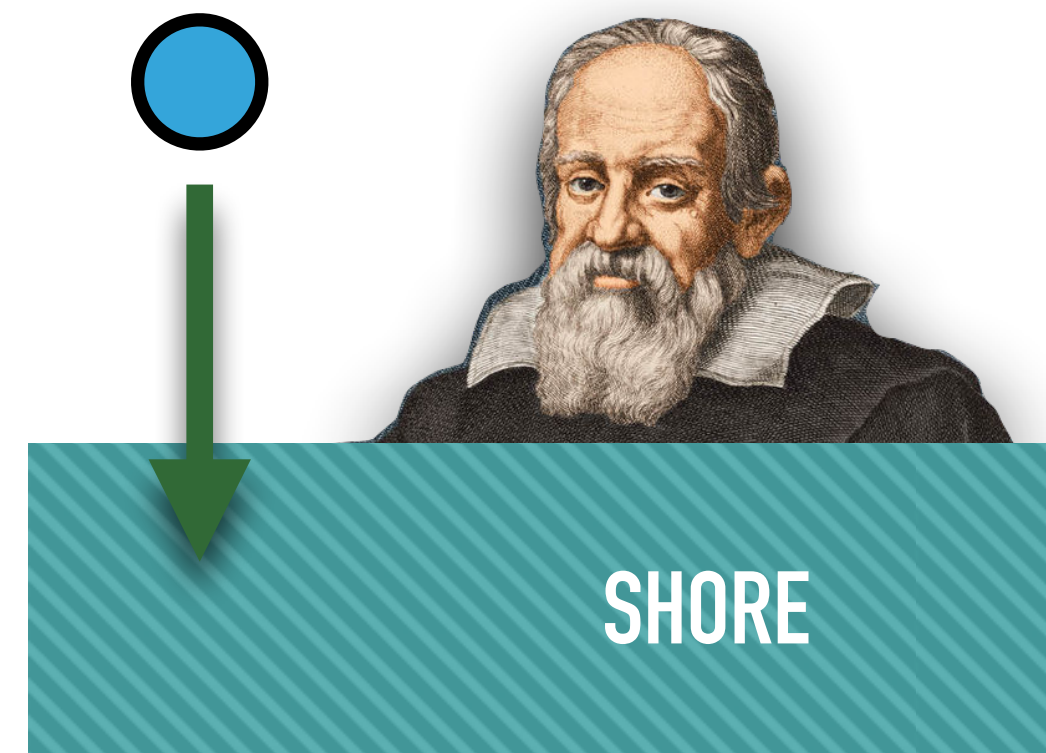
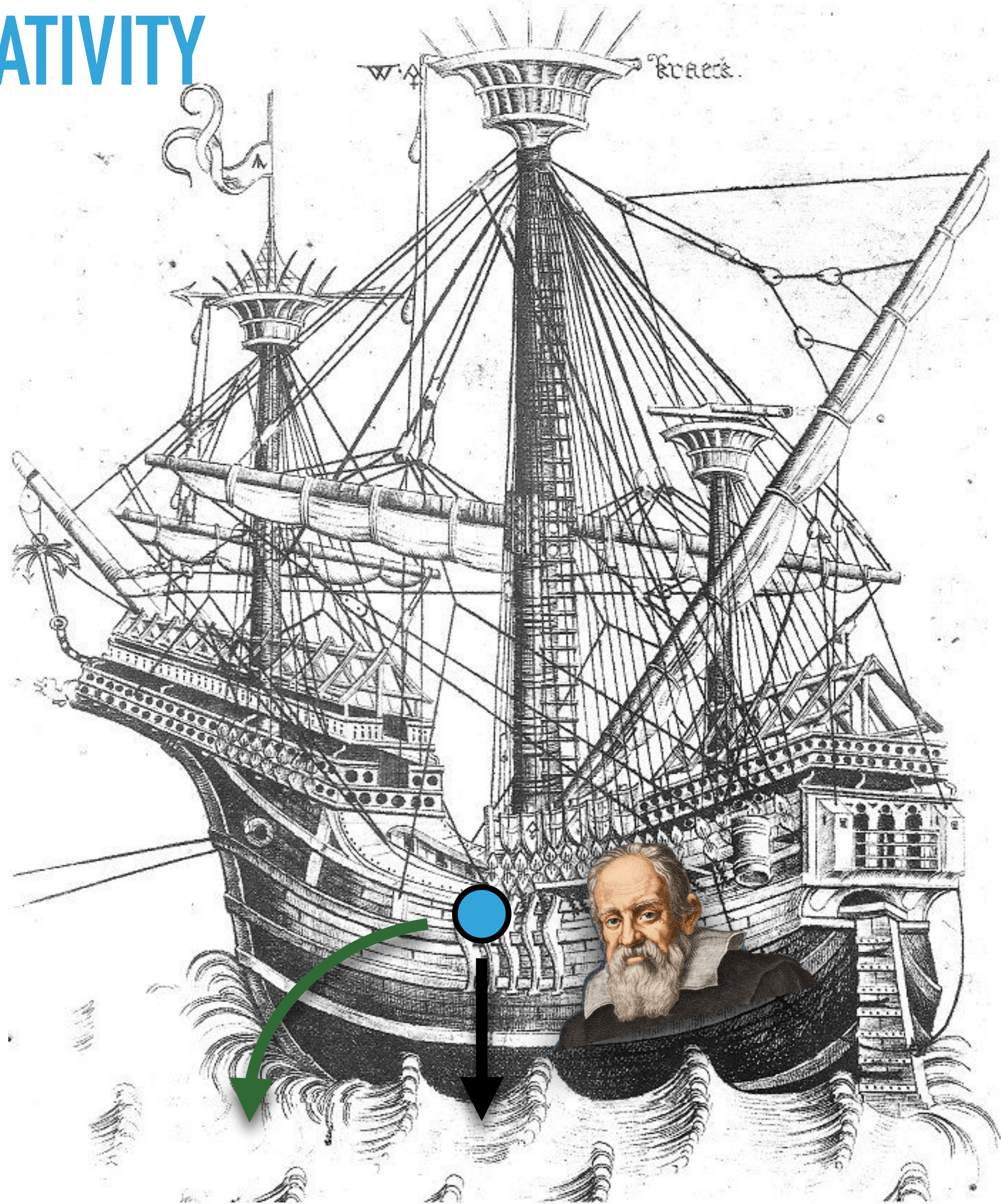


