Einstein and his theories of relativity

Øyvind G. Grøn

Forum for matematiske Perler
Trondheim, 16. september 2016

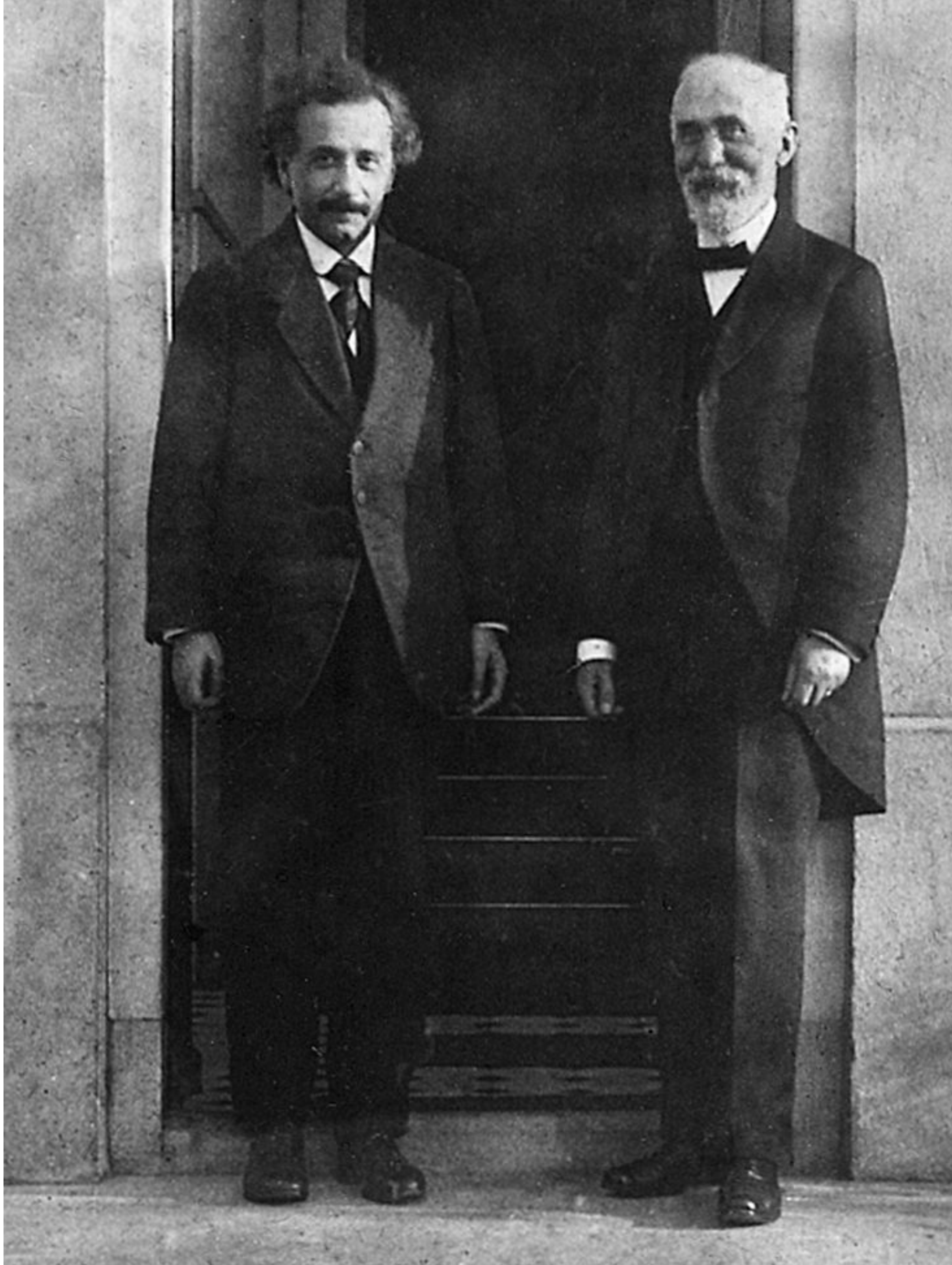
Albert Einstein 1879 – 1955

and

Hendrik Antoon Lorentz
1853-1928

Lorentz presented the
Lorenz transformations
between inertial frames.

But they were interpreted by him
in a non-relativistic manner,
in terms of an ether that was
absolutely at rest.



Henri Poincaré (1854 - 1912)

A polymath, he is known in mathematical circles as the Last Universalist due to the large number of significant contributions he made to various fields of mathematics and physics

Science is built up of facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house.

— *Henri Poincare* —

AZ QUOTES

"Mathematics is the art of giving the same name to different objects."

Henri Poincaré


HENRI POINCARE
1854 + 1912
Zum Gedenken
17. Juli 1912
Mathematiker
Theoretischer Physiker
2012
MaPhyPhil
MARKE INDIVIDUELL
Deutsche Post
55

Both Lorentz and Poincaré showed that Maxwell's equations are invariant against a Lorentz transformation

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$$

$$t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}$$

Poincaré and the Special Theory of Relativity

Supurna Sinha

In 1895 Poincaré wrote:

"Experiment has revealed a multitude of facts which can be summed up in the following statement: it is impossible to detect the absolute motion of matter, or rather the relative motion of ponderable matter with respect to the ether; all that one can exhibit is the motion of ponderable matter with respect to ponderable matter."

But Poincaré was not ready to take the important step of eliminating the ether.

Poincaré and Einstein met only once, at the Solvay meeting of 1911.

On September 14th of 1904, Henri Poincaré (1854-1912) gives a talk at the congress of arts and science in Saint-Louis, Missouri [1], which title is *The Principles of Mathematical Physics* in which he defines :

« *The principle of relativity, according to which the laws of physical phenomena must be the same for a stationary observer as for an observer carried along in a uniform motion of translation ; so that we have not and can not have any means of discerning whether or not we are carried along in such a motion.* » (Poincaré, 1904, p306)

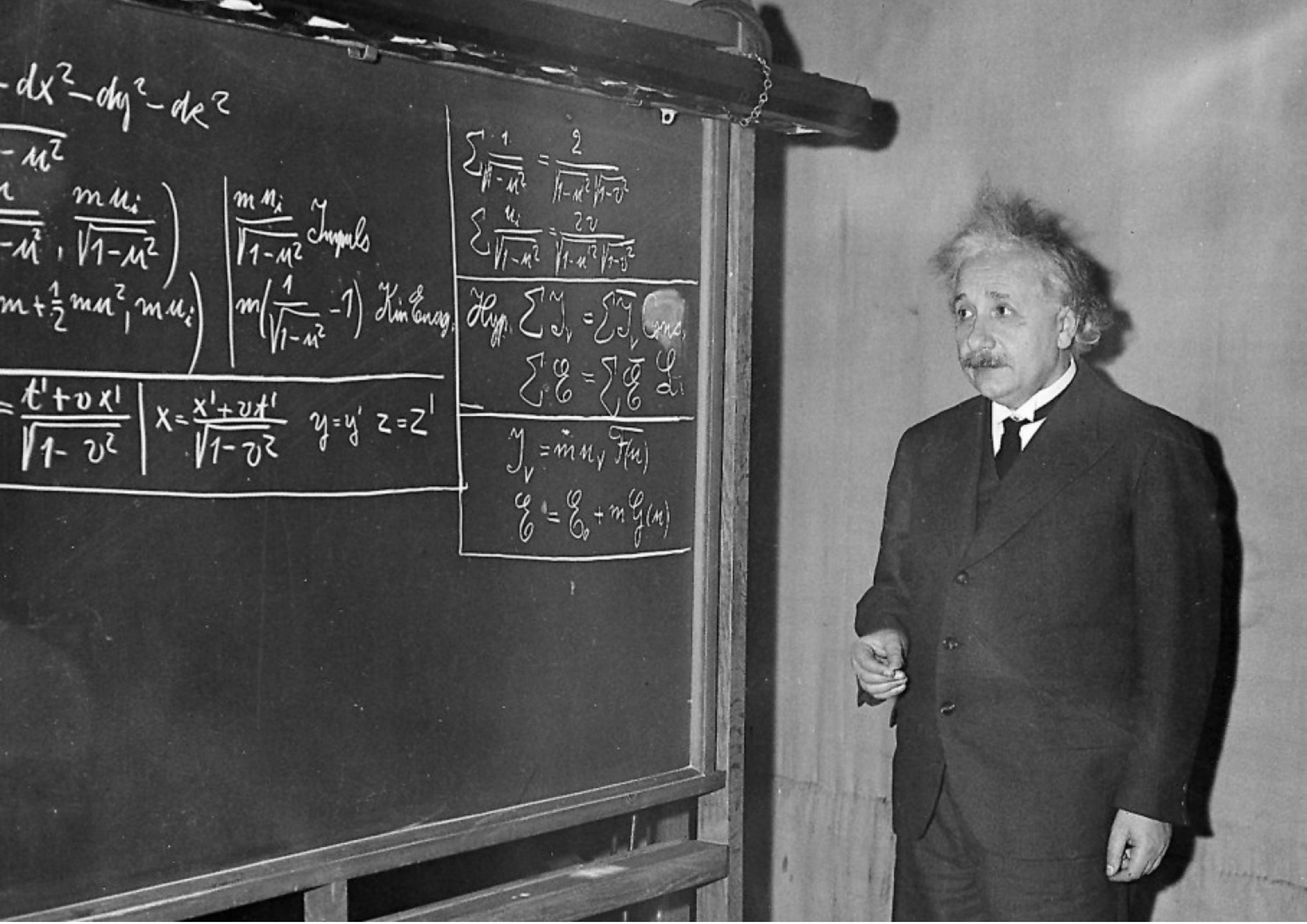
In Poincaré's view, the principle of relativity is the consequence of a dynamics he tries to identify under the hypotheses of an electromagnetic origin of inertia and of all forces.

We saw that it is Poincaré who names and formulates the principle of relativity, names and corrects Lorentz transformations, reports and exploits its group structure. To these examples, we could add that he establishes the method for synchronizing clocks by light signals (*La mesure du temps*, Revue de métaphysique et de morale, T.6, janv 1898), the formula of additivity of velocities, the invariance of Maxwell's equations in a vacuum, and the hypothesis of the speed of light limit (Poincaré, 1905). Let's not forget that he also already uses a quadridmensional formalism that will inspire the future works of Minkowski, and then some. What is left ?

He clearly masters most of the concepts and technical tools of what we call now the special relativity theory, except (and it is fundamental !) that it is to him just **corrections** brought to Lorentz works, part of a **dynamics**, and what's more, **depending upon** Maxwell's electromagnetic theory.

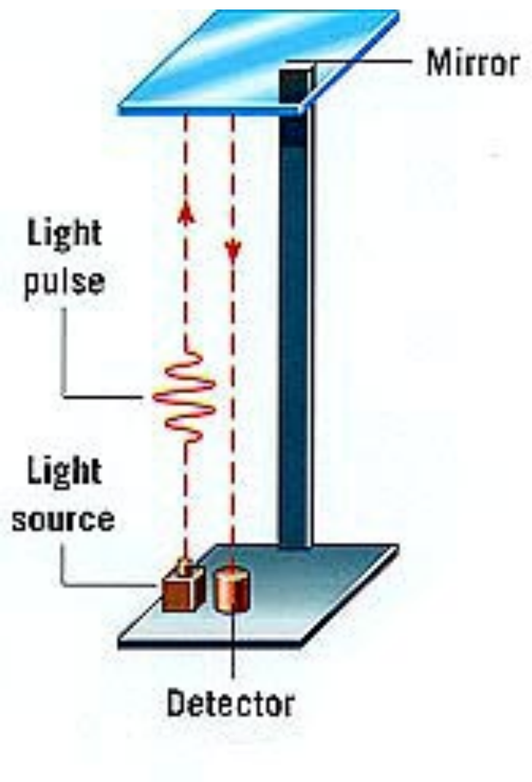
That's what makes Einstein the real father of the theory, because he presents in his 1905 paper all of these points (except the importance of the group structure of Lorentz transformations) in a **coherent theory**, building a kinematics on which the laws of physics **will depend** (and not the other way around), including those of electromagnetism.

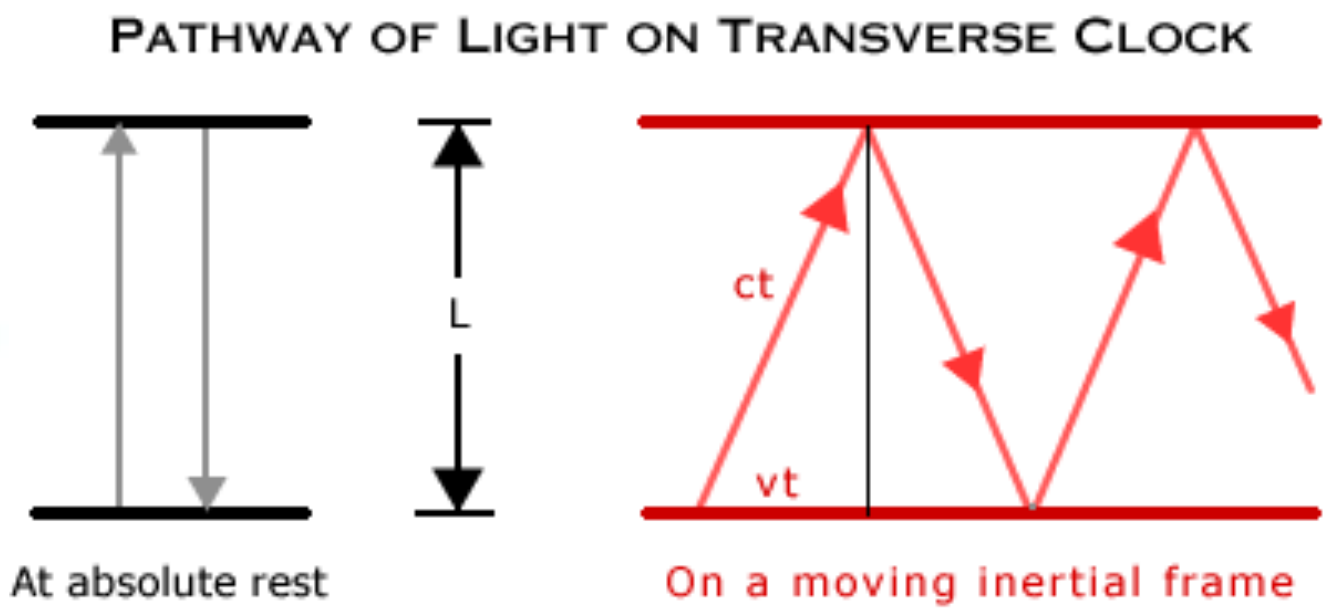
Einstein receives the relay batton from Poincaré
in a relay where also Maxwell and Lorentz participated.



Albert Einstein 1879 - 1955

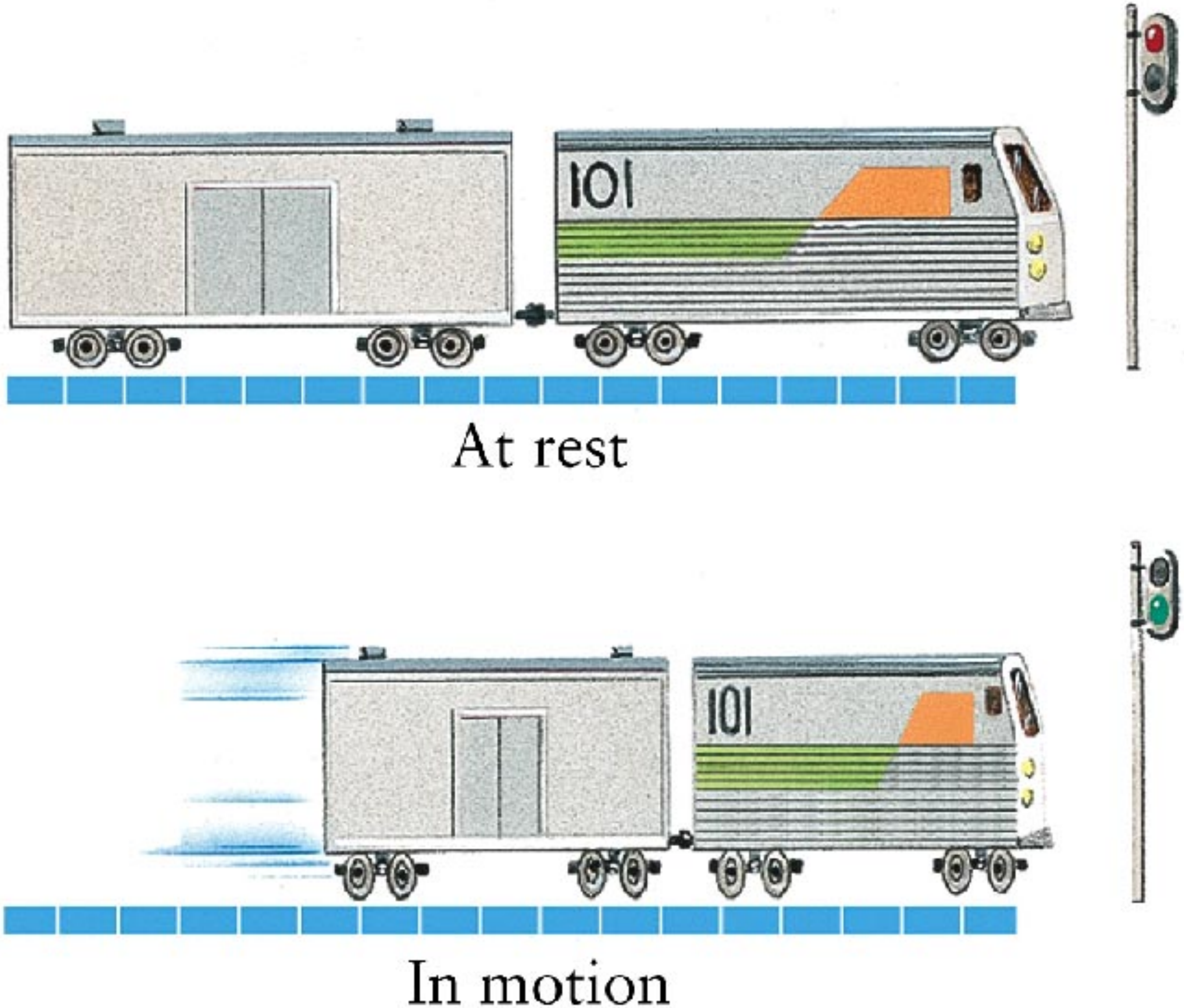
En av relativitetsteoriens konsekvenser er at
legemer (klokker) som beveger seg, eldes langsommere enn legemer som er i ro.





