth}} \approx \sqrt{\frac{\alpha}{G m_p^2}} L_{\text{atom}}$$

$$L_{\text{cow}} \approx \left(\sqrt{\frac{\alpha}{G m_p^2}} \right)^{2/3} L_{\text{atom}}$$

$$L_{\text{Earth}} \approx \sqrt{\frac{\alpha}{G m_p^2}} L_{\text{atom}}$$

$$M_{\text{Sun}} \approx \frac{m_p}{(G m_p^2)^{3/2}} \approx 10^{57} m_p$$

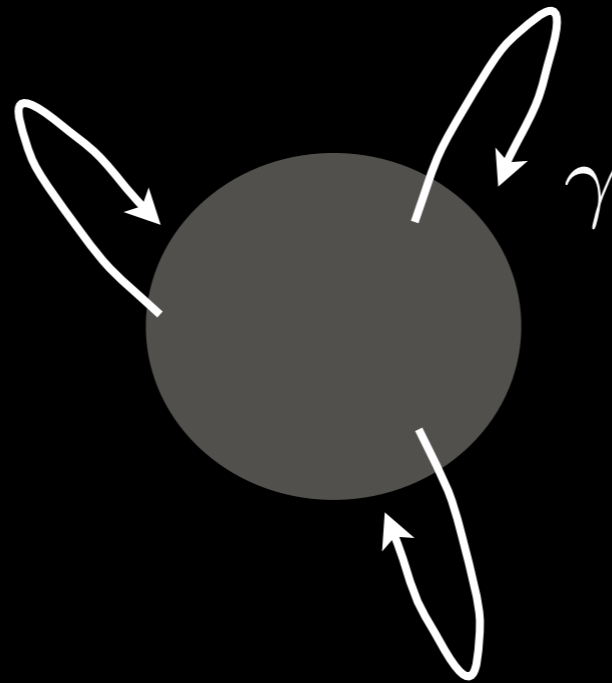
LA EXISTENCIA DEL MUNDO

MACROSCOPICO

DEPENDE DE

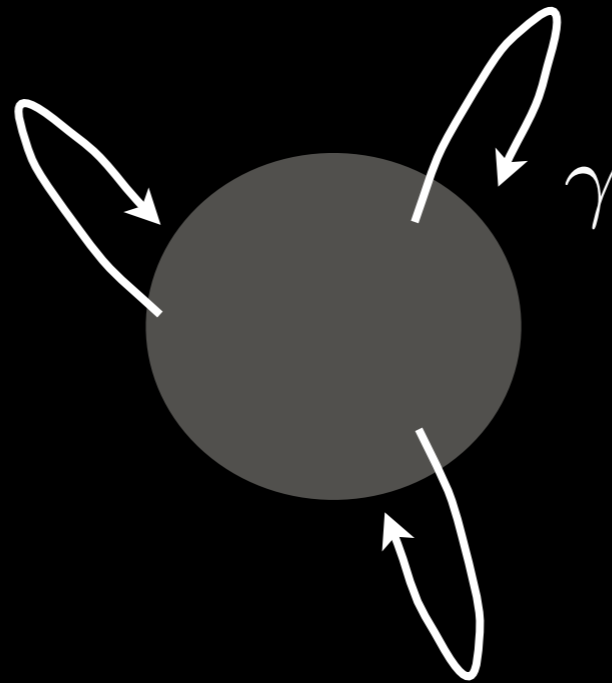
$$G m_p^2 = \left(\frac{m_p}{M_{\text{Planck}}} \right)^2 \sim 10^{-38}$$

Primer modelo de AGUJERO NEGRO:
una región en la que la luz está atrapada
por efecto de la gravedad



Primer modelo de AGUJERO NEGRO:

una región en la que la luz está atrapada
por efecto de la gravedad

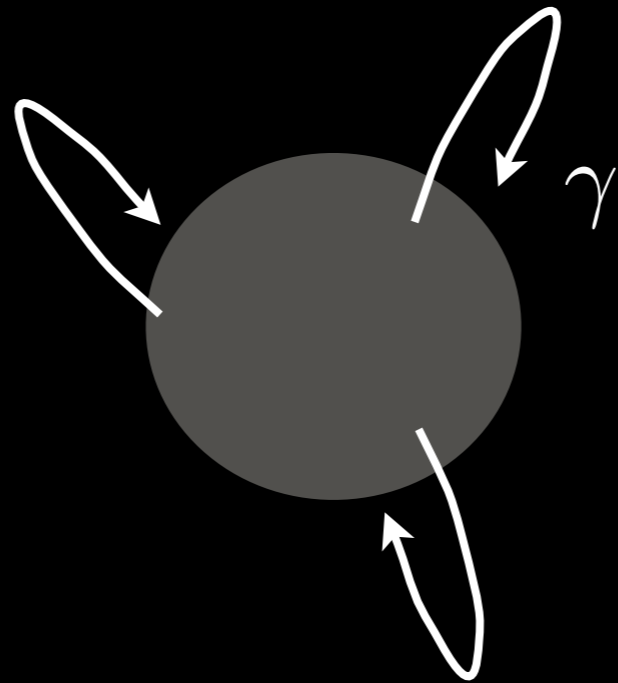


$$E = m c^2$$

Primer modelo de AGUJERO NEGRO:
una región en la que la luz está atrapada
por efecto de la gravedad

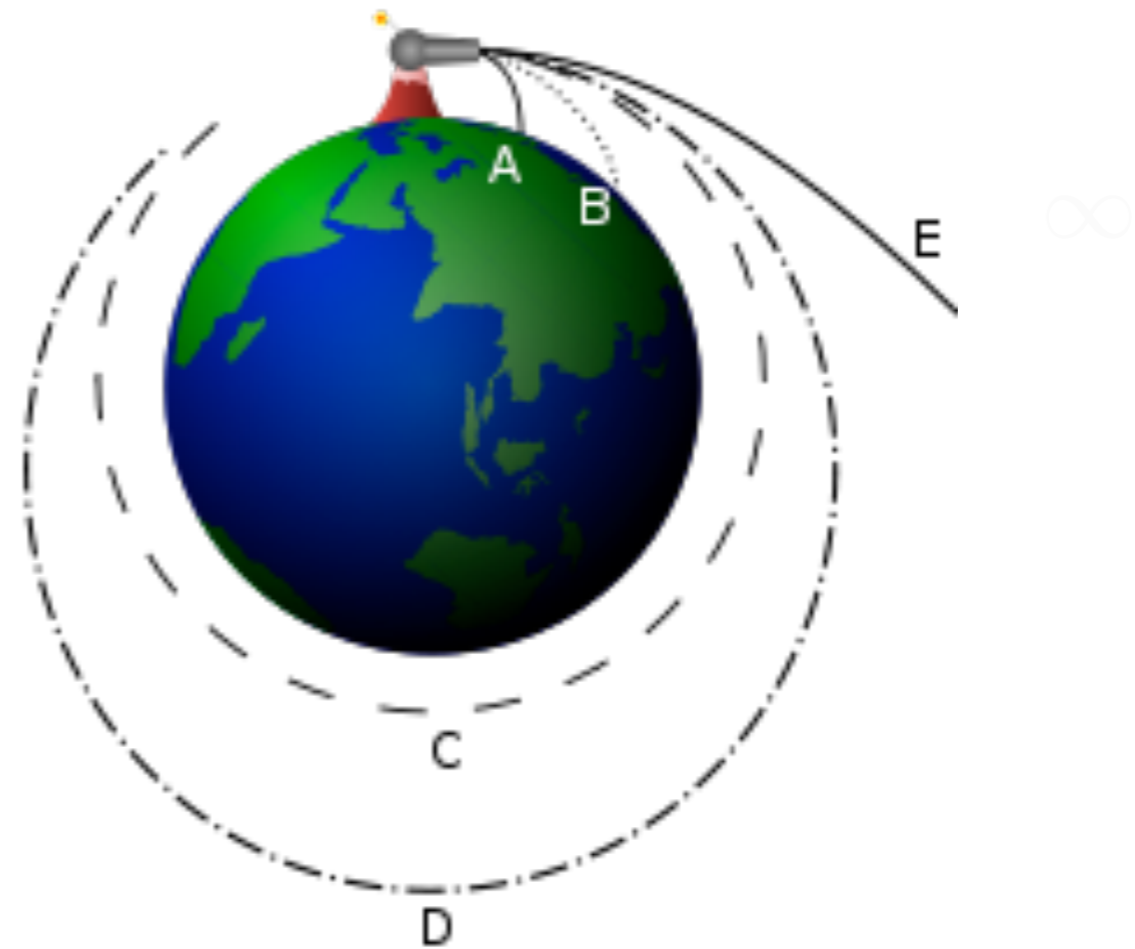
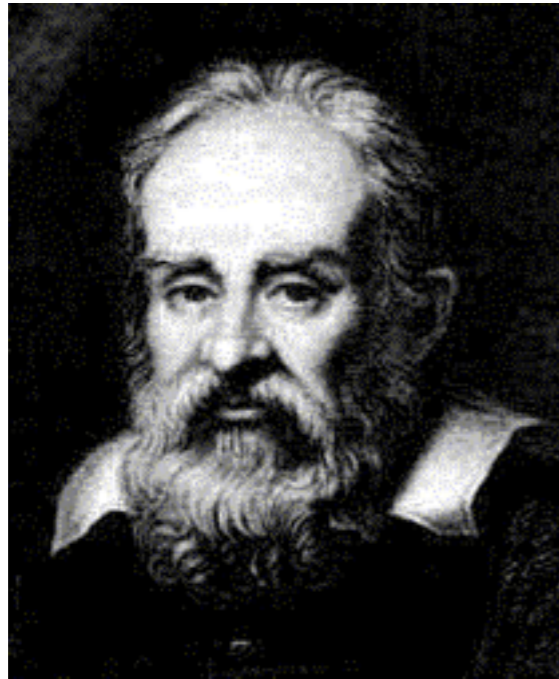


1796

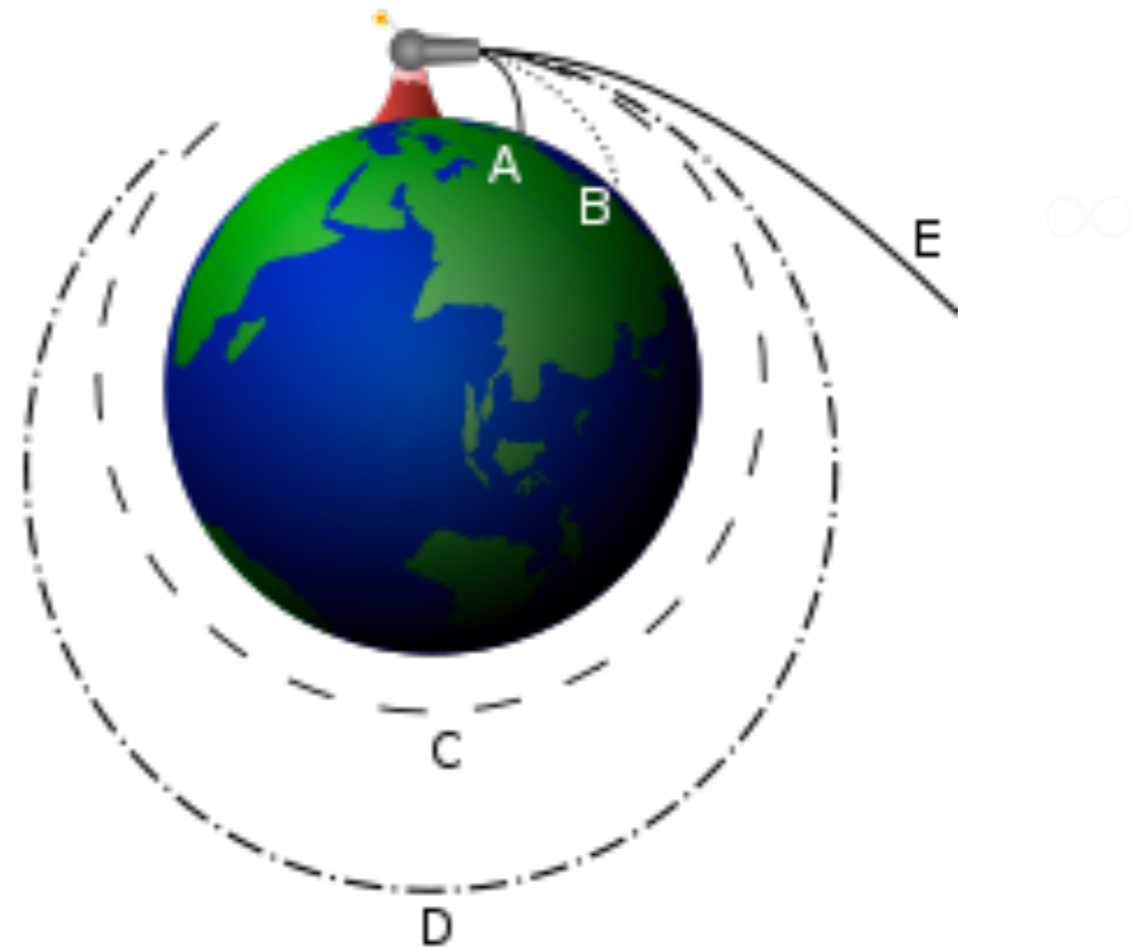
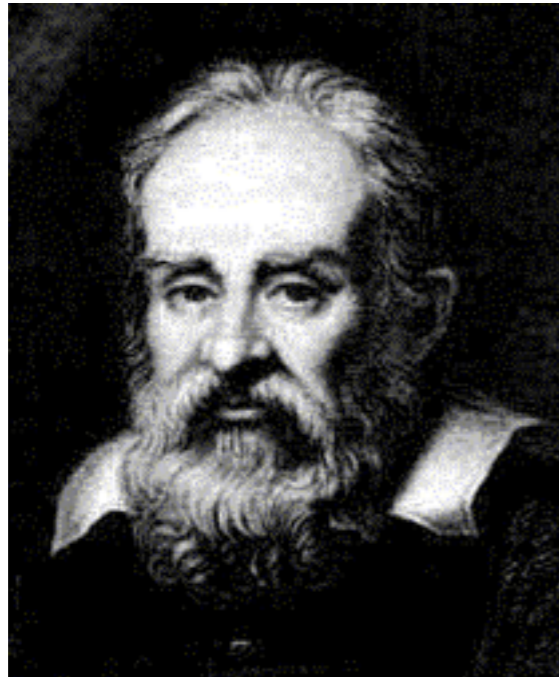


$$E = m c^2$$

Velocidad de escape



Velocidad de escape



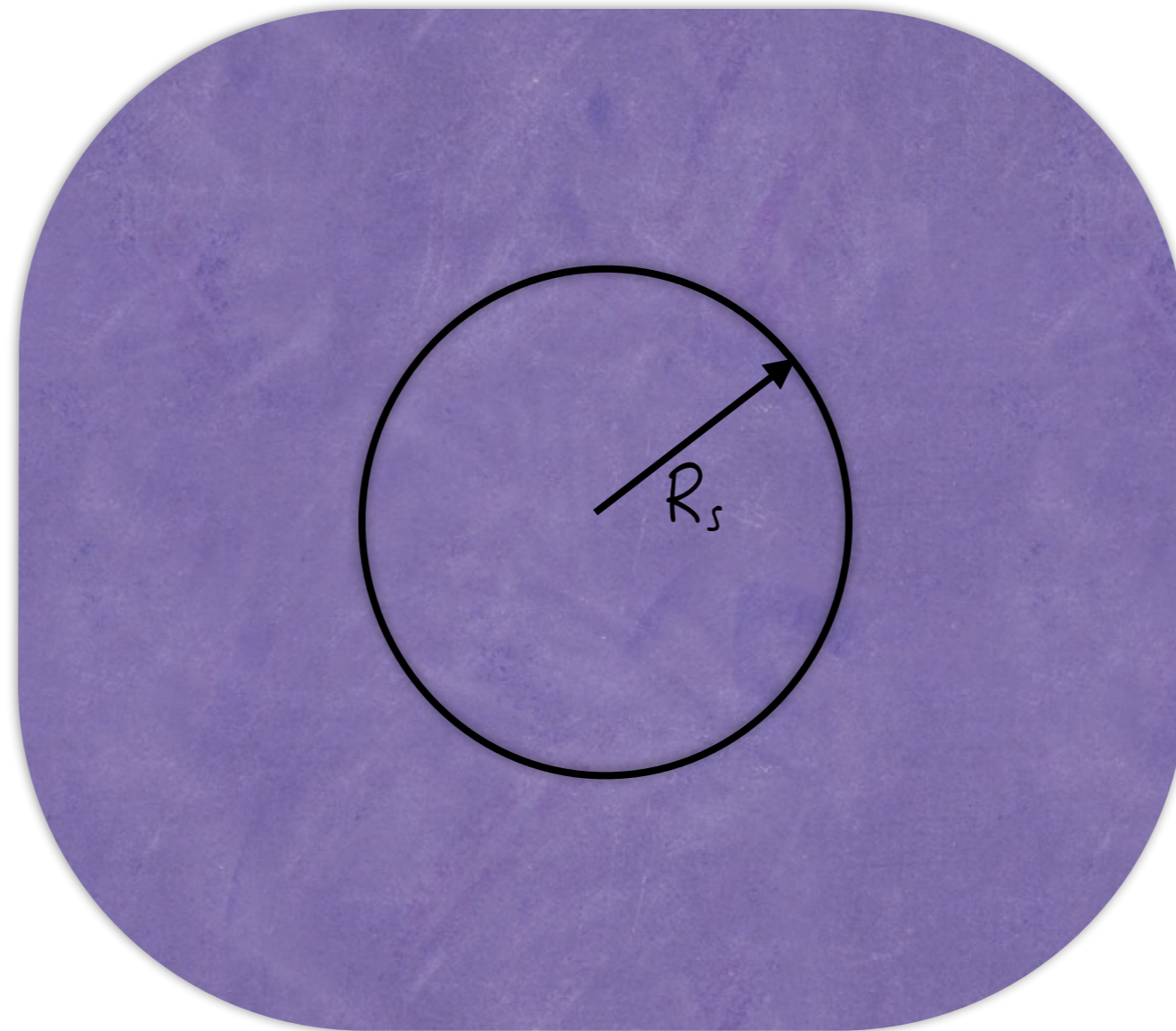
$$V_{\text{escape}} = \sqrt{\frac{2GM}{R}}$$