RELATIVITY

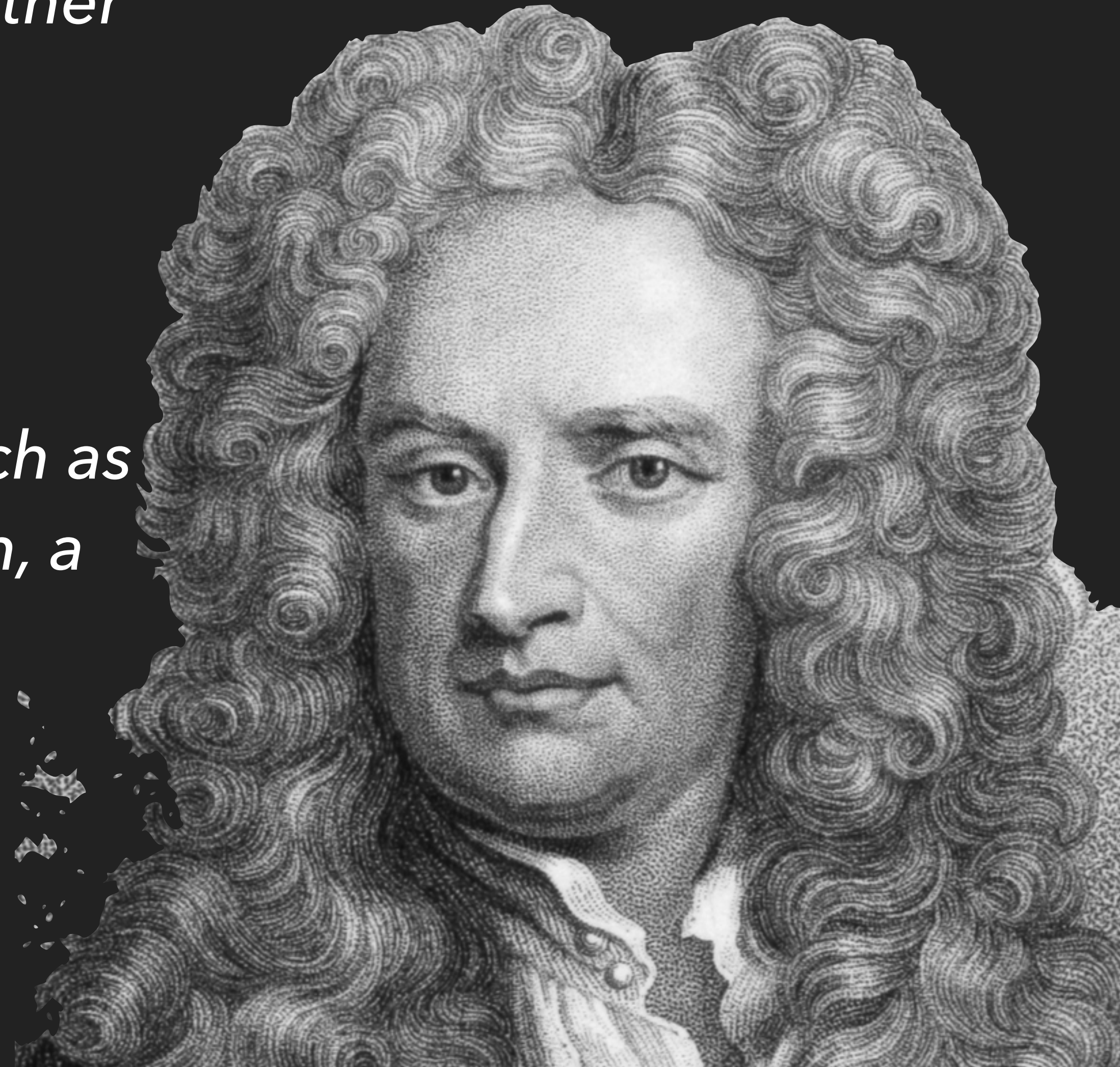
GALILEAN RELATIVITY



SHORE

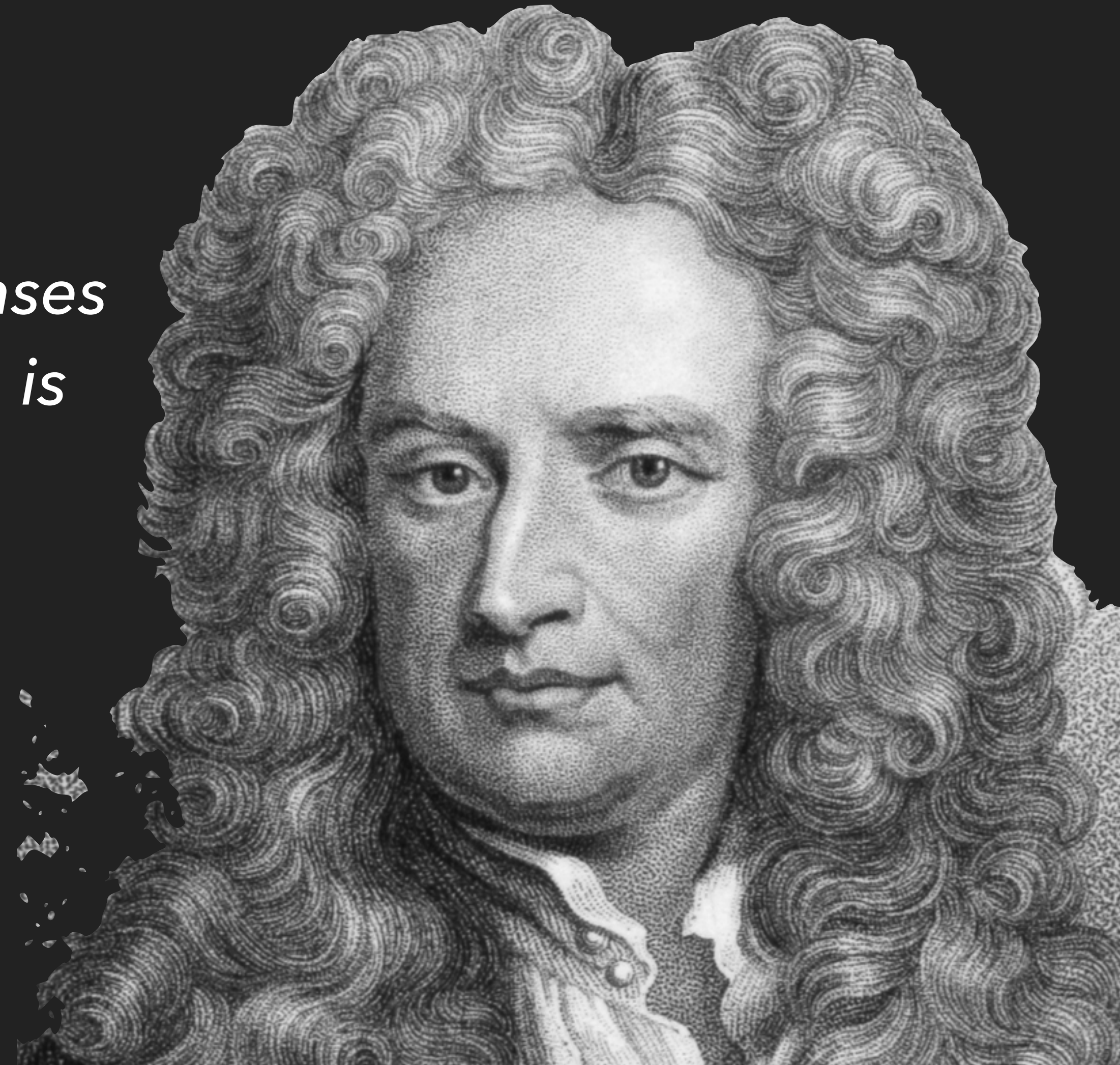
*“**Absolute, true, and mathematical time**, in and of itself and of its own nature, without reference to anything external, **flows uniformly** and by another name is called duration.*

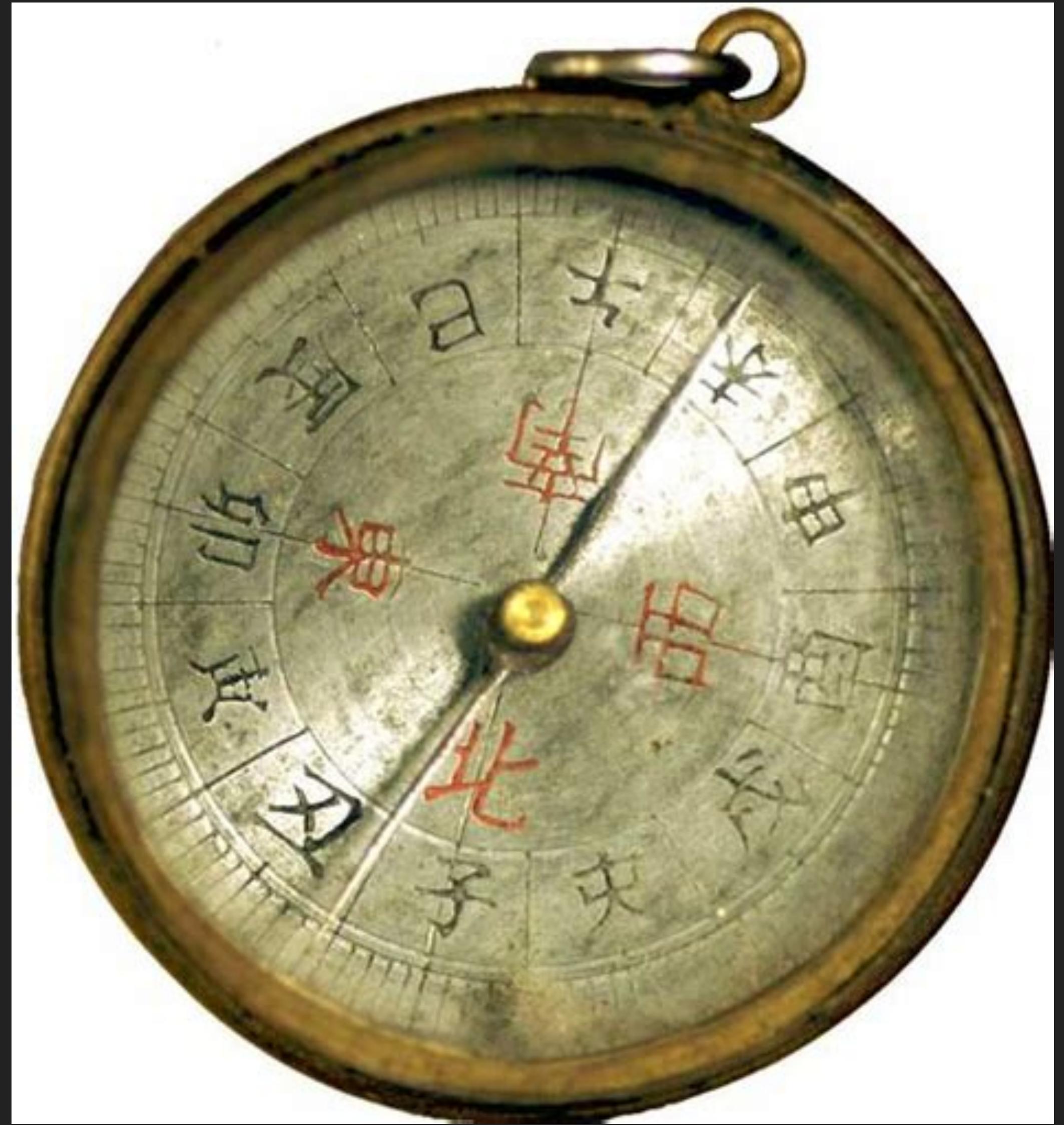
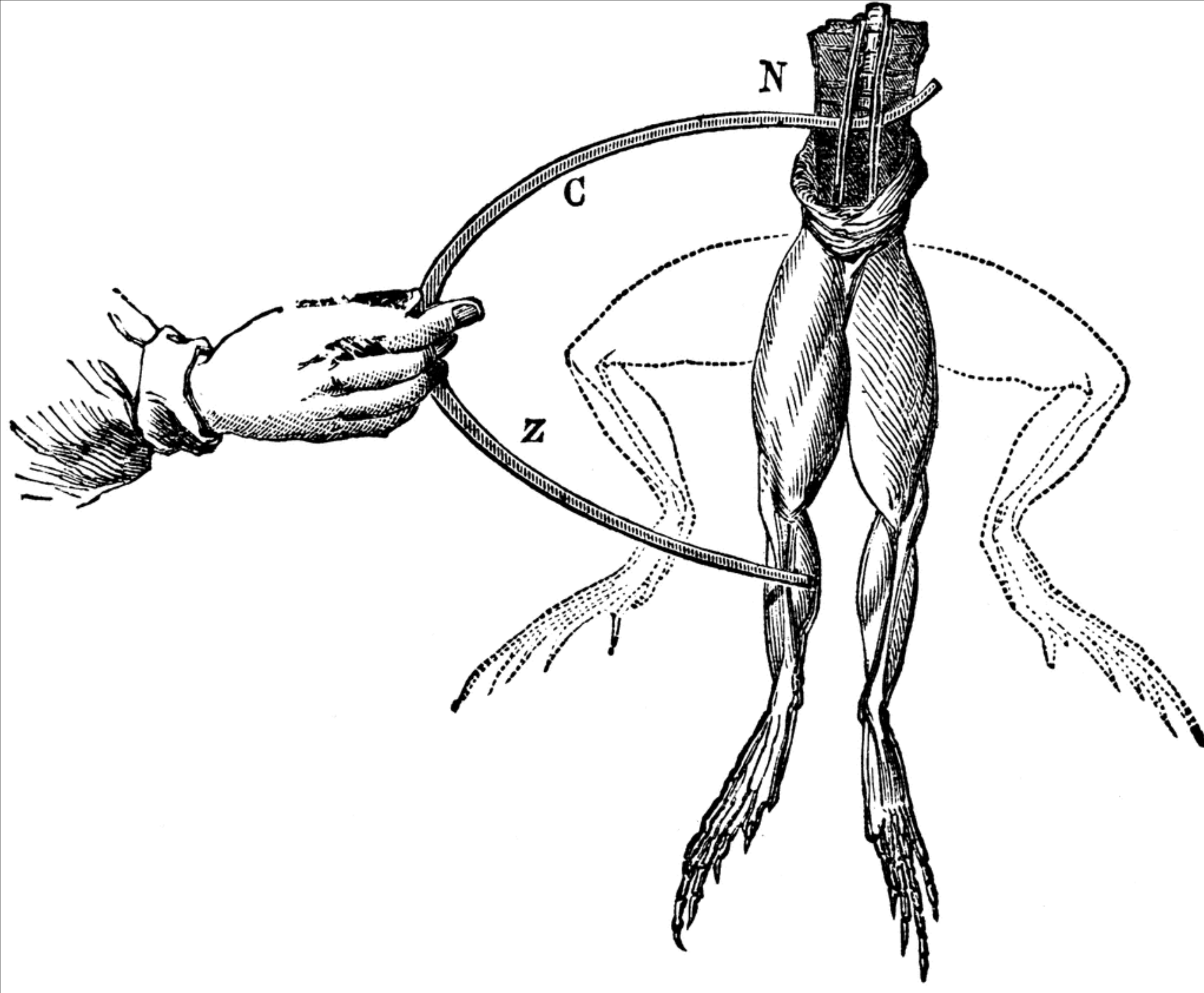
Relative, apparent, and common time is any sensible and external measure (precise or imprecise) of duration by means of motion; such as a measure—for example, an hour, a day, a month, a year—is commonly used instead of true time.”