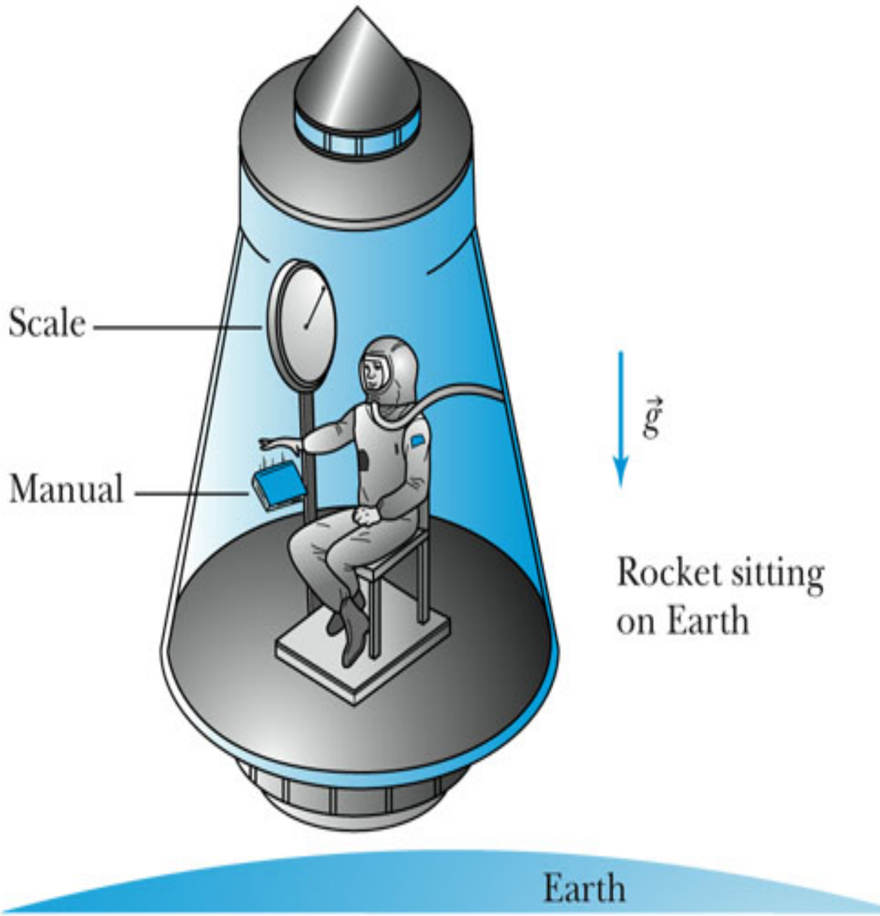
Lysklokke i tog **observert fra toget** **observert fra perrongen**

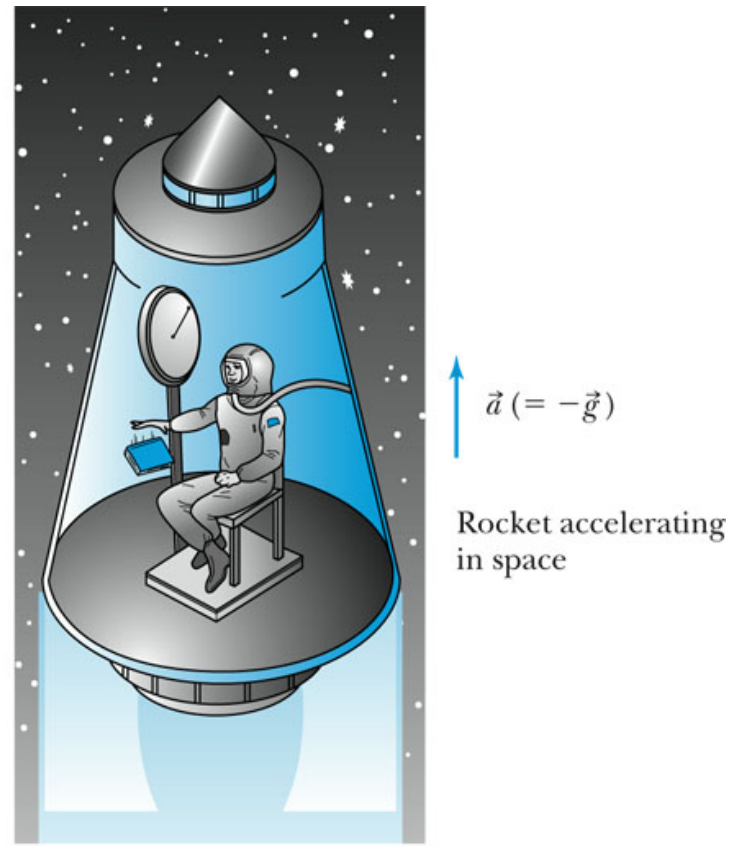
Lengdekontraksjon



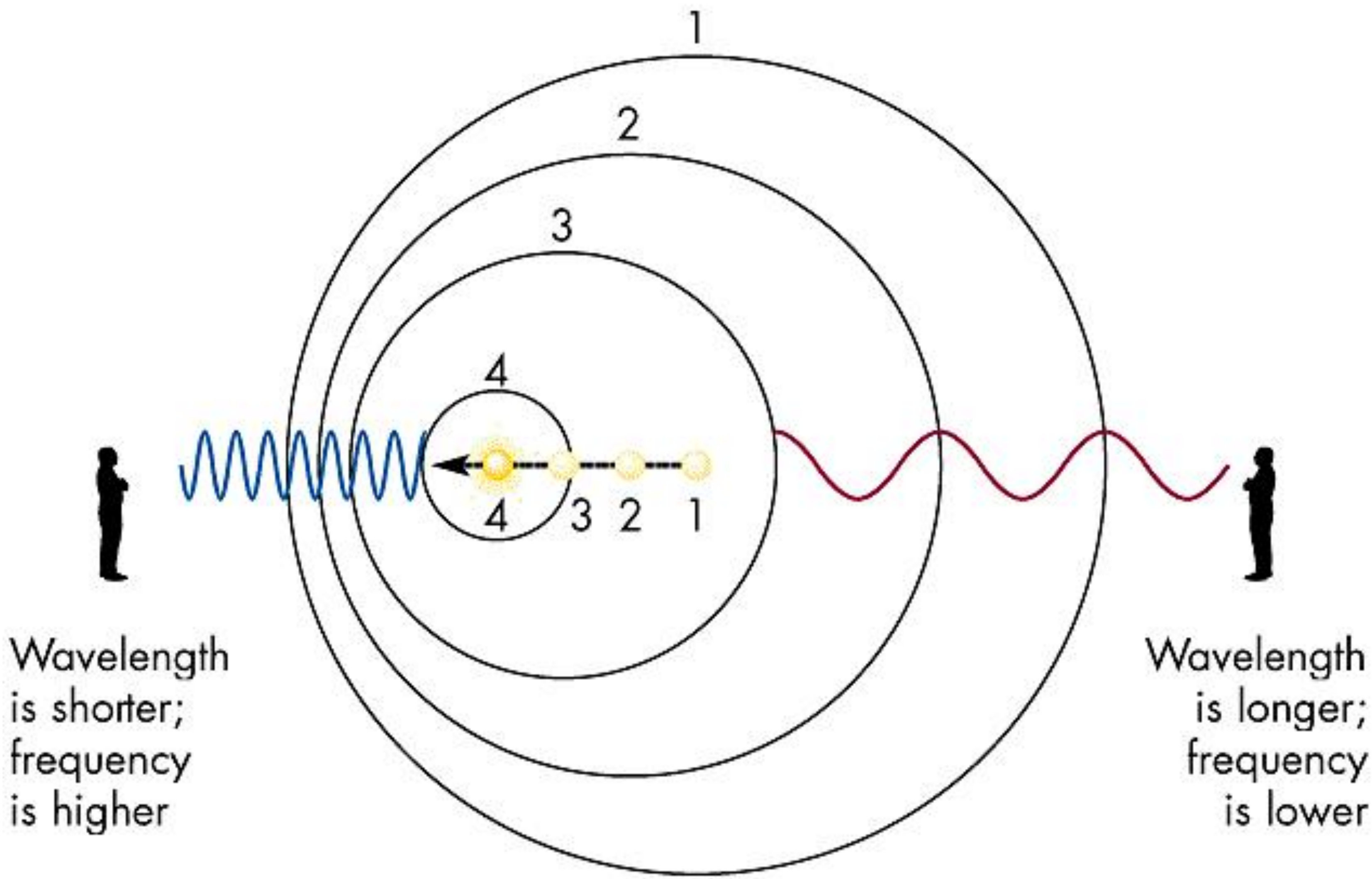
Målt ved samtidighet er avstanden mellom forreste og bakerste ende av en gjenstand kortere jo raskere gjenstanden beveger seg.

The principle of equivalence

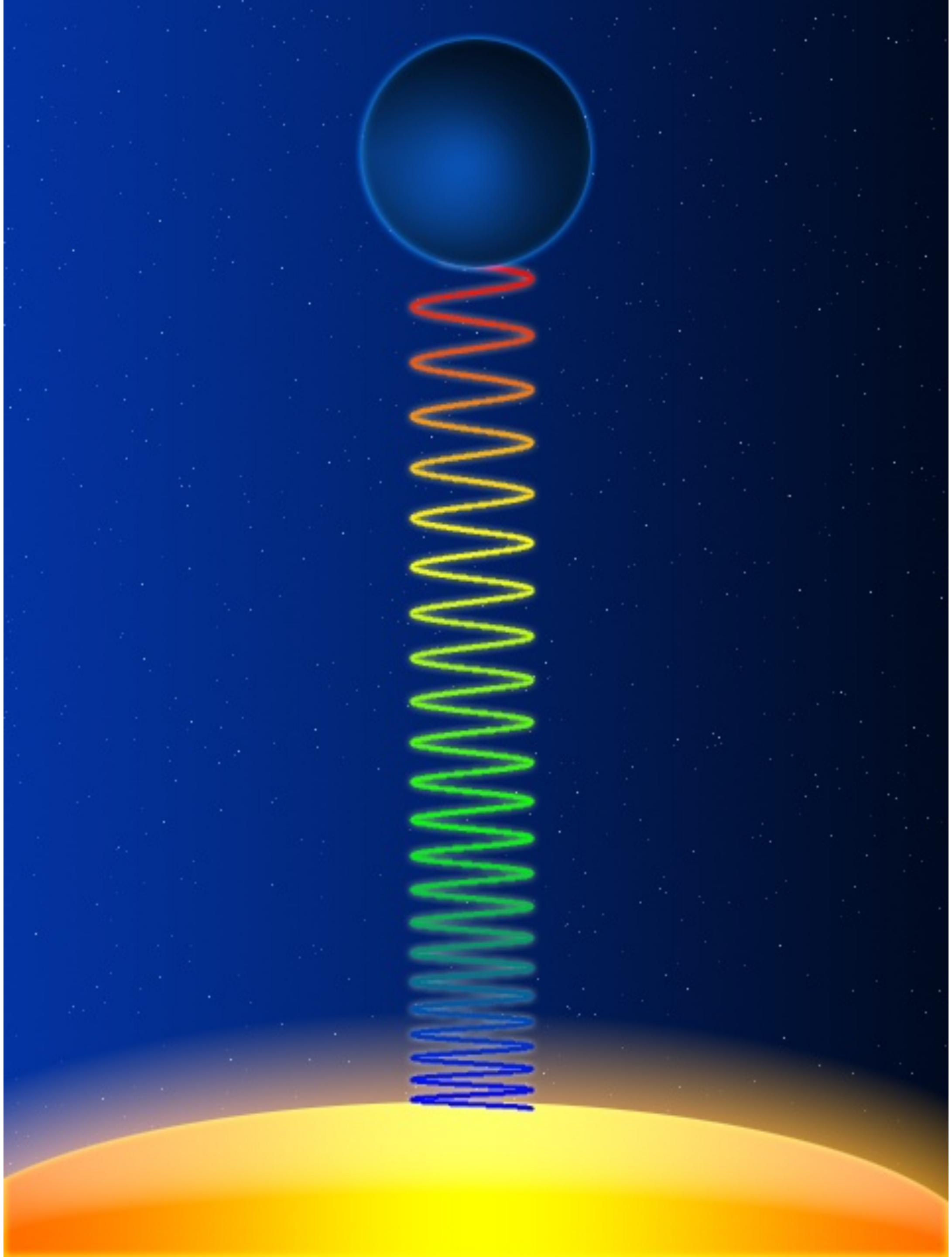




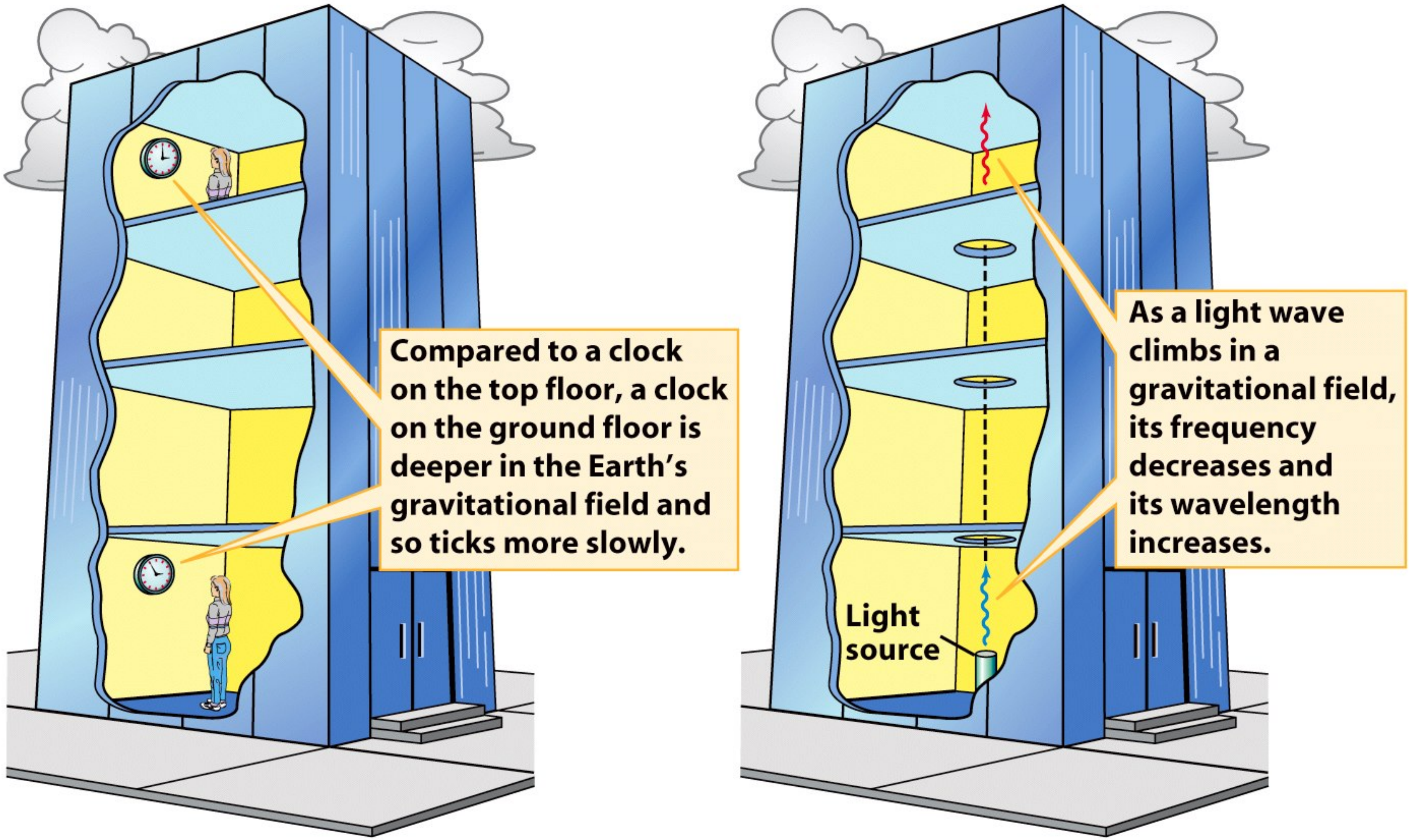
The Doppler effect



The numbers on the circles show wave fronts emitted at the events 1, 2, 3, 4

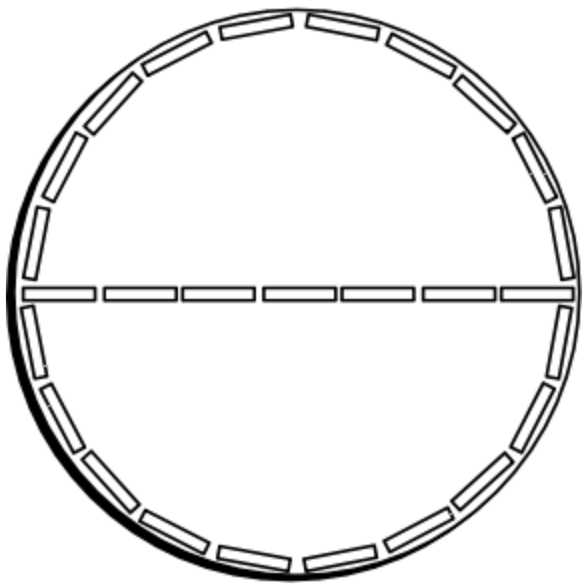


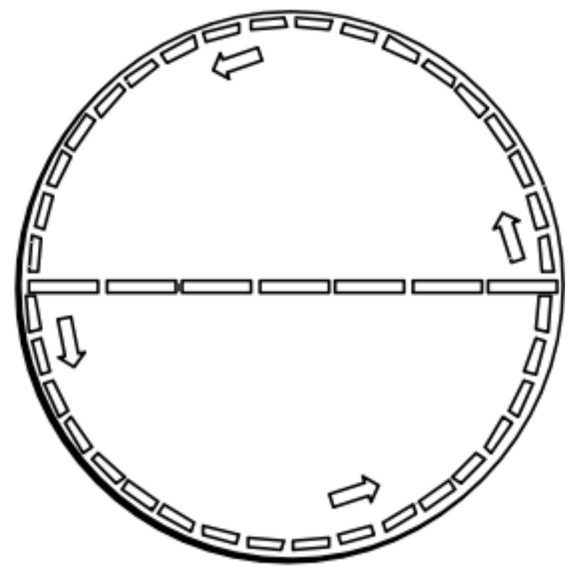
Gravitational time dilation and red shift