RADIO DE SCHWARZSCHILD



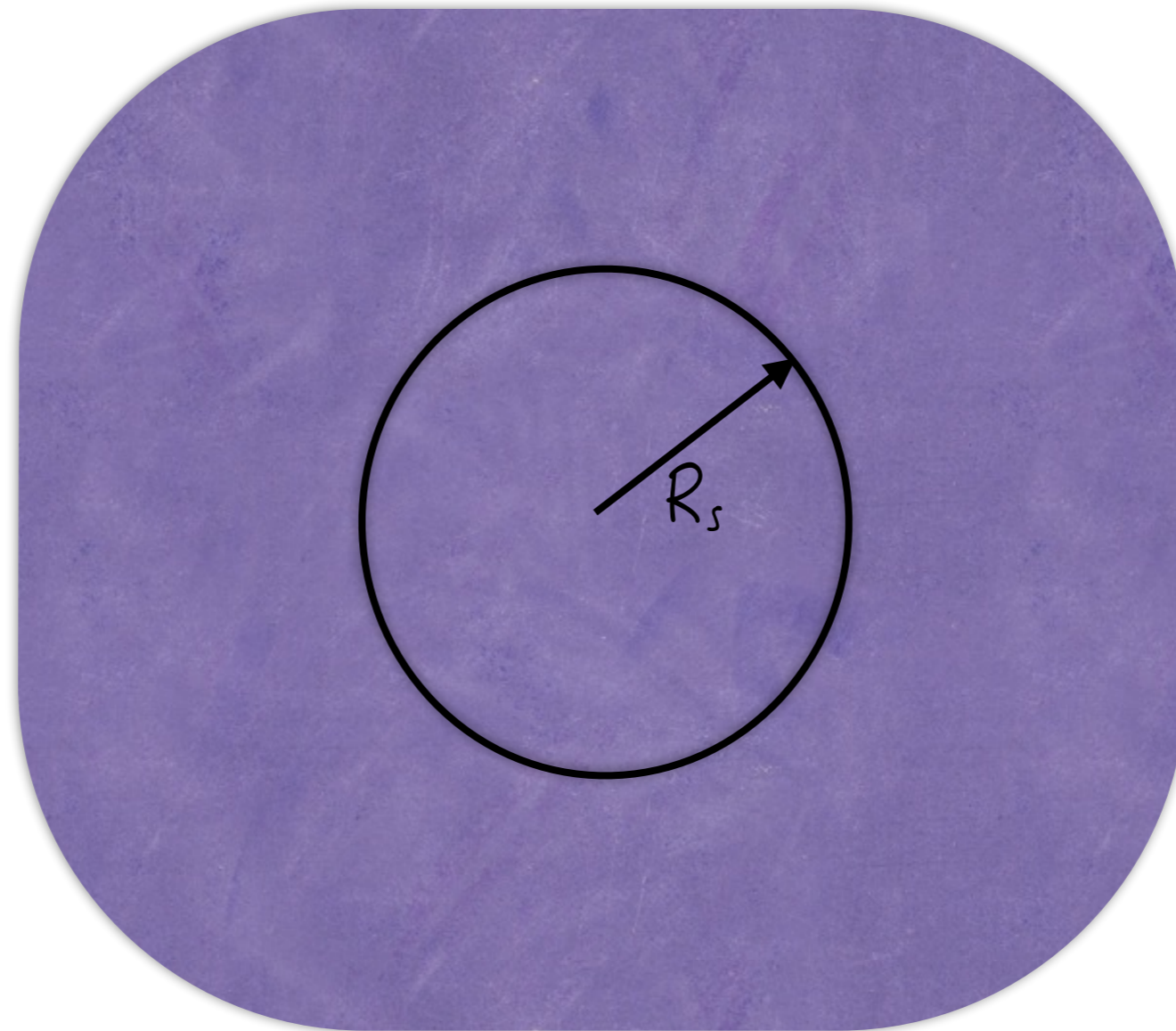
$$R_s = \frac{2GM}{c^2}$$

velocidad de escape = velocidad de la luz



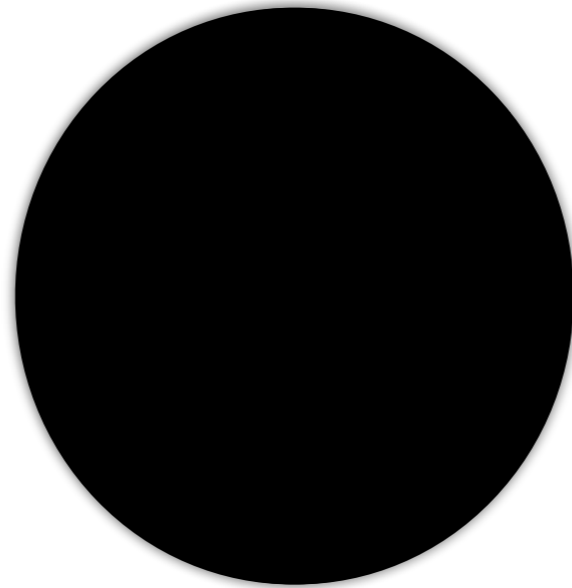
$$R_s(\text{🌍}) \sim 3 \text{ cm}$$

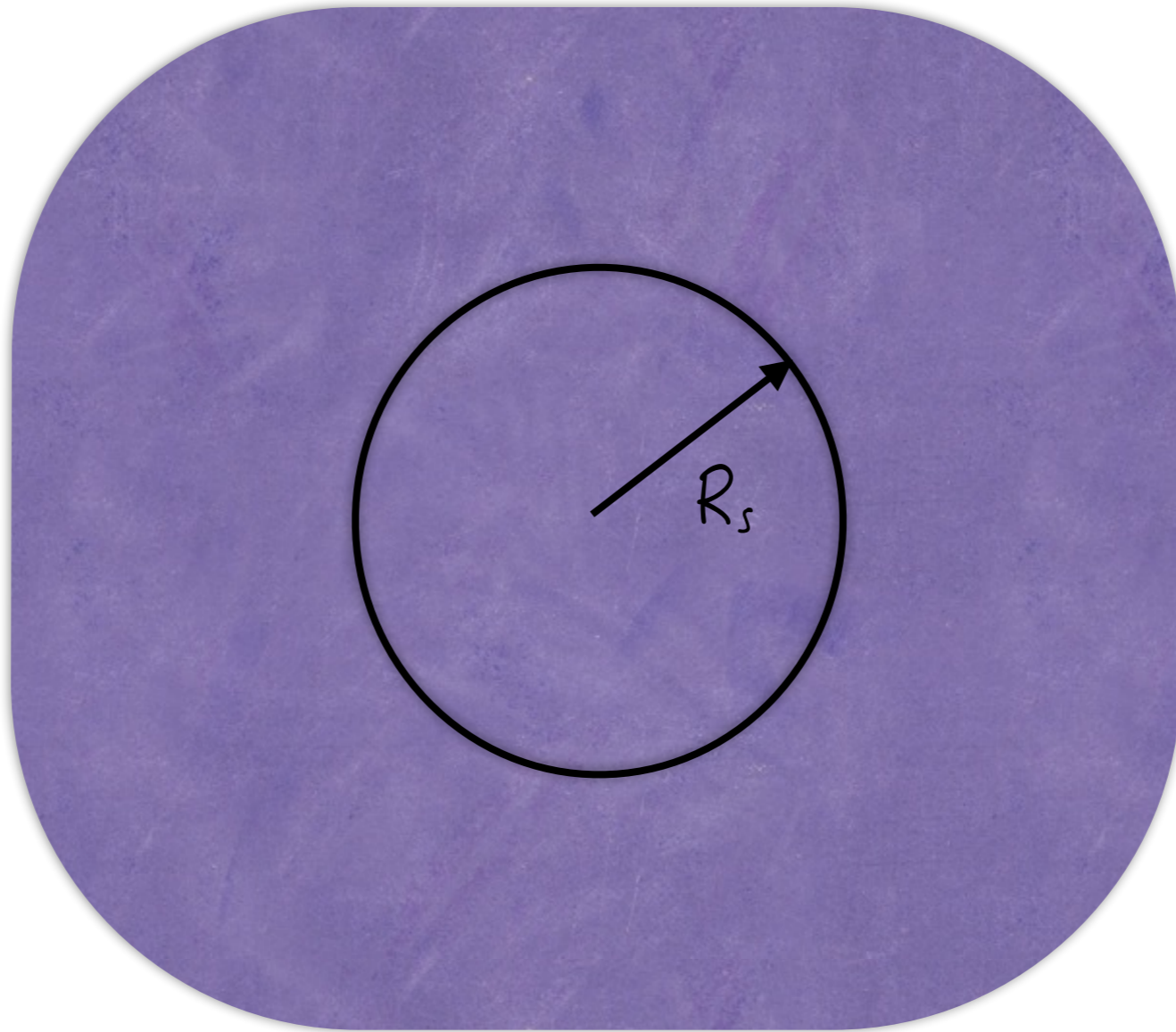
$$R_s(\text{☀️}) \sim 3 \text{ Km}$$

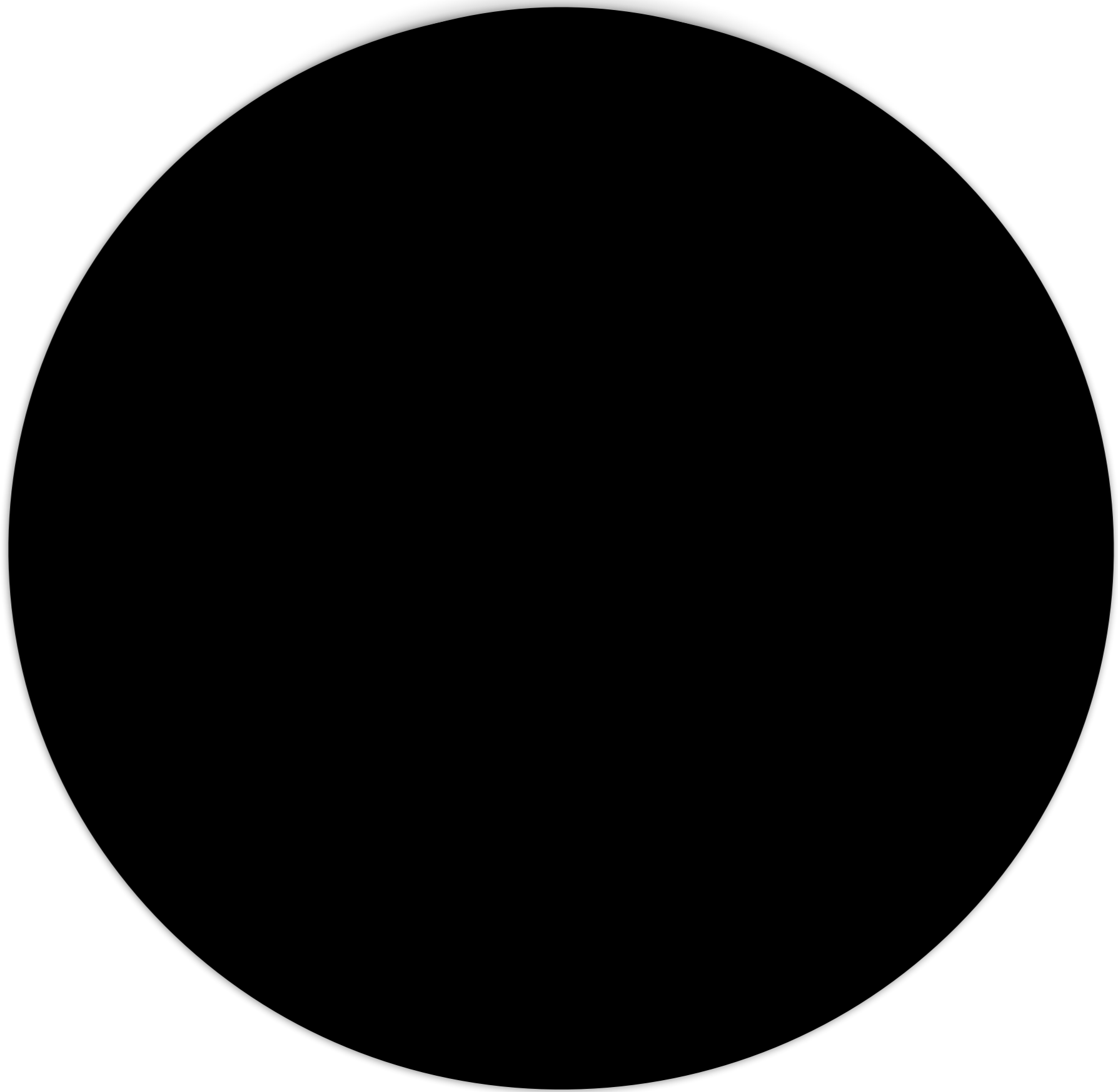


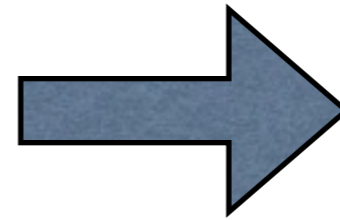
$$R_s(\text{🌍}) \sim 3 \text{ cm}$$

$$R_s(\text{☀️}) \sim 3 \text{ Km}$$









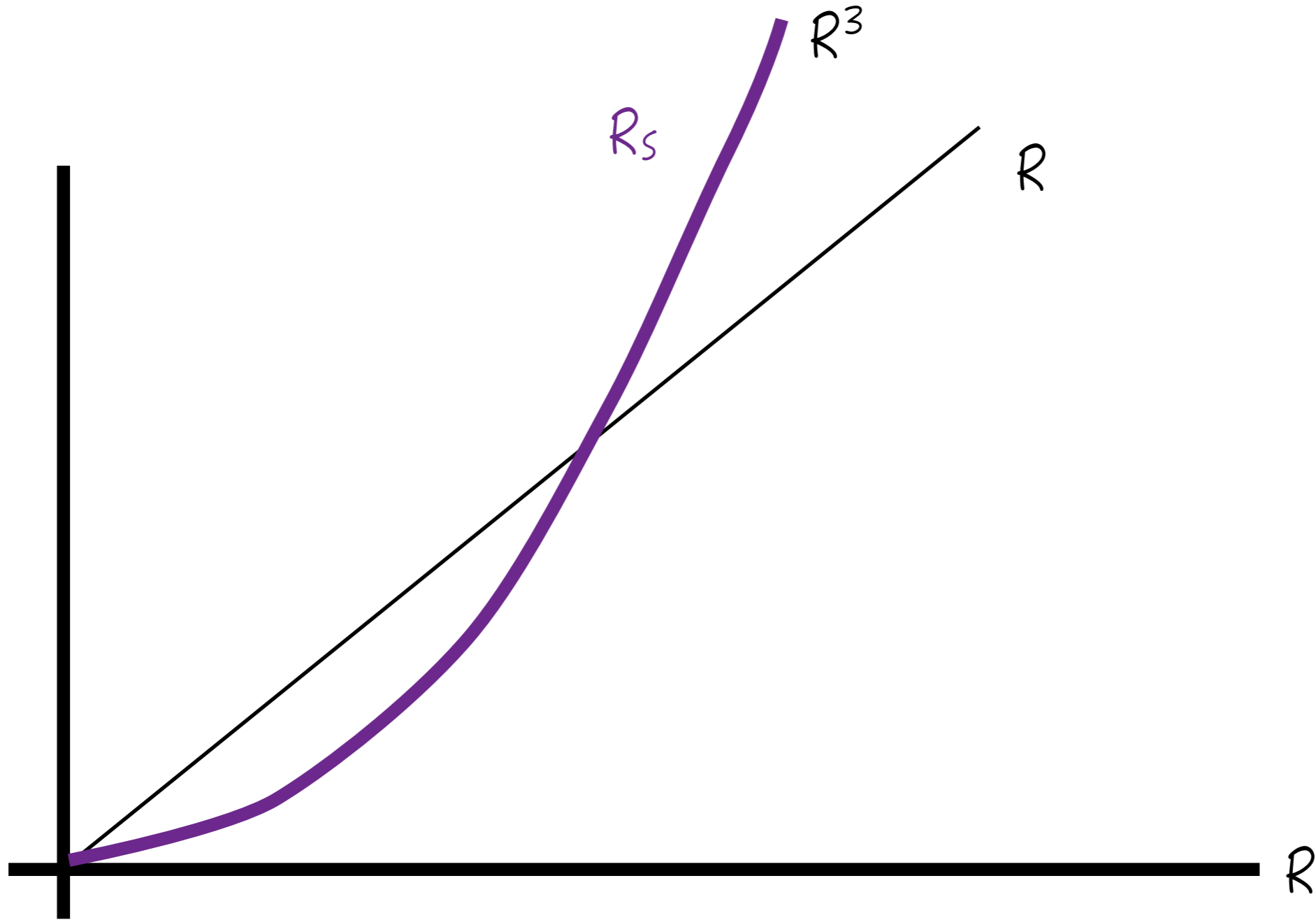
●
↔
3 Km

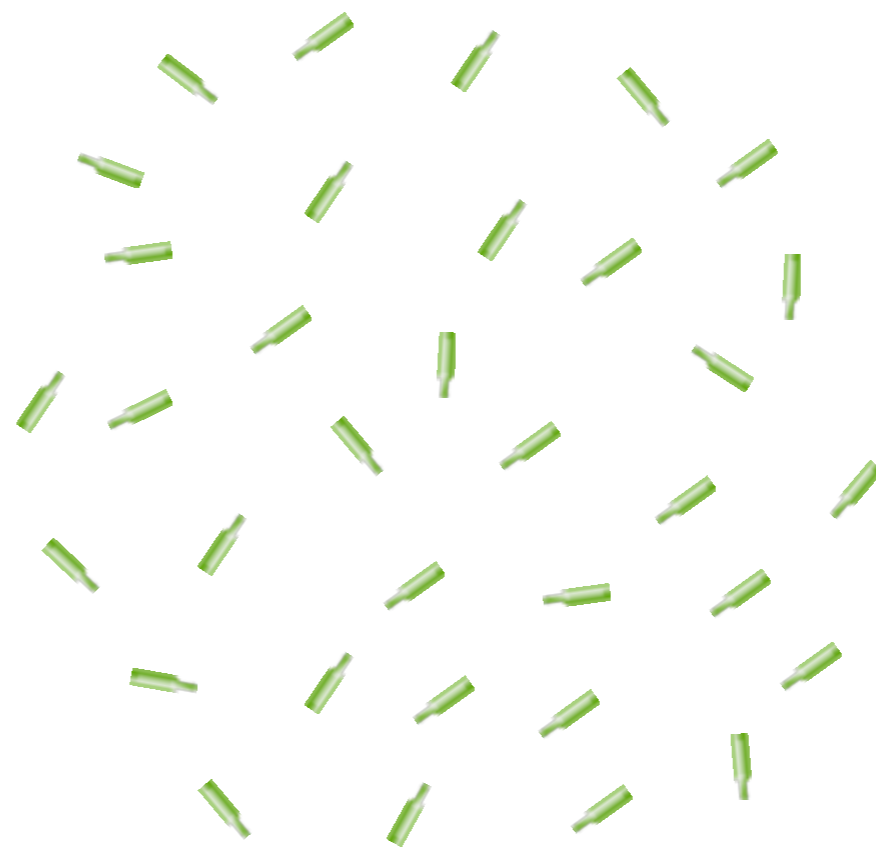
¡PERO!

$$R_s \sim \text{Masa} \sim \text{Densidad} \times \text{Volumen} \sim R^3$$

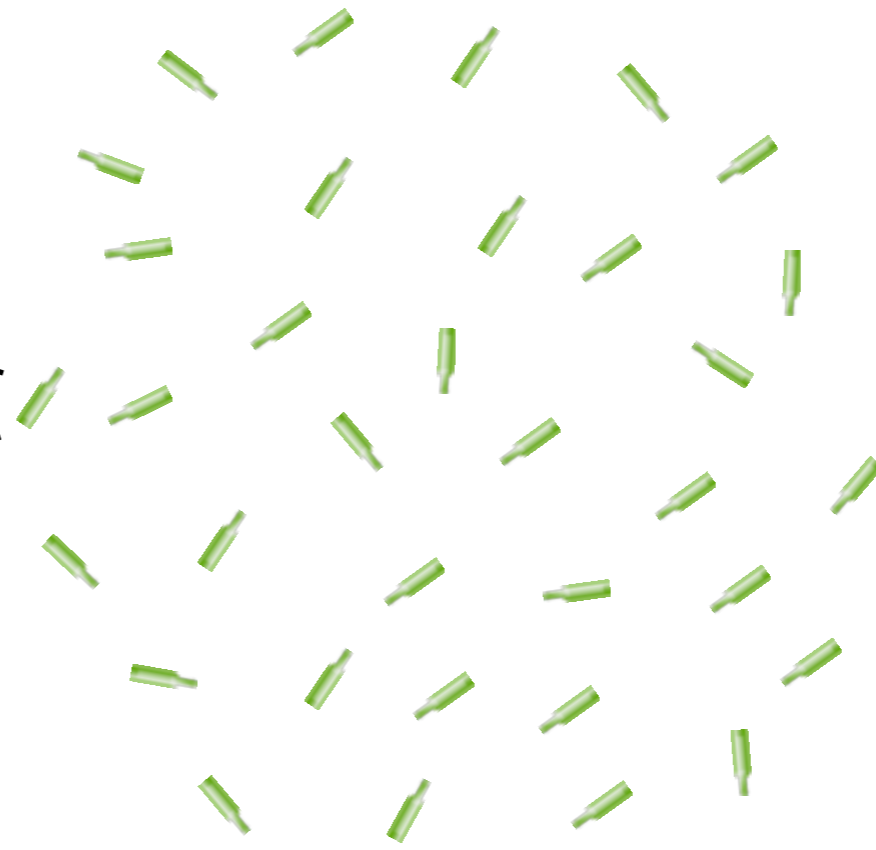
¡PERO!

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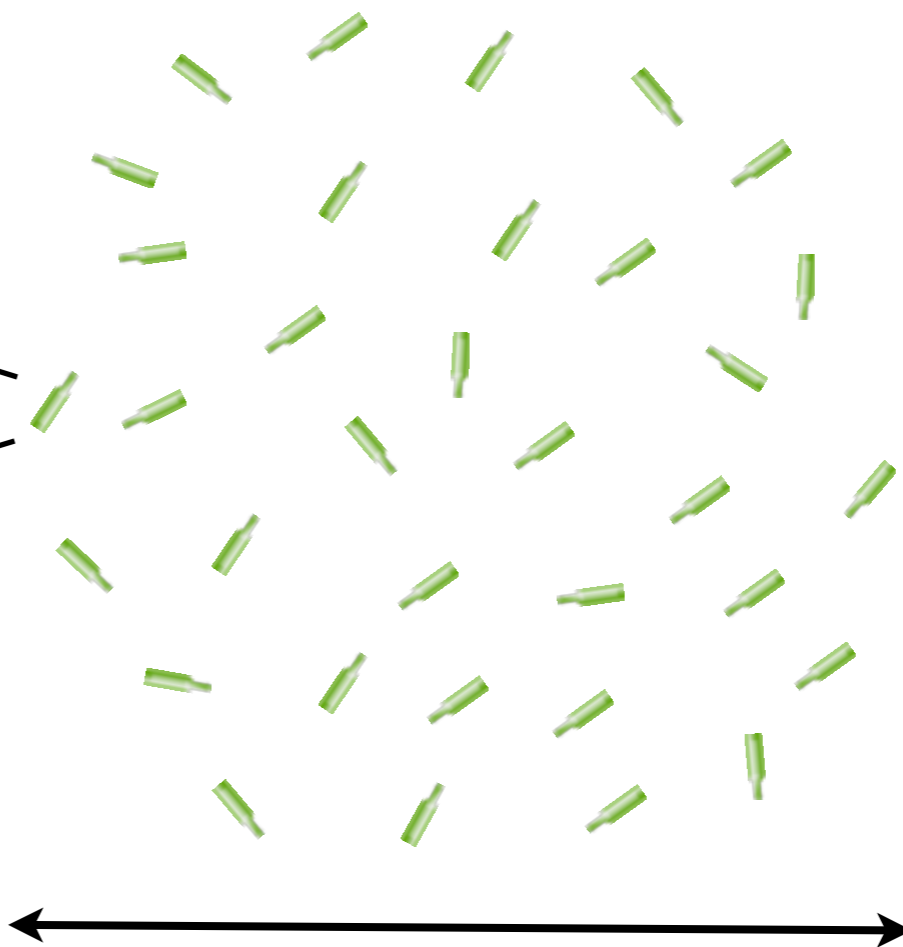