“Absolute space, in its own nature, without regard to anything external, remains always similar and immovable.

Relative space is some movable dimension or measure of the absolute spaces, which our senses determine by its position to bodies, and which is vulgarly taken for immovable space.”





Electromagnetism is fundamental but also weird and subtle, and it took people a long time to figure it out

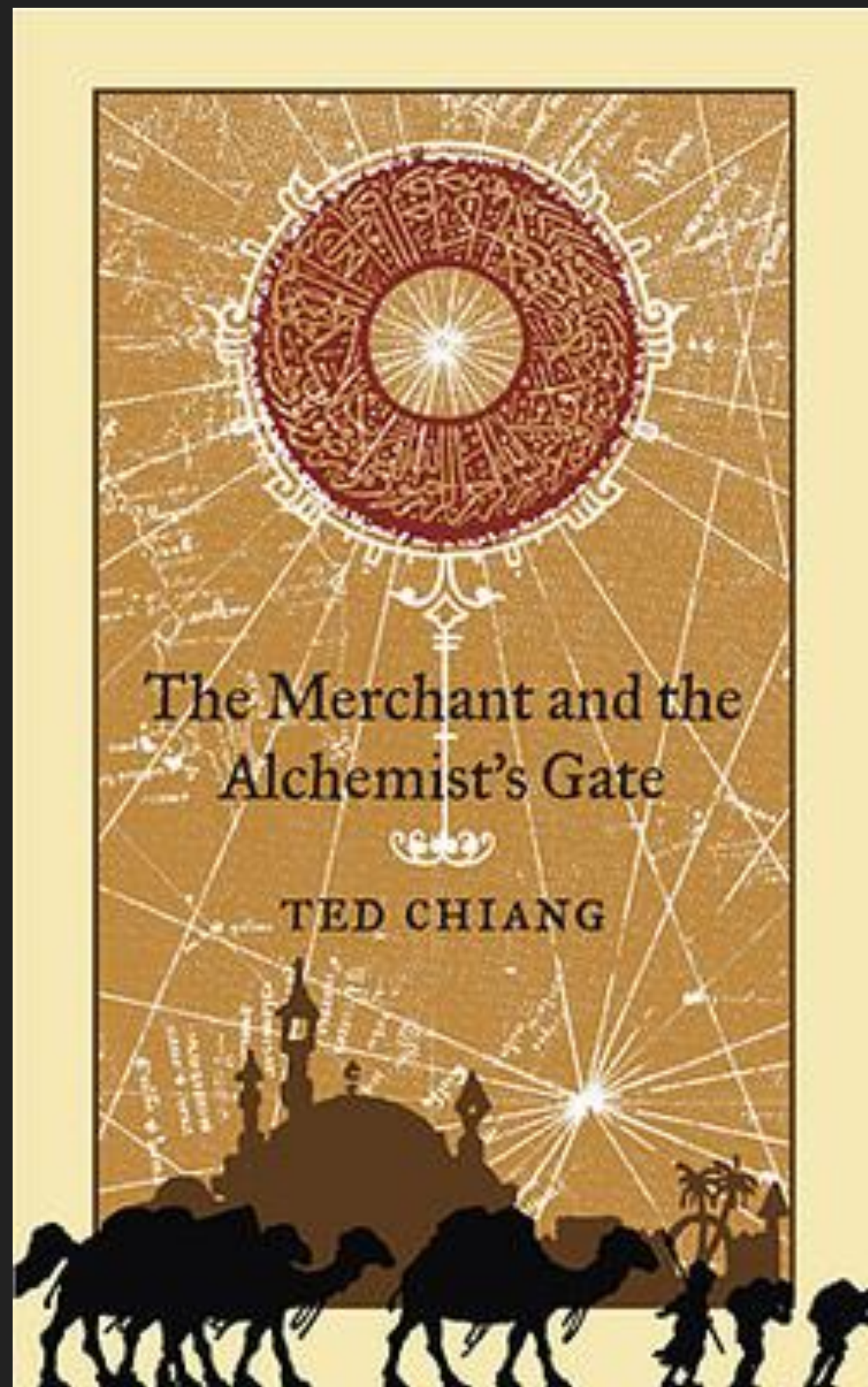
Two random examples over 3000 years

Maxwell's Equations

$$\nabla \cdot \mathbf{B} = 0 \quad \nabla \cdot \mathbf{D} = \rho$$

$$\nabla \times \mathbf{E} = - \frac{\partial \mathbf{B}}{\partial t}$$

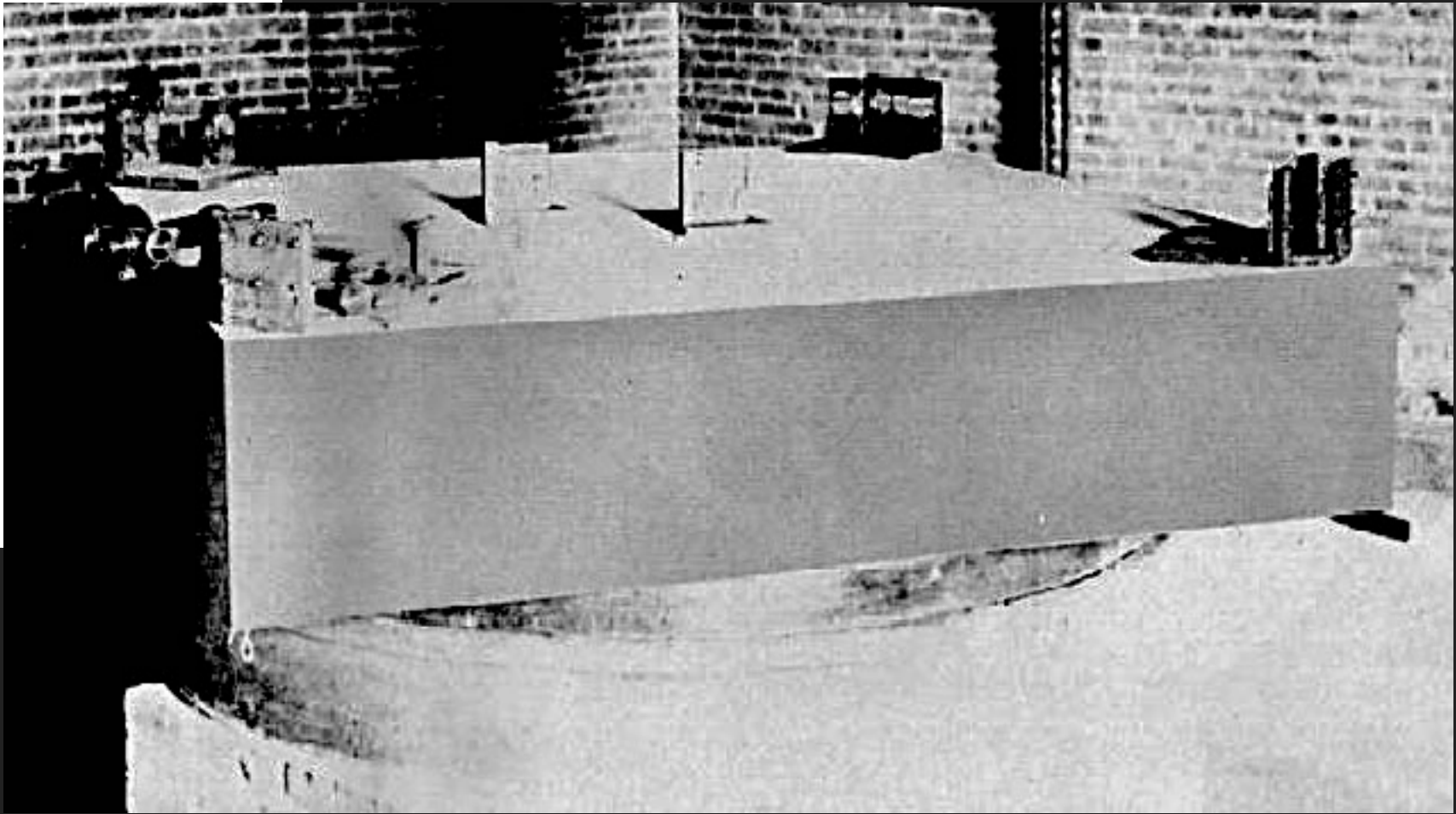
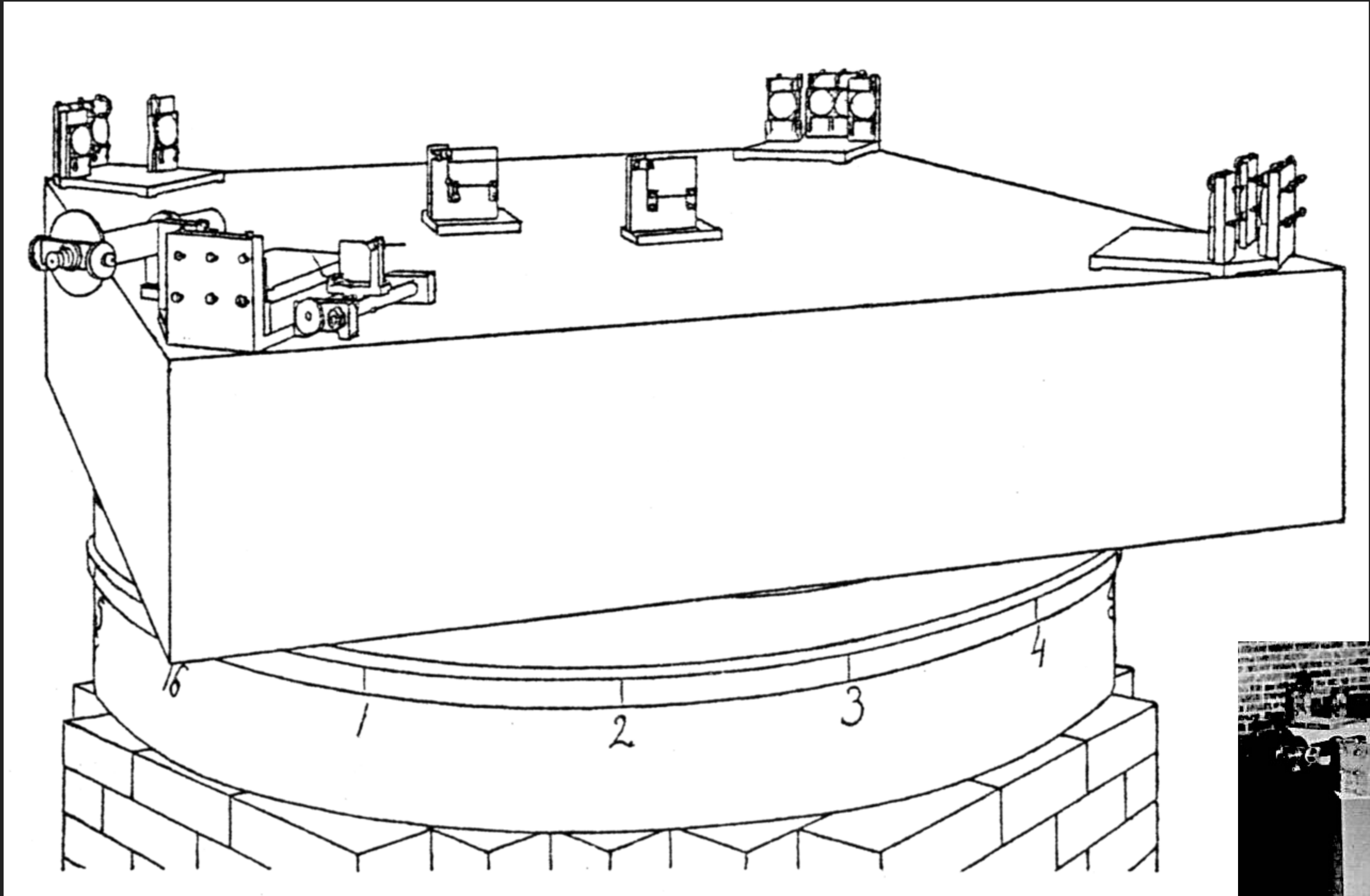
$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$$