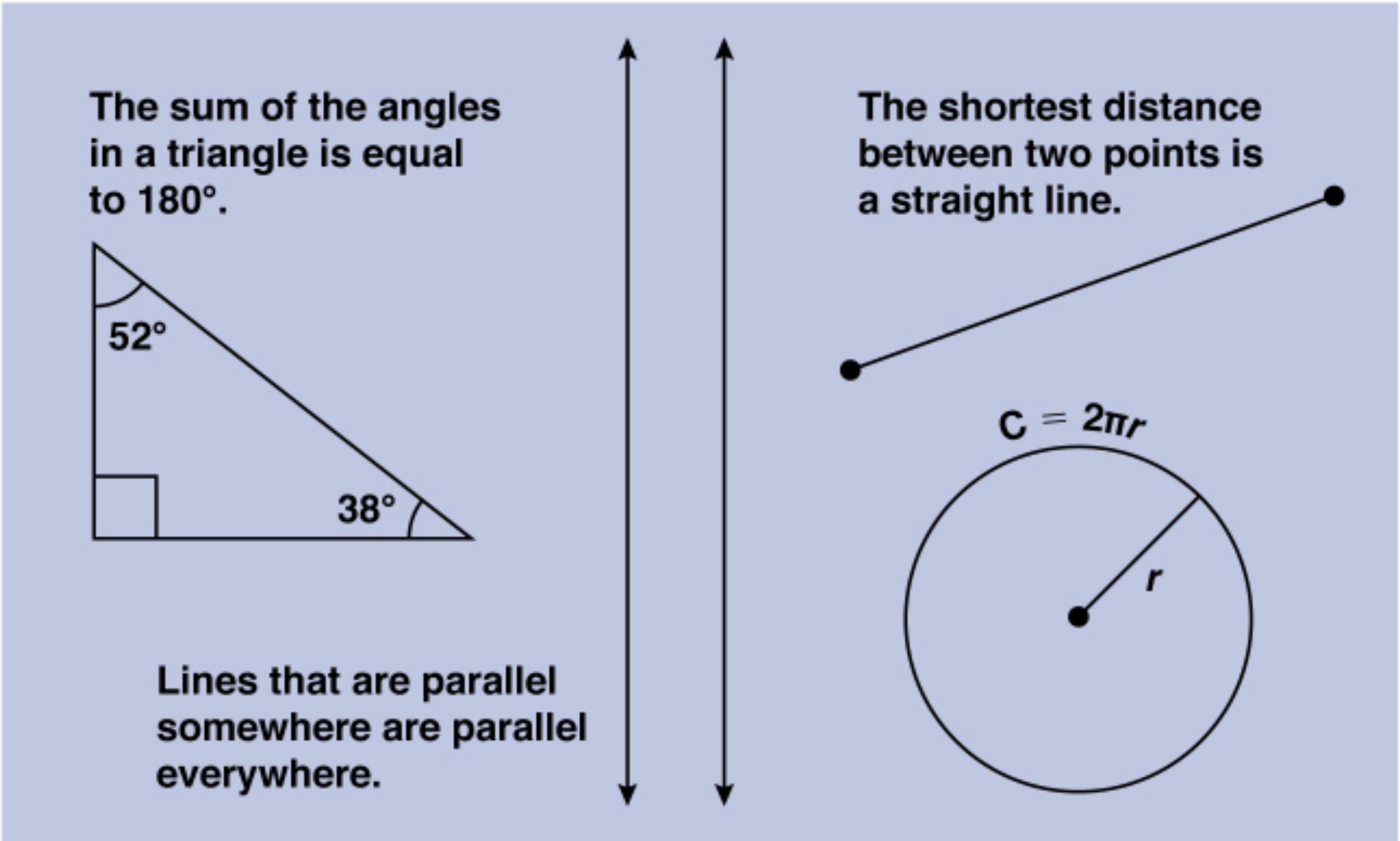


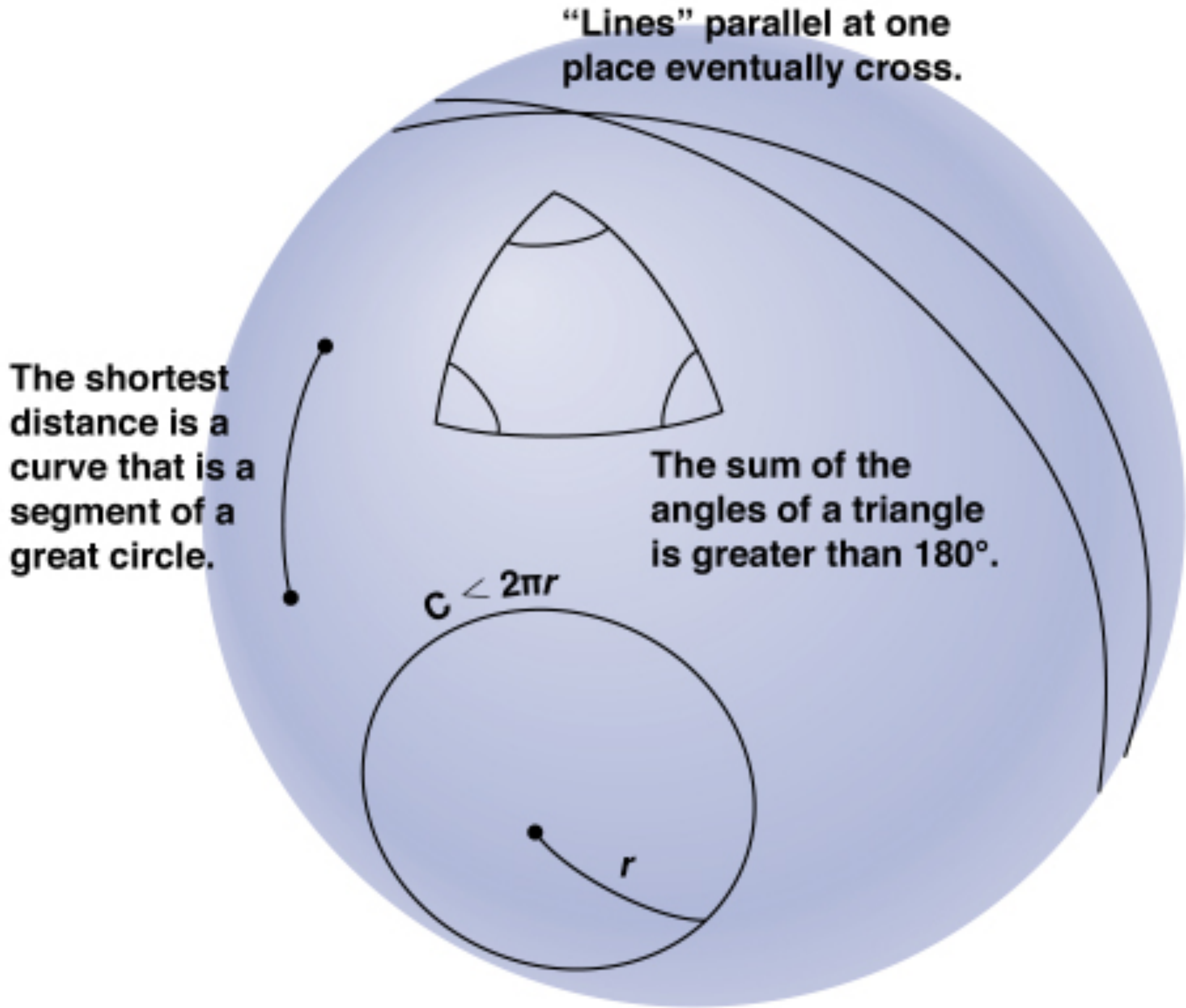
(a) The gravitational slowing of time **(b) The gravitational redshift**

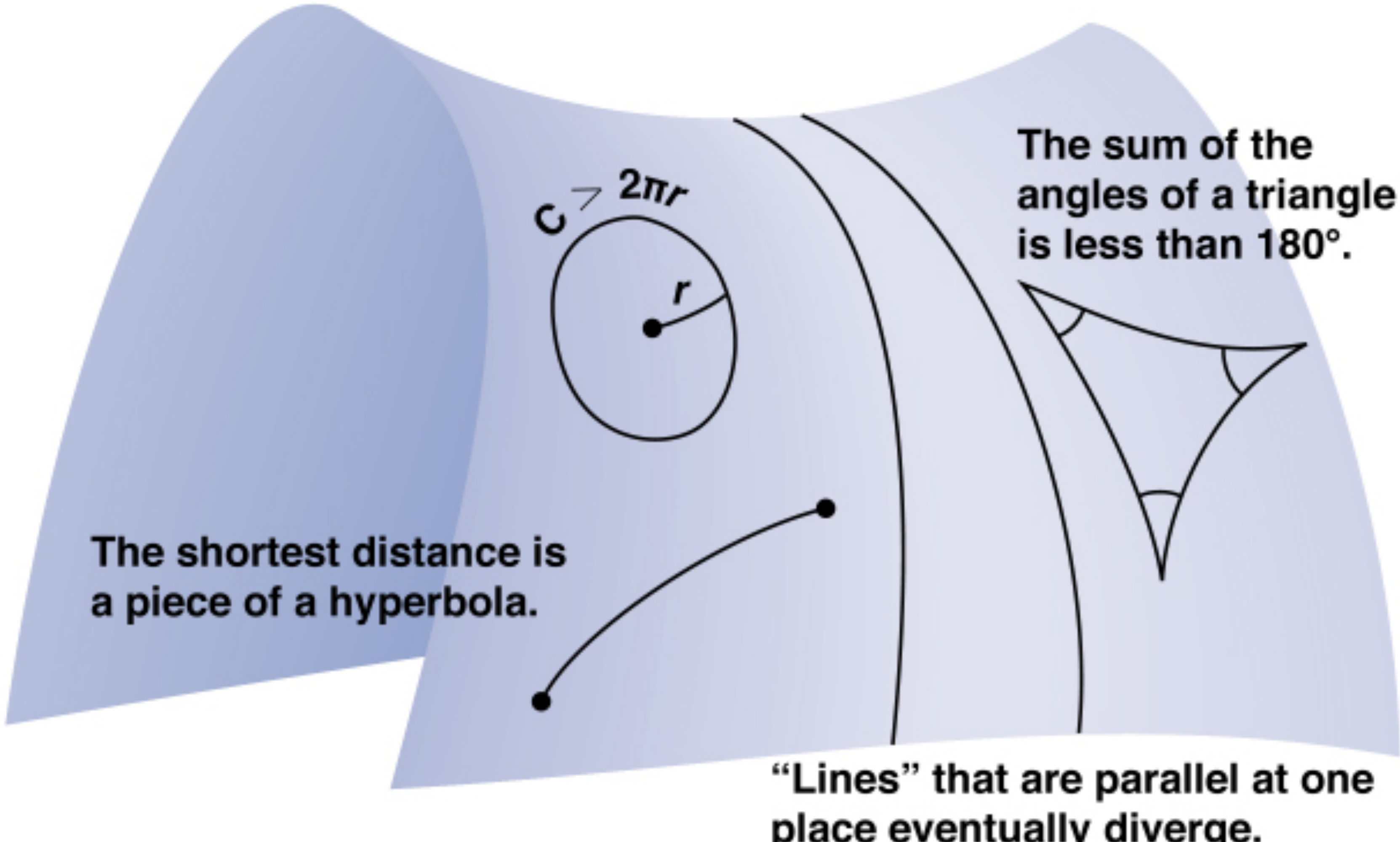
Geometri on a rotating disk



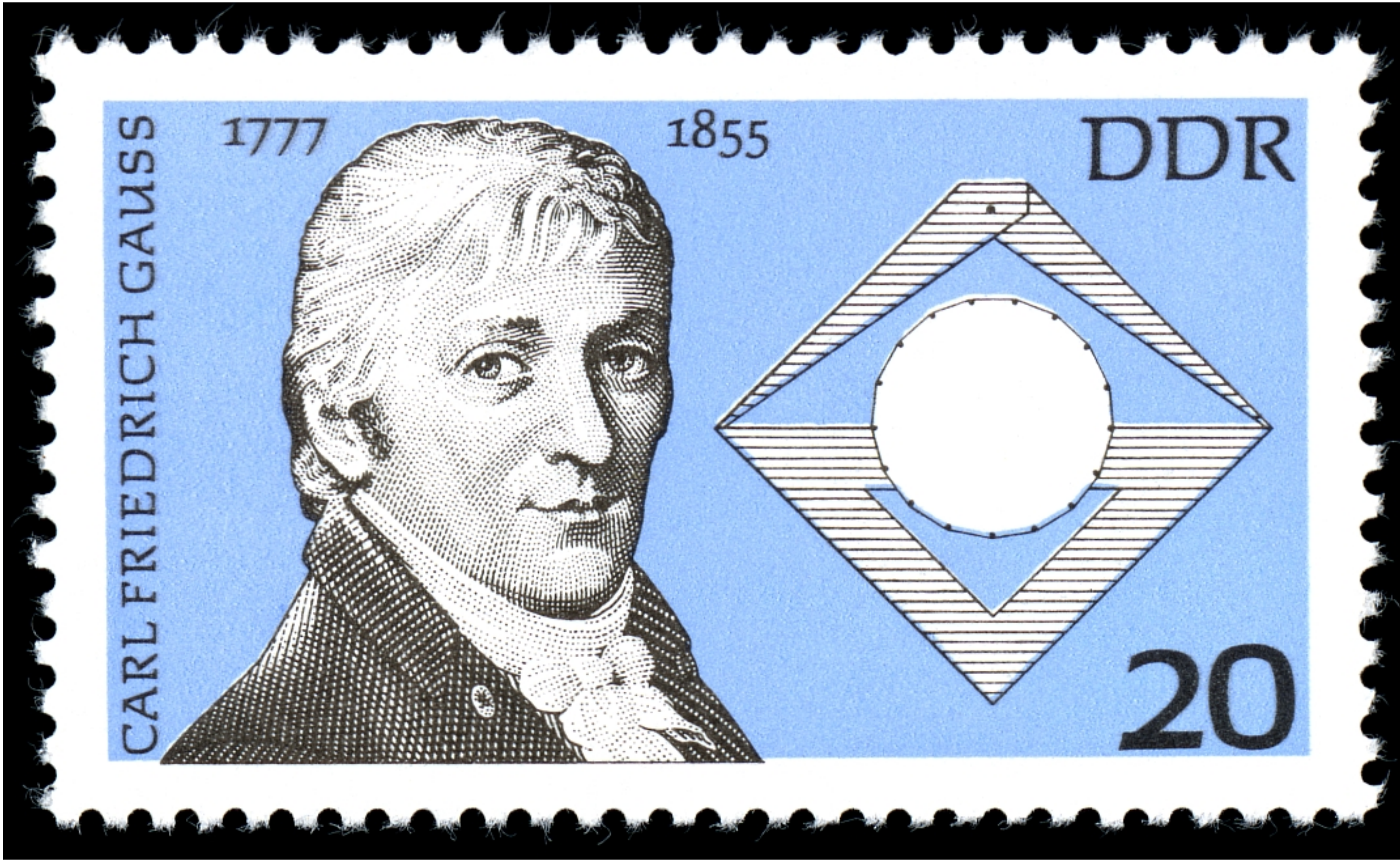



The sum of the angles in a triangle is equal to 180°.
52°
38°
Lines that are parallel somewhere are parallel everywhere.
The shortest distance between two points is a straight line.
C = 2πr
r

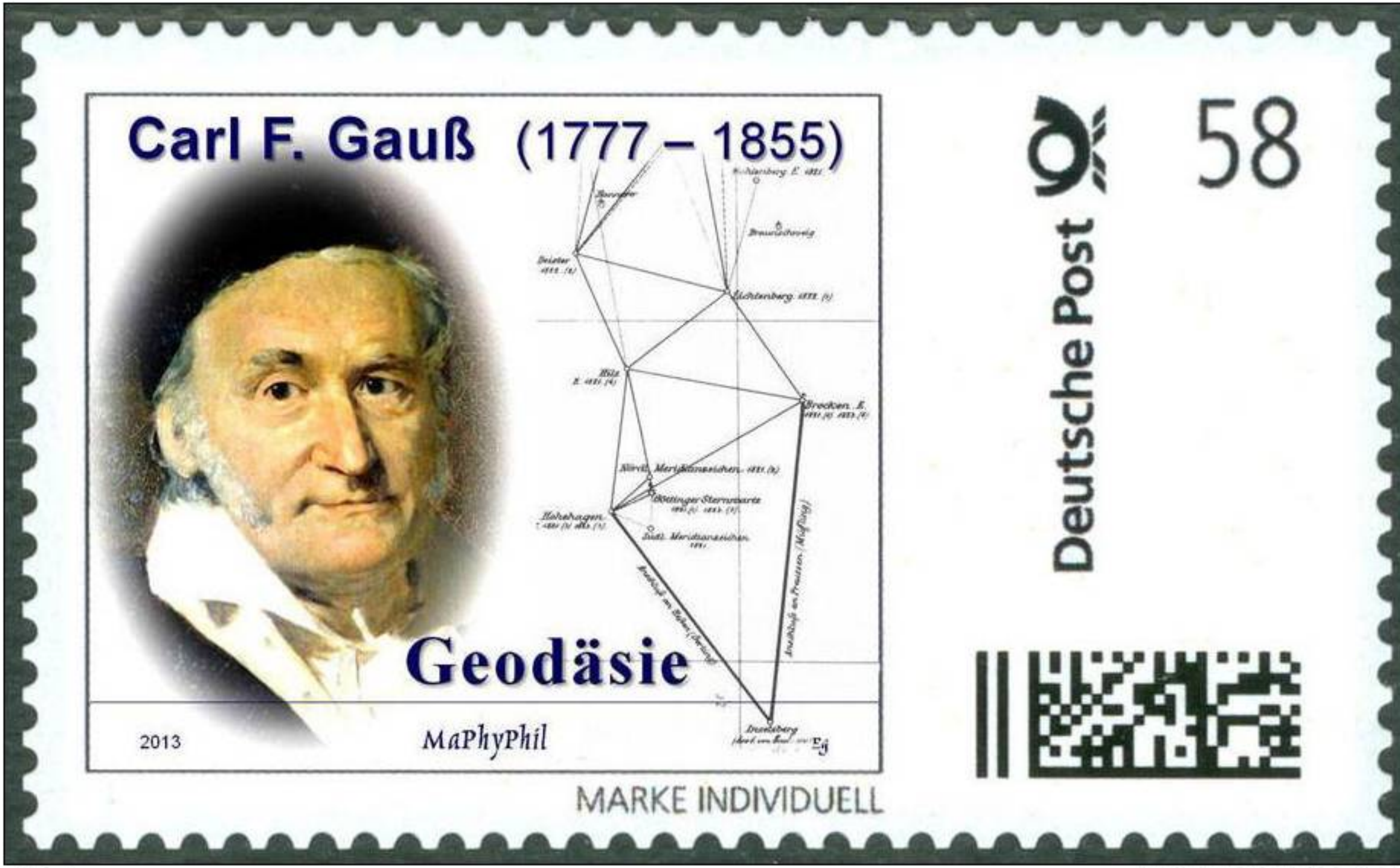

"Lines" parallel at one place eventually cross.
The shortest distance is a curve that is a segment of a great circle.
The sum of the angles of a triangle is greater than 180°.
$C < 2\pi r$
r

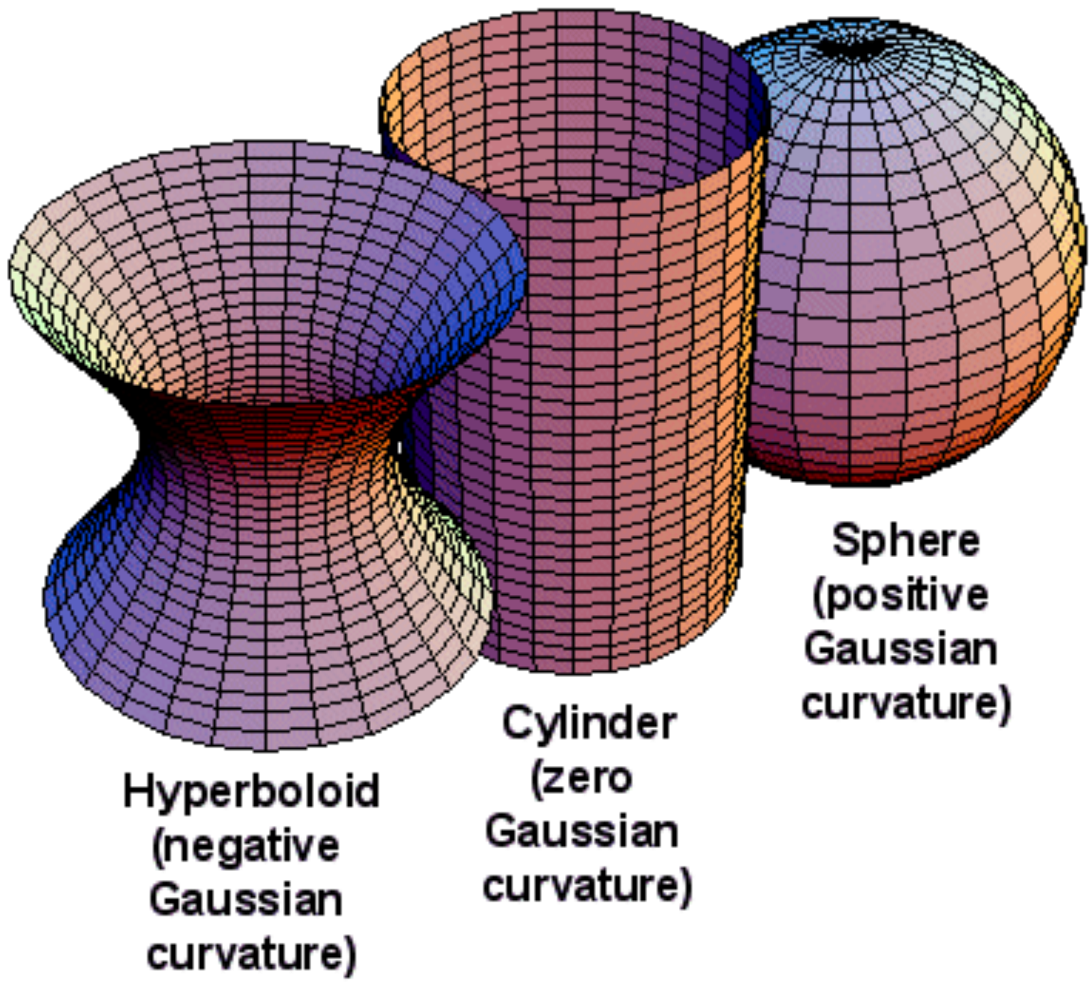


The sum of the angles of a triangle is less than 180°.
C > 2πr
r
The shortest distance is a piece of a hyperbola.
"Lines" that are parallel at one place eventually diverge.