10 botellas/m³



10 botellas/m³



10 botellas/m³

órbita de Urano ~ R_s

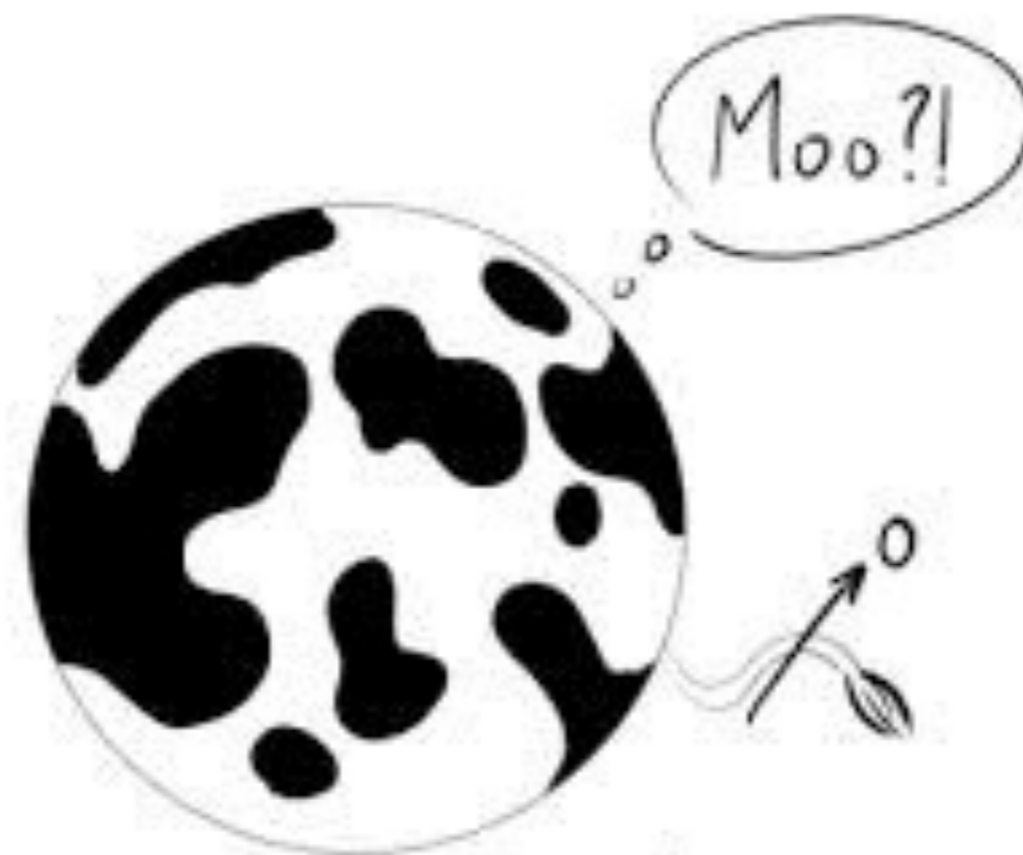
$$M \approx 10^9 M_{\odot}$$



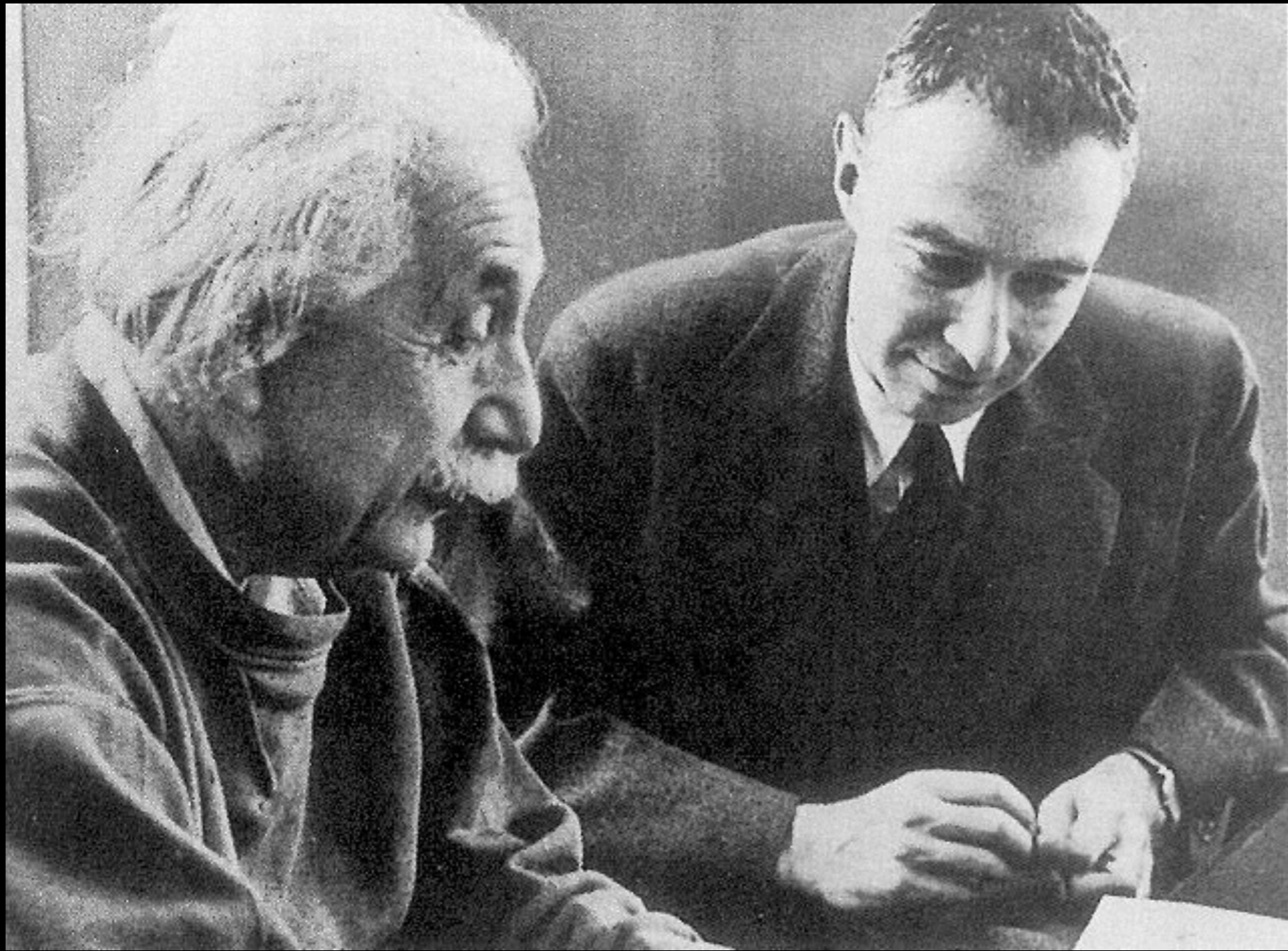
¡No se precisan situaciones extremas!

LOS AGUJEROS NEGROS
SON

INEVITABLES



Consider a spherical cow
of radius R ... \square





CLASSICAL

QUANTUM

t

x

A B

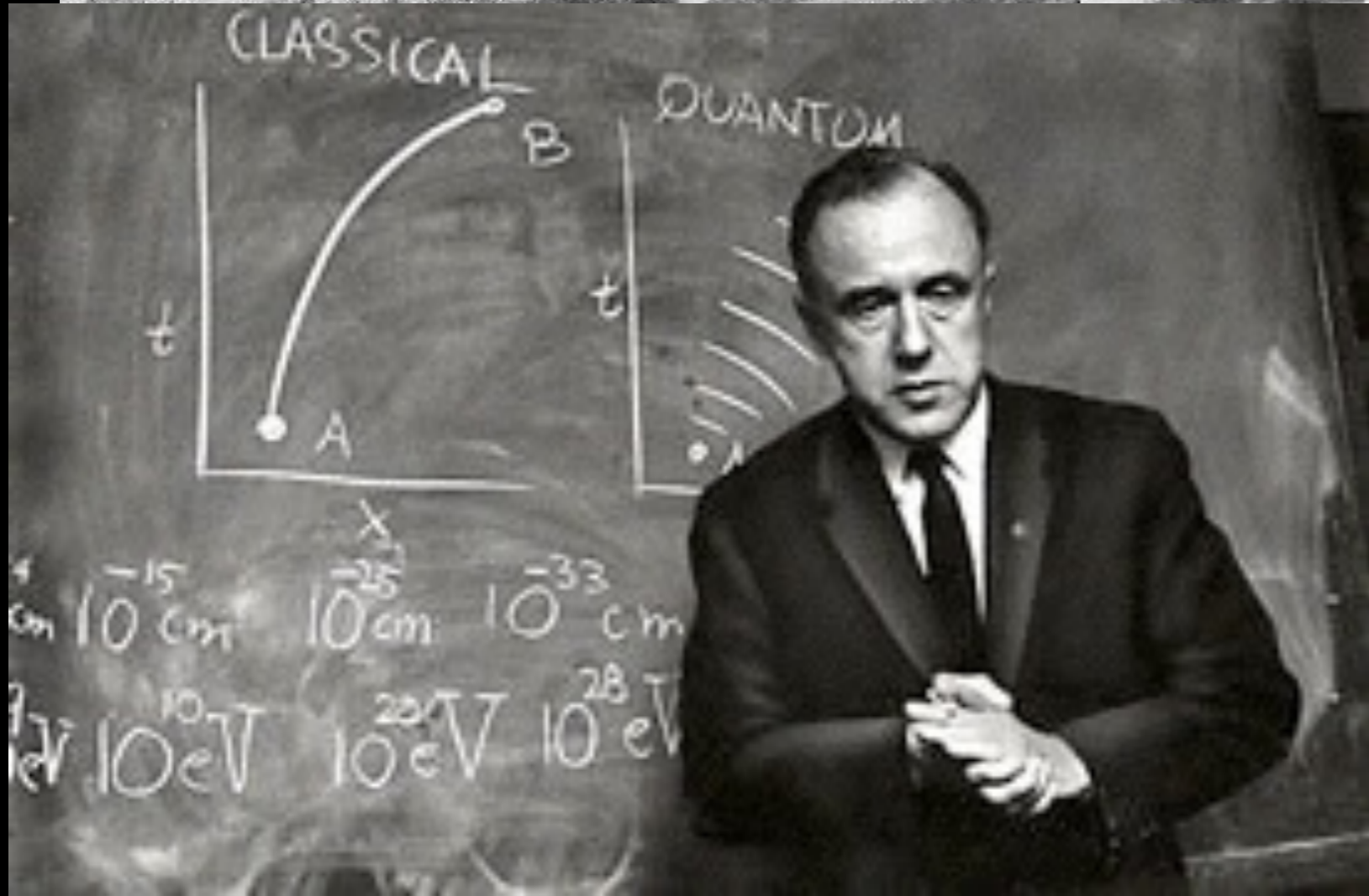
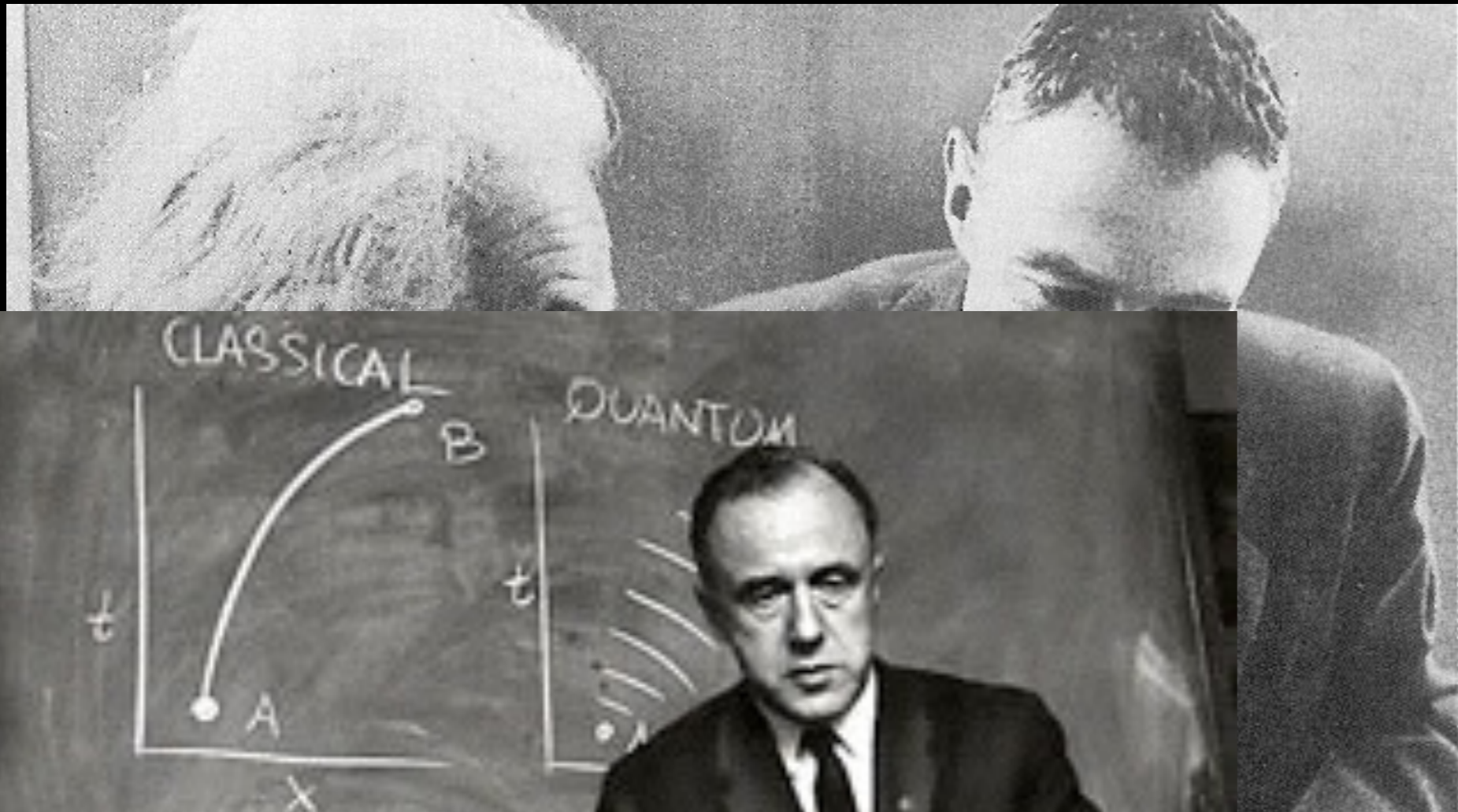
10^{-15} 10^{-25} 10^{-33} cm

10^{10} 10^{20} 10^{28} eV

10 eV 10 eV 10 eV

Albert Einstein





1967



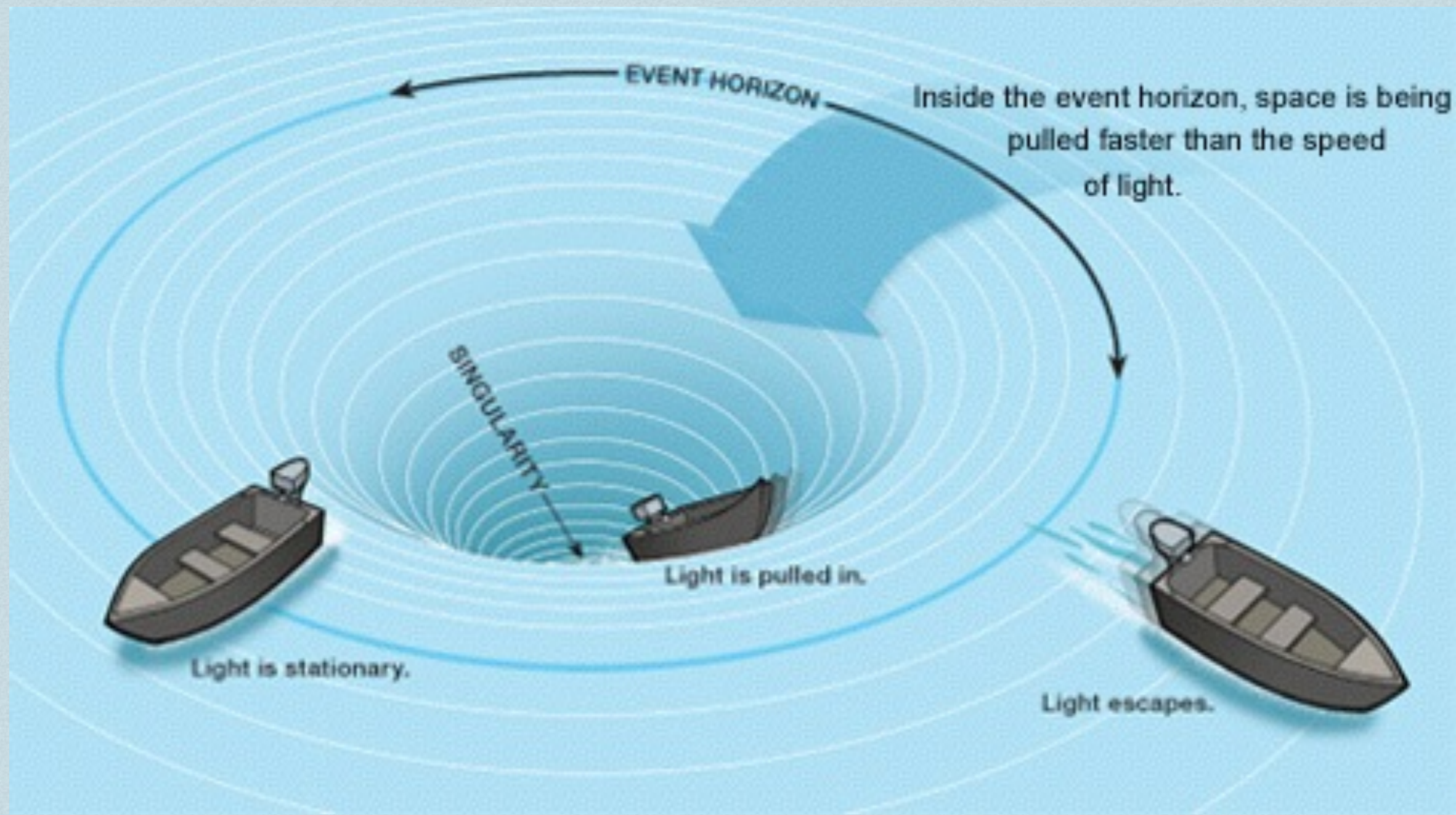
¿Por qué un AGUJERO?







Maelstrom!!!



EVENT HORIZON

Inside the event horizon, space is being pulled faster than the speed of light.

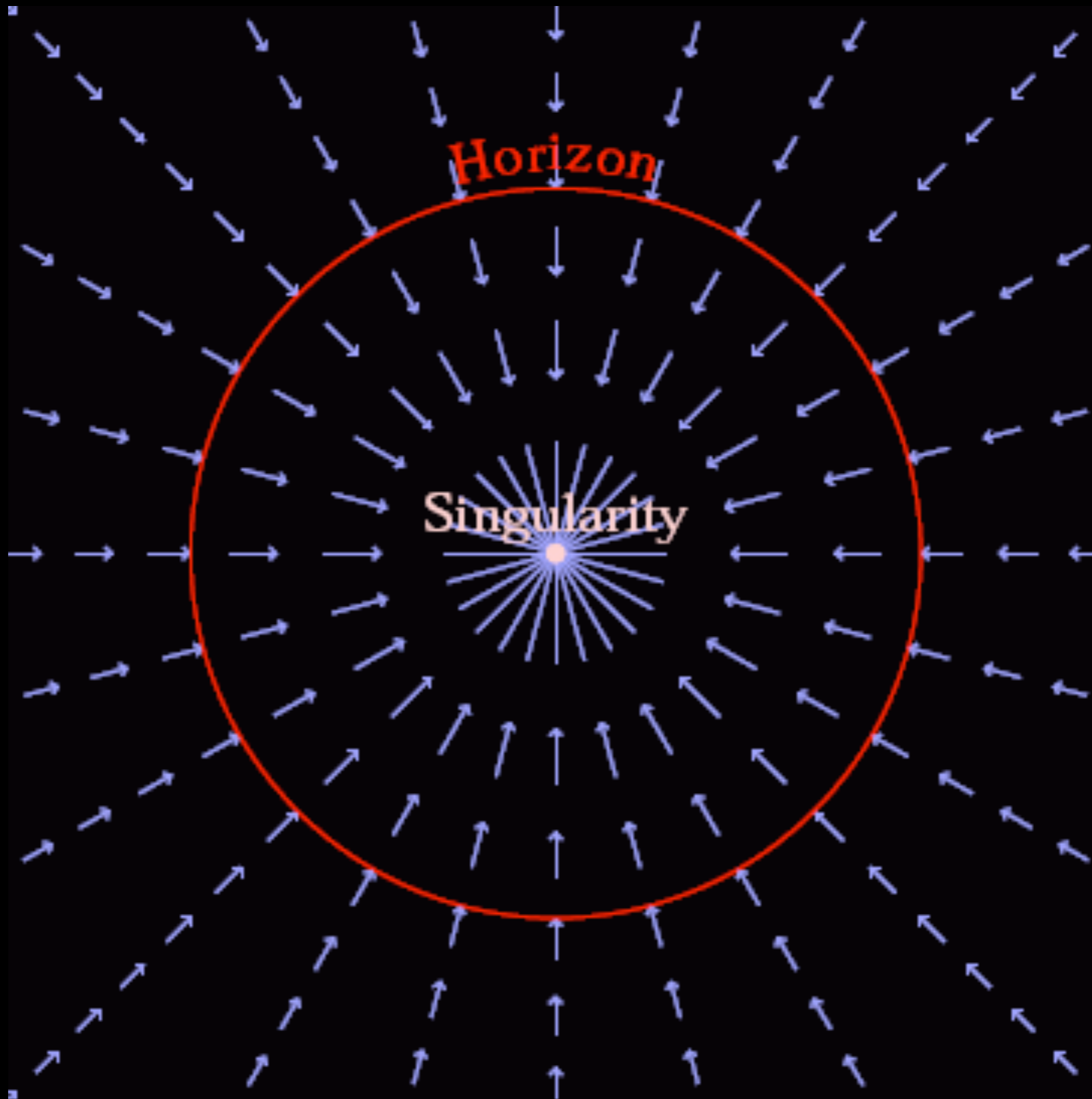
SINGULARITY

Light is stationary.

Light is pulled in.

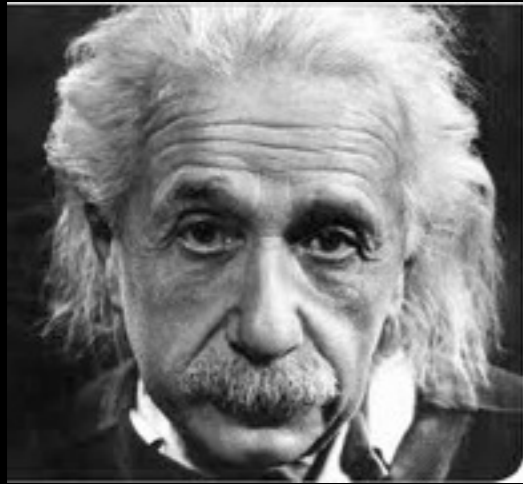
Light escapes.