'Bashaarat looked at me and considered. "I have recently built something that may change your opinion. You would be the first person I have shown it to. Would you care to see it?"

"It would be a great pleasure."

*"Please follow me." He led me through the doorway in the rear of his shop. The next room was a workshop, arrayed with devices whose functions I could not guess—bars of metal wrapped with enough copper thread to reach the horizon, **mirrors mounted on a circular slab of granite floating in quicksilver**—but Bashaarat walked past these without a glance.'*



Michelson-Morley experiment, 1887



*"He handed the manuscript to me, and I saw the title was 'On the Relative Motion of the Sun and the Luminiferous Aether.' I have only a layperson's understanding of the aether, the medium that carries light waves: I know that, just as a shout carries farther when traveling with the wind than against it, **the speed of light varies relative to the Earth's own motion through the aether...** there appears to be a steady aetheric wind across the solar system as a whole..."*

From 'Omphalos' by Ted Chiang.

Image: The Omphalos ('religious stone') of Delphi, wikipedia.

ON THE ELECTRODYNAMICS OF MOVING BODIES EINSTEIN, 1905

3. *Zur Elektrodynamik bewegter Körper;* *von A. Einstein.*

Daß die Elektrodynamik Maxwells — wie dieselbe gegenwärtig aufgefaßt zu werden pflegt — in ihrer Anwendung auf bewegte Körper zu Asymmetrien führt, welche den Phänomenen nicht anzuhaften scheinen, ist bekannt. Man denke z. B. an die elektrodynamische Wechselwirkung zwischen einem Magneten und einem Leiter. Das beobachtbare Phänomen hängt hier nur ab von der Relativbewegung von Leiter und Magnet, während nach der üblichen Auffassung die beiden Fälle, daß der eine oder der andere dieser Körper der bewegte sei, streng voneinander zu trennen sind. Bewegt sich nämlich der Magnet und ruht der Leiter, so entsteht in der Umgebung des Magneten ein elektrisches Feld von gewissem Energiewerte, welches an den Orten, wo sich Teile des Leiters befinden, einen Strom erzeugt. Ruht aber der Magnet und bewegt sich der Leiter, so entsteht in der Umgebung des Magneten kein elektrisches Feld, dagegen im Leiter eine elektromotorische Kraft, welcher an sich keine Energie entspricht, die aber — Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen vorausgesetzt — zu elektrischen Strömen von derselben Größe und demselben Verlaufe Veranlassung gibt, wie im ersten Falle die elektrischen Kräfte.

Beispiele ähnlicher Art, sowie die mißlungenen Versuche, eine Bewegung der Erde relativ zum „Lichtmedium“ zu konstatieren, führen zu der Vermutung, daß dem Begriffe der absoluten Ruhe nicht nur in der Mechanik, sondern auch in der Elektrodynamik keine Eigenschaften der Erscheinungen entsprechen, sondern daß vielmehr für alle Koordinatensysteme, für welche die mechanischen Gleichungen gelten, auch die gleichen elektrodynamischen und optischen Gesetze gelten, wie dies für die Größen erster Ordnung bereits erwiesen ist. Wir wollen diese Vermutung (deren Inhalt im folgenden „Prinzip der Relativität“ genannt werden wird) zur Voraussetzung erheben und außerdem die mit ihm nur scheinbar unverträgliche



ON THE ELECTRODYNAMICS OF MOVING BODIES

EINSTEIN, 1905

New t
New x
Same y
Same z

$$\xi = a \frac{c^2}{c^2 - v^2} x'.$$

In an analogous manner we find, by considering rays moving along the two other axes, that

$$\eta = c\tau = ac \left(t - \frac{v}{c^2 - v^2} x' \right)$$

when

$$\frac{y}{\sqrt{c^2 - v^2}} = t, \quad x' = 0.$$

Thus

$$\eta = a \frac{c}{\sqrt{c^2 - v^2}} y \quad \text{and} \quad \zeta = a \frac{c}{\sqrt{c^2 - v^2}} z.$$

Substituting for x' its value, we obtain

$$\begin{aligned} \tau &= \phi(v)\beta(t - vx/c^2), \\ \xi &= \phi(v)\beta(x - vt), \\ \eta &= \phi(v)y, \\ \zeta &= \phi(v)z, \end{aligned}$$