18 years old Gauss proved that a seventeen sided regular polygon can be contructed by ruler-and-compass

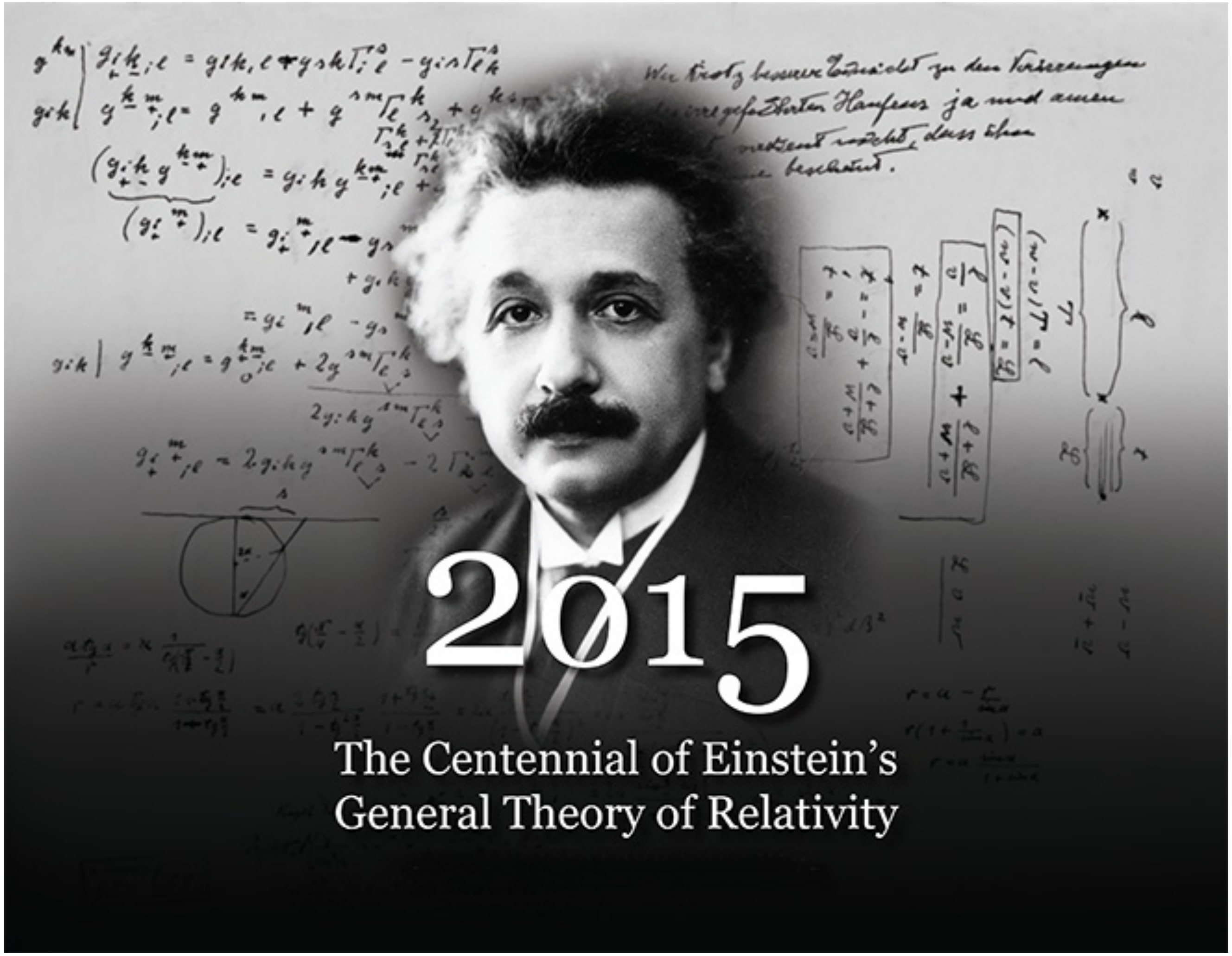

Carl F. Gauß (1777 – 1855)
Geodäsie
2013
MaPhyPhil
Deutsche Post
58
MARKE INDIVIDUELL


Hyperboloid
(negative
Gaussian
curvature)
Cylinder
(zero
Gaussian
curvature)
Sphere
(positive
Gaussian
curvature)

Bernhard Riemann (1826 – 1866)
$ds^2 = \sum_{i,k}^{1\dots n} g_{ik}\, dx_i\, dx_k$
R^n
ALBERT EINSTEIN
n-dimensionale
Mannigfaltigkeiten
2010
MaPhyPhil
Deutsche Post
45
BRIEFMARKE INDIVIDUELL

Pzbrig2

Marcel Grossman 1912.


2015
The Centennial of Einstein's
General Theory of Relativity

Einstein and Hilbert

David Hilbert 1862 - 1943

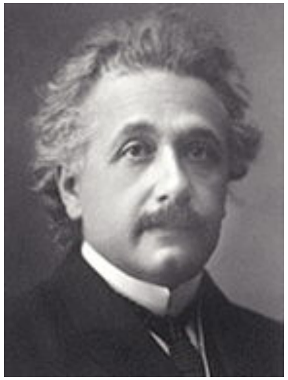
Einstein visited David Hilbert at the University of Gottingen in June and July 1915. Hilbert was very impressed by Einstein's theory but Hilbert being very energetic and brilliant he raced Einstein to find the covariant forms of the equations. This created tremendous pressure on Einstein. Between June 1915 and November 25, 1915 Einstein was a driven man. He worked with superhuman intensity until he finally found the covariant forms of his equations. Hilbert came up with the covariant equations at the same time as Einstein did.

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$


Allgemeine Relativitätstheorie
20. Nov. 1915
Königliche Akademie zu Göttingen :
$\sqrt{g}\,(R_{ik} - ½\, R\, g_{ik}) = - \frac{\partial \sqrt{g}\, L}{\partial g_{ik}}$
D. Hilbert
Gravitations-
gleichungen
25. Nov. 1915
Preußische Akademie
der Wissenschaften :
$R_{ik} = - \gamma\, (T_{ik} - ½\, g_{ik}\, T)$
A. Einstein
2012
MaPhyPhil
Deutsche Post
45
BRIEFMARKE INDIVIDUELL

Albert Einstein, 1915



The general theory of relativity:

- Spacetime is generally curved. Non Euclidean geometry.

The line element $$ds^2 = g_{\mu\nu}\, dx^\mu dx^\nu$$

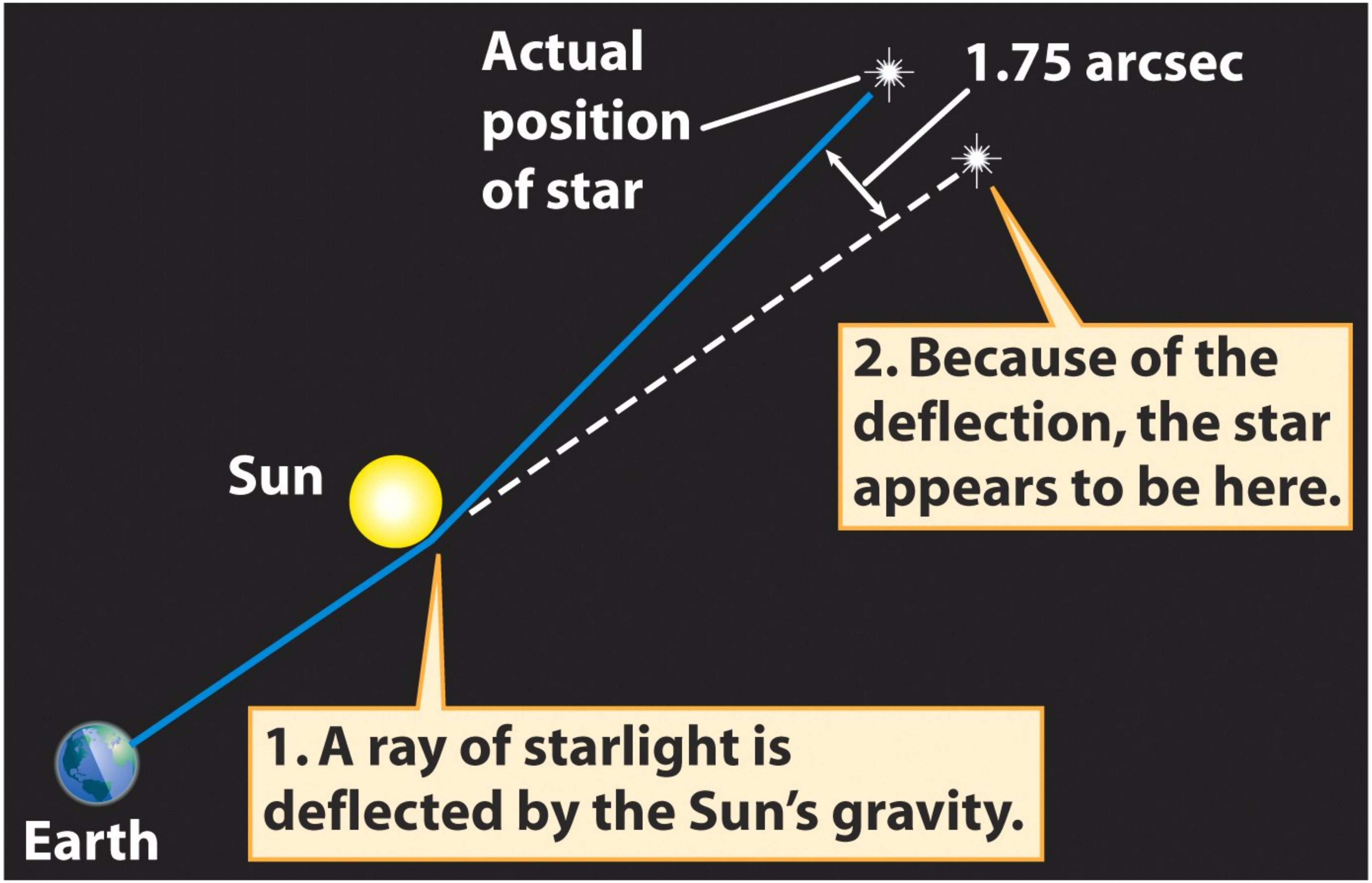
- Matter and energy curve spacetime.

Einstein's field equations: $$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- Curved spacetime tells matter how to move according to the equation of geodesic curves.

The geodesic equation: $$\frac{d^2 x^\mu}{ds^2} + \Gamma^\mu_{\lambda\nu} \frac{dx^\lambda}{ds} \frac{dx^\nu}{ds} = 0$$

Gravitational light deflection



LIGHTS ALL ASKEW IN THE HEAVENS

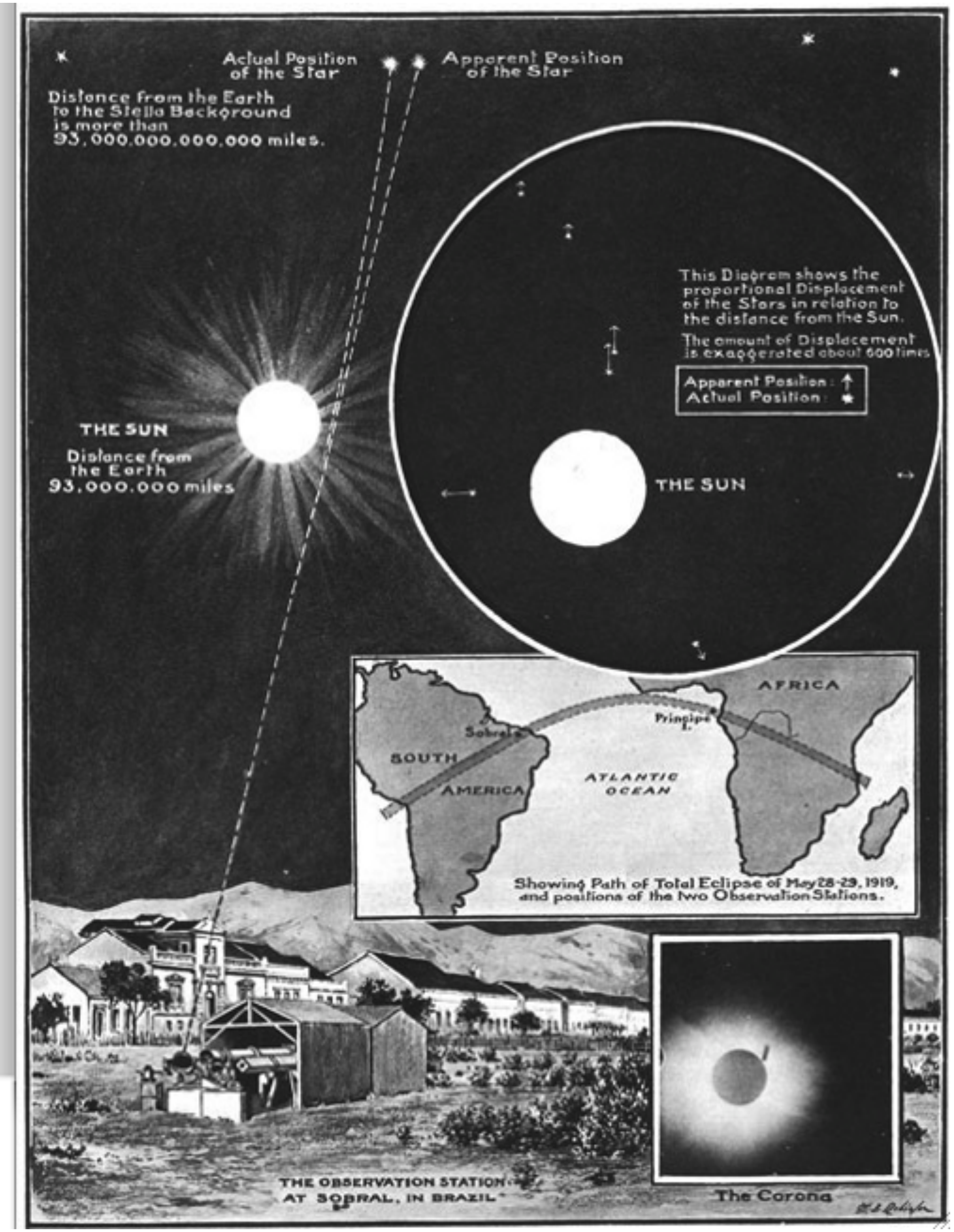
Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

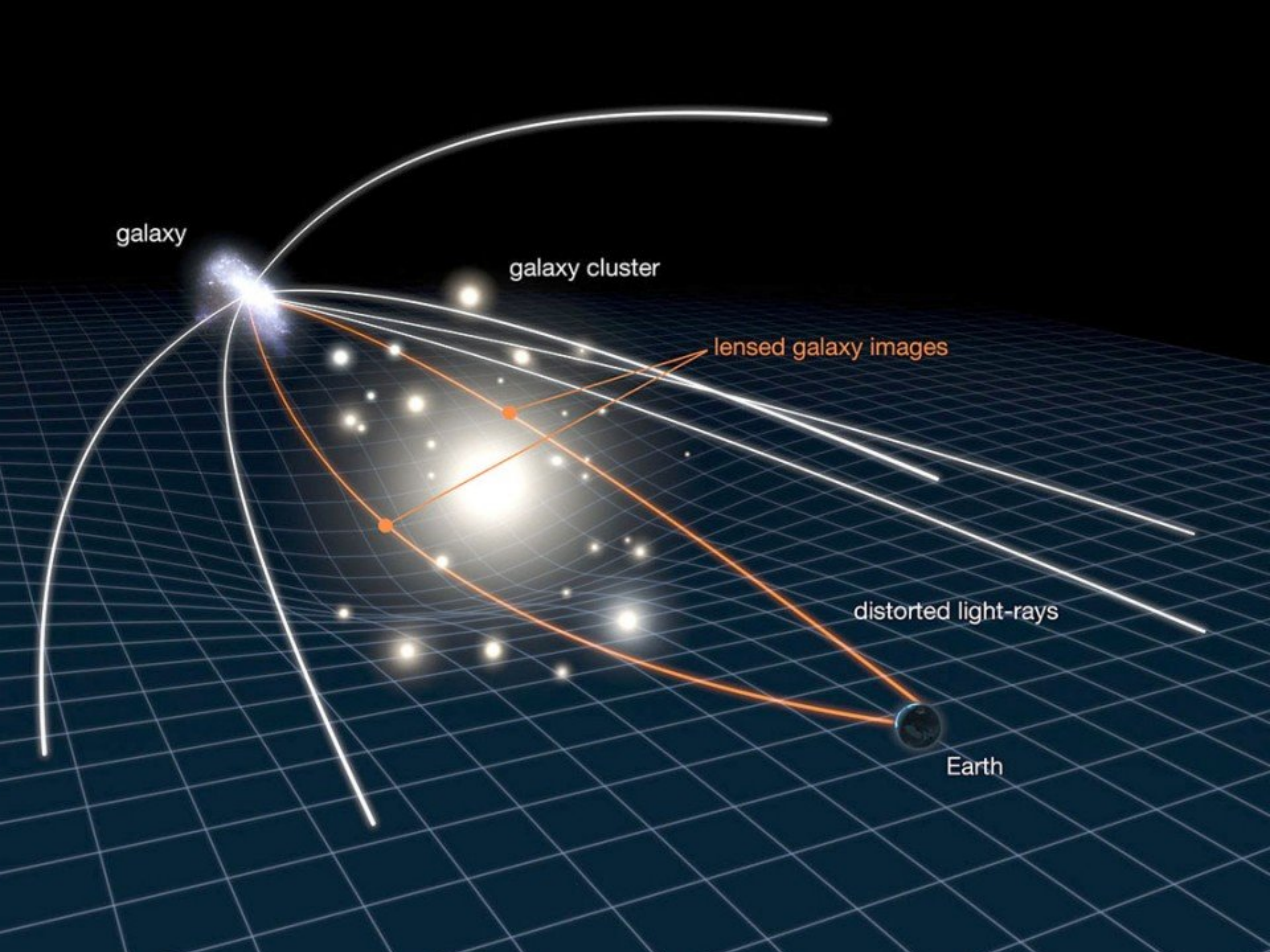
Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

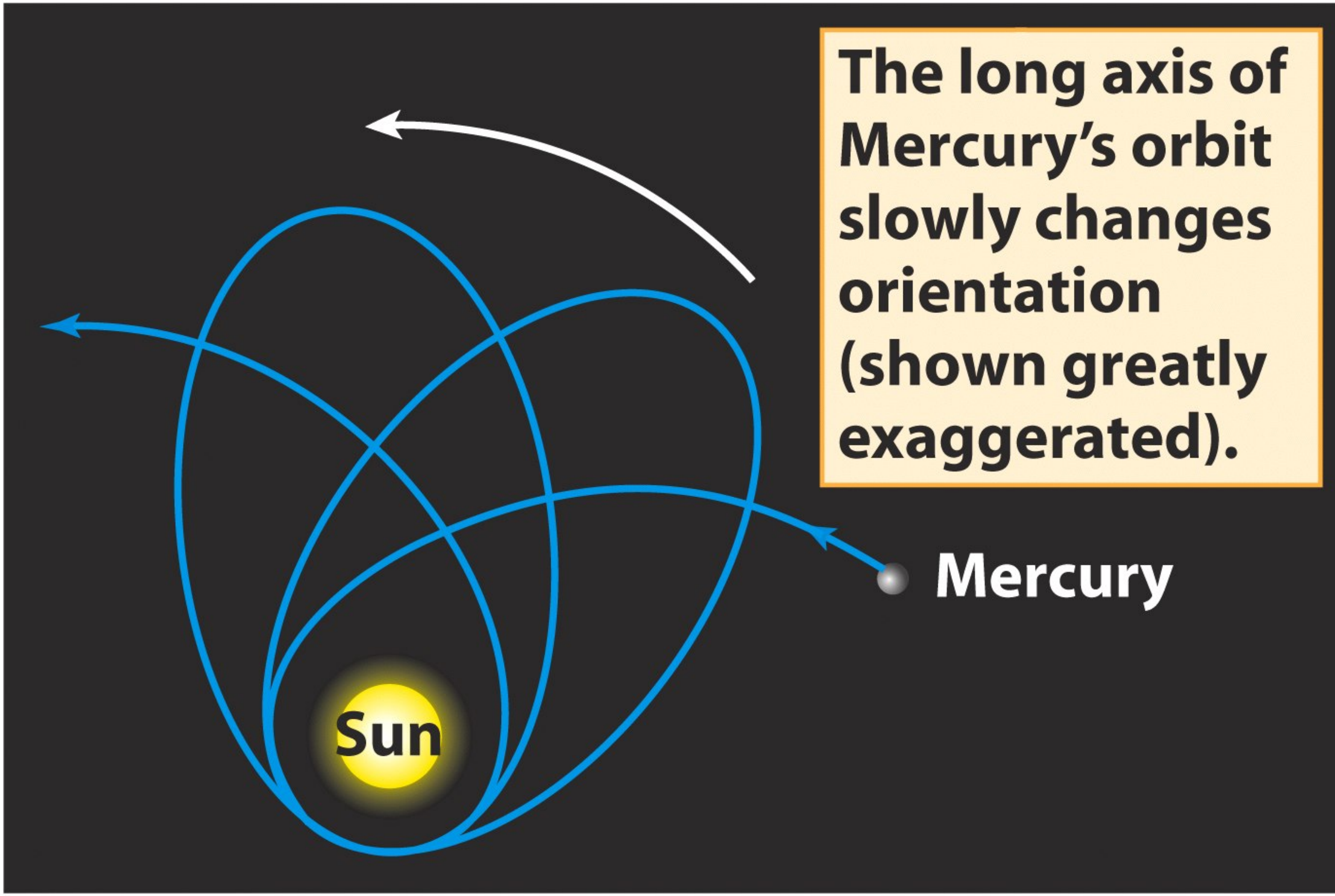
No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.