El espacio “fluye” a la velocidad de escape



VIDA INTERIOR

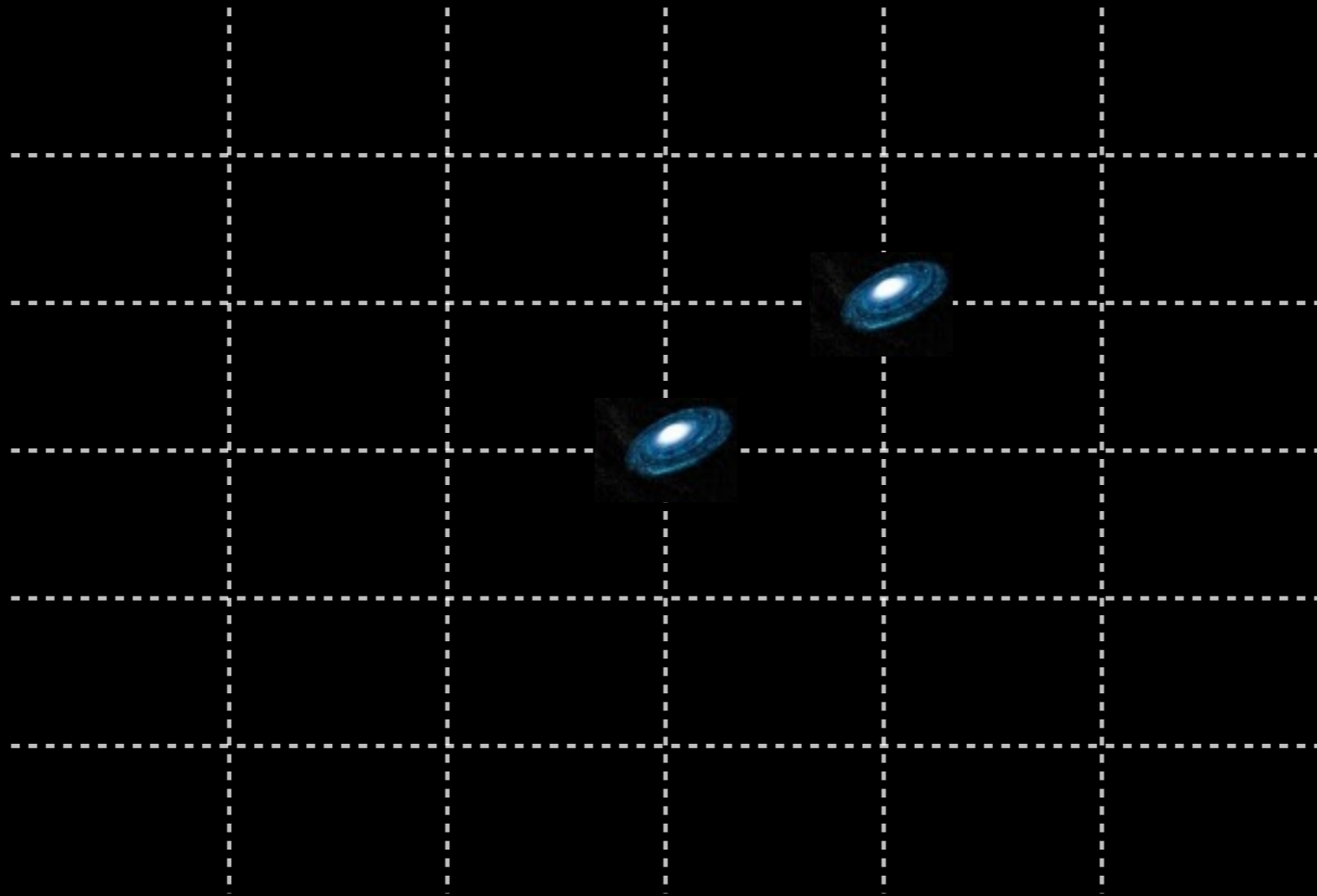




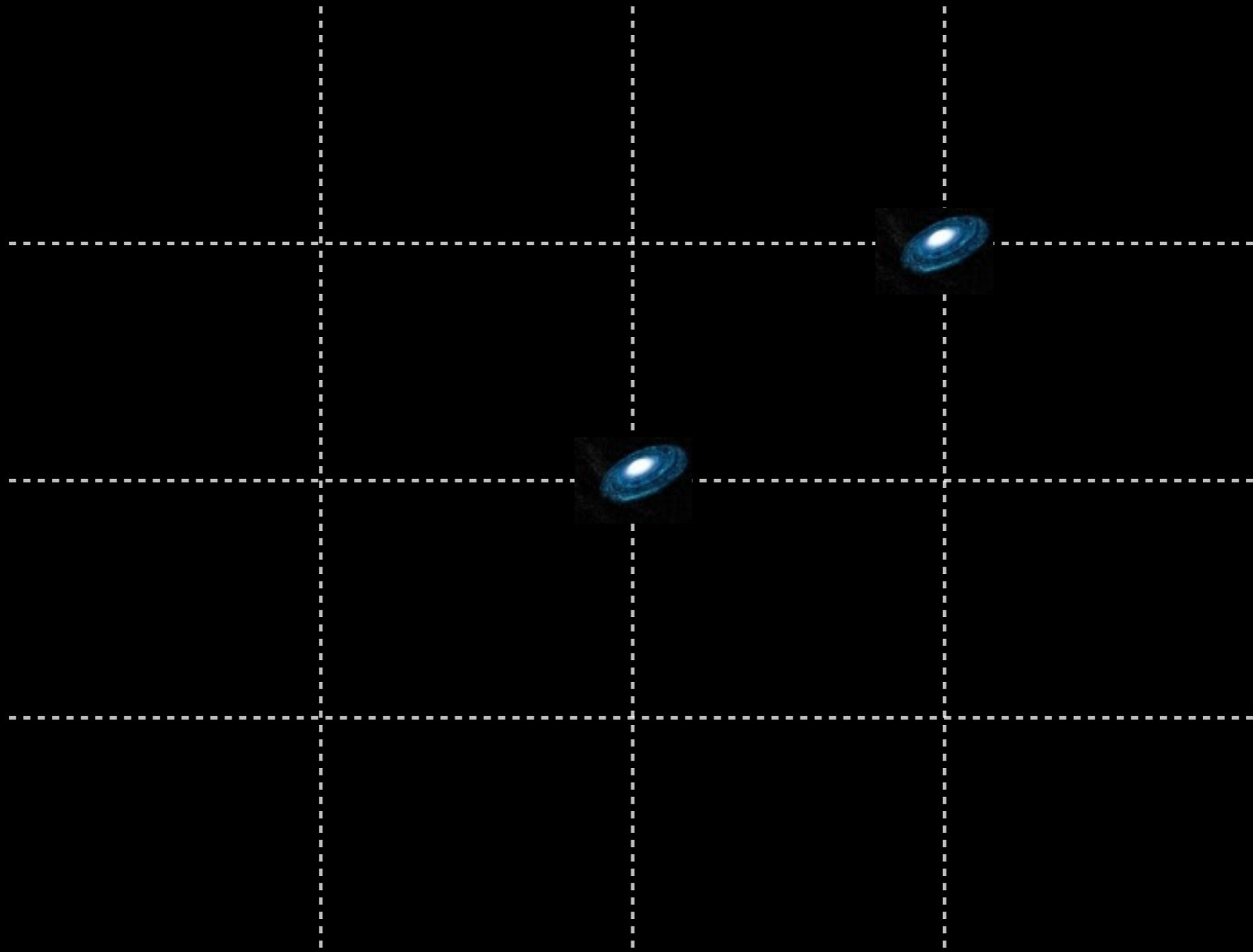
SLOGAN

Gravitación ~ “elasticidad” del espacio

A grandes distancias, el universo se
expande porque el espacio se
“inventa” continuamente



A grandes distancias, el universo se
expande porque el espacio se
“inventa” continuamente



Y sin embargo

son

SUTILES...

G



C

\hbar

G



c

h

G



C

h

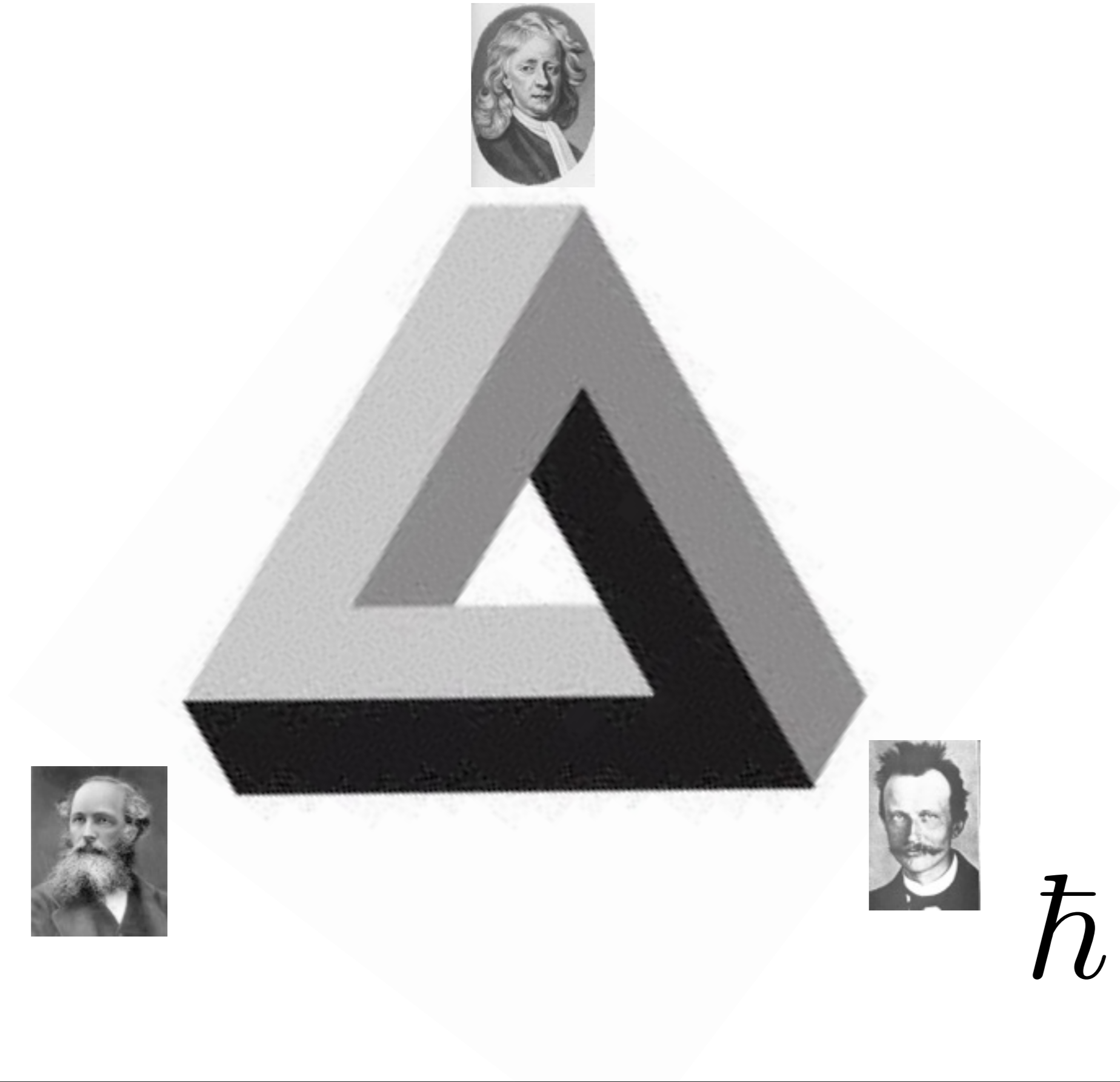
G



c



h



G



c

h

G



c

\hbar

G



?

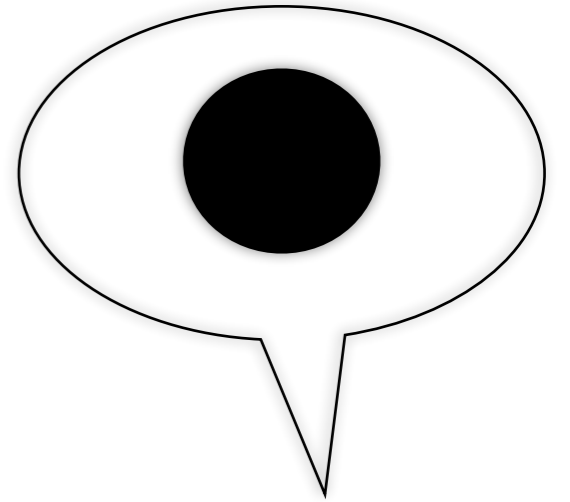


c



\hbar

G



?



c



\hbar

Φ

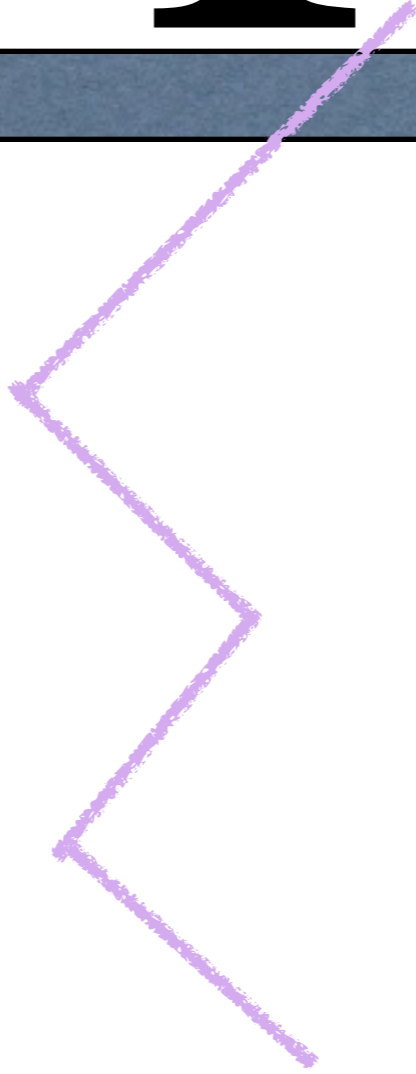
RELATIVIDAD

CUANTICA

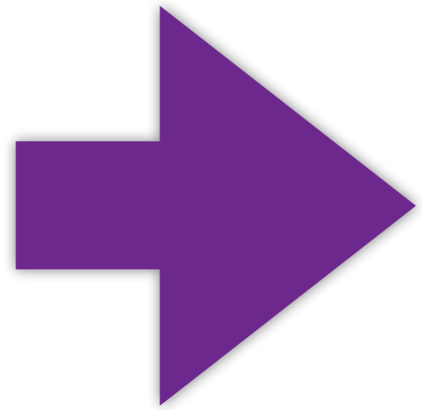
Φ

RELATIVIDAD

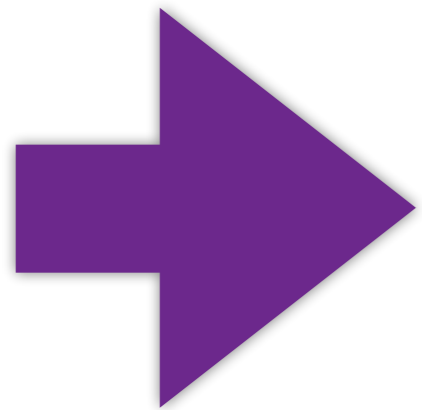
CUANTICA



LA INFORMACION. . .

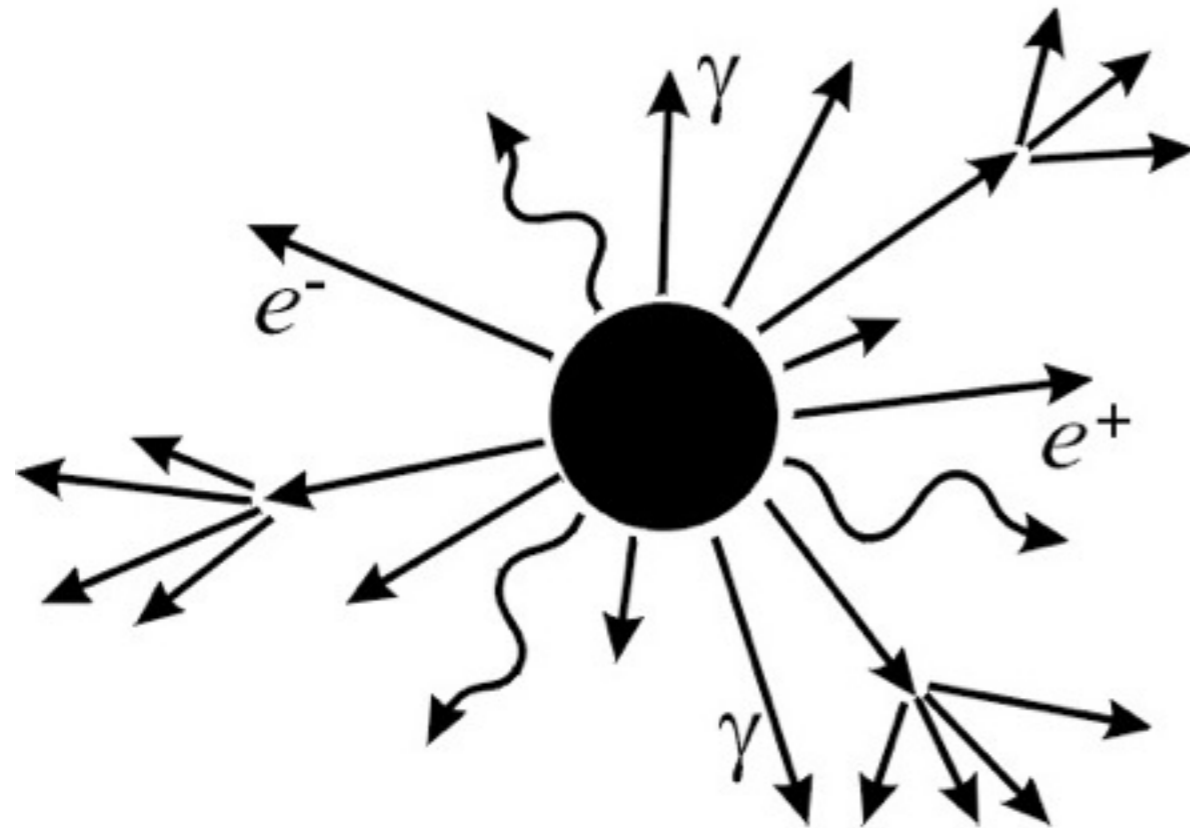


SE CONSERVA



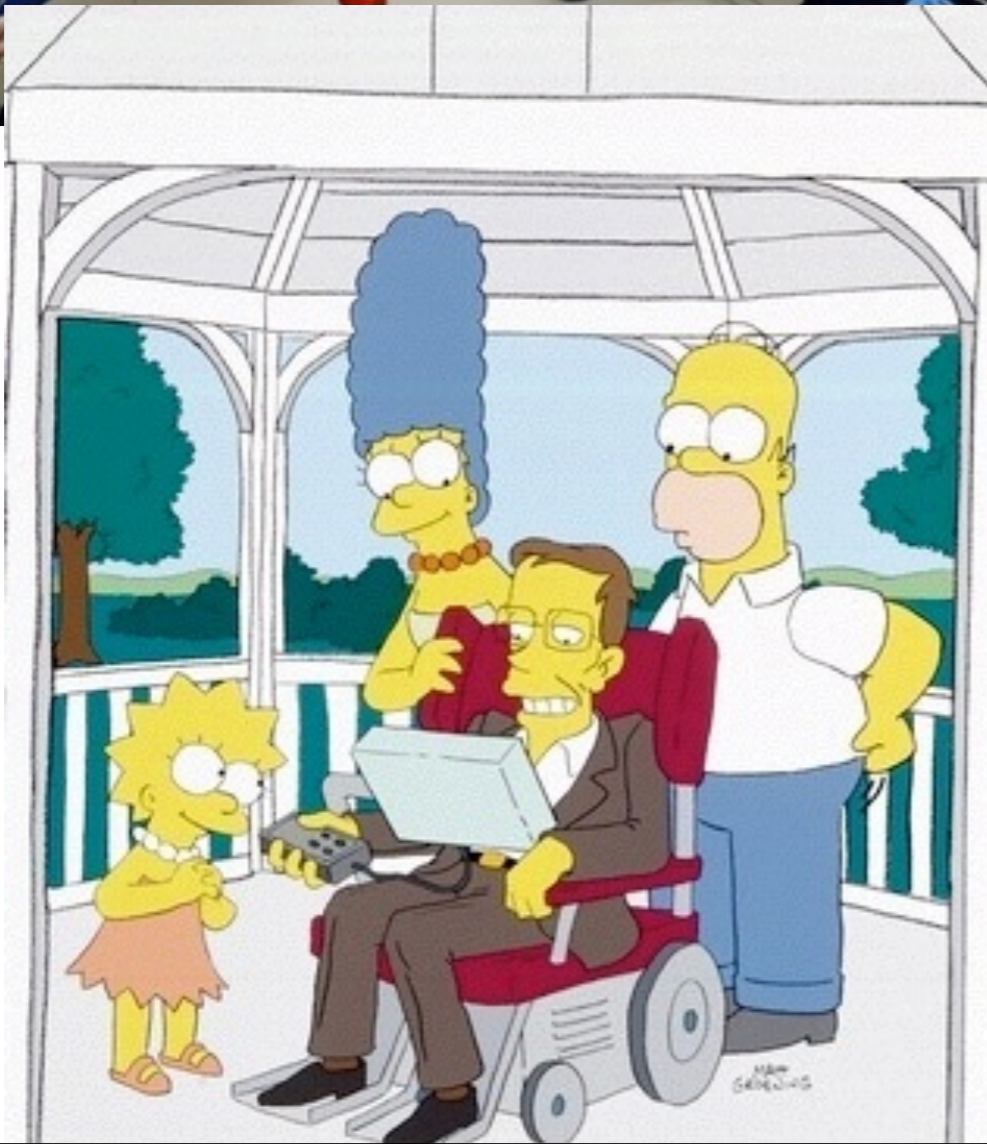
NO PUEDE VIAJAR
AL PASADO

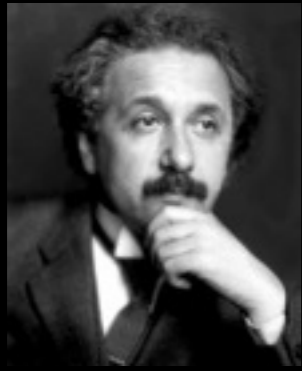
Stephen Hawking



$$T_H = \frac{\hbar c^3}{8\pi G M}$$

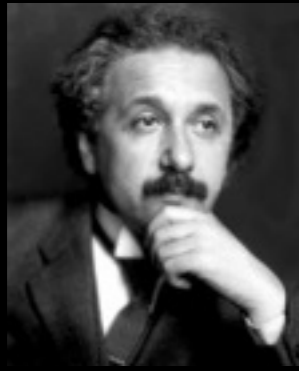
¡Primera fórmula
de la gravitación
cuántica!