where

$$\beta = \frac{1}{\sqrt{1 - v^2/c^2}},$$



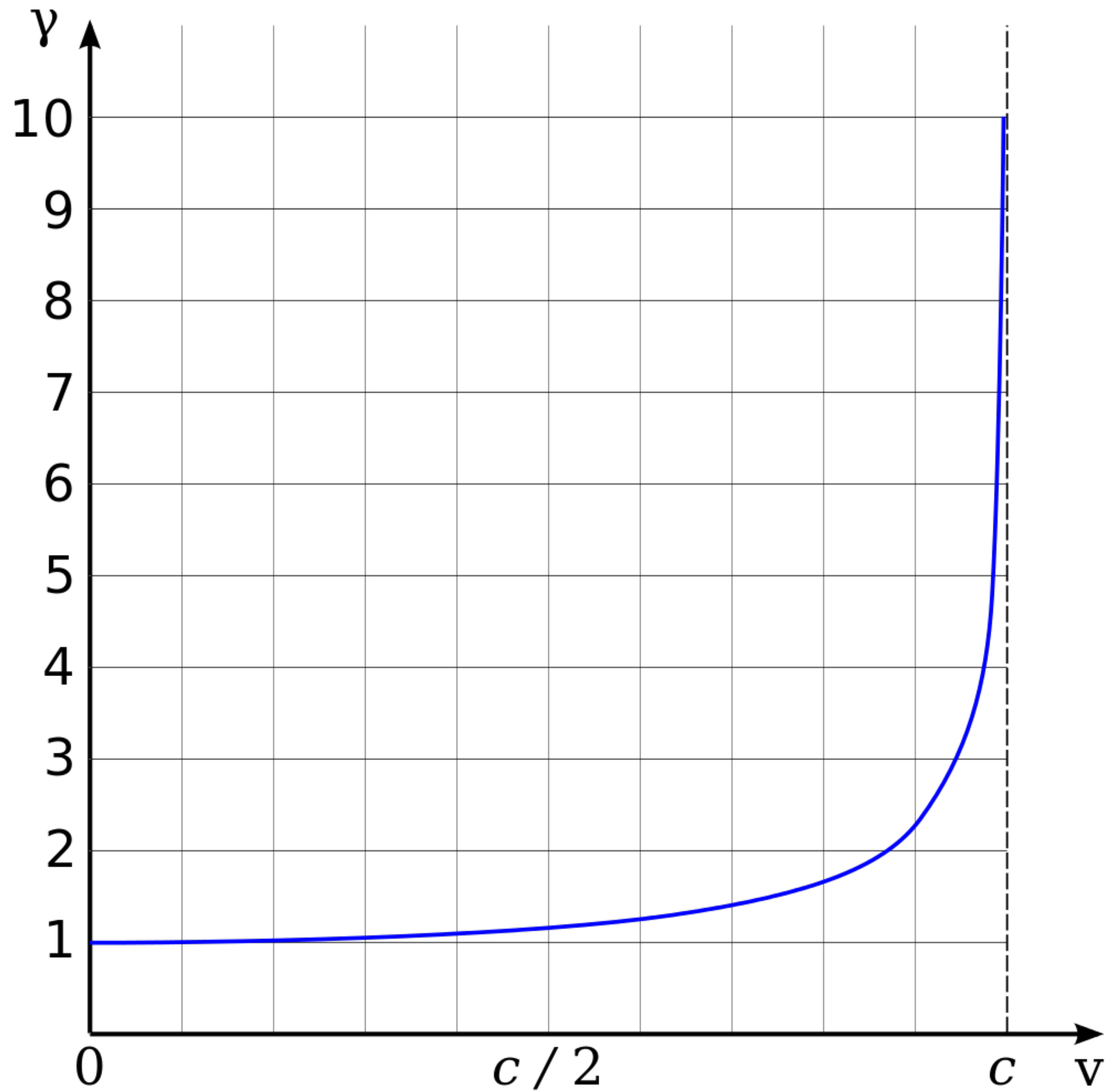
ON THE ELECTRODYNAMICS OF MOVING BODIES

EINSTEIN, 1905

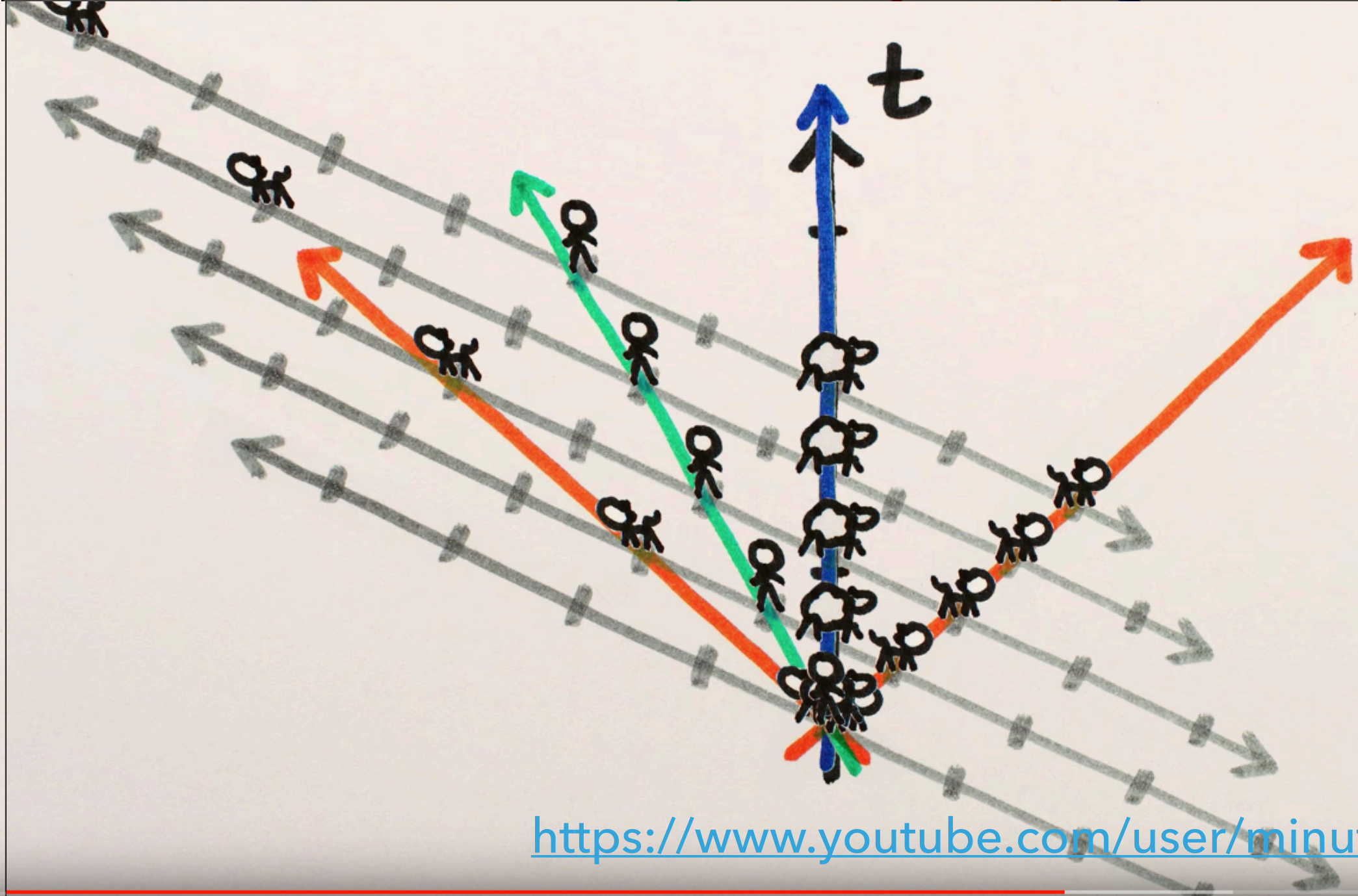
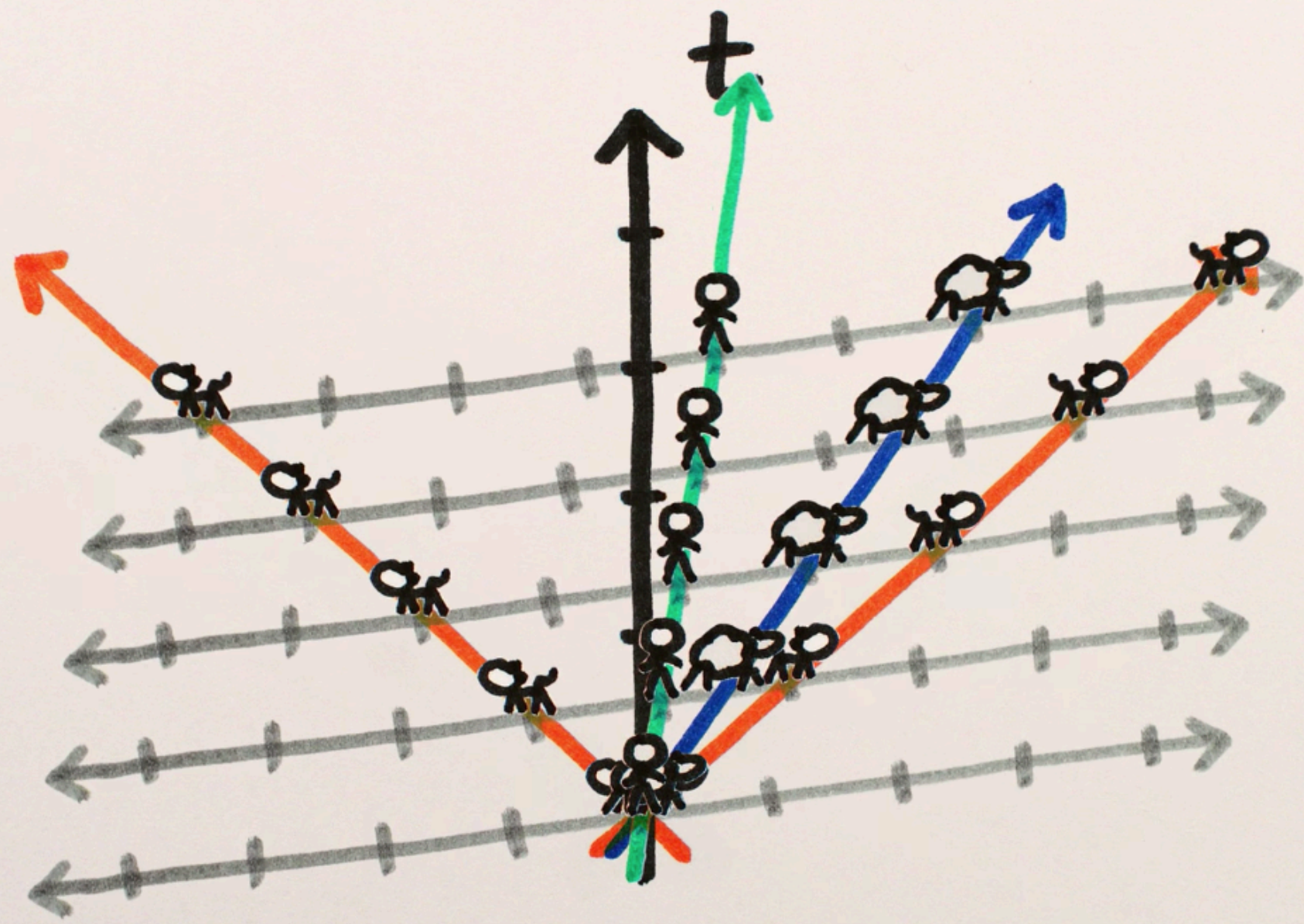
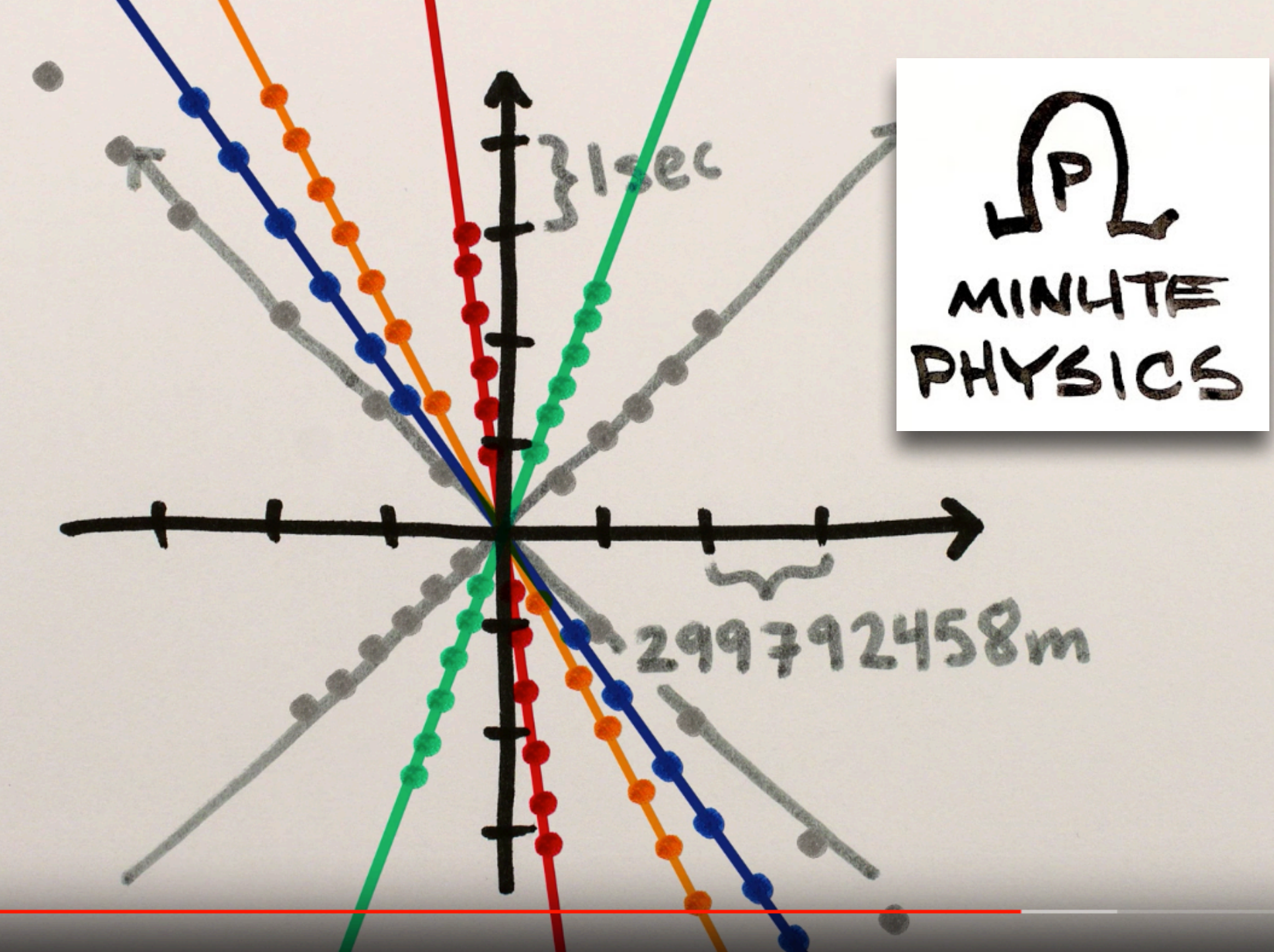
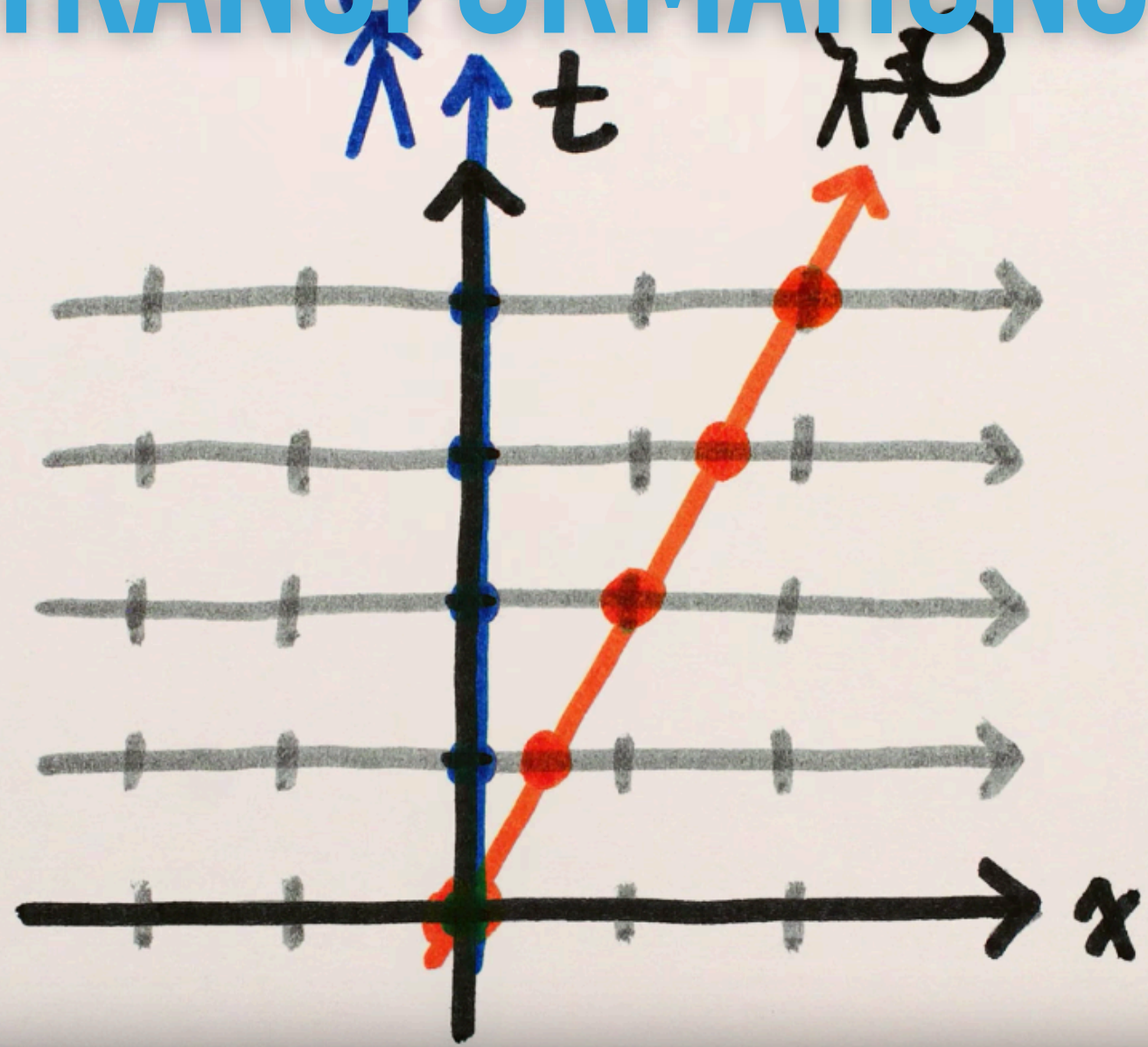
$$\frac{1}{\sqrt{1 - v^2/c^2}}$$