New York Times, 10 November 1919 (L); Illustrated London News, 22 November 1919 (R)

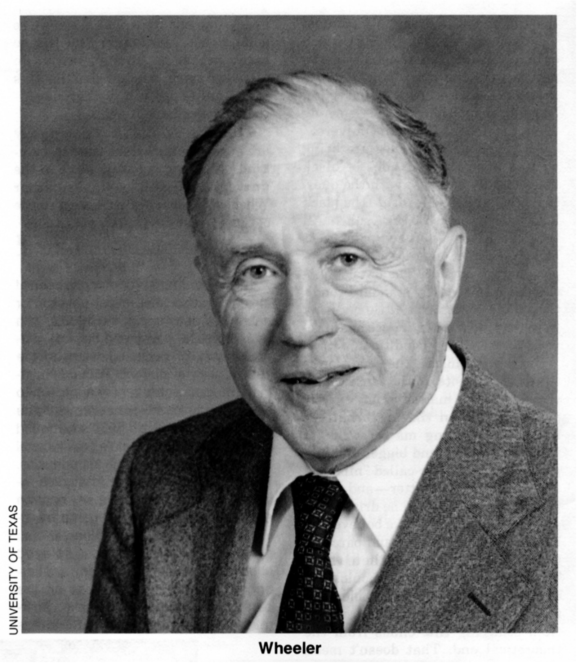

galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

The perihelion prcession of Mercury



When forced to summarize the general theory of relativity in one sentence; *time* and *space* and *gravity* have no separate existence from *matter*

- Albert Einstein



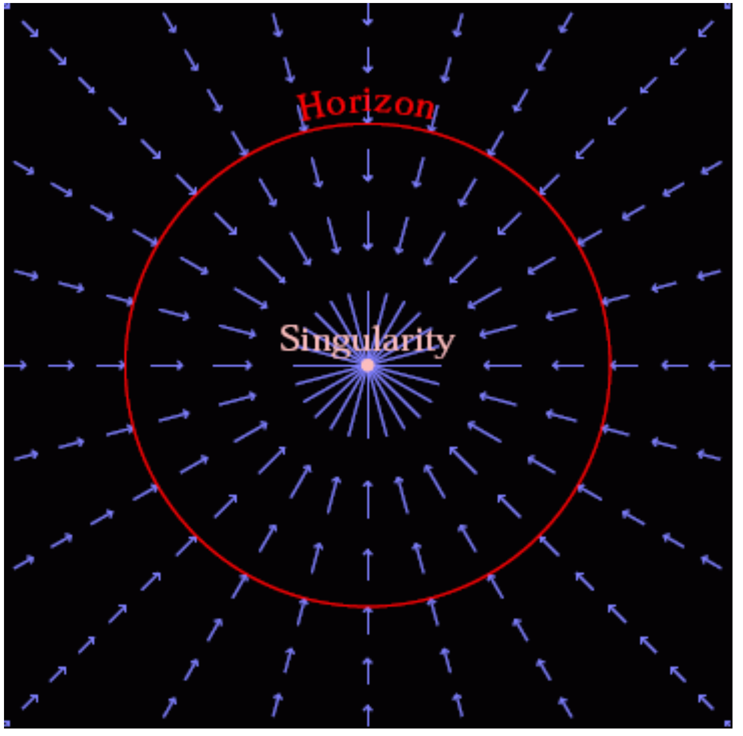
Matter tells *space* how to curve
Space tells *matter* how to move

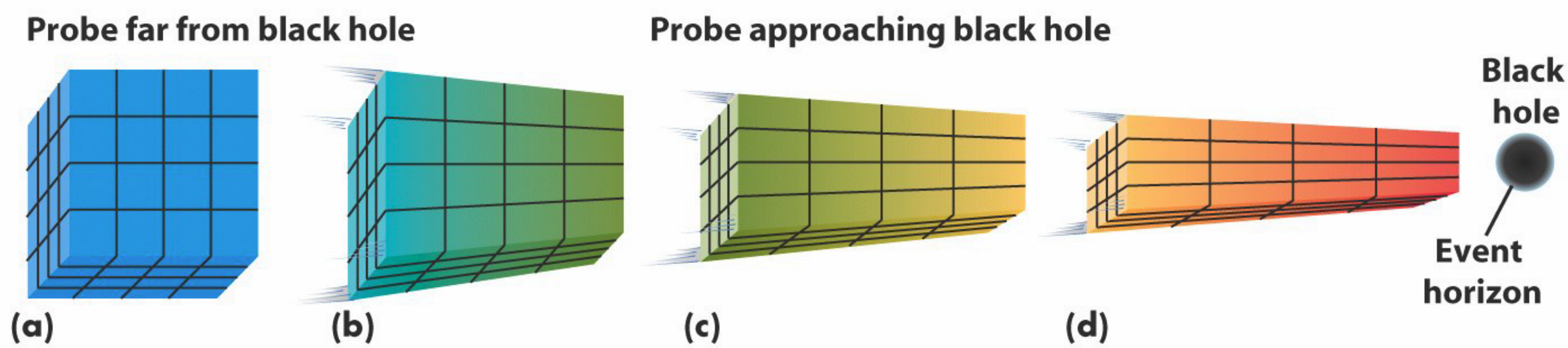
John Archibald Wheeler (1911 – 2008)

A river model of space

Simen Braeck and Øyvind Grøn

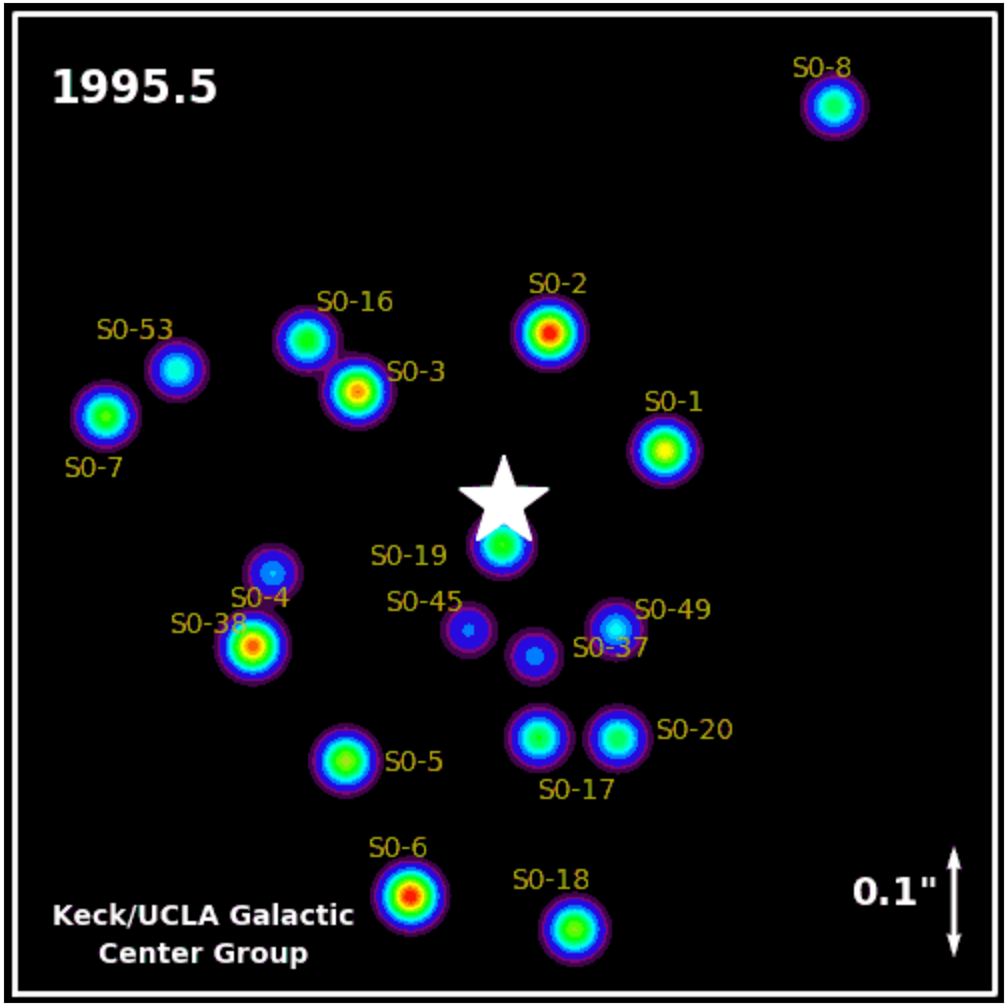
inspired by an article by Andrew J. S. Hamilton and Jason P. Lisle

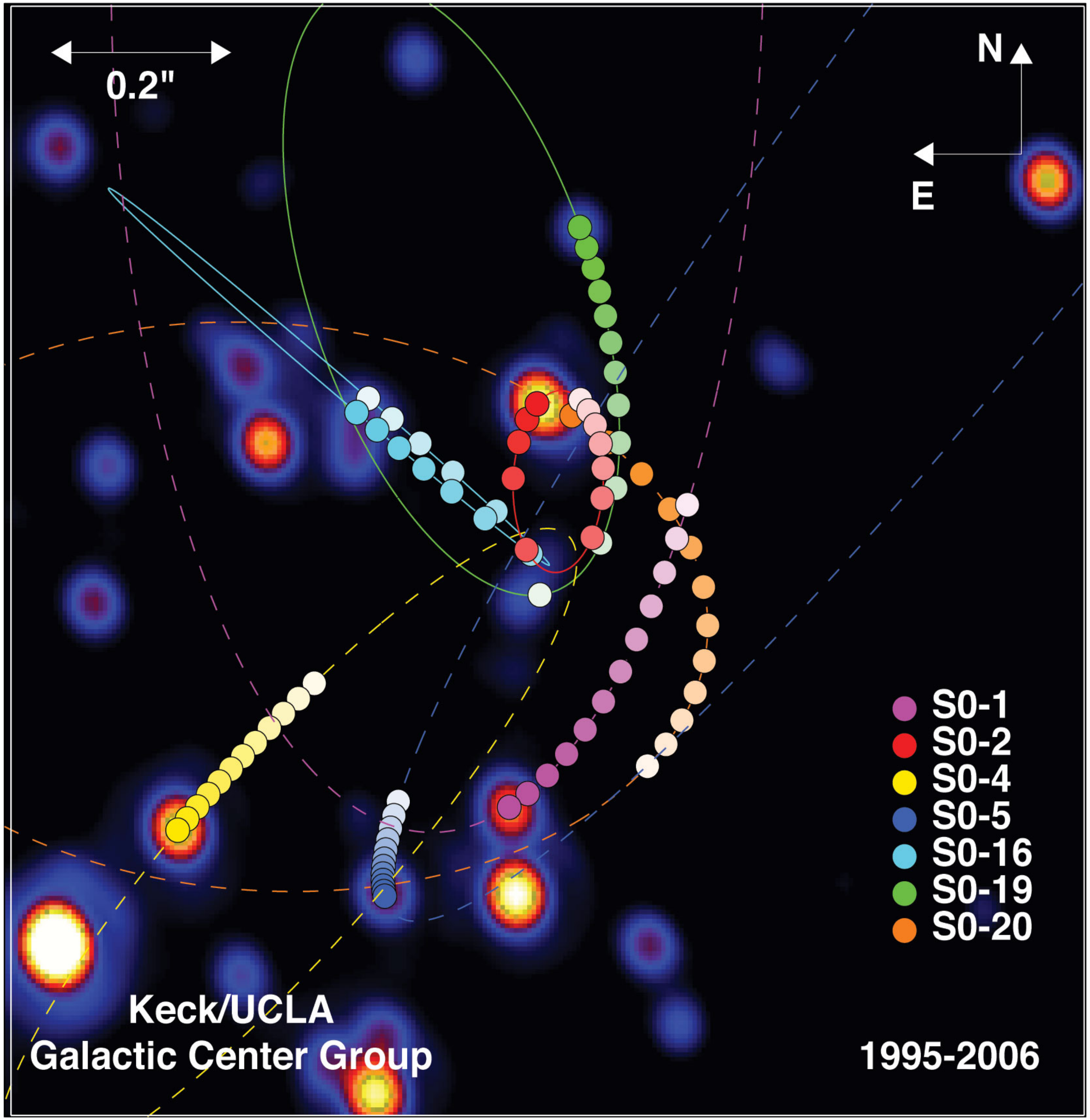




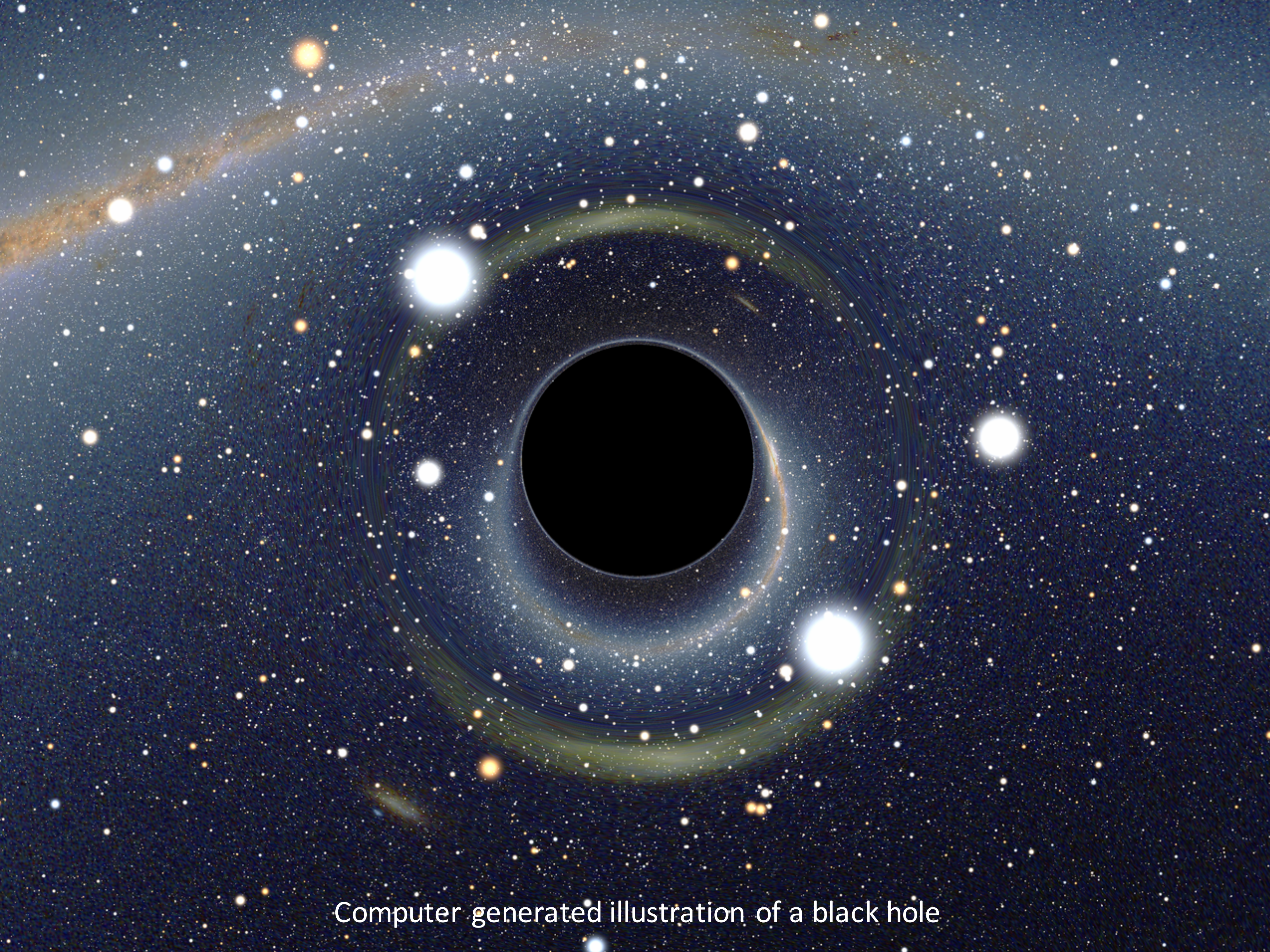
Probe far from black hole
Probe approaching black hole
Black hole
Event horizon
(a)
(b)
(c)
(d)