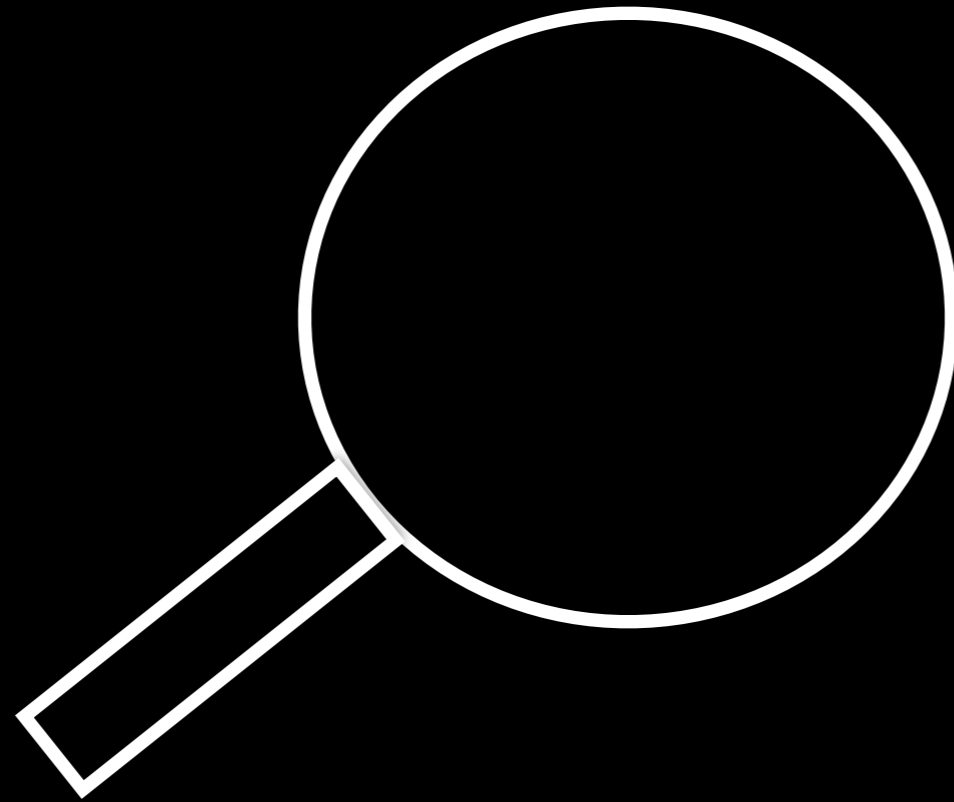


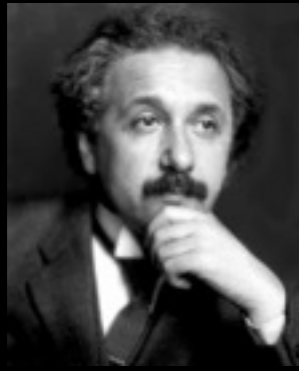
EL "VACIO" CUANTICO



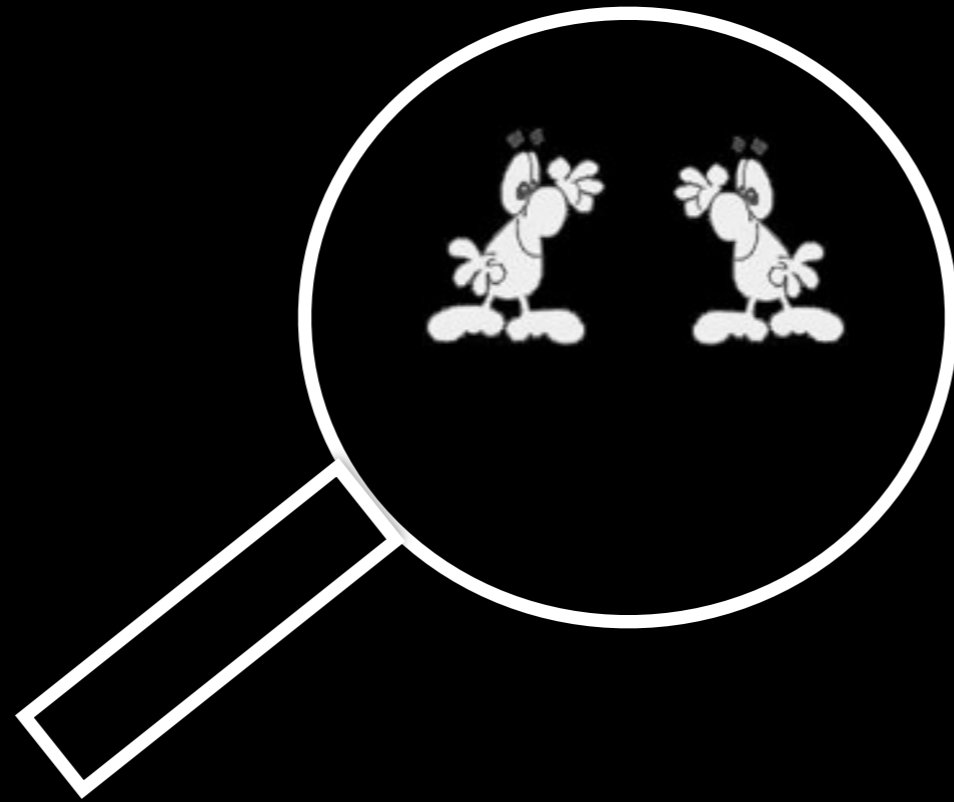


EL "VACIO" CUANTICO



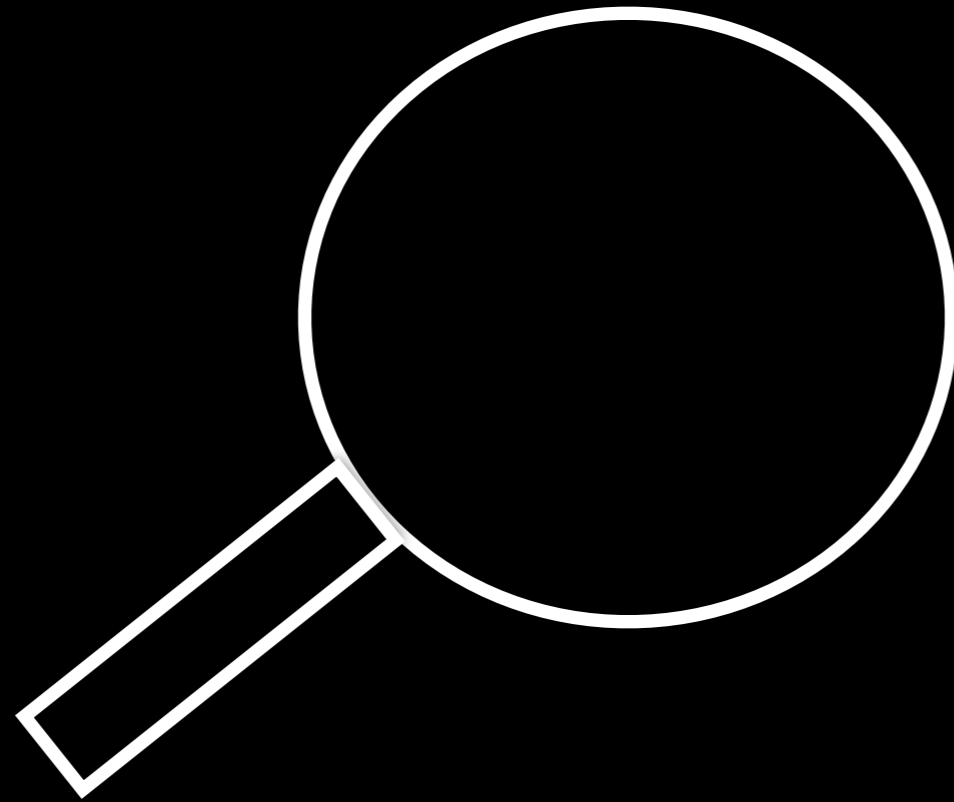


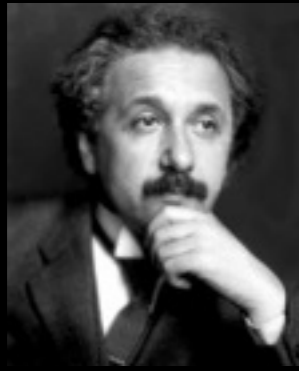
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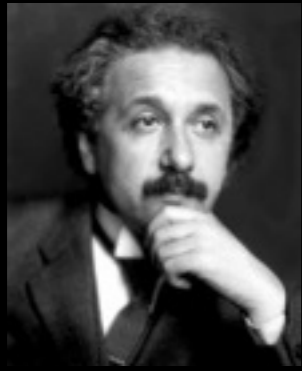
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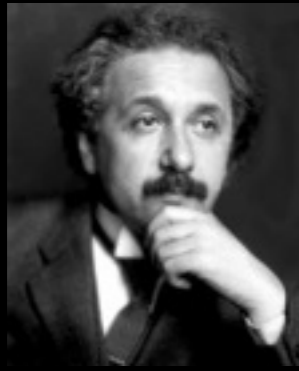
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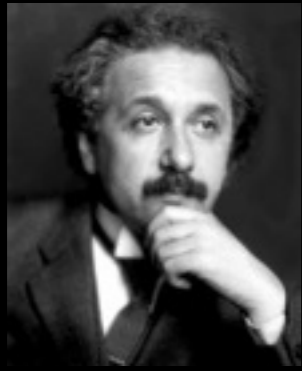
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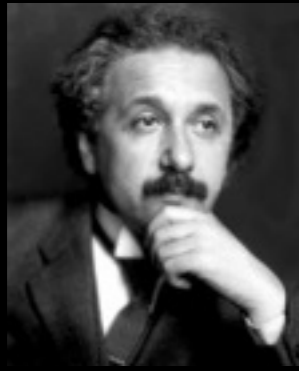
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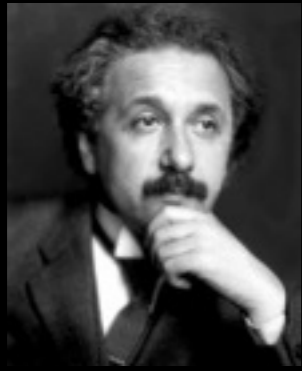
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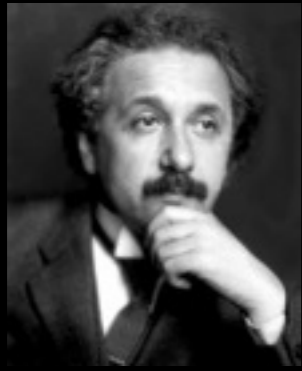
EL "VACIO" CUANTICO





EL "VACIO" CUANTICO





EL "VACIO" CUANTICO



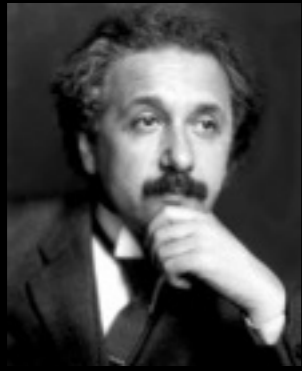
UV



EL "VACIO" CUANTICO

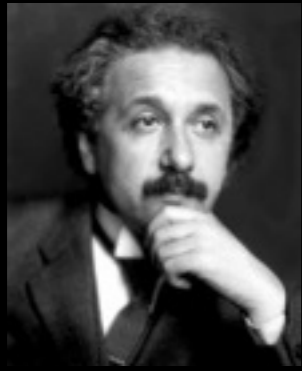


UV



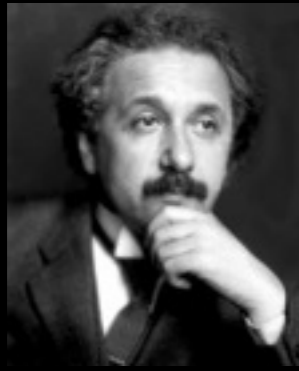
EL "VACIO" CUANTICO





EL "VACIO" CUANTICO



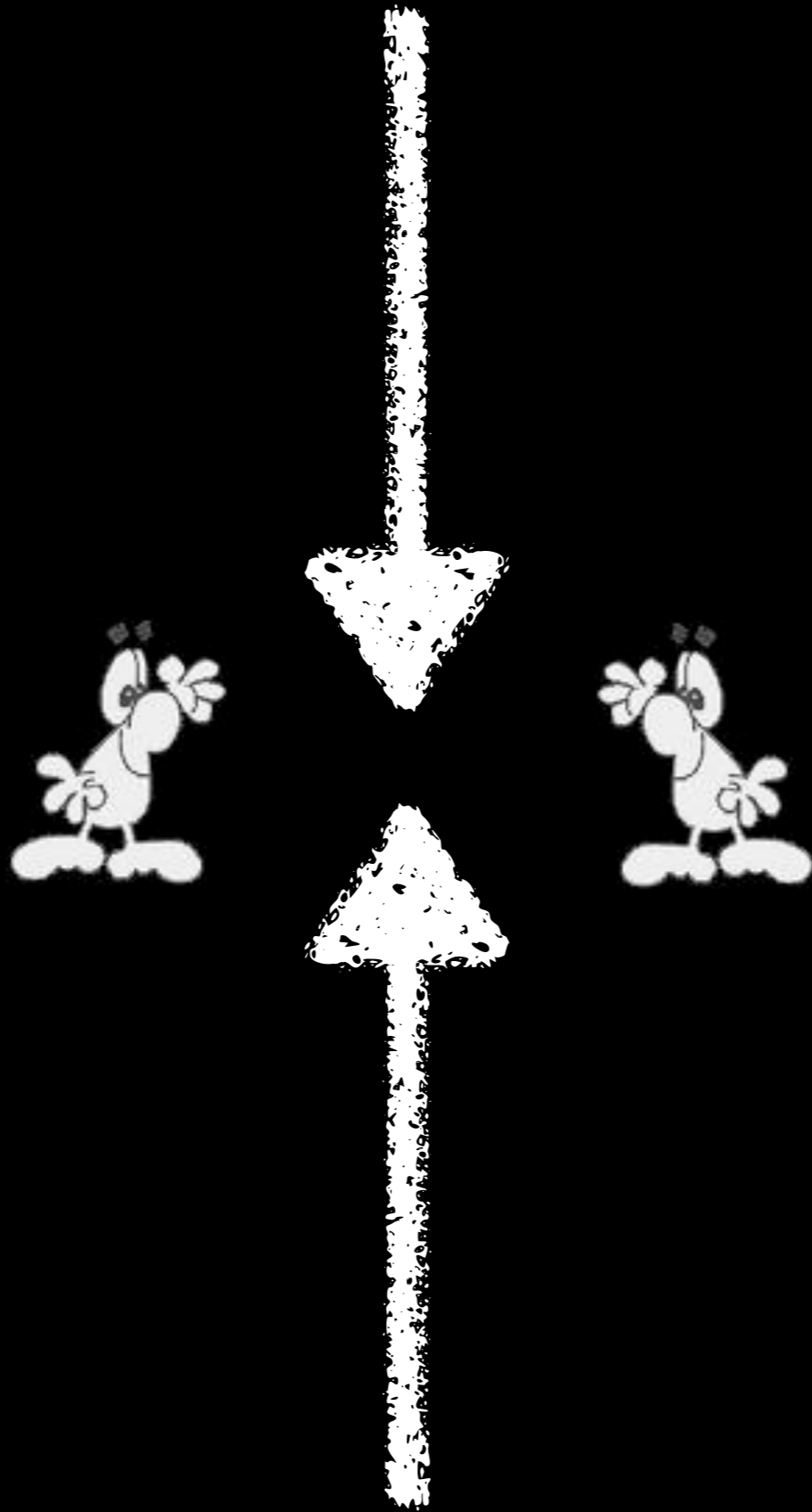


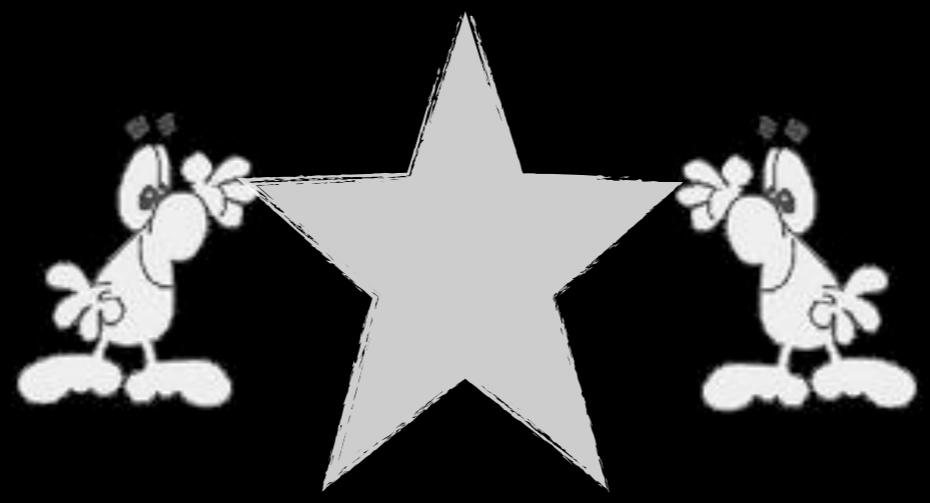
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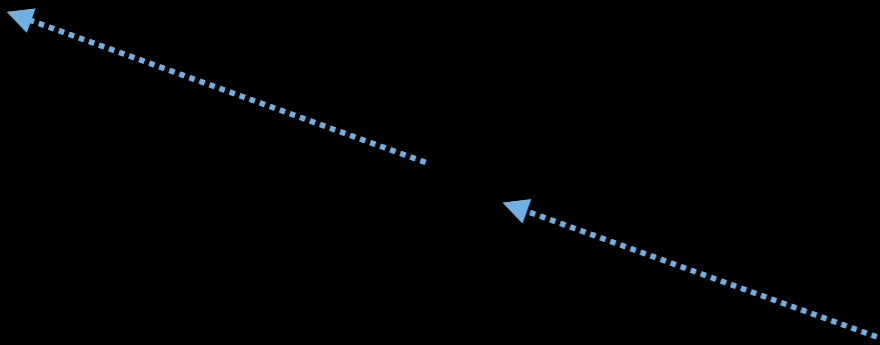
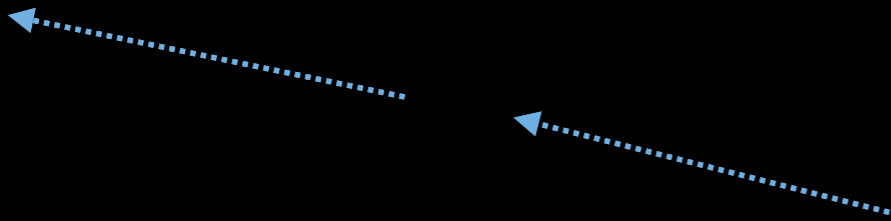
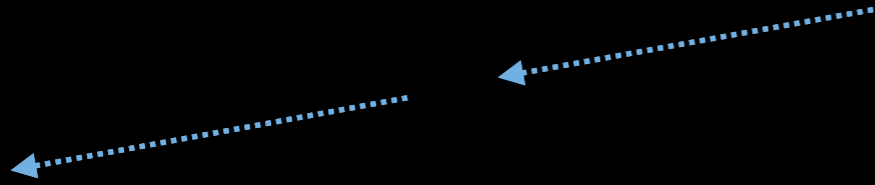
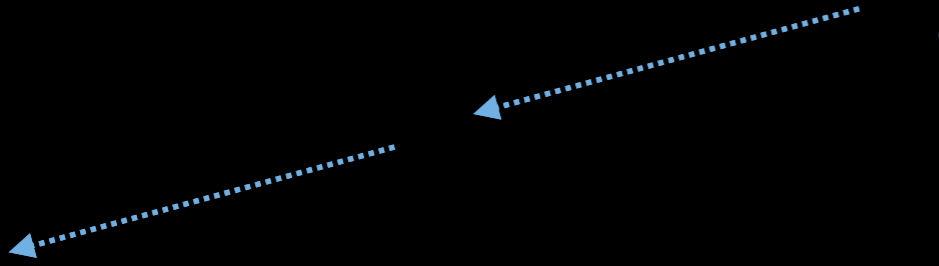
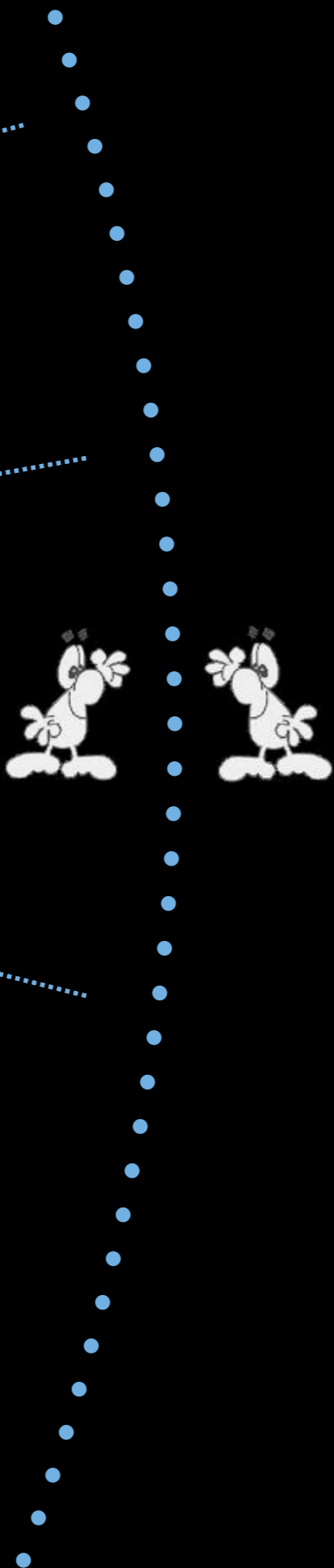
IR

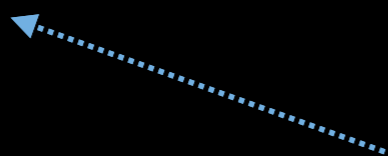
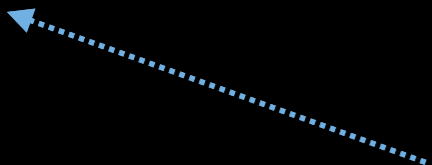
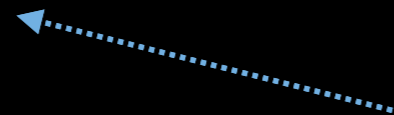
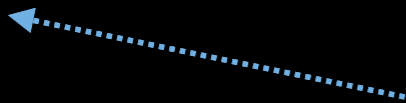
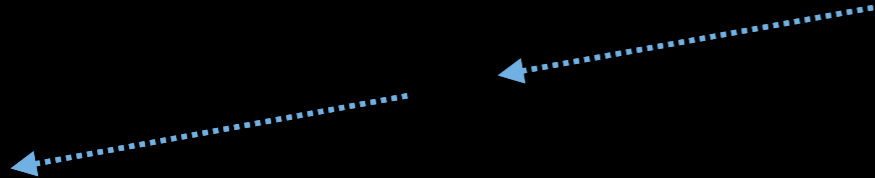
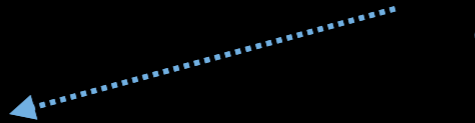
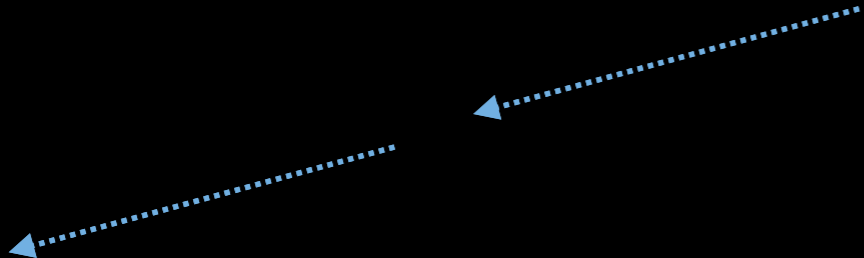