$v^2 / c^2 \approx 0$ for all "normal" velocities,
so this factor is usually ≈ 1

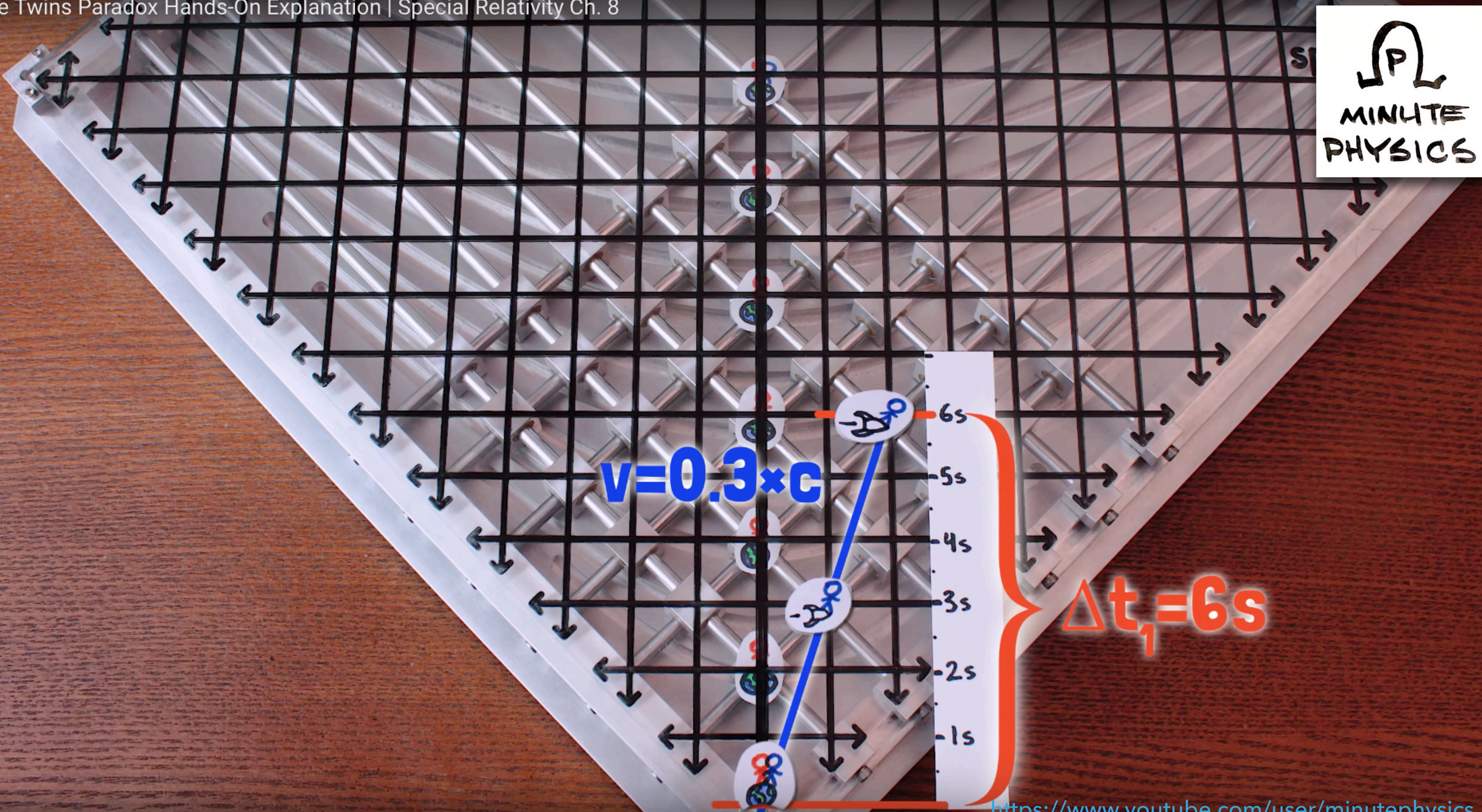
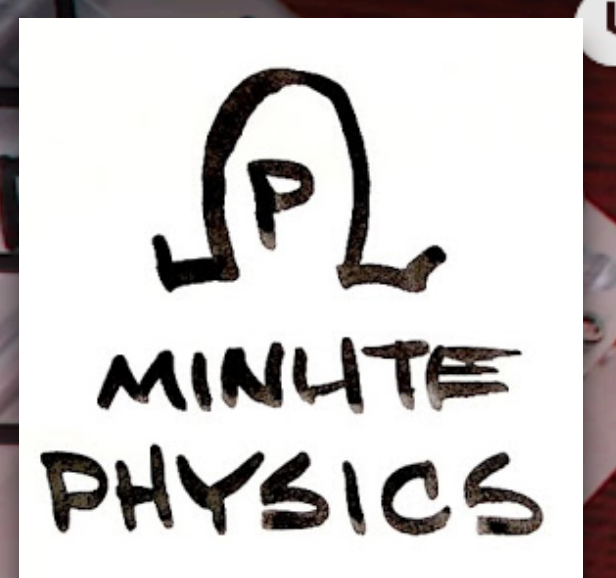