The motion of the stars close to the center of the Milky way

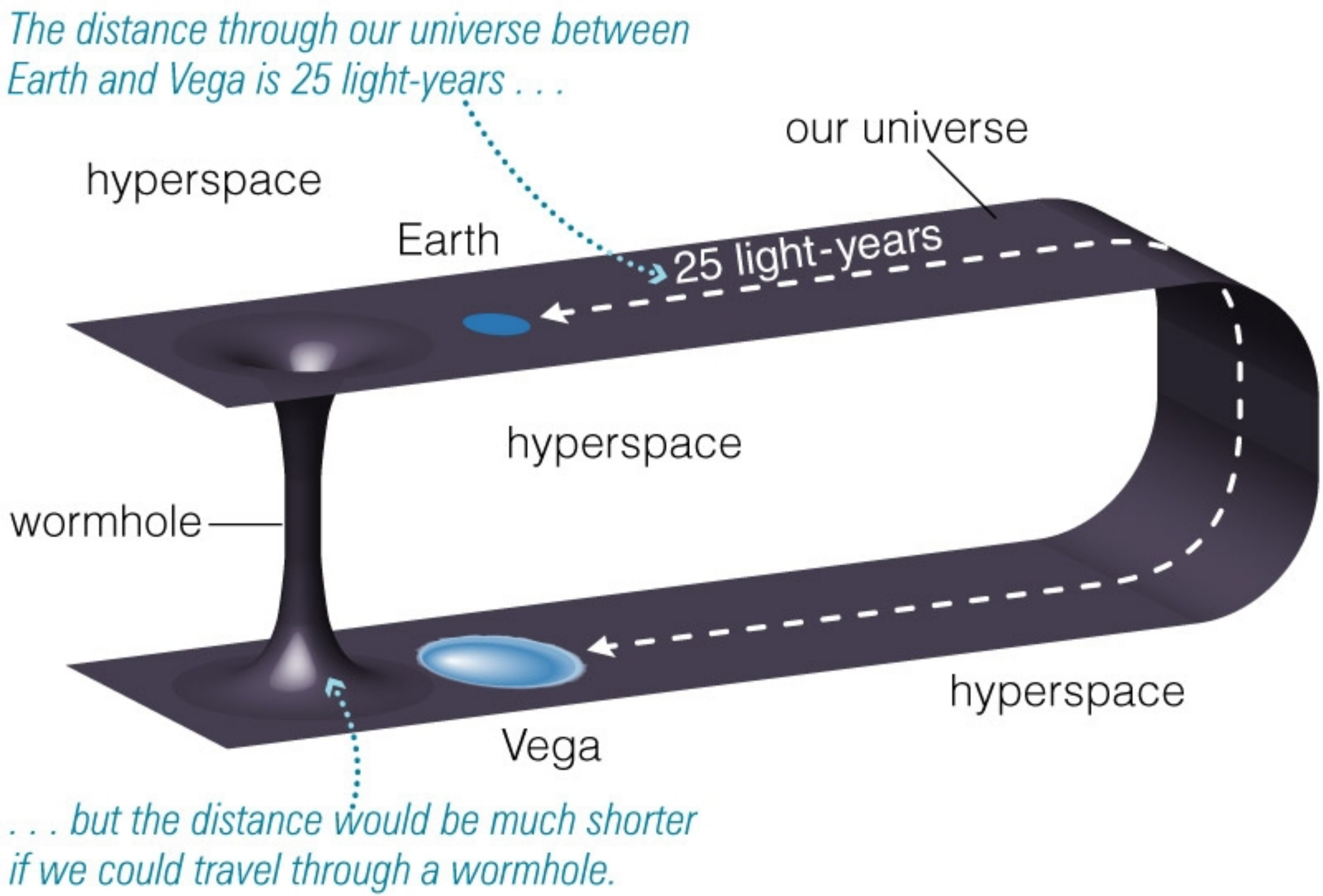


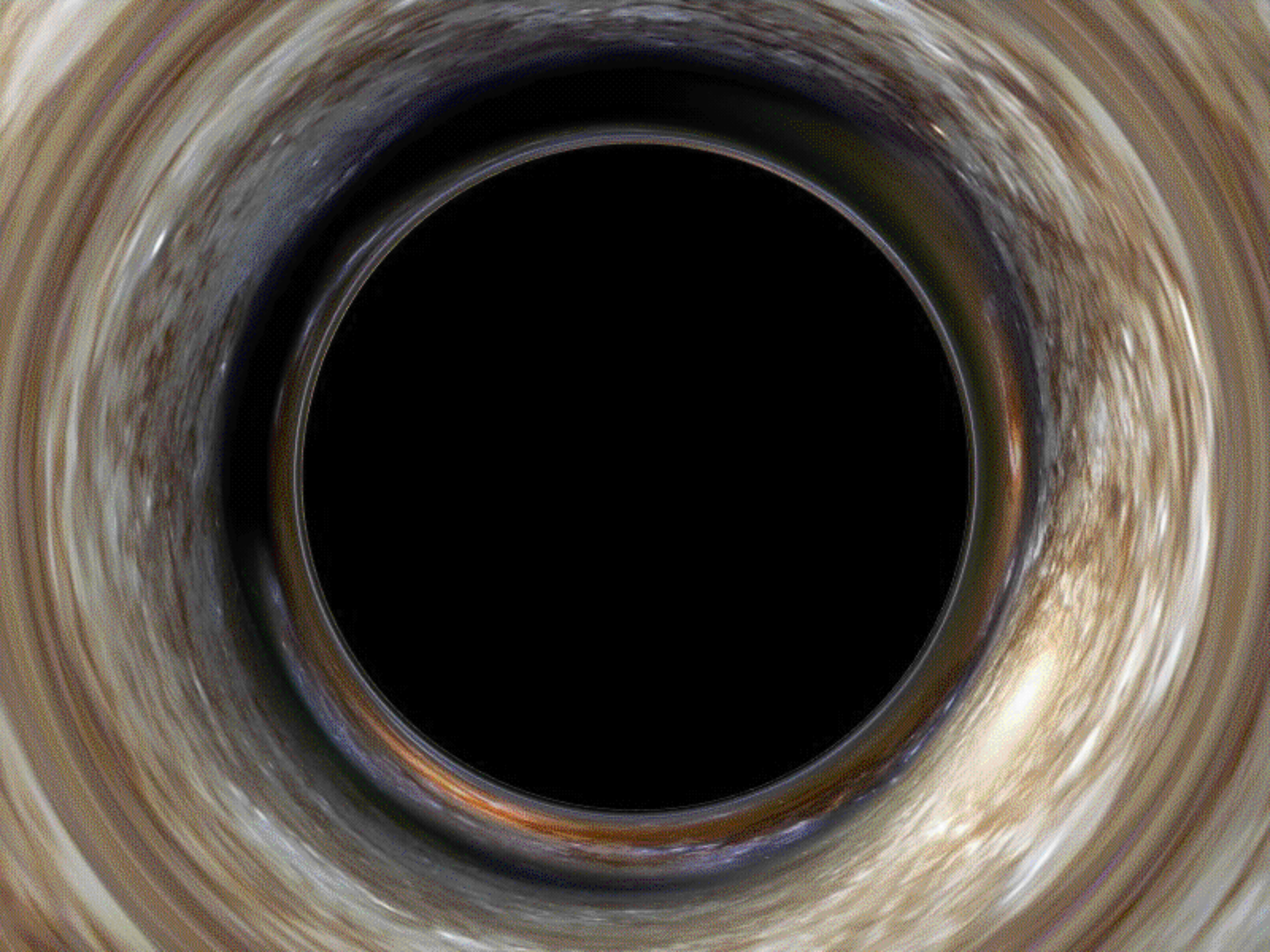


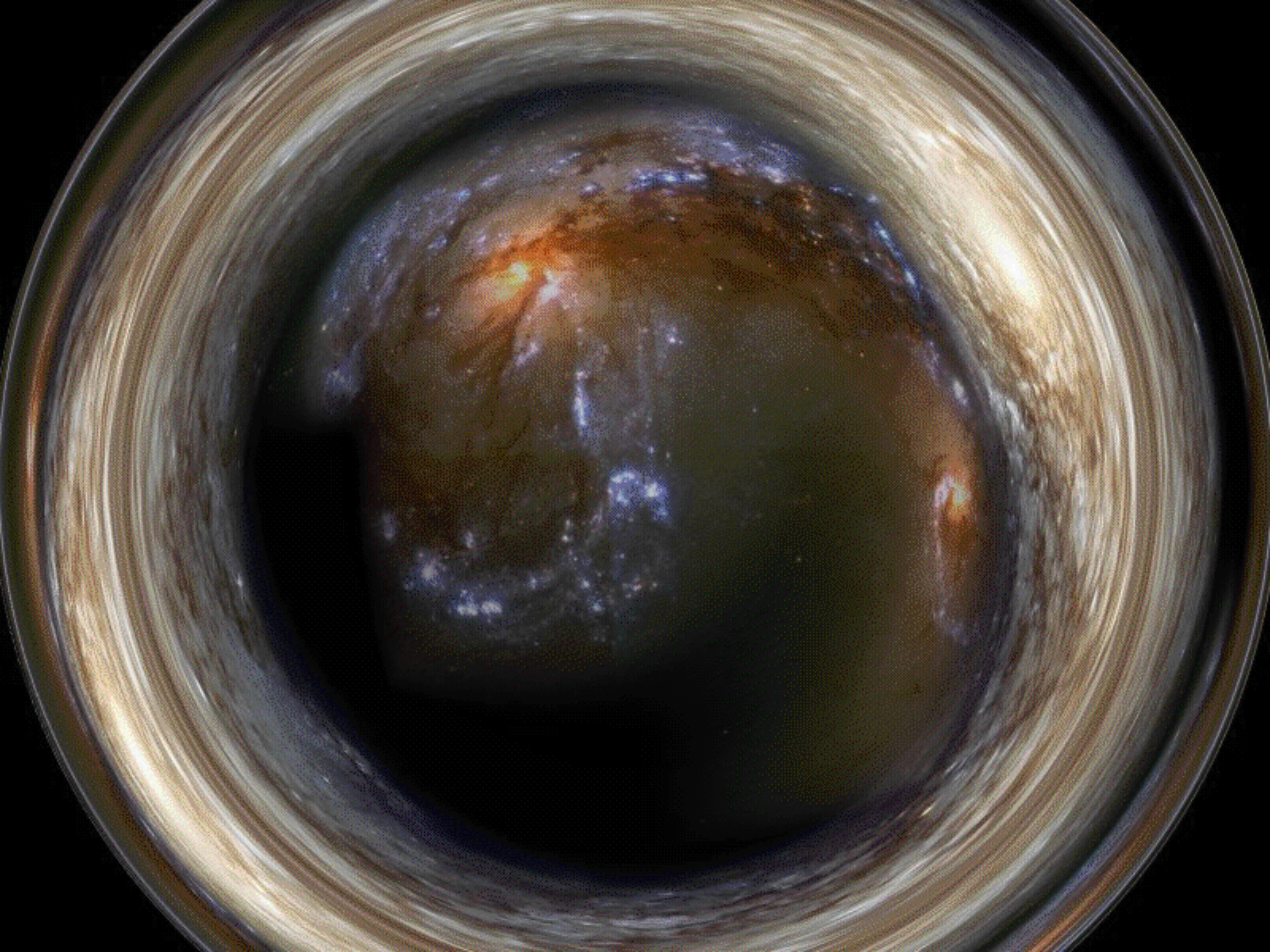
0.2"
N
E
S0-1
S0-2
S0-4
S0-5
S0-16
S0-19
S0-20
Keck/UCLA
Galactic Center Group
1995-2006



Computer generated illustration of a black hole


The distance through our universe between Earth and Vega is 25 light-years . . .
our universe
hyperspace
Earth
25 light-years
hyperspace
wormhole
hyperspace
Vega
. . . but the distance would be much shorter if we could travel through a wormhole.






Panasonic
AS SERIOUS AS YOU CAN GET
Sidewalks of New York


Worth1000.com
Status: STABLE

Elie Cartan 1869 – 1951

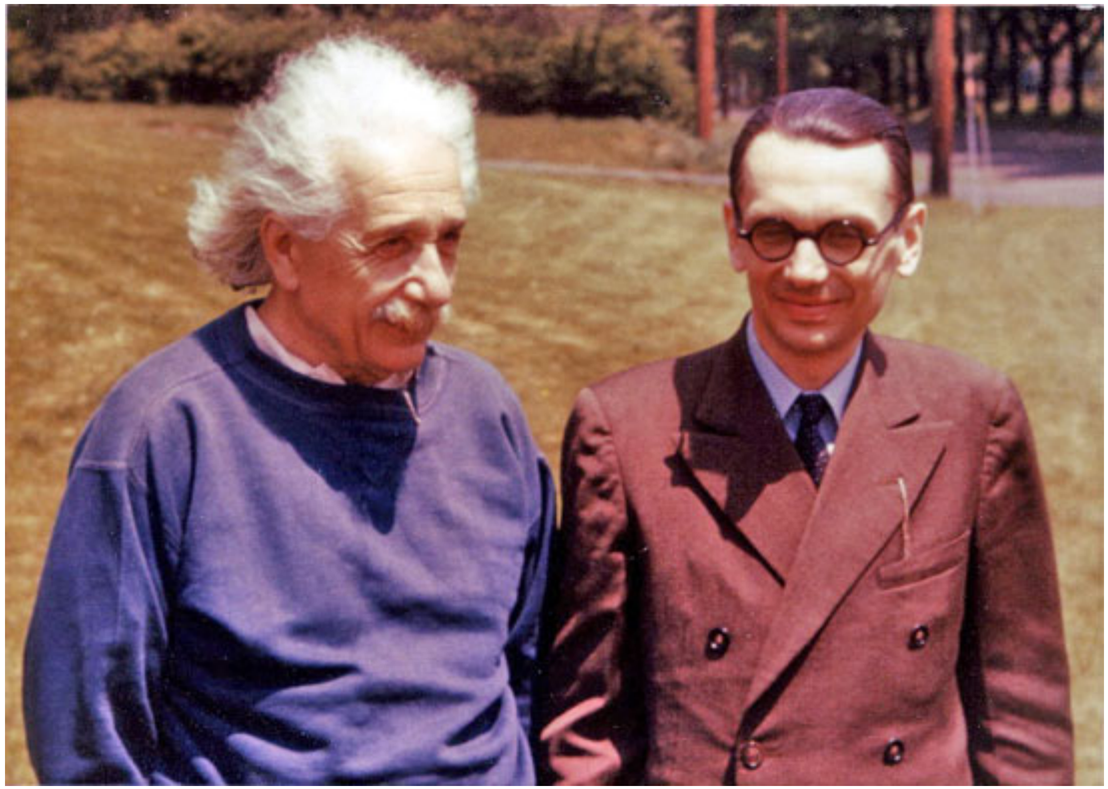
Cartan constructed
an antisymmetric tensor formalism:
The theory of differential forms.

He formulated Einstein's equations
in terms of forms.

Also he generalized Einstein's
General theory of relativity
by constructing a new theory
where spacetime not only
had curvature, but also
a new property called *torsion*,
a sort of twist.

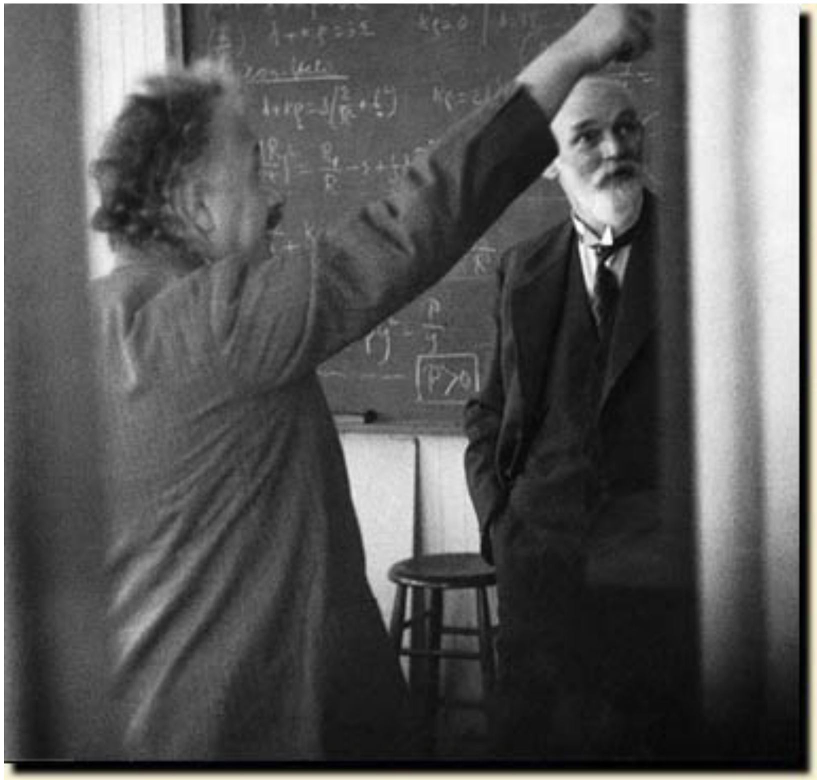
Emmy Noether 1882 - 1935

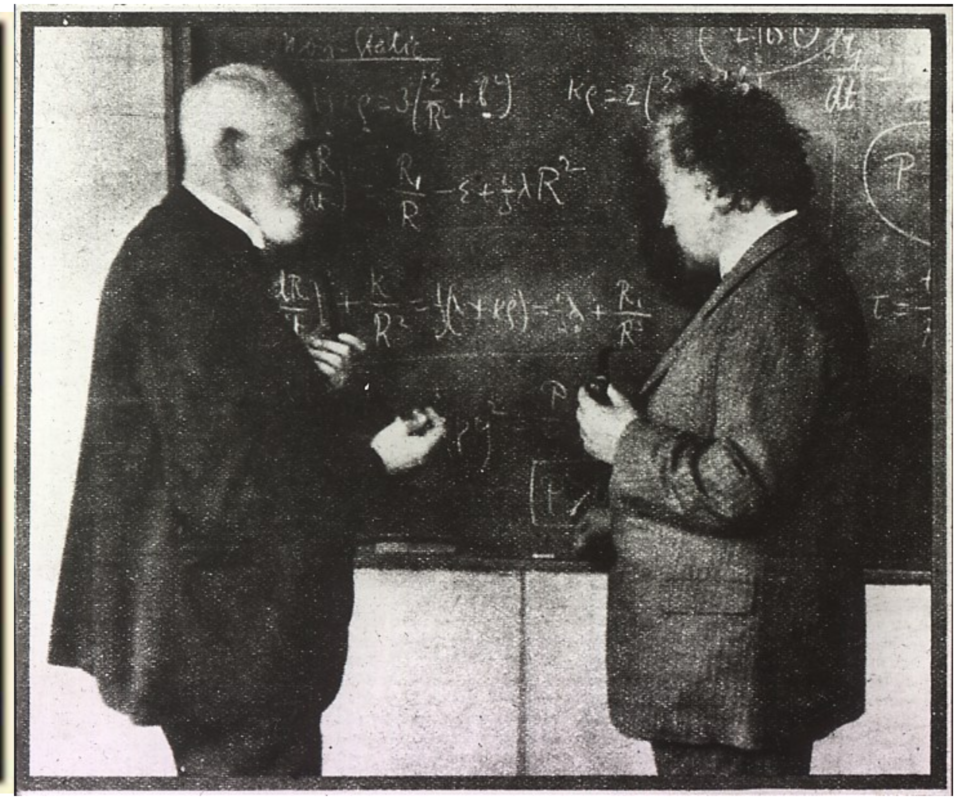
Emmy Noether proved that
to every symmetry
there belongs
a conserved quantity.



Albert Einstein and Kurt Gödel

Gödel constructed a rotating universe model as a solution of Einstein’s field equations