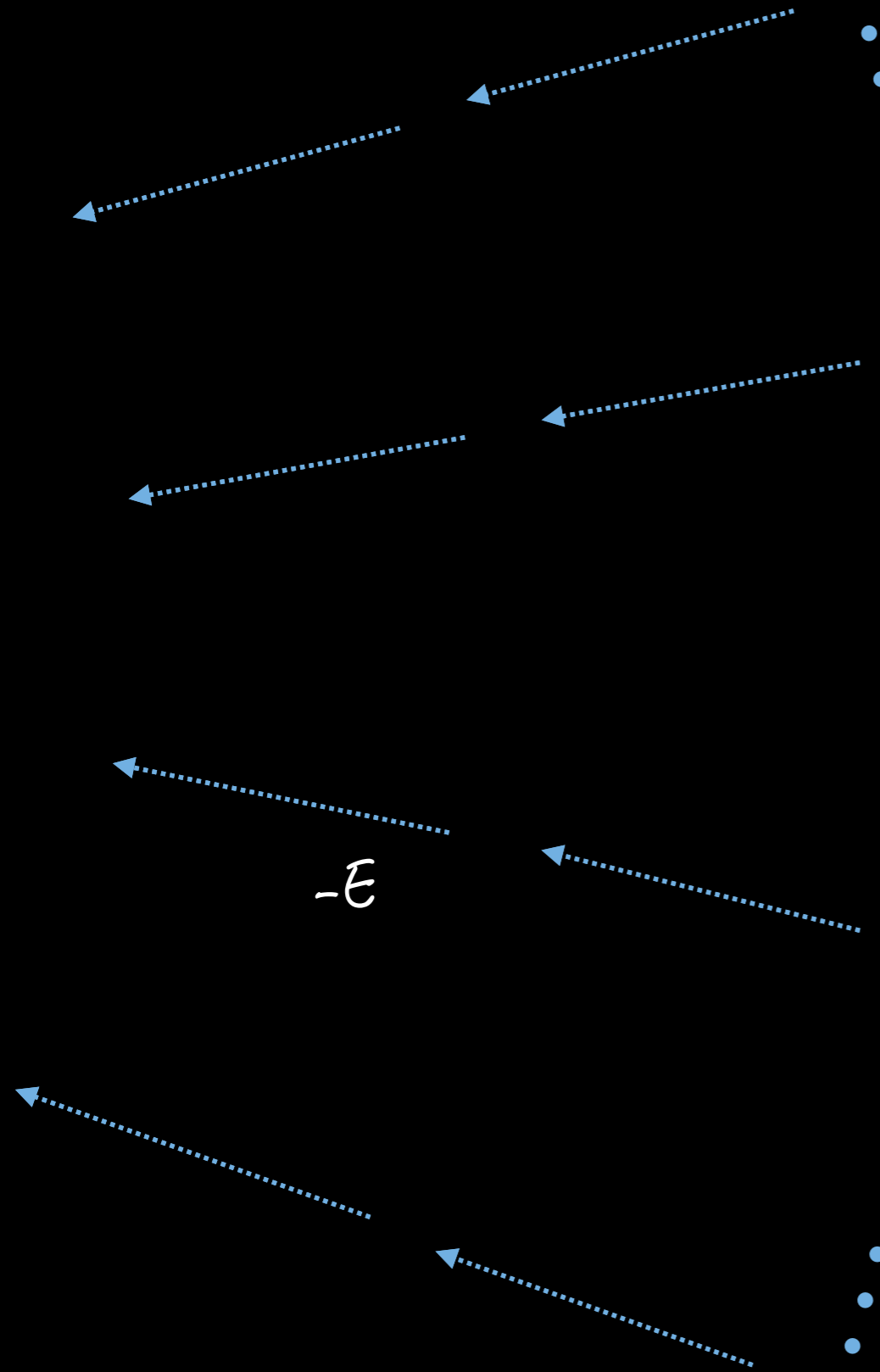






$+E$

$-E$





+E

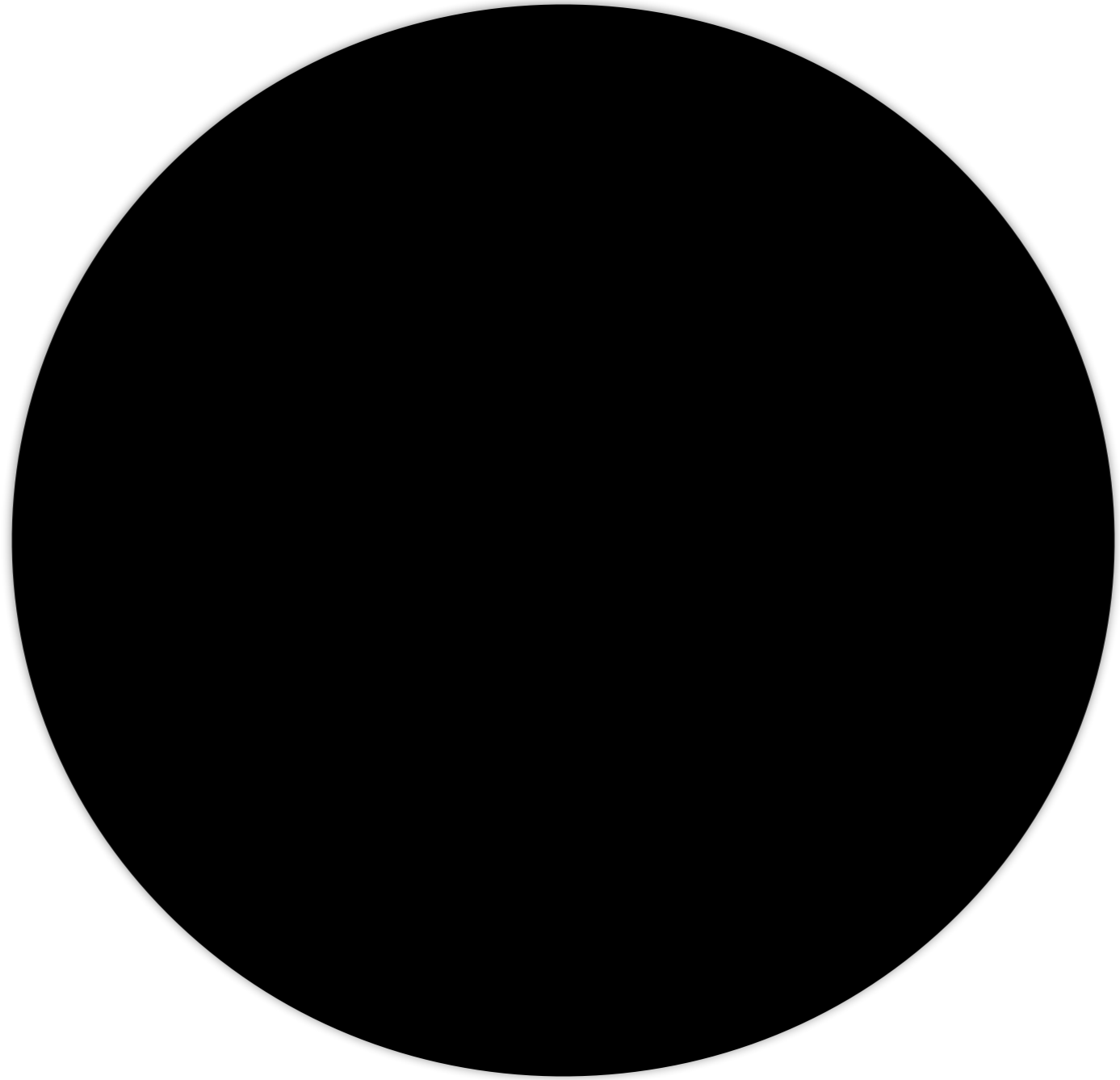


+E

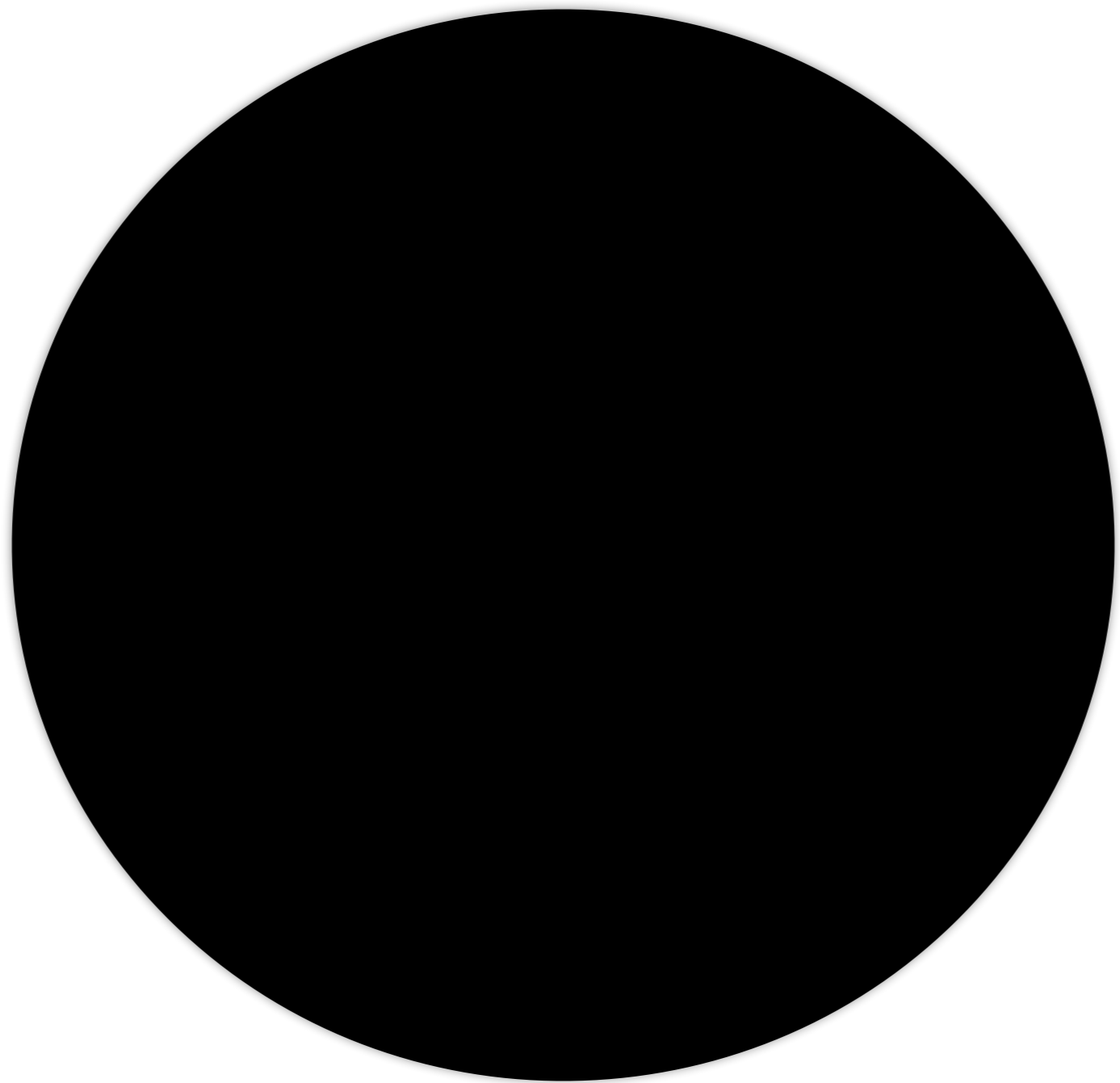
Esto explica la extracción
de energía pero. . .

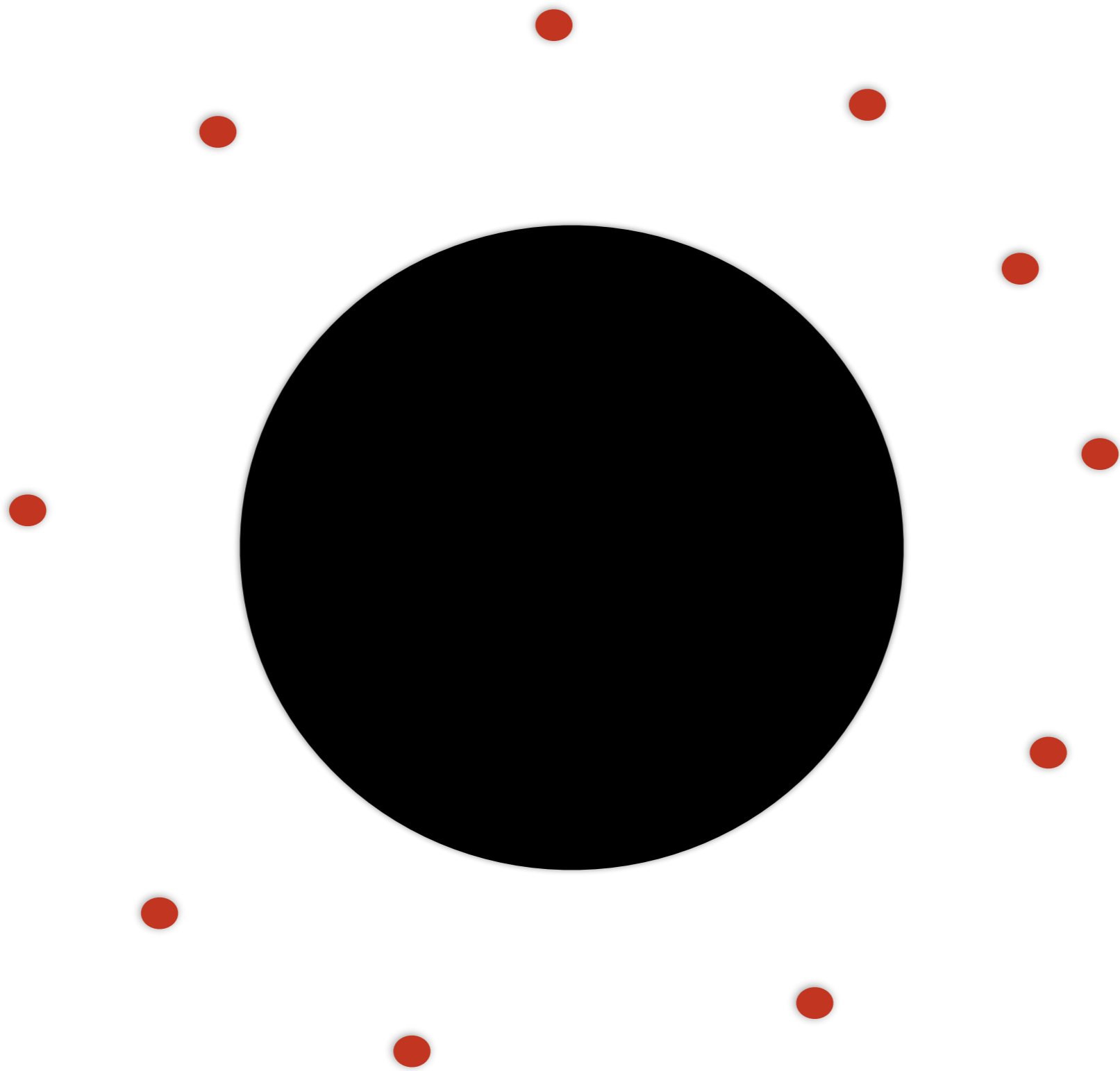
¿Qué pasa
con la
Información?

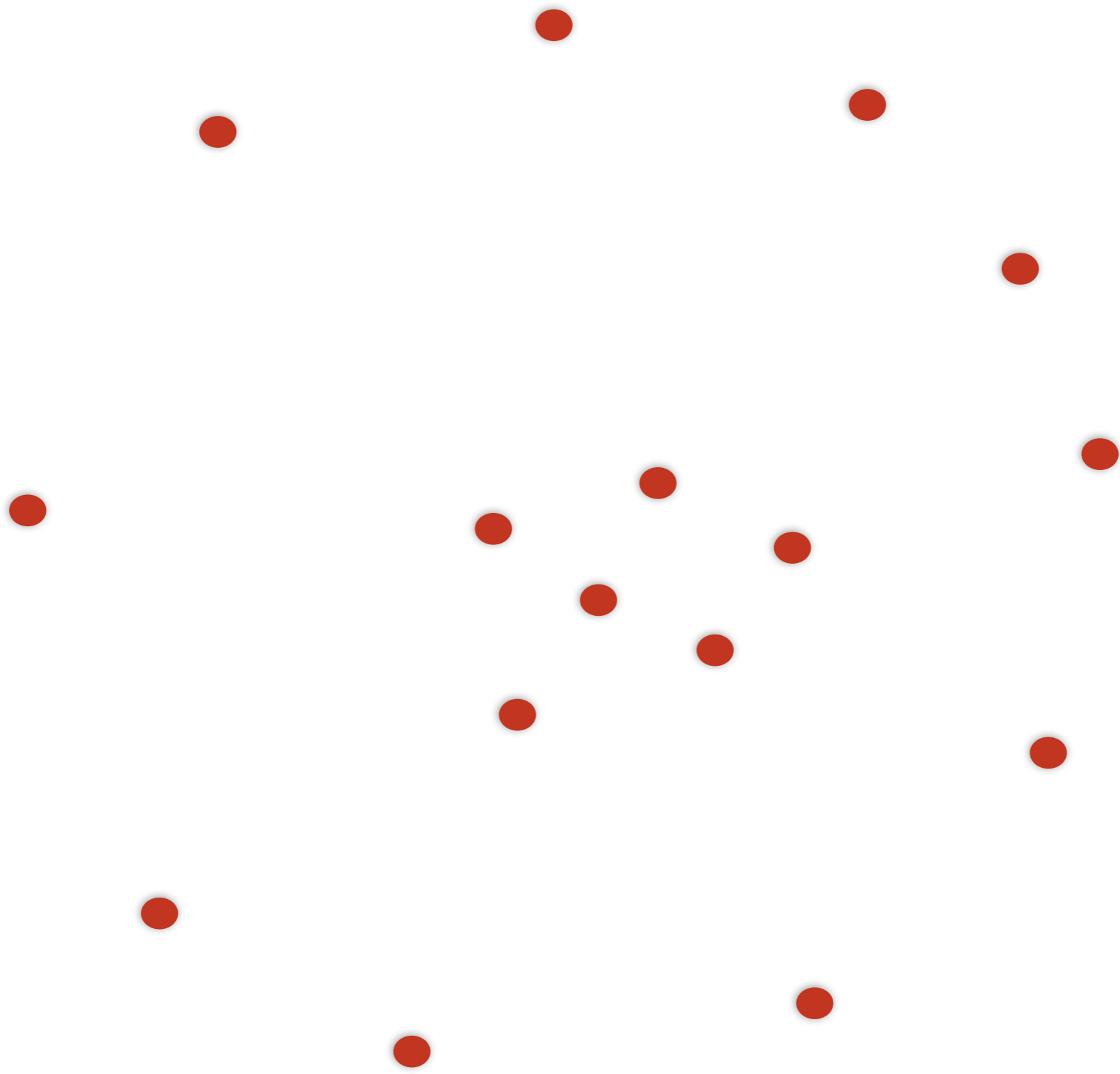












DILEMA:

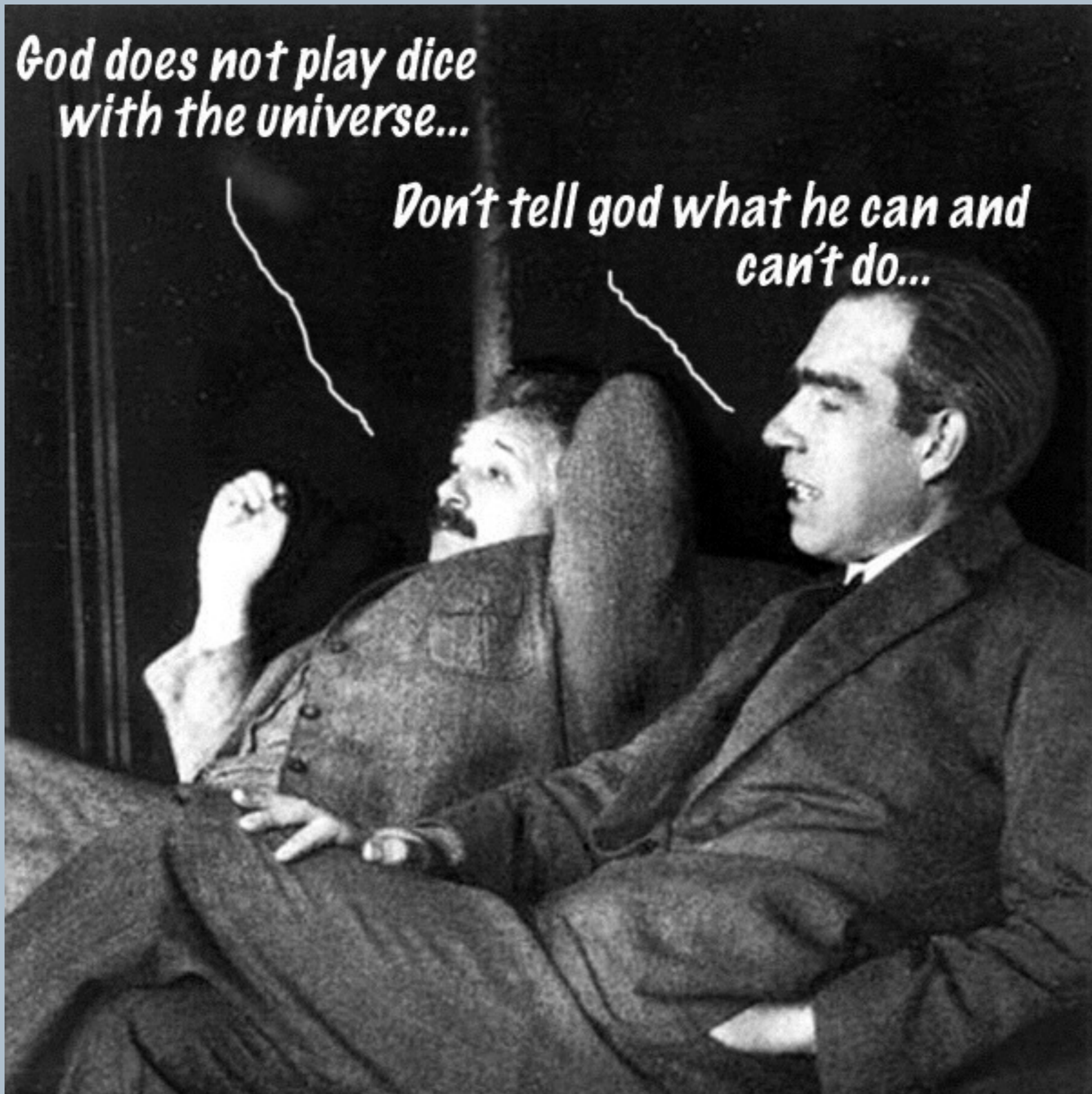
LOCALIDAD DEL ESPACIO-TIEMPO

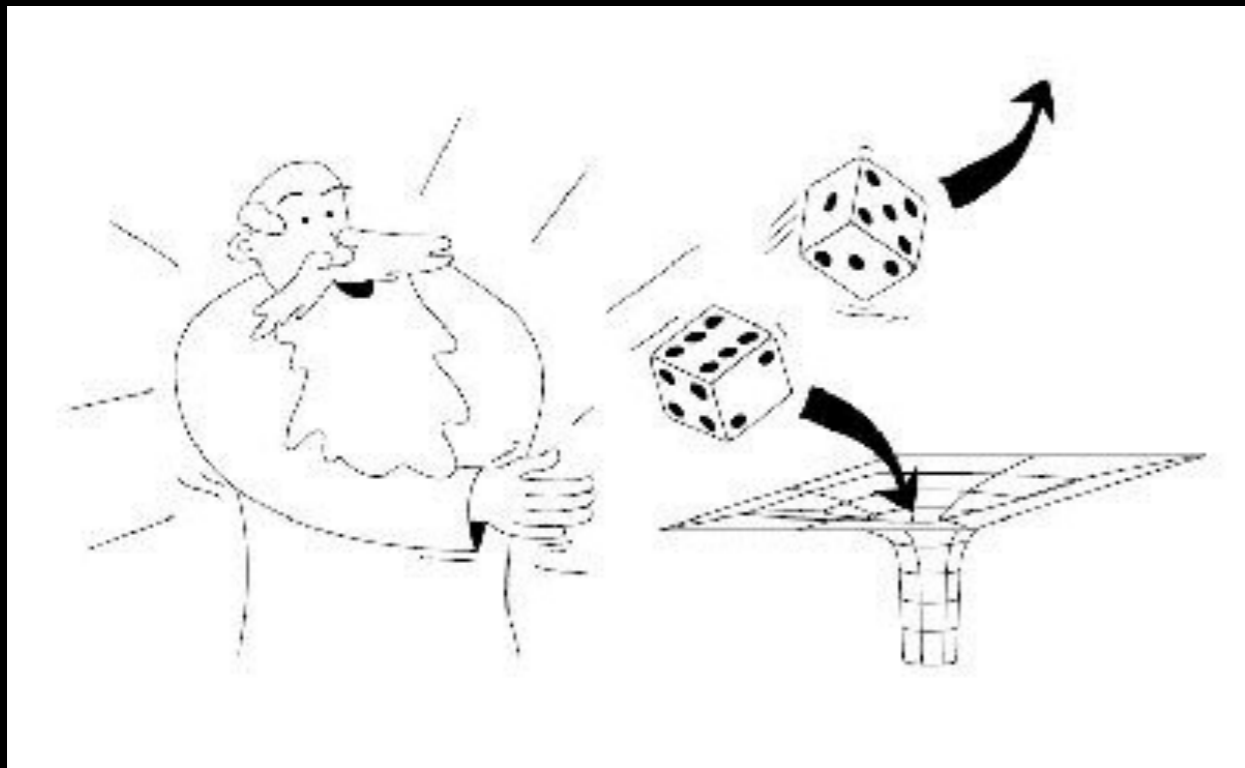
VS

PERMANENCIA DE LA INFORMACION

*God does not play dice
with the universe...*

*Don't tell god what he can and
can't do...*





Not only does God play dice, but... he sometimes
throws them where they cannot be seen.

(Stephen Hawking)

En los años 80, Hawking aventuró apuestas informales con colegas asegurando que la información se destruye en ANs



How Predictable is Quantum Gravity?

Don Page bets Stephen Hawking one pound Sterling that strong quantum cosmic censorship holds, namely, that a pure initial state composed entirely of regular field configurations on complete, asymptotically flat hypersurfaces will have a unique S-matrix evolution under the laws of physics to a pure final state composed entirely of regular field configurations on complete, asymptotically flat hypersurfaces.

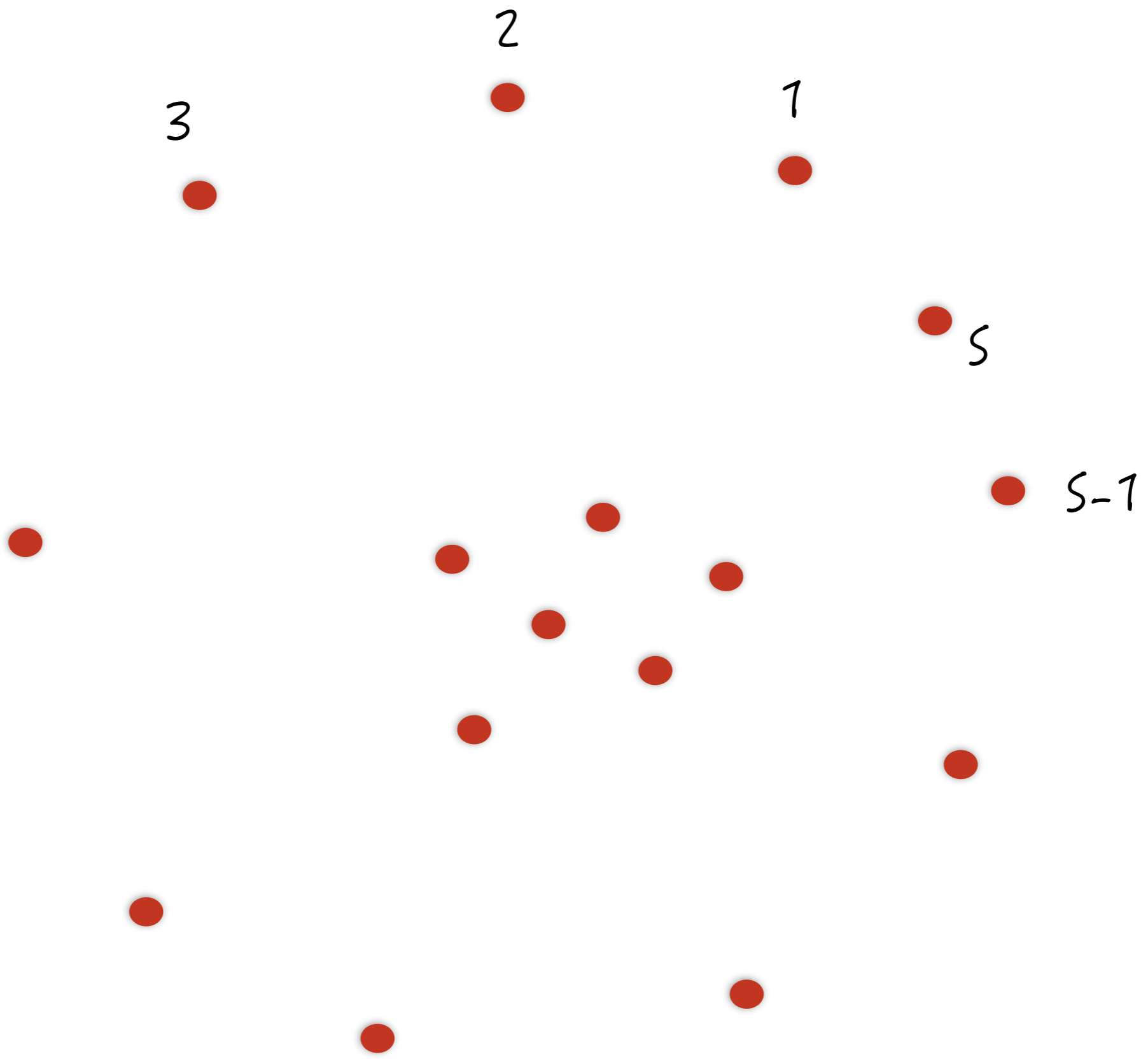
Stephen Hawking bets Don Page \$1.00 that in quantum gravity the evolution of such a pure initial state can be given in general only by a \mathcal{H} -matrix to a mixed final state and not always by an S-matrix to a pure final state.

"I concede in light of the weariness of the \$"
Don N. Page
Stephen Hawking

Stephen Hawking, 23 April 2007

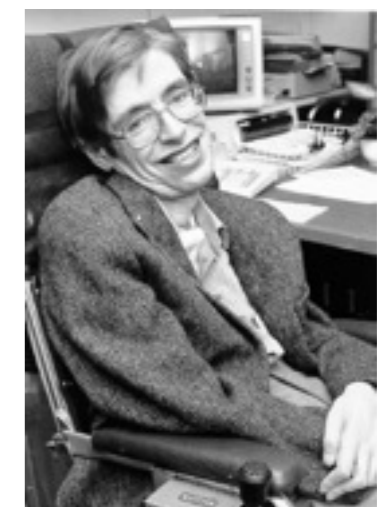
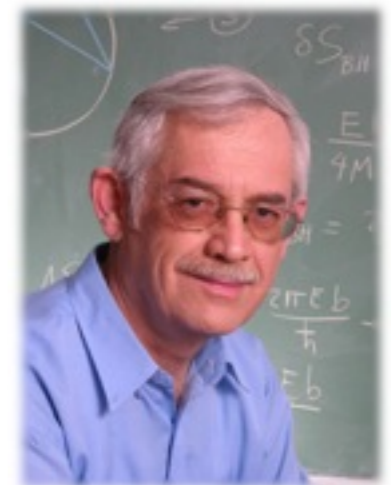
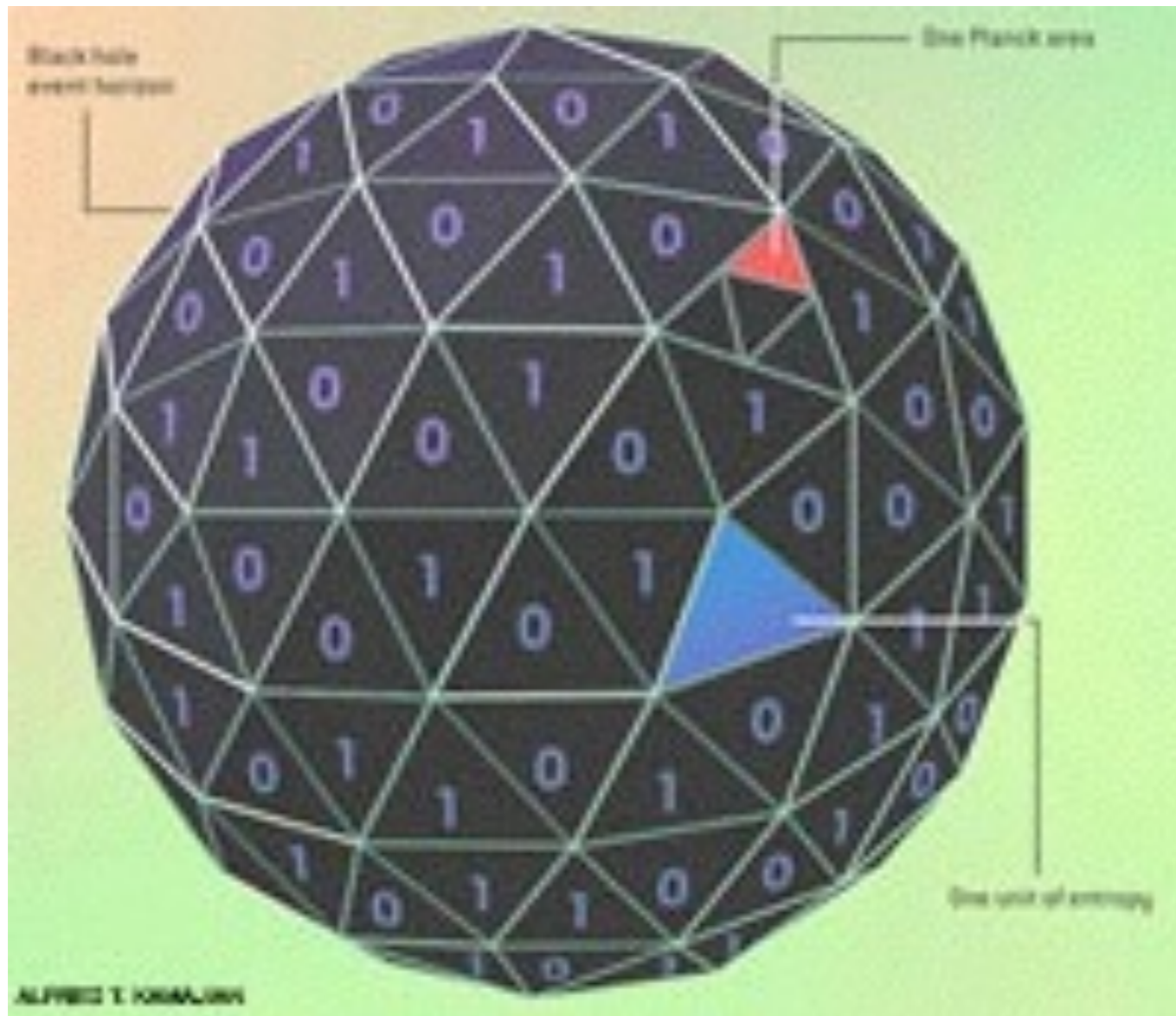
¿Cuál es el precio de mantener

la FE en la Mecánica Cuántica?

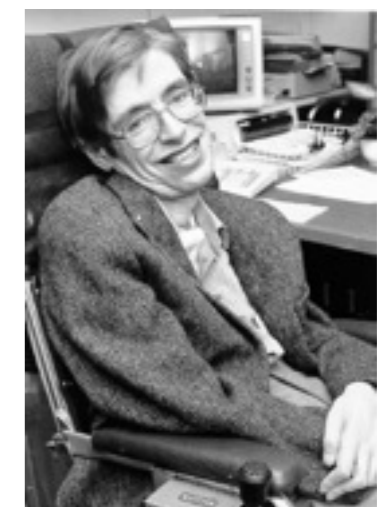
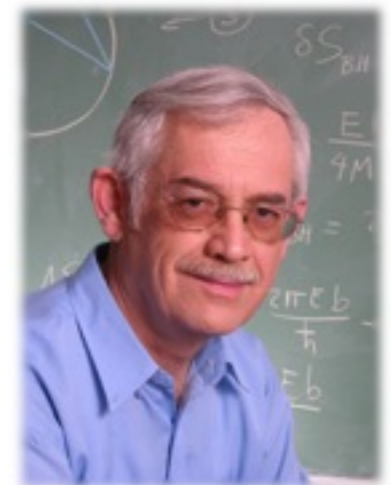
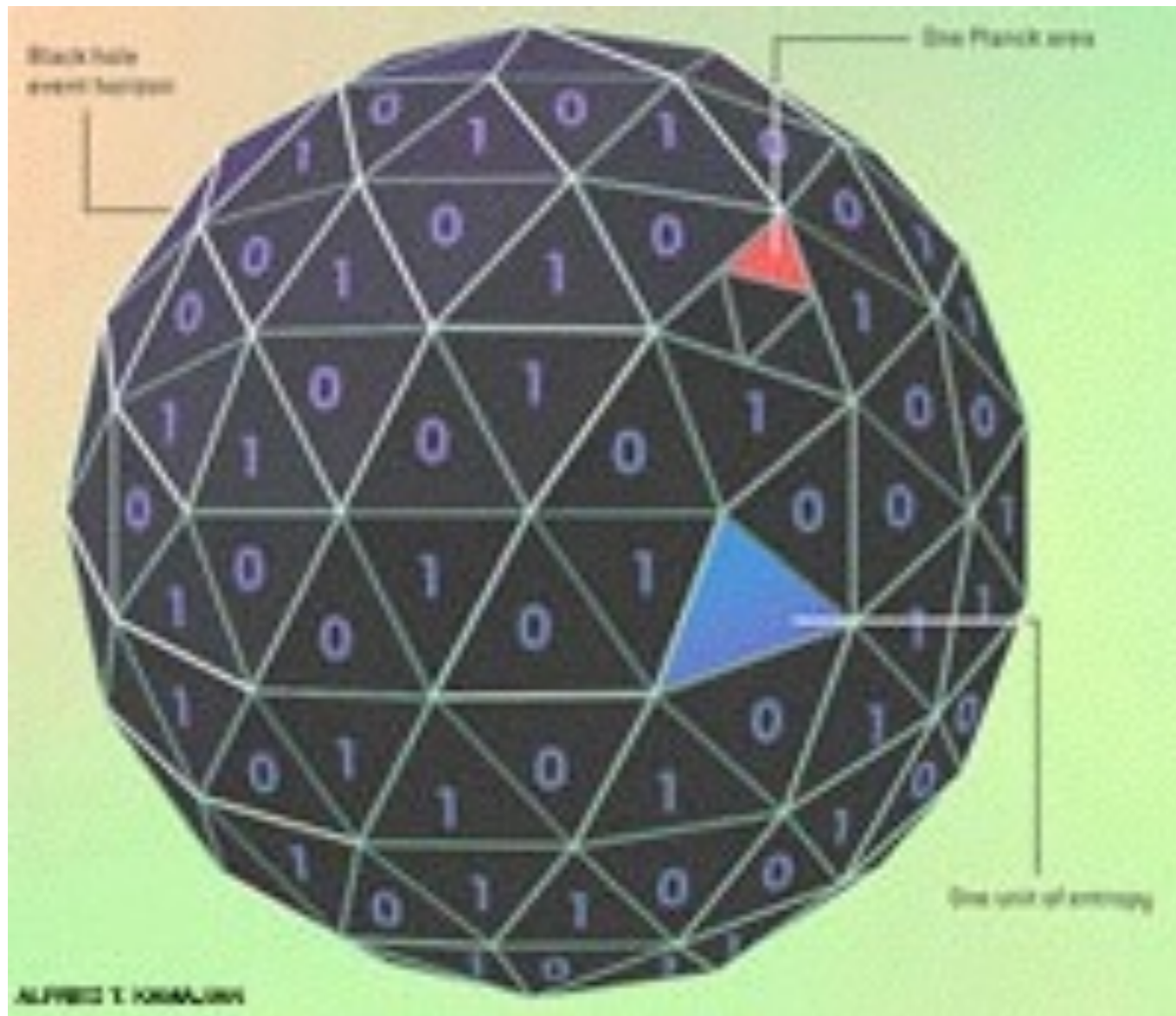


$$S \sim \text{Entropia} \sim \frac{\text{Area horizonte}}{G}$$

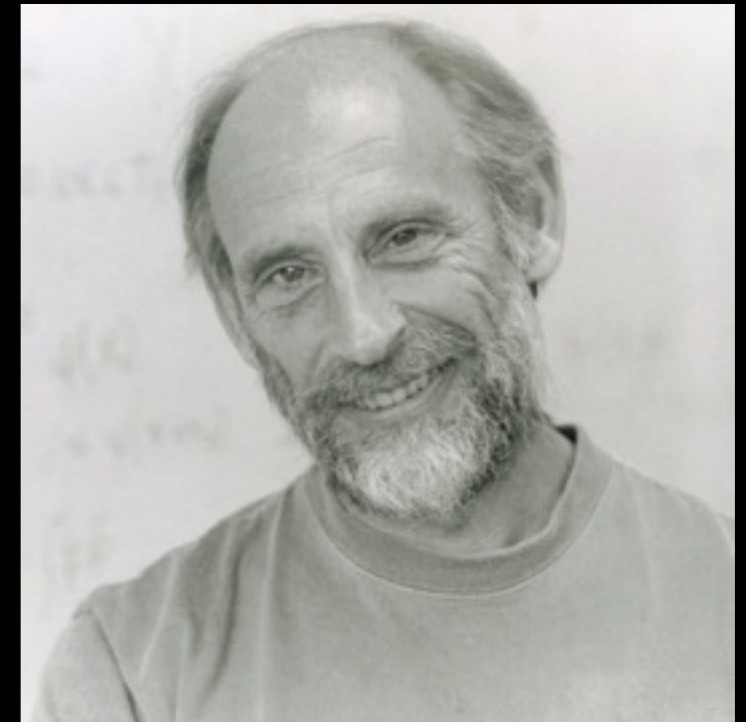
$$S \sim \text{Entropia} \sim \frac{\text{Area horizonte}}{G}$$



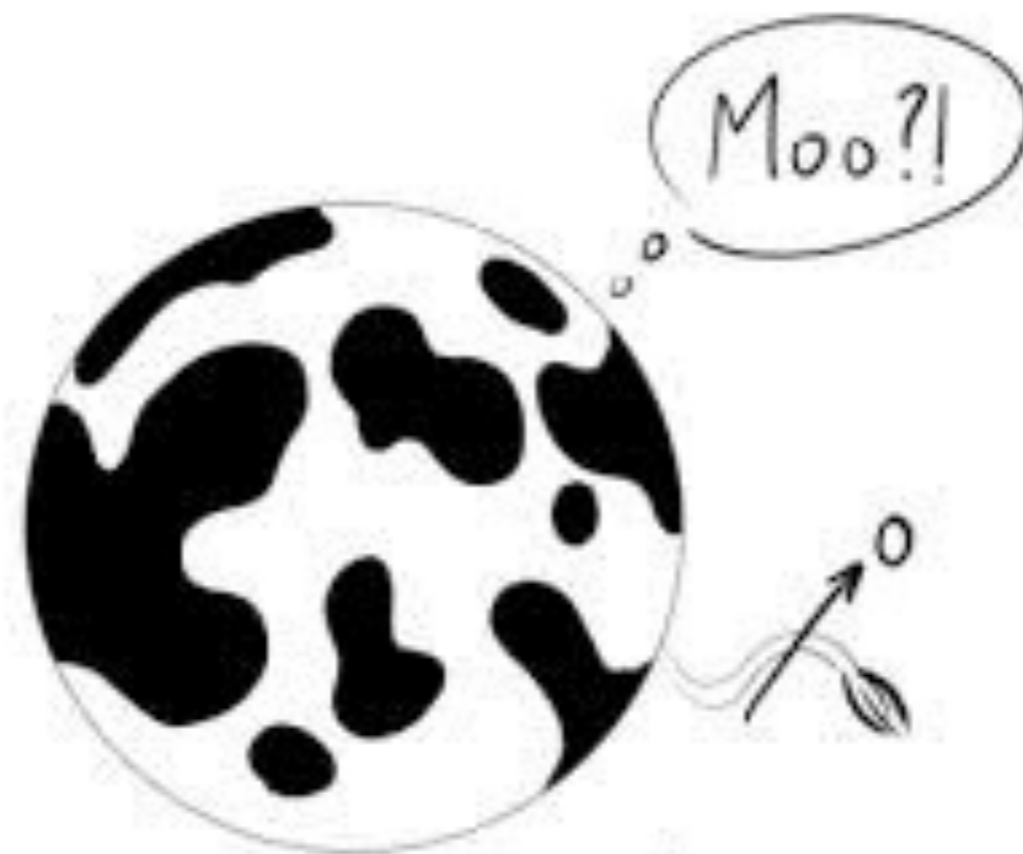
$$S \sim \text{Entropia} = \frac{\text{Area horizonte}}{4 G}$$



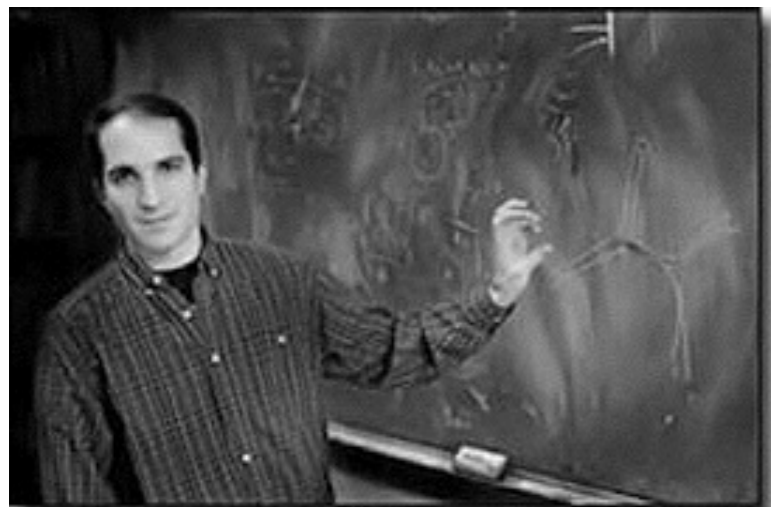
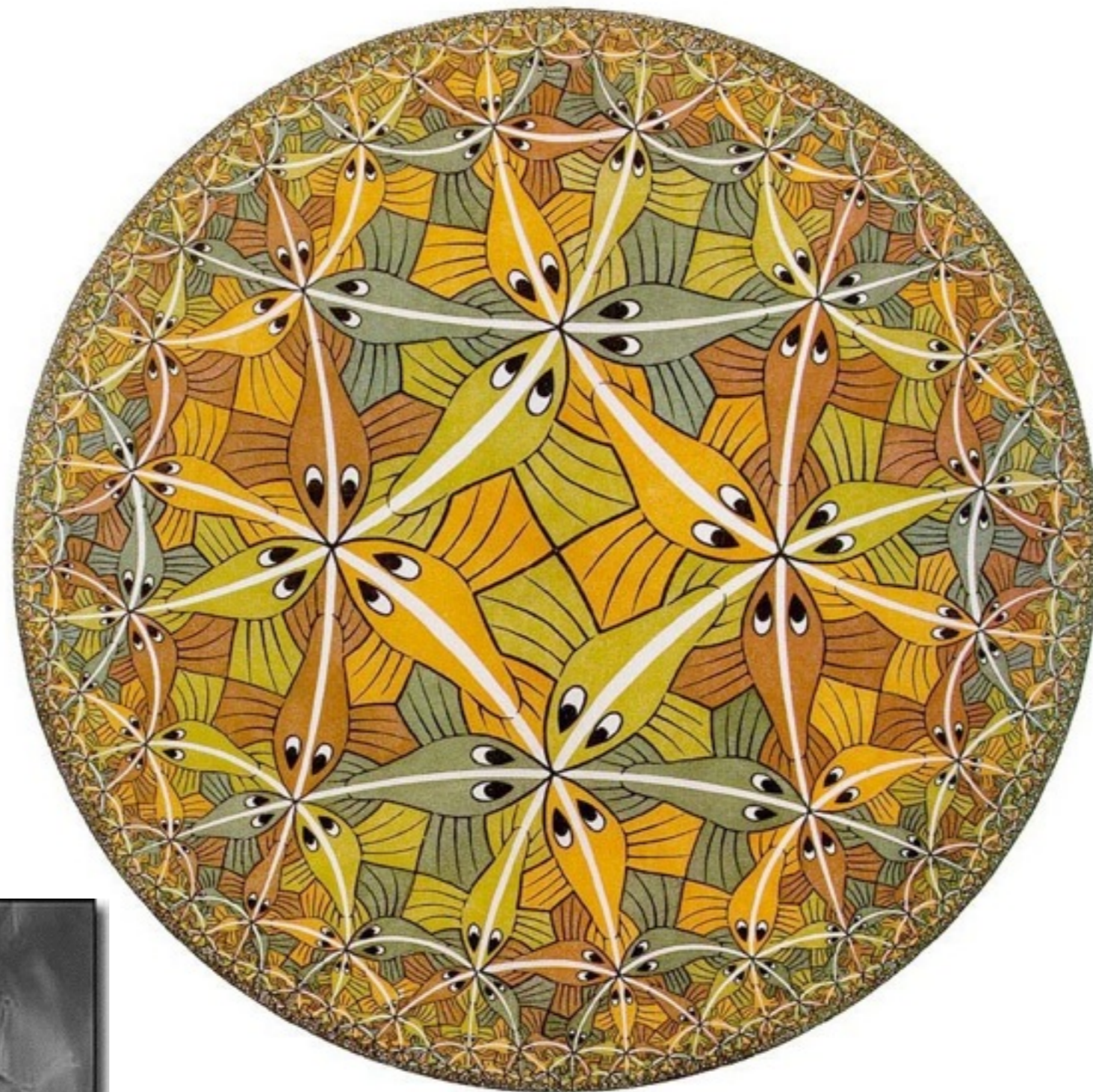
...si el interior fuera emergente?

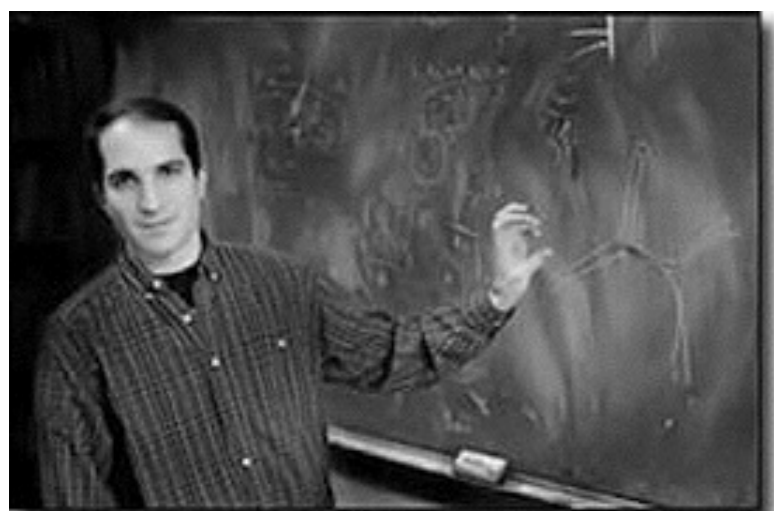
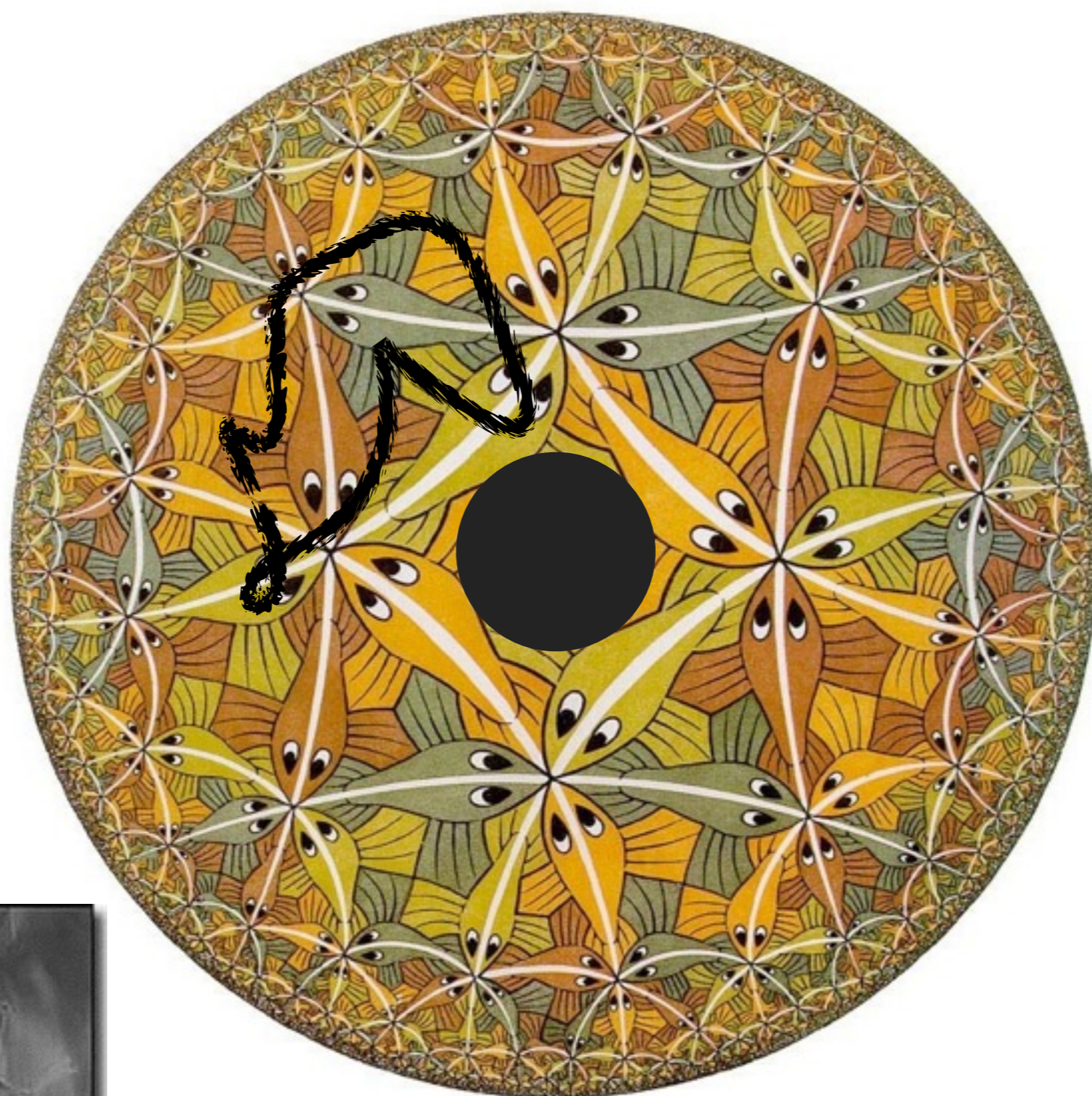


EL PRINCIPIO HOLOGRAFICO



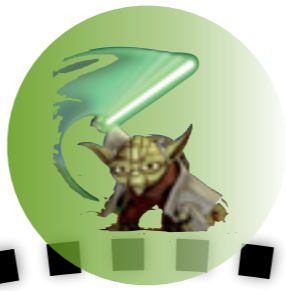
Consider a spherical cow
of radius R ... □



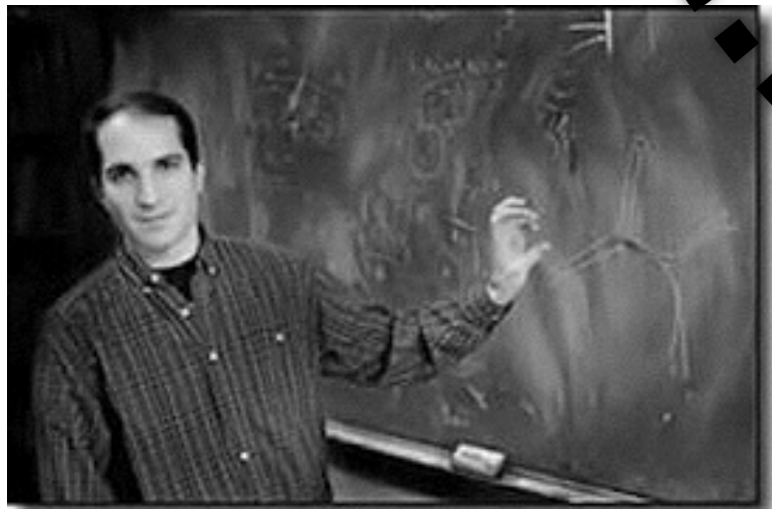
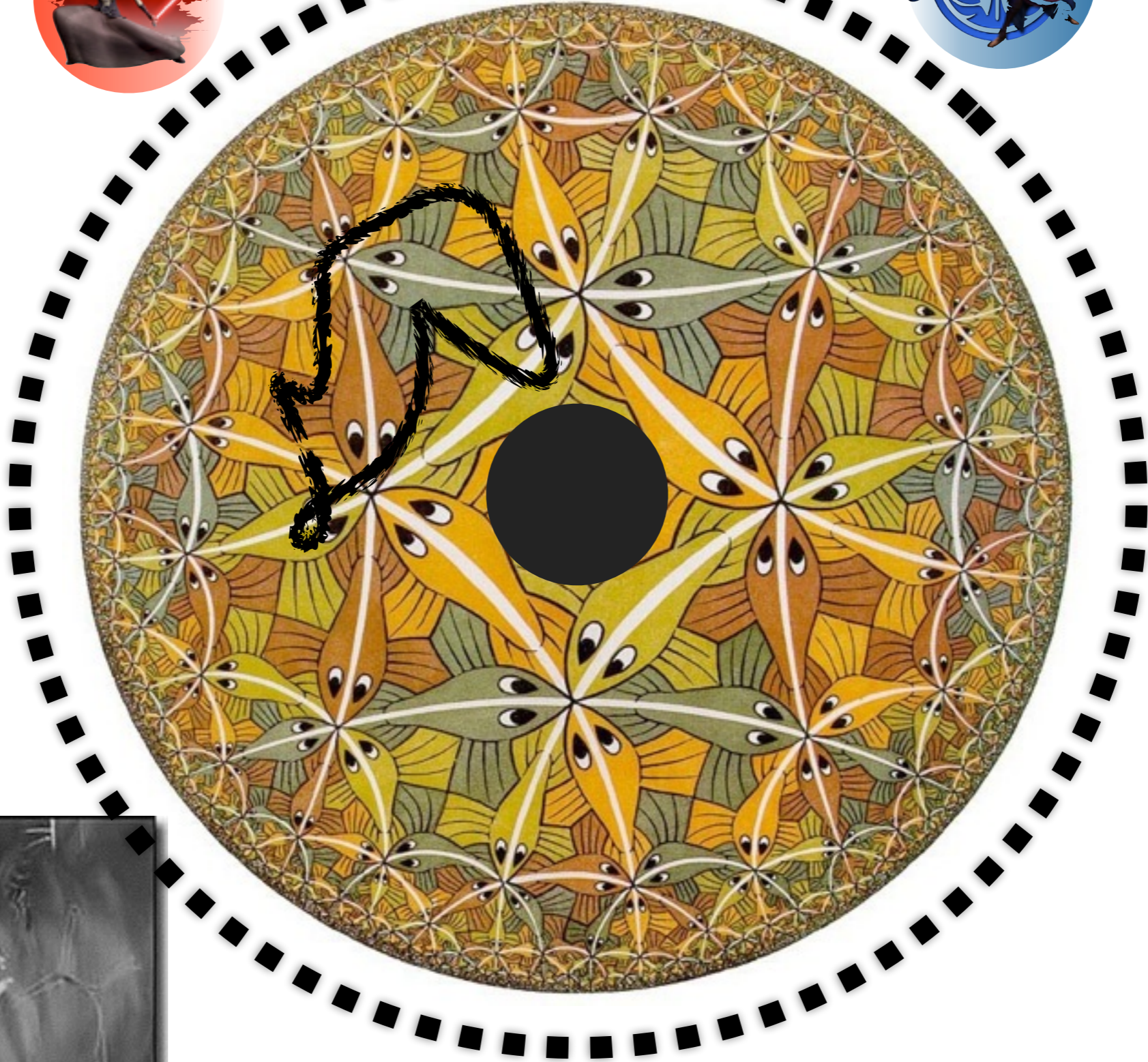


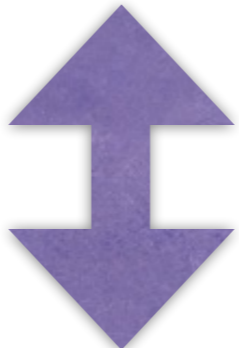


quarks



gluones



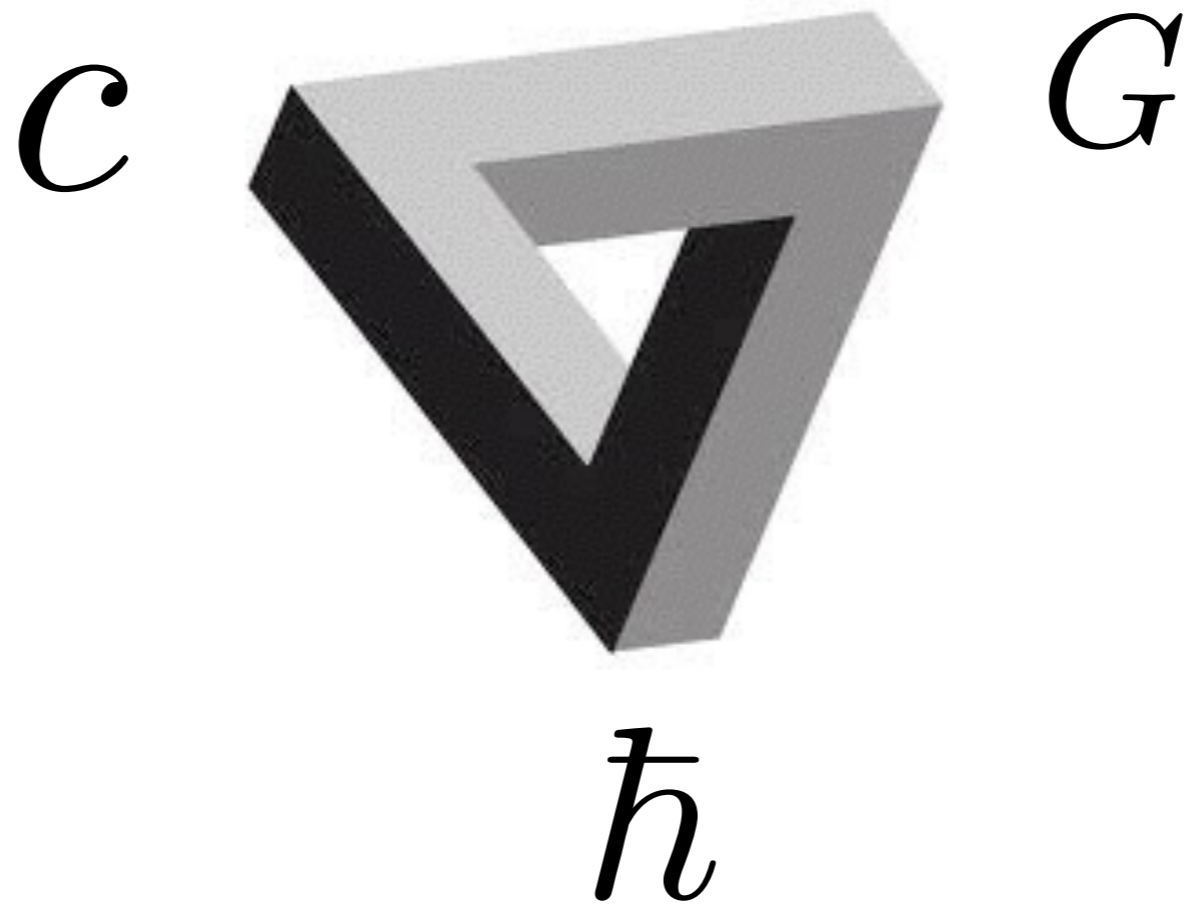


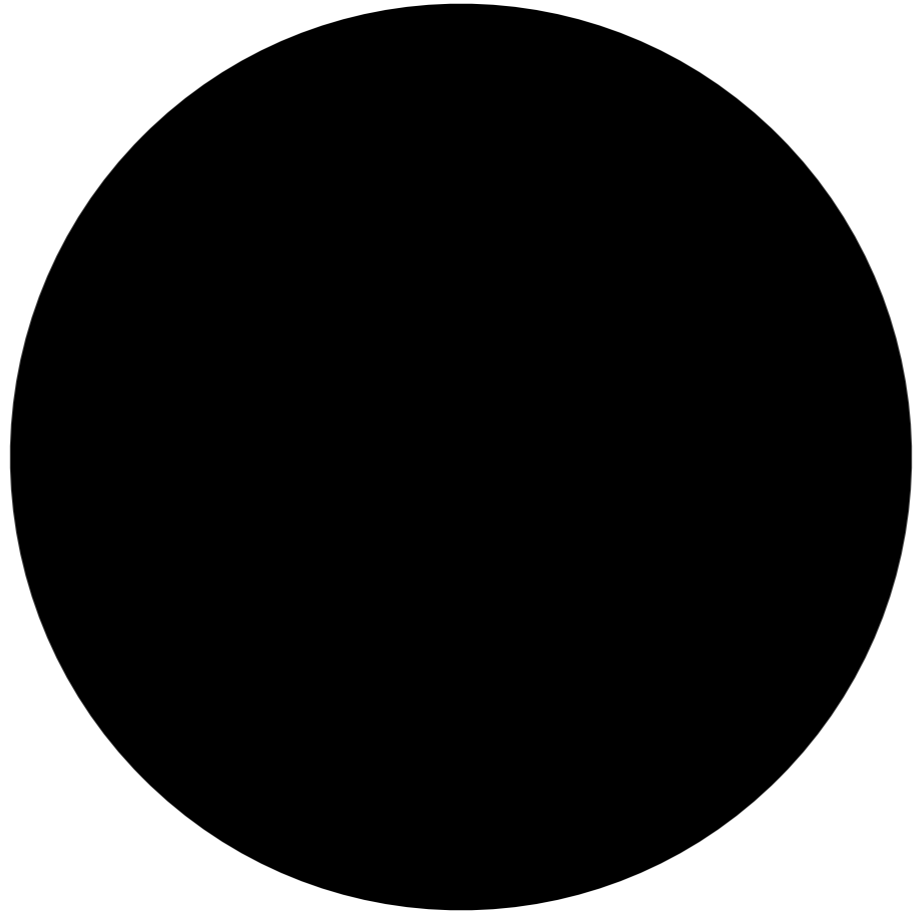
EPILOGO:

... tras los resultados de Maldacena...
Hawking finalmente concedió en 2004



¿Existe un holograma
para la energía oscura?







GRACIAS