LORENTZ TRANSFORMATIONS



<https://www.youtube.com/user/minutephysics>



<https://www.youtube.com/user/minutephysics>

Express Lanes

New York and Chicago, America's two great trading centers, are 720 miles apart as the photon flies — about 3.9 milliseconds at the speed of light. But variations in transmission technology or how long the route is can make millions of dollars' worth of difference to high-frequency traders. — *Katie M. Palmer*



ORIGINAL CABLE

Technology
Buried fiber-optic cable

Completion
Mid-1980s

Path length
~ 1,000 miles

Round-trip time for data

14.5
milliseconds and up

Approach
Multiple routes followed the easiest rights-of-way—along rail lines. But that means time-sucking jogs and detours.



SPREAD NETWORKS

Technology
Buried fiber-optic cable

Completion
August 2010

Path length
825 miles

Round-trip time for data

13.1
milliseconds

Approach
Spread bought its own rights-of-way, avoiding a Philadelphia-ward dip in favor of a shorter path northwest through central Pennsylvania.



MCKAY BROTHERS

Technology
Microwave beams through air

Completion
July 4, 2012

Path length
744 miles

Round-trip time for data

9
milliseconds

Approach
Microwaves generally move faster than photons in optical fiber, and McKay's network uses just 20 towers on a nearly perfect great circle.



TRADEWORX

Technology
Microwave beams through air

Completion
Winter 2012

Path length
~ 731 miles

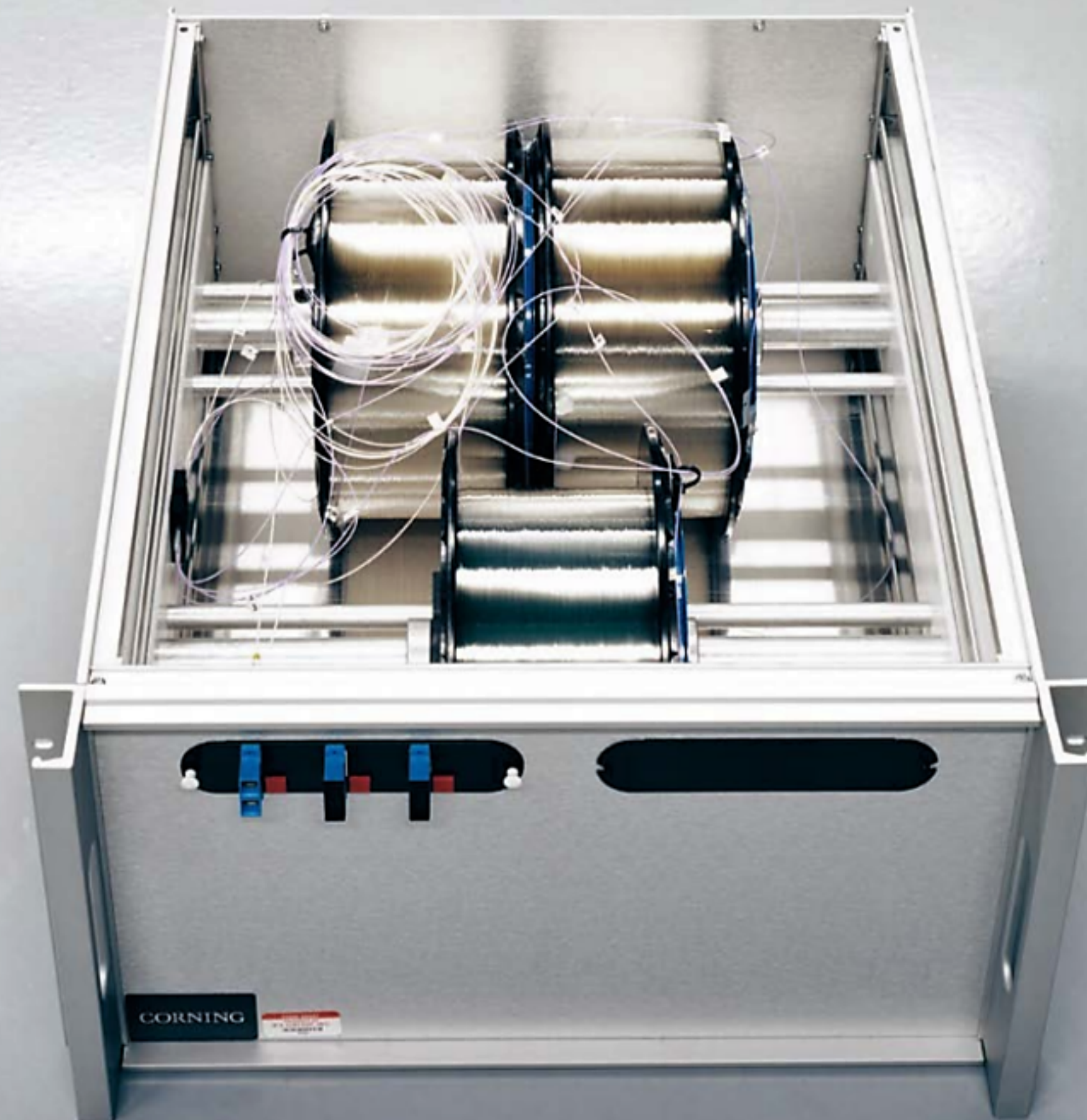
Round-trip time for data

8.5
milliseconds (est.)

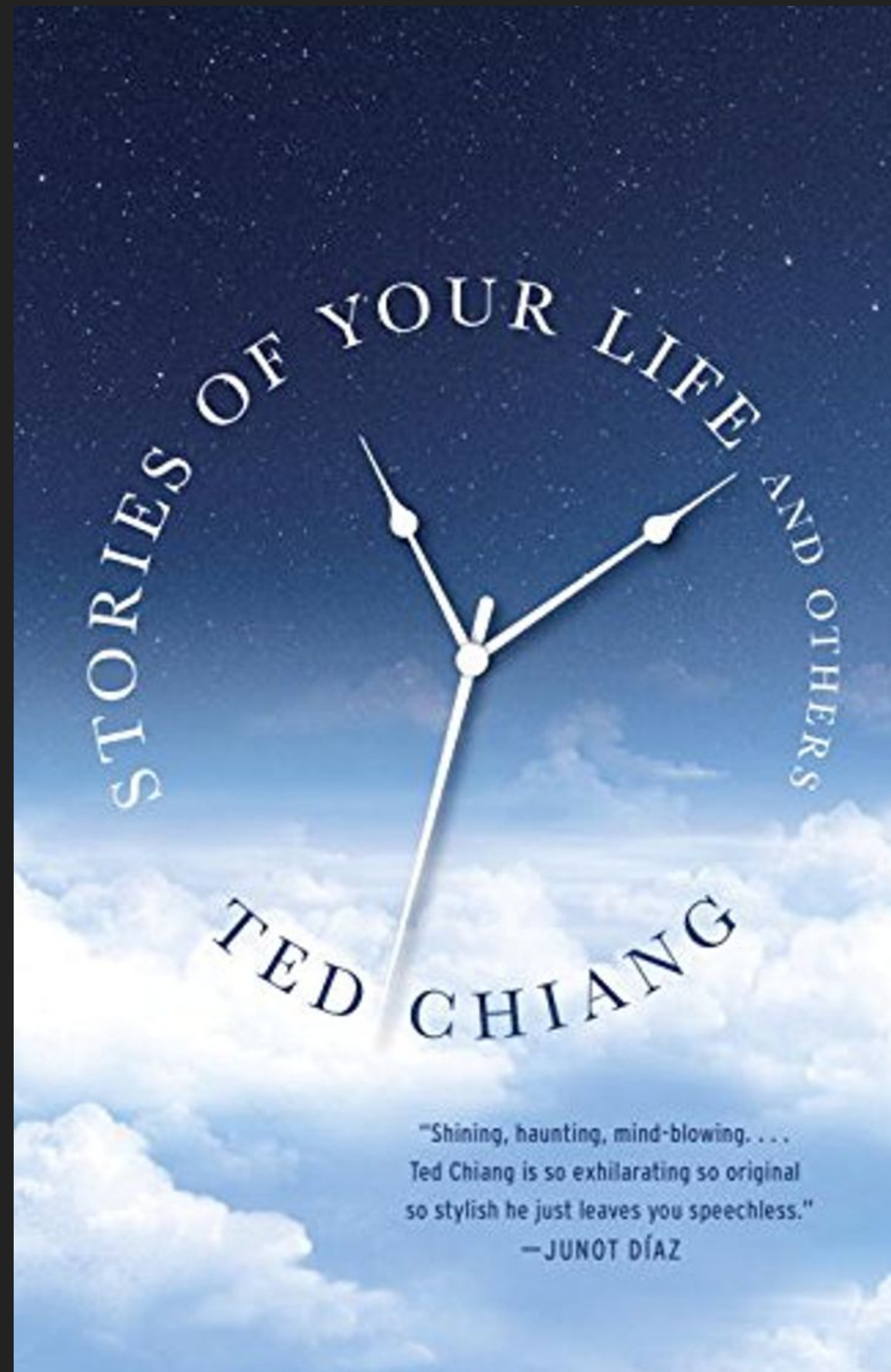
Approach
Tradeworx is highly secretive, but the company is open about the price of a subscription: \$250,000 a year.