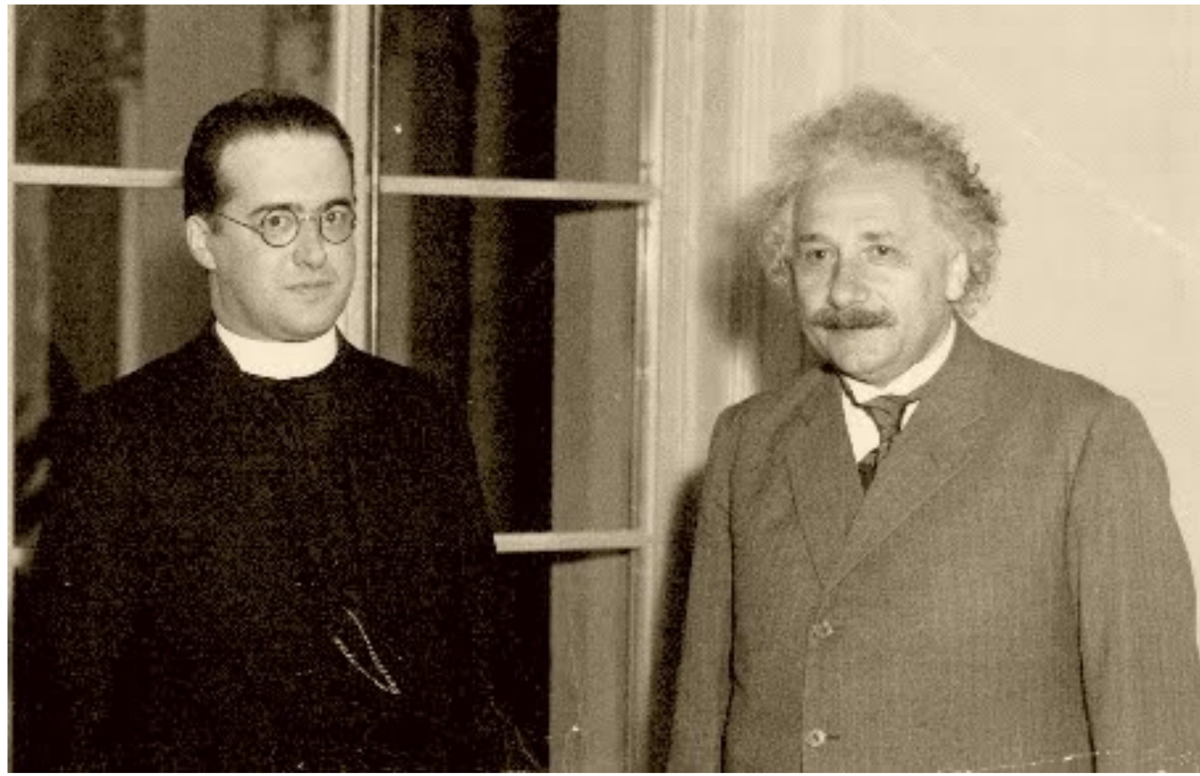




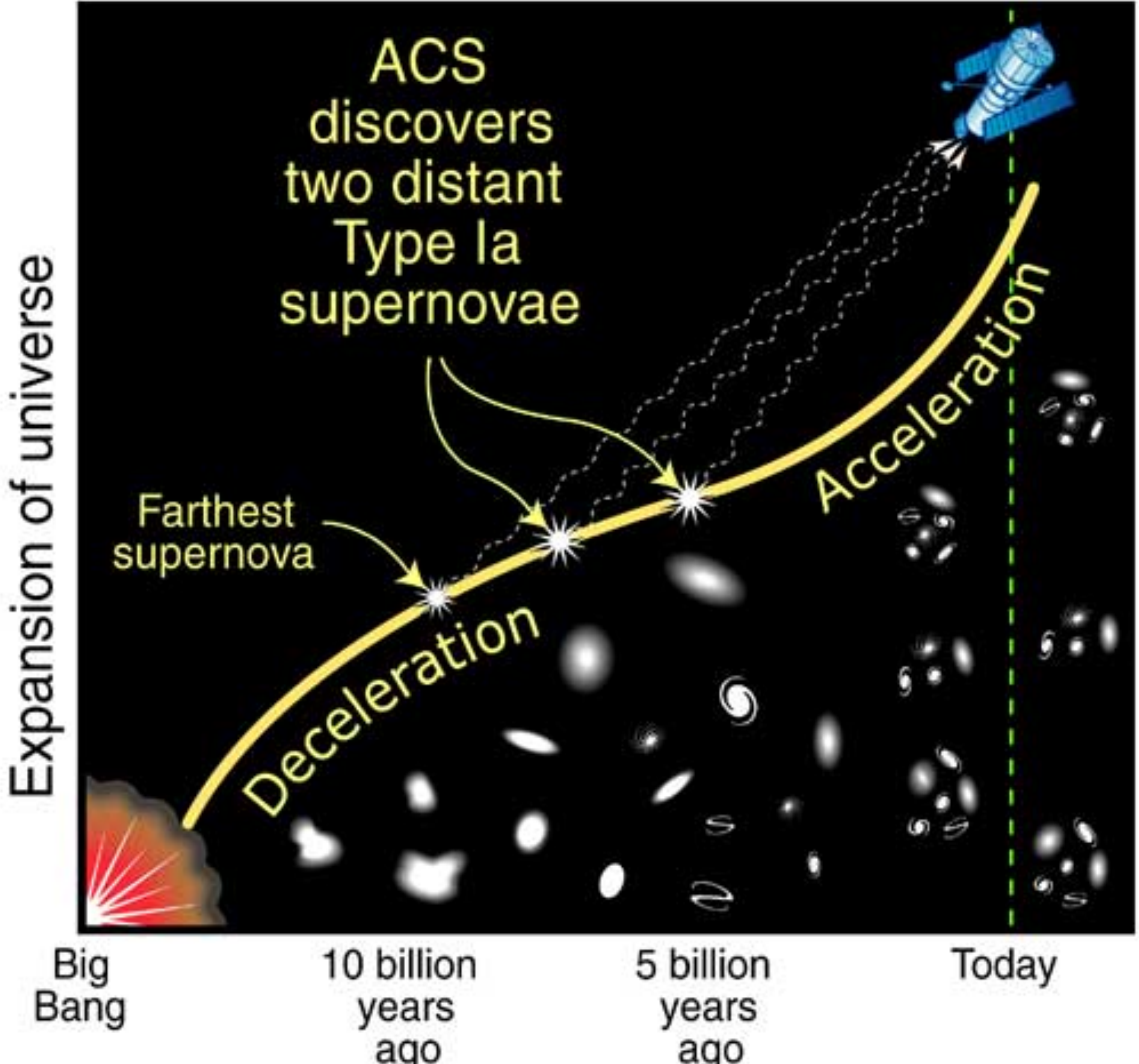
Einstein and De Sitter 1932

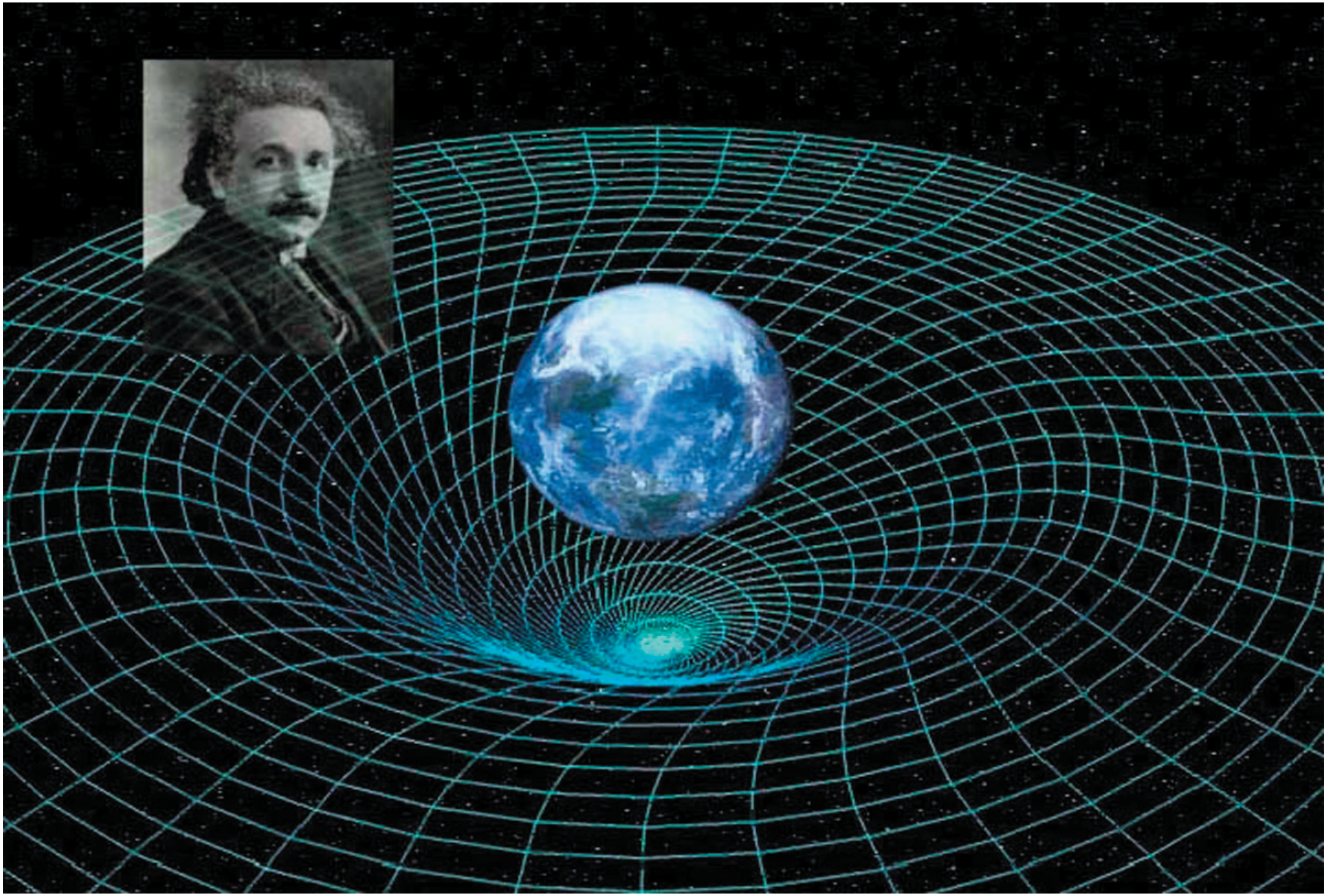
They constructed the so called Einstein-de Sitter universe model,

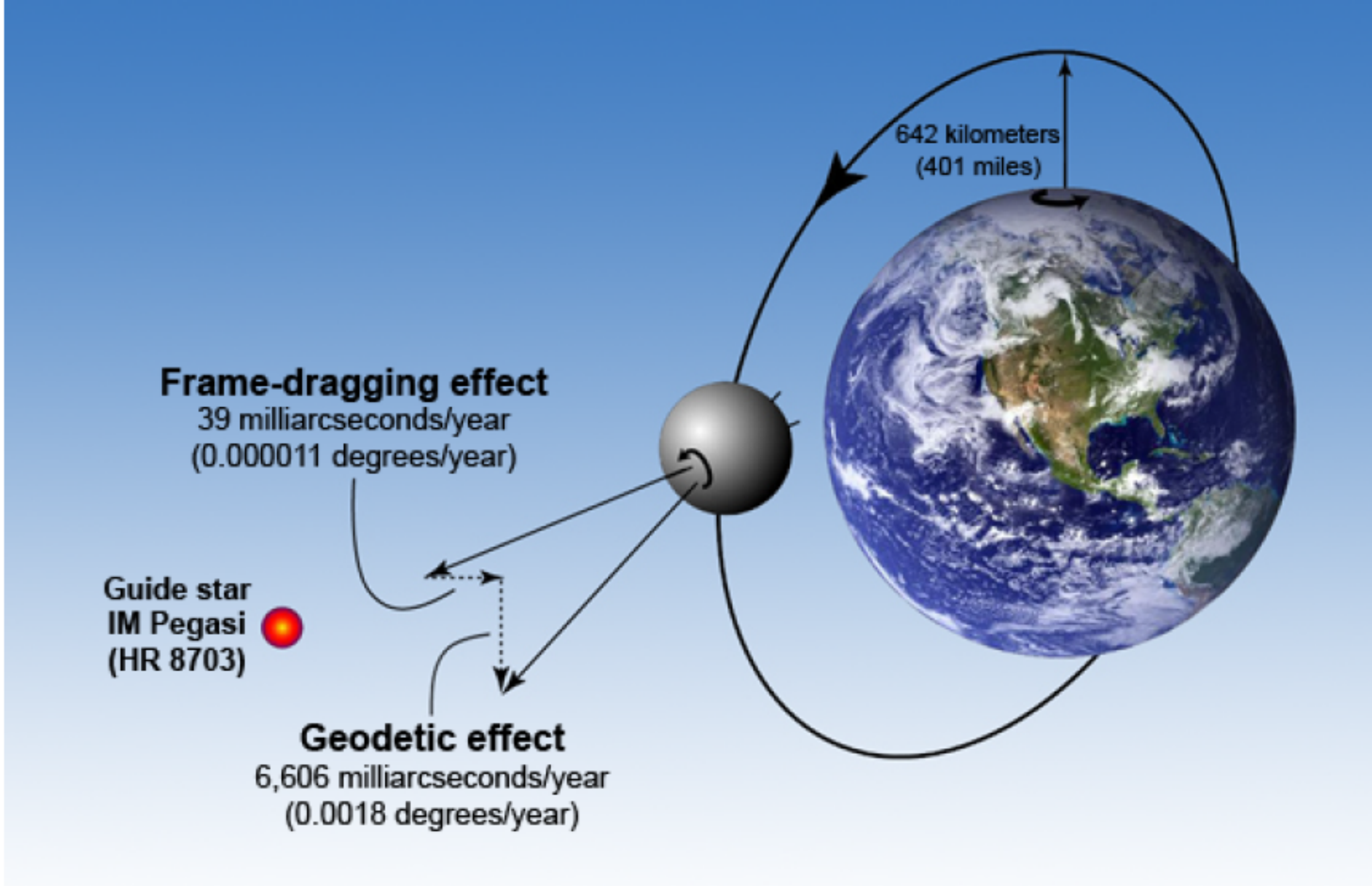
a model with Euclidean spatial geometry filled by cold, pressure free matter.



Alexander Friedmann 1888-1925 Georges Lemaitre 1894-1966 with Einstein


ACS discovers two distant Type Ia supernovae
Farthest supernova
Deceleration
Acceleration
Expansion of universe
Big Bang
10 billion years ago
5 billion years ago
Today





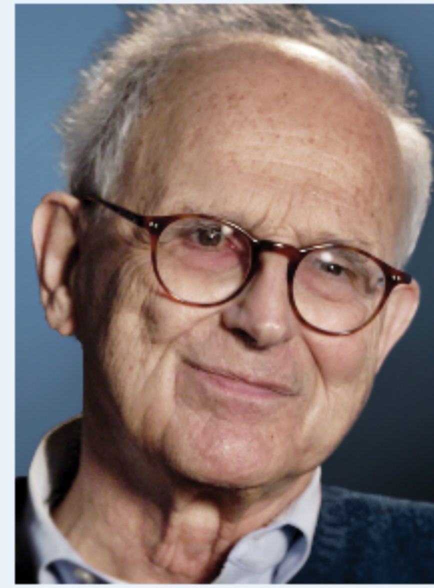
	Measured	Predicted
Geodetic precession (mas)	6602 ± 18	6606
Frame-dragging (mas)	37.2 ± 7.2	39.2

https://delorian64.wordpress.com/page/5/

The Norwegian Academy of Science and Letters awards the 2016 Kavli Prize in Astrophysics to:

Ronald Drever
California Institute of Technology, USA

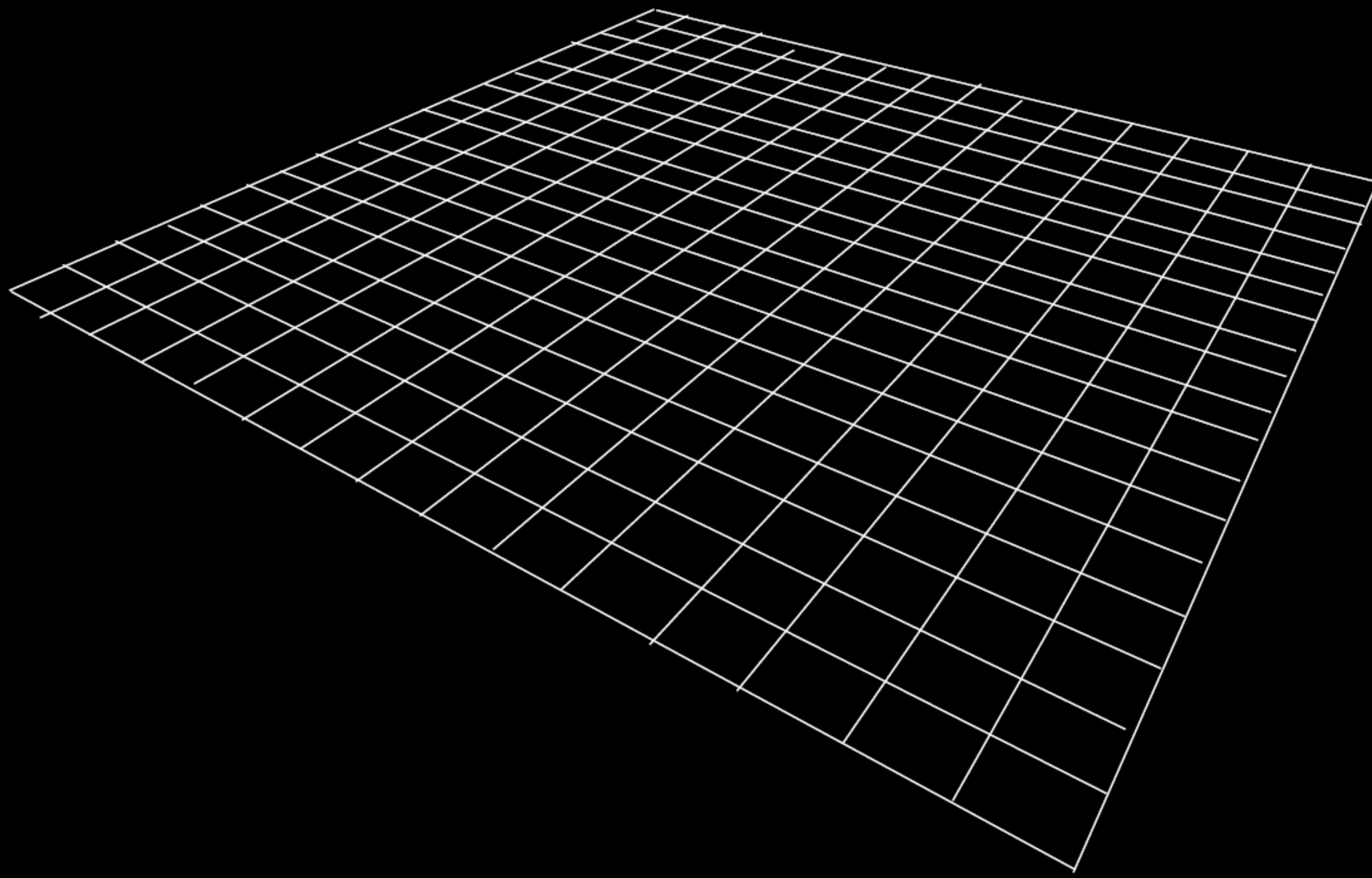
Kip Thorne
California Institute of Technology, USA

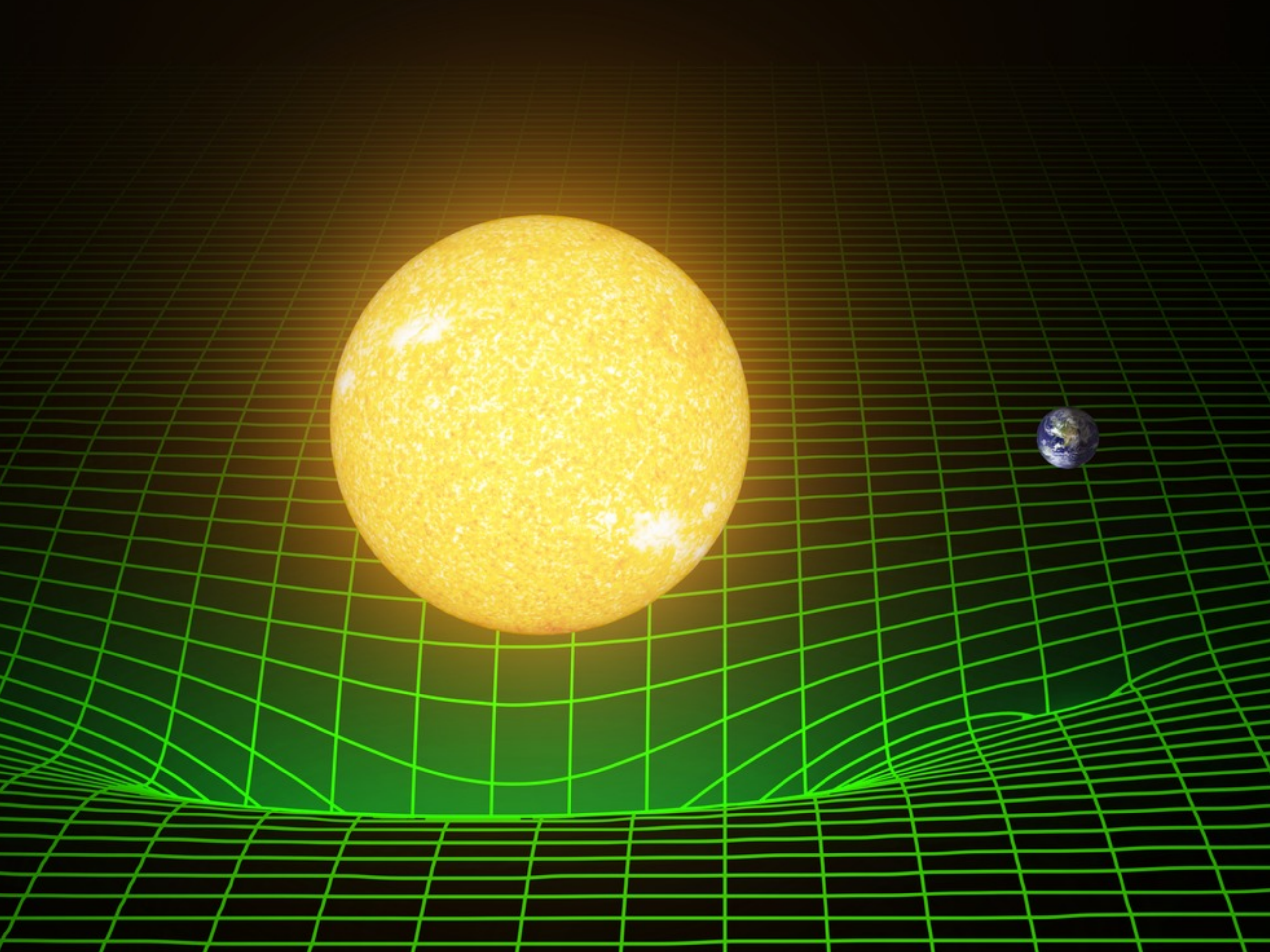


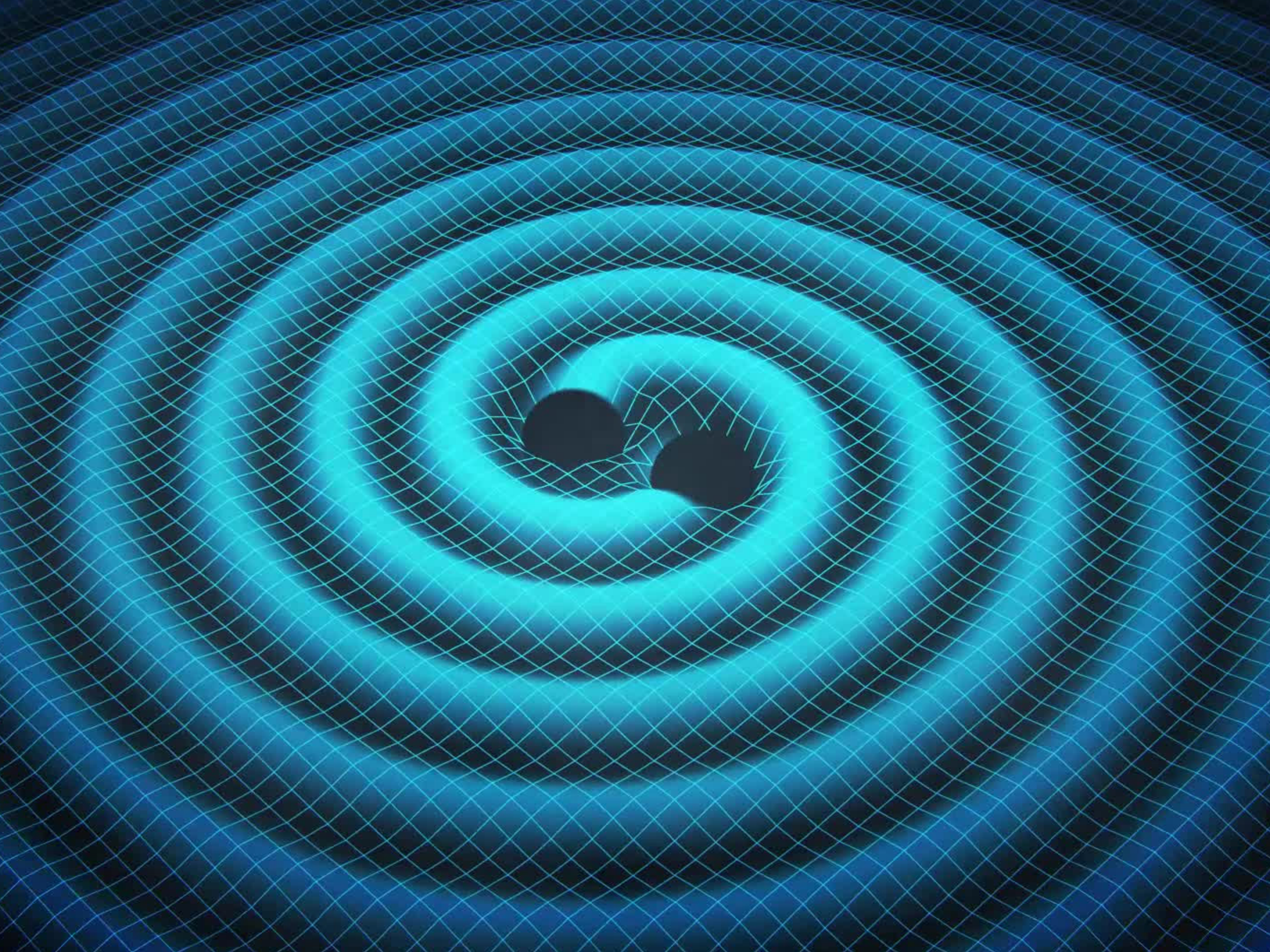
Rainer Weiss
Massachusetts Institute of Technology, USA