IEX SHOEBOX

61 km fiber loop
adds 350
microseconds

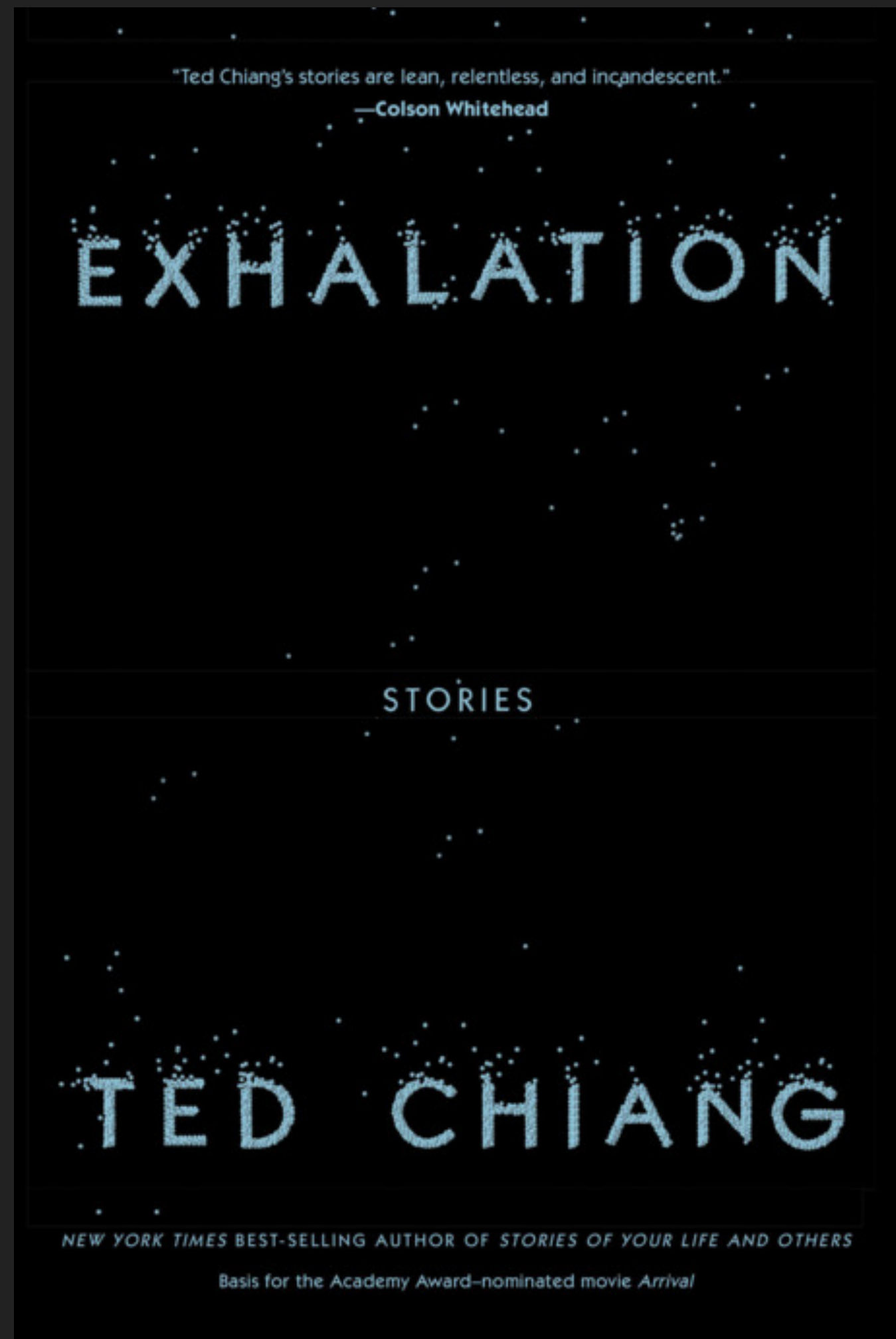


<https://iextrading.com/>
via Hackaday



*"Physical attributes that humans defined using integral calculus were seen as fundamental by the heptapods. As an example, Gary described an attribute that, in physics jargon, bore the deceptively simple name 'action,' which represented **'the difference between kinetic and potential energy, integrated over time,'** whatever that meant. Calculus for us; elementary to them.*

Conversely, to define attributes that humans thought of as fundamental, like velocity, the heptapods employed mathematics that were, Gary assured me, 'highly weird.' The physicists were ultimately able to prove the equivalence of heptapod mathematics and human mathematics; even though their approaches were almost the reverse of one another, both were systems of describing the same physical universe."



*"...the suggestion was made that these discrepancies might be evidence of a defect in the mechanism common to all the turret clocks, albeit a curious one to cause the clocks to run faster rather than slower. **Horologists investigated the turret clocks** in question, but on inspection they could discern no imperfection. In fact, when compared against the timepieces normally employed for such calibration purposes, the turret clocks were all found to have resumed keeping perfect time."*

$\Delta S \geq 0$

"Ted Chiang's stories are lean, relentless, and incandescent."
—Colson Whitehead

EXHALATION

STORIES

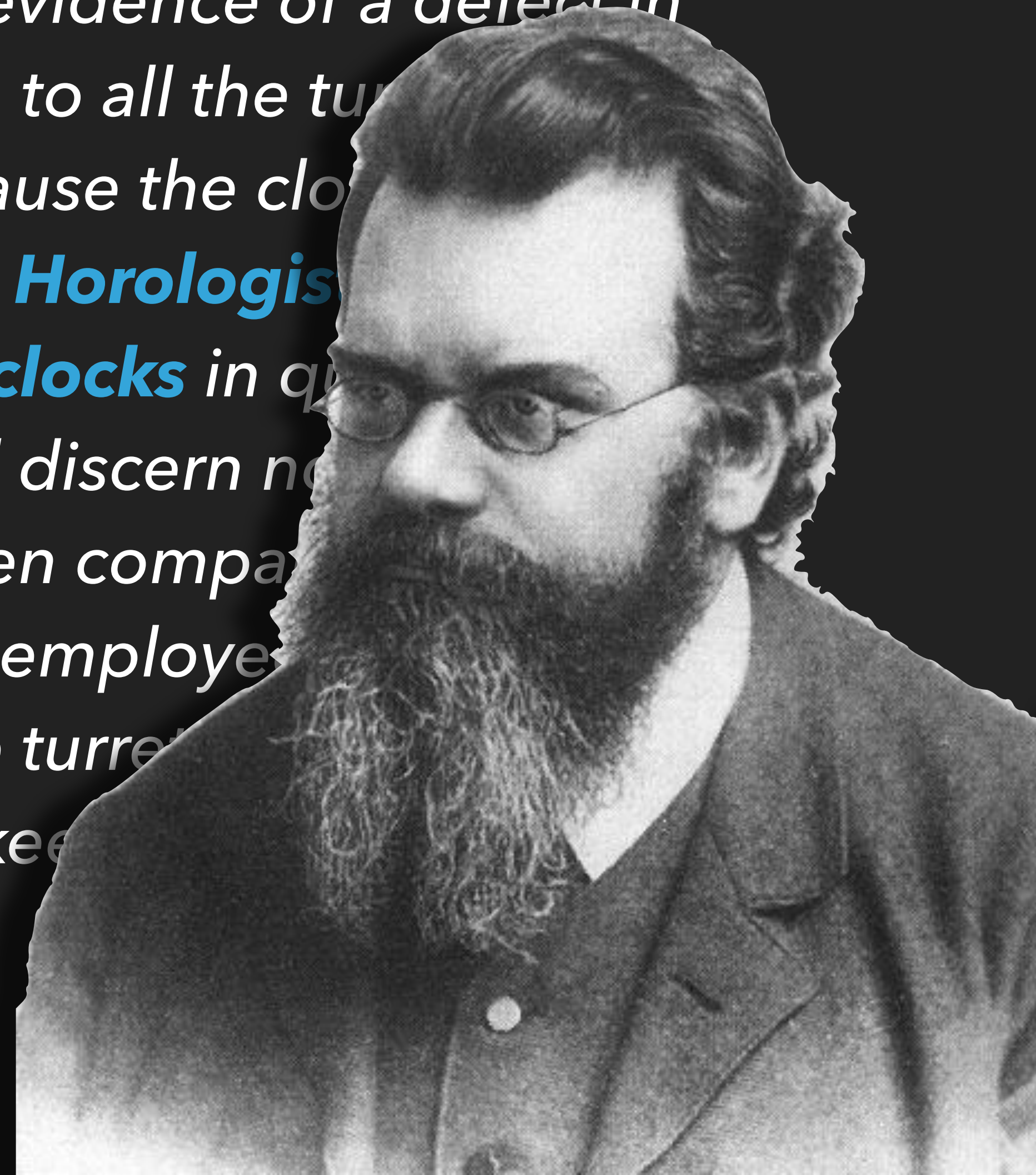
TED CHIANG

NEW YORK TIMES BEST-SELLING AUTHOR OF STORIES OF YOUR LIFE AND OTHERS

Basis for the Academy Award-nominated movie *Arrival*

←----- basically, a story about this equation, our perception of time, and how minds work

"...the suggestion was made that these discrepancies might be evidence of a defect in the mechanism common to all the turrets, albeit a curious one to cause the clocks to run faster rather than slower. **Horologists investigated the turret clocks** in question. On inspection they could discern no imperfection. In fact, when compared to the timepieces normally employed for calibration purposes, the turret clocks were found to have resumed keeping



FOR NEXT WEEK