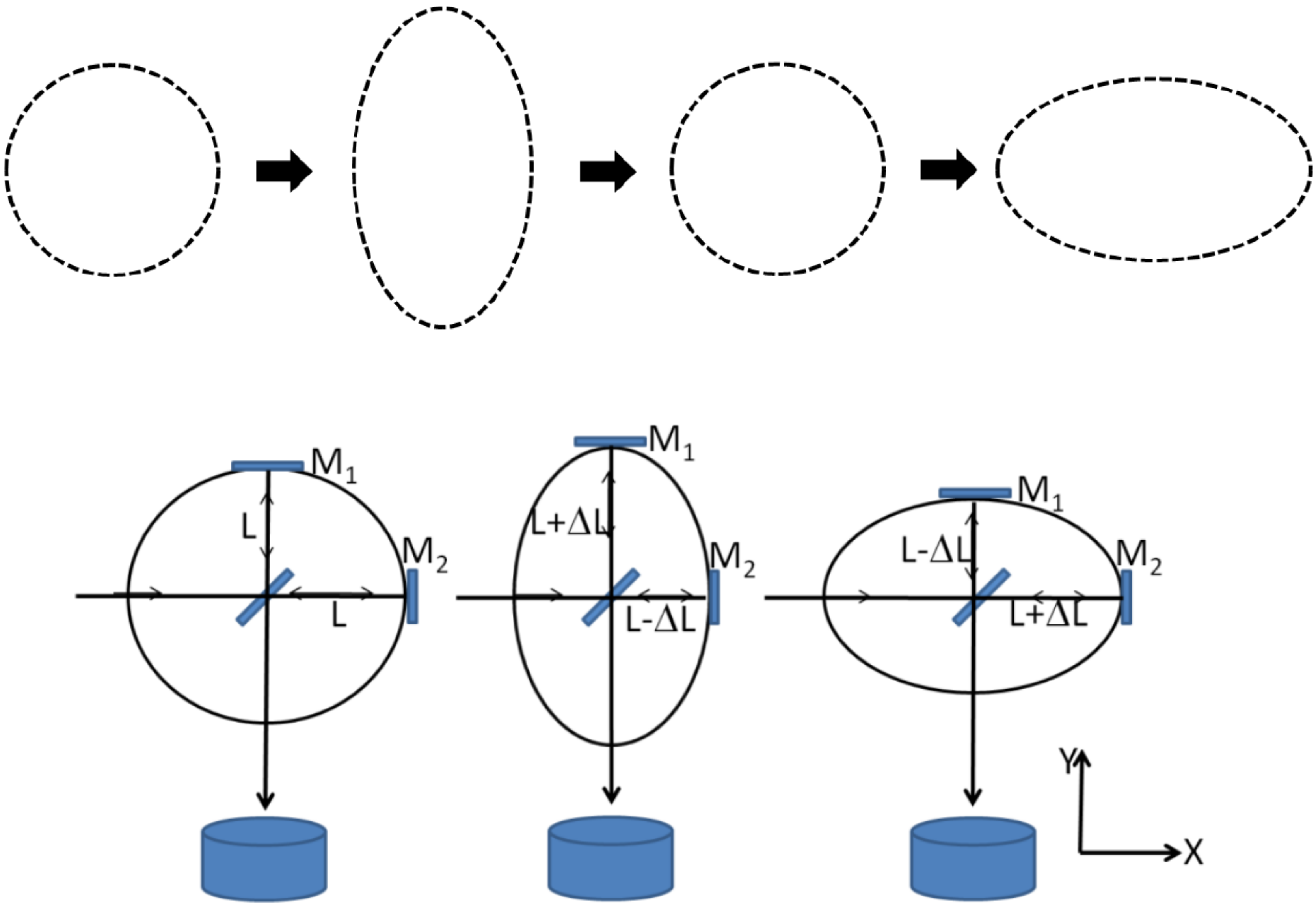
"for the direct detection of gravitational waves."

Mass-free “flat” Space-time

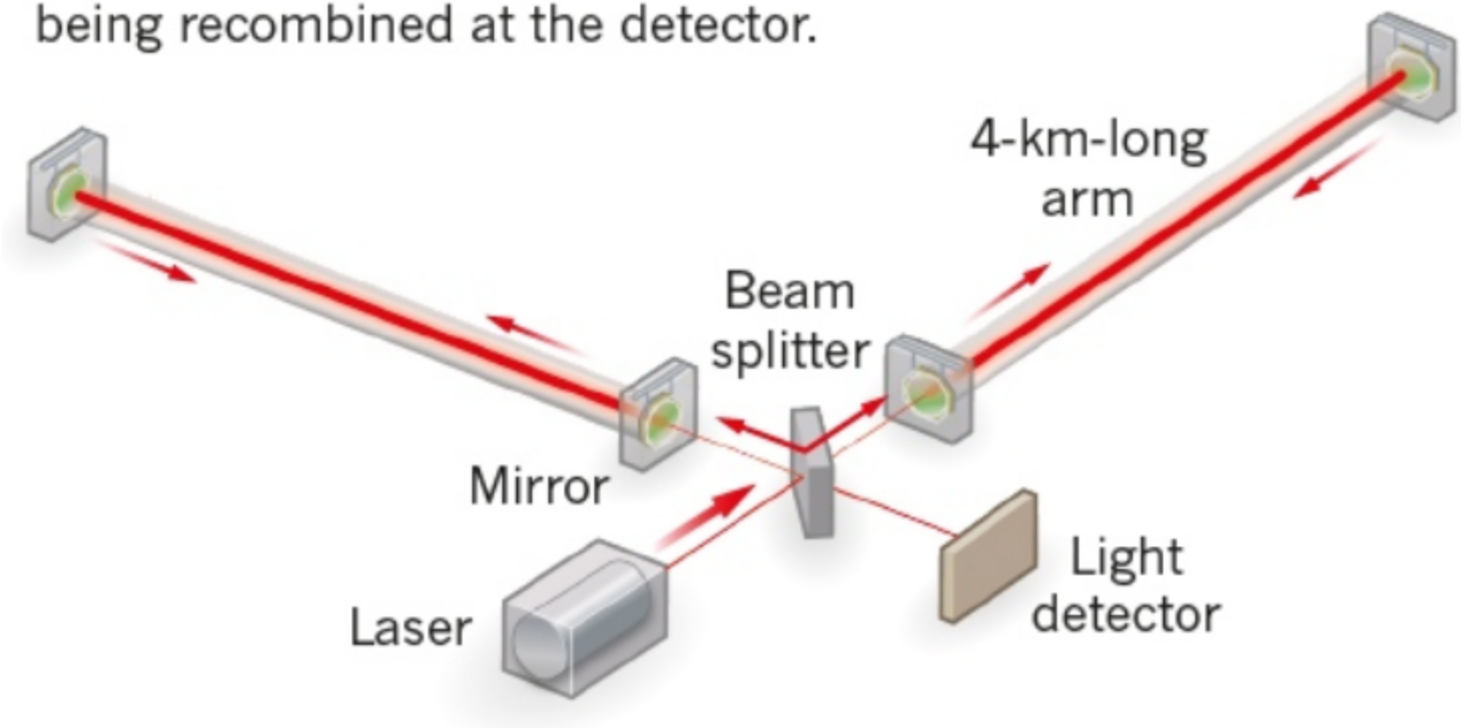




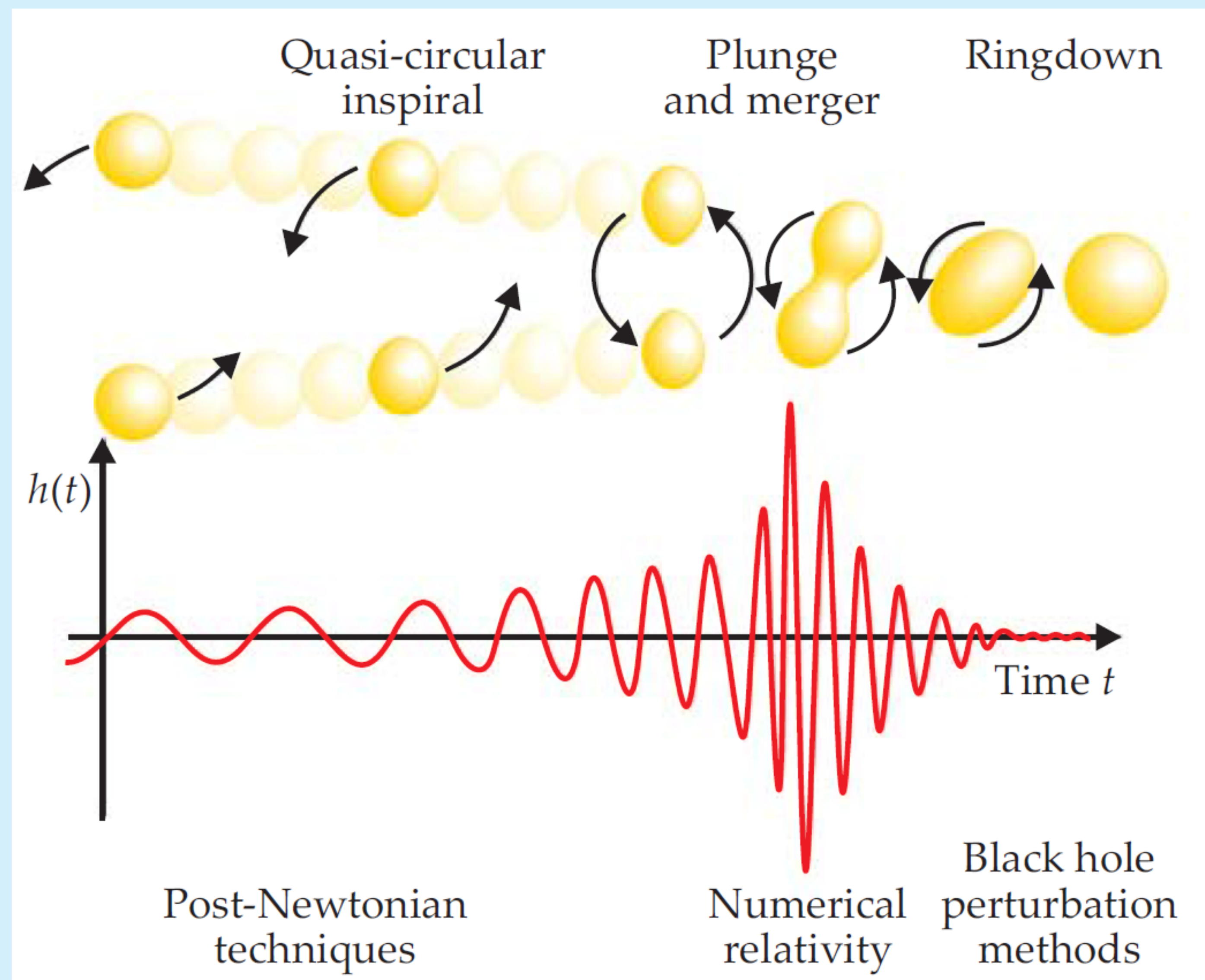



M_1
M_2
L
L
M_1
M_2
L+ΔL
L-ΔL
M_1
M_2
L-ΔL
L+ΔL
Y
X

In the LIGO facility, a laser beam is split to travel down two perpendicular 4-kilometre tunnels. The beams then reflect back and forth before being recombined at the detector.



Binary black hole mergers in Physics Today October 2011

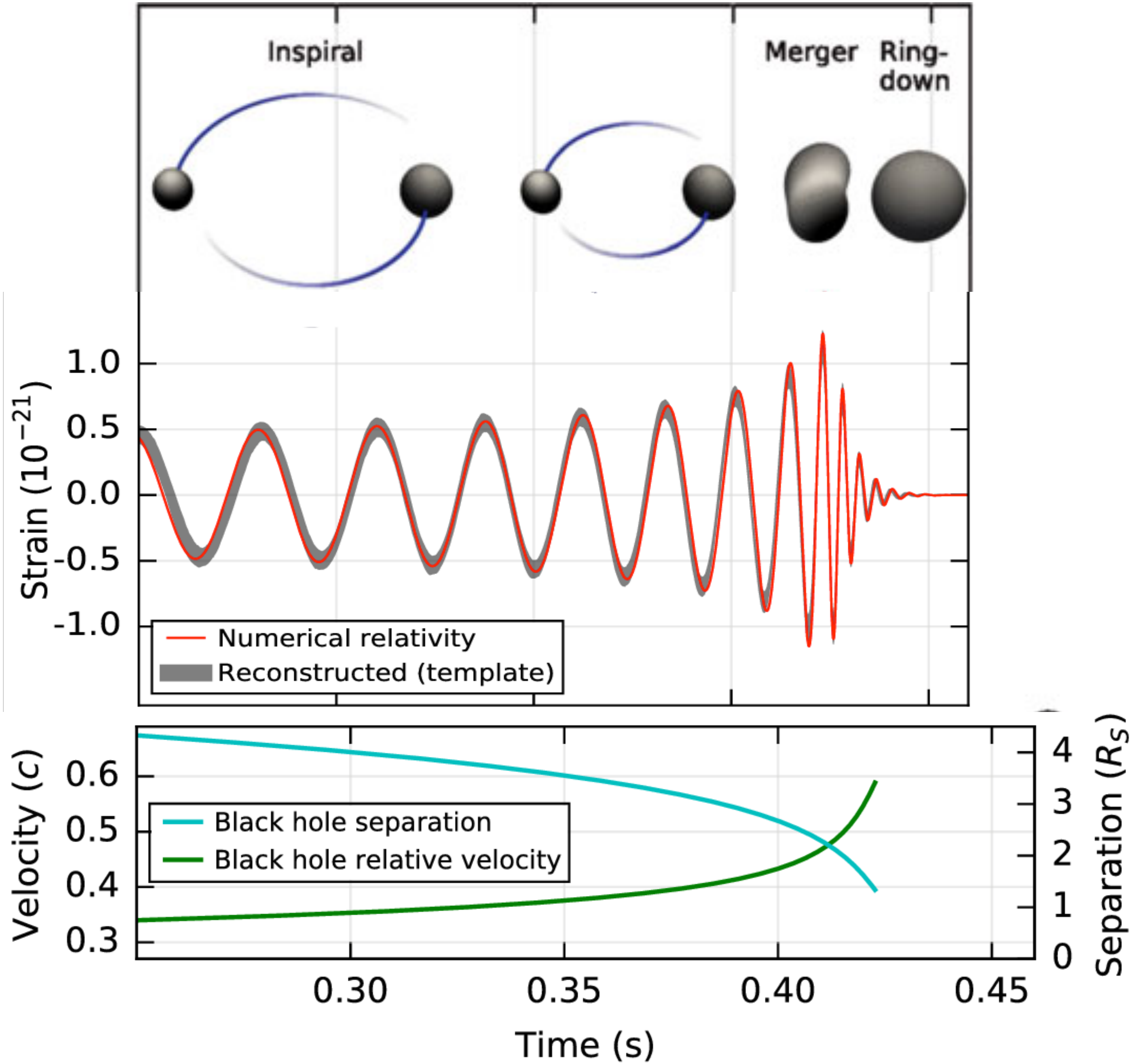


Selected for a Viewpoint in *Physics*
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

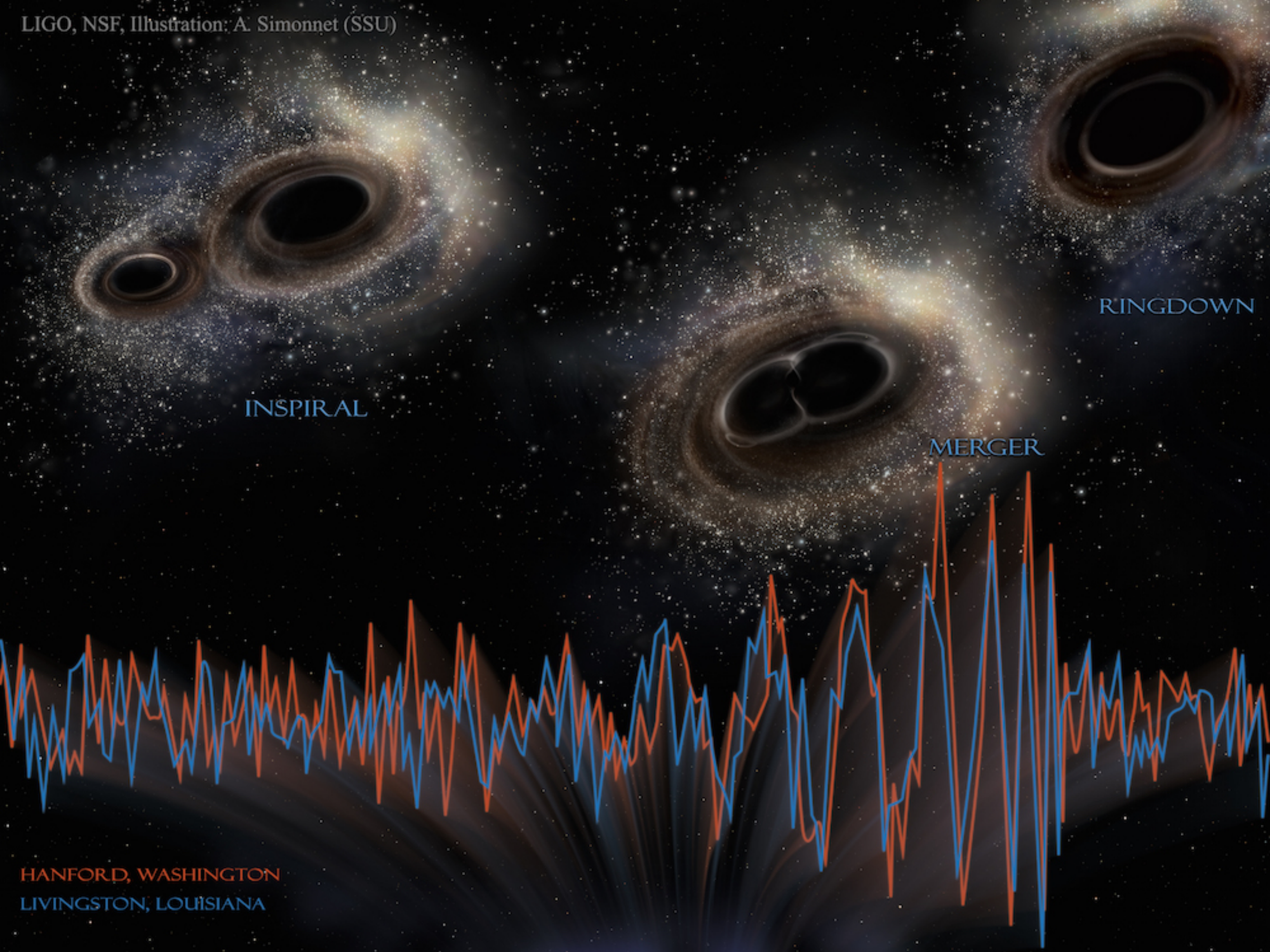
Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.



Inspiral
Merger
Ring-
down
1.0
0.5
0.0
-0.5
-1.0
Strain (10^{-21})
Numerical relativity
Reconstructed (template)
Velocity (c)
0.6
0.5
0.4
0.3
Black hole separation
Black hole relative velocity
4
3
2
1
0
Separation (R_S)
0.30
0.35
0.40
0.45
Time (s)


LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA