Astronomy 350L

(Fall 2006)

The History and Philosophy of Astronomy

(Lecture 19: Einstein II)

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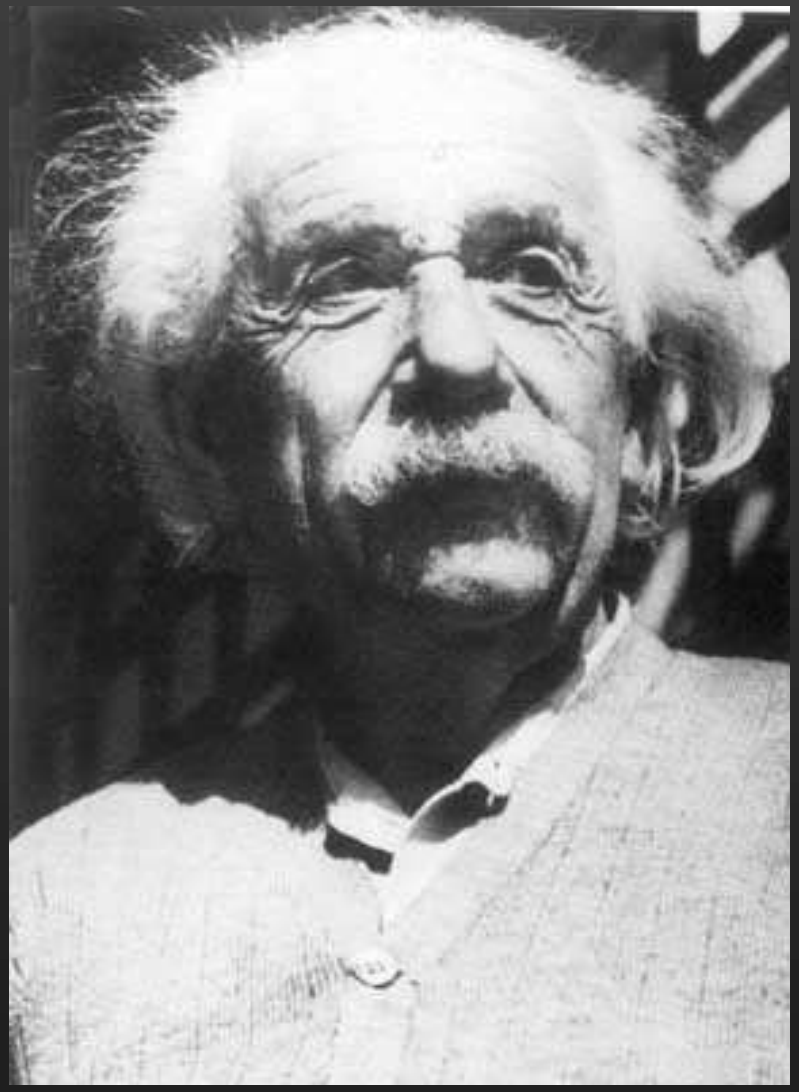
The University of Texas at Austin

Albert Einstein: Revolutionary of Physics

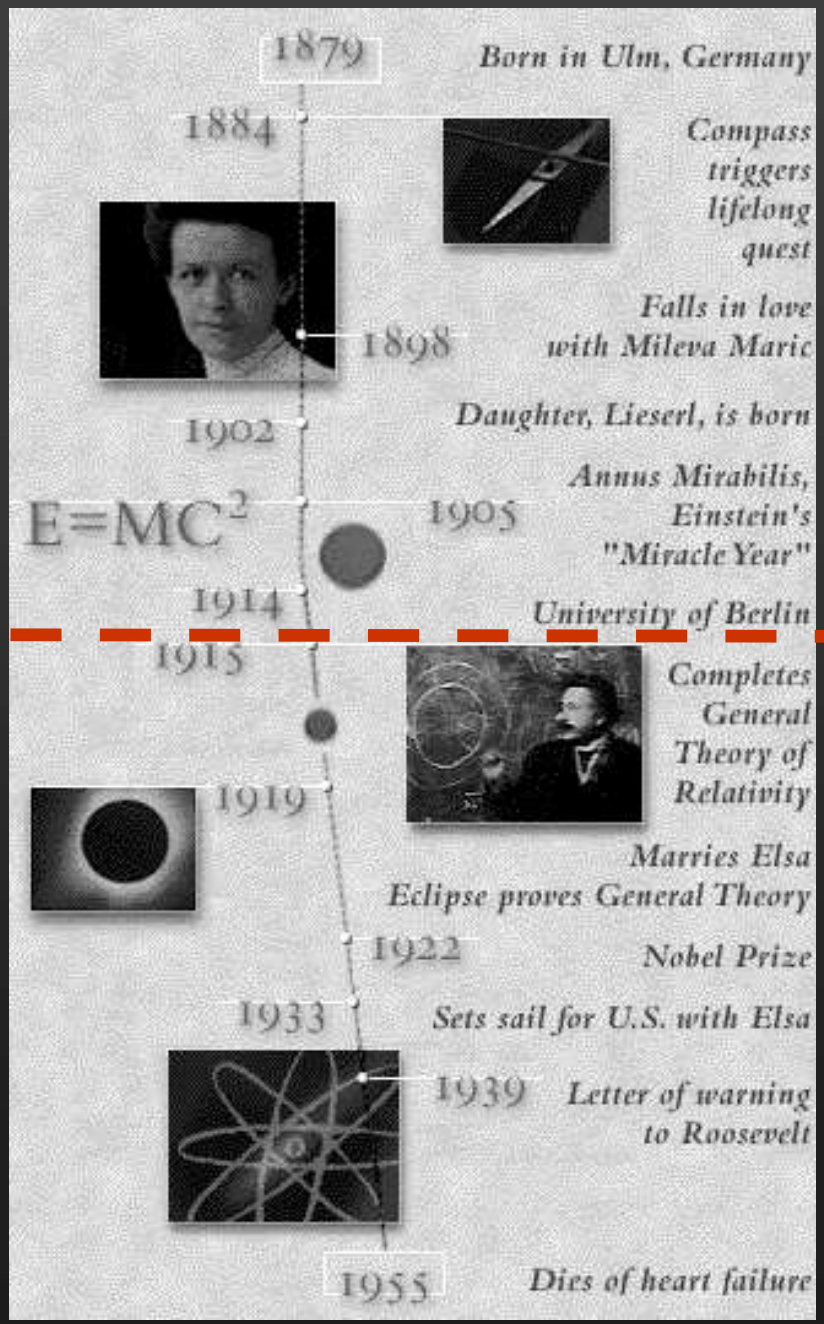


- 1879 (Ulm) – 1955 (Princeton)

- revolutionized concepts of space, time, and gravity
  - Special Relativity (1905):
    à $E=mc^2$
  - General Relativity (1915):
    à new theory of gravity

- co-founder of quantum theory
  à photons

Overview: Einstein's Life



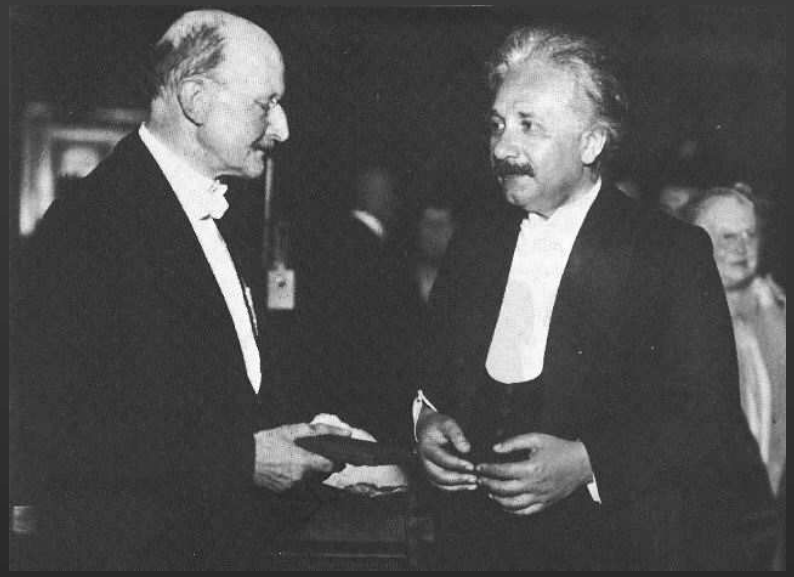
Nov. 2

Nov. 7

Einstein in Berlin: 1914-32

- 1914: Max Planck secures Einstein's appointment as professor at the Prussian Academy of Sciences (founded 1700 by Leibniz, German equivalent of Royal Society)

Berlin 1914: World Center of Science



- Einstein becomes part of vibrant scientific community!

Berlin 1914: Outbreak of WW I

- All European nations excited to go to war!
- Einstein takes lone pacifist stand!

General Theory of Relativity (1915-16)

- Big Q: What *is* gravity???

Newton (1687): -- `action-at-a-distance'

-- doesn't really answer the question

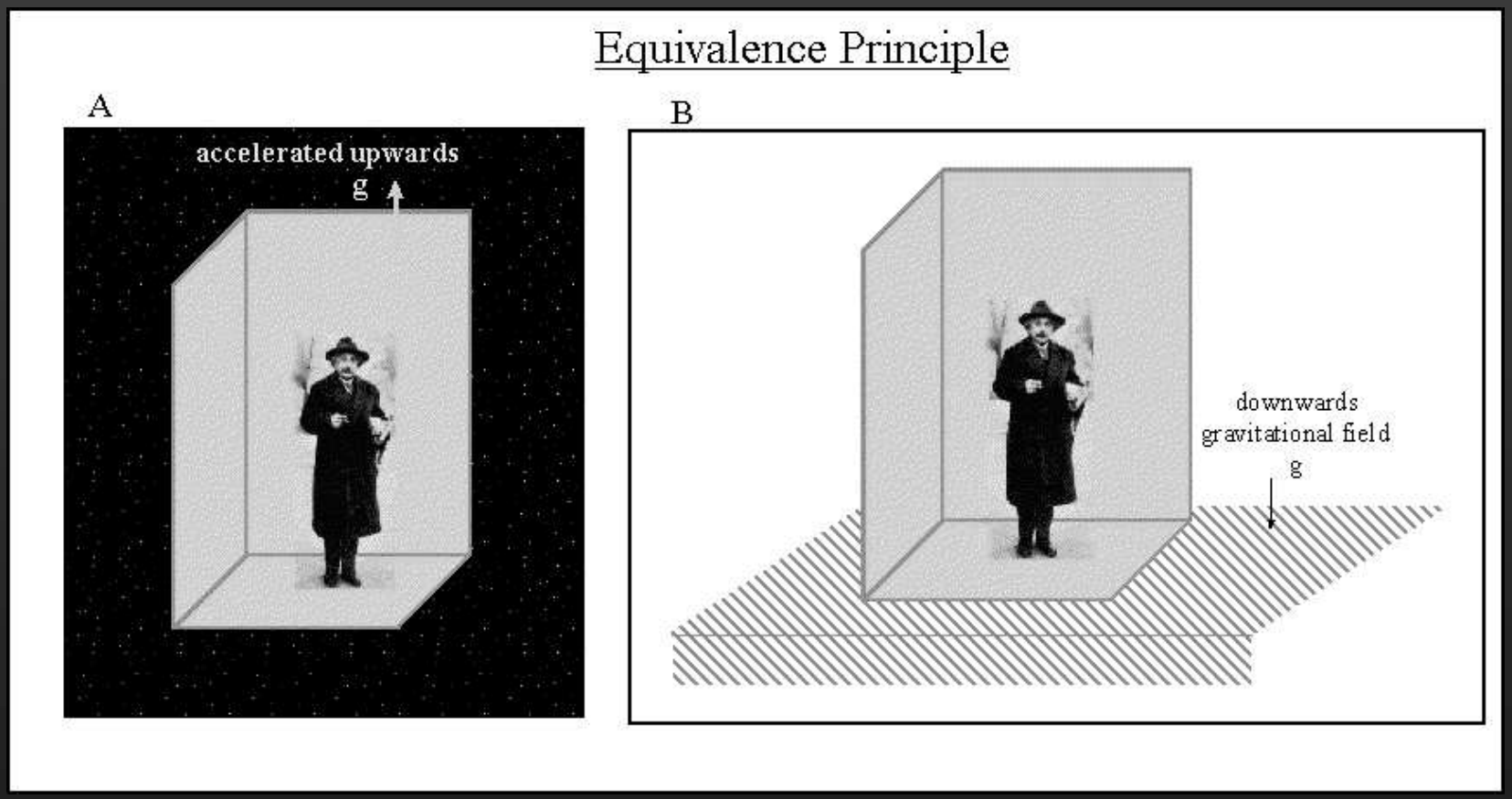
Einstein (1915): -- principle of equivalence'

-- great idea: GRAVITY = ACCELERATION

-- his "happiest thought"

General Theory of Relativity (1915-16)

- Principle of Equivalence (gravity = acceleration)



General Theory of Relativity (1915-16)

- Principle of Equivalence (gravity = acceleration)

General Theory of Relativity (1915-16)

- Big Q: What *is* gravity???

- **principle of equivalence: GRAVITY = ACCELERATION**

- **you don't feel effect of gravity in freely falling spaceship (`weightlessness')**

- **it is possible to "transform away" gravity (locally)!**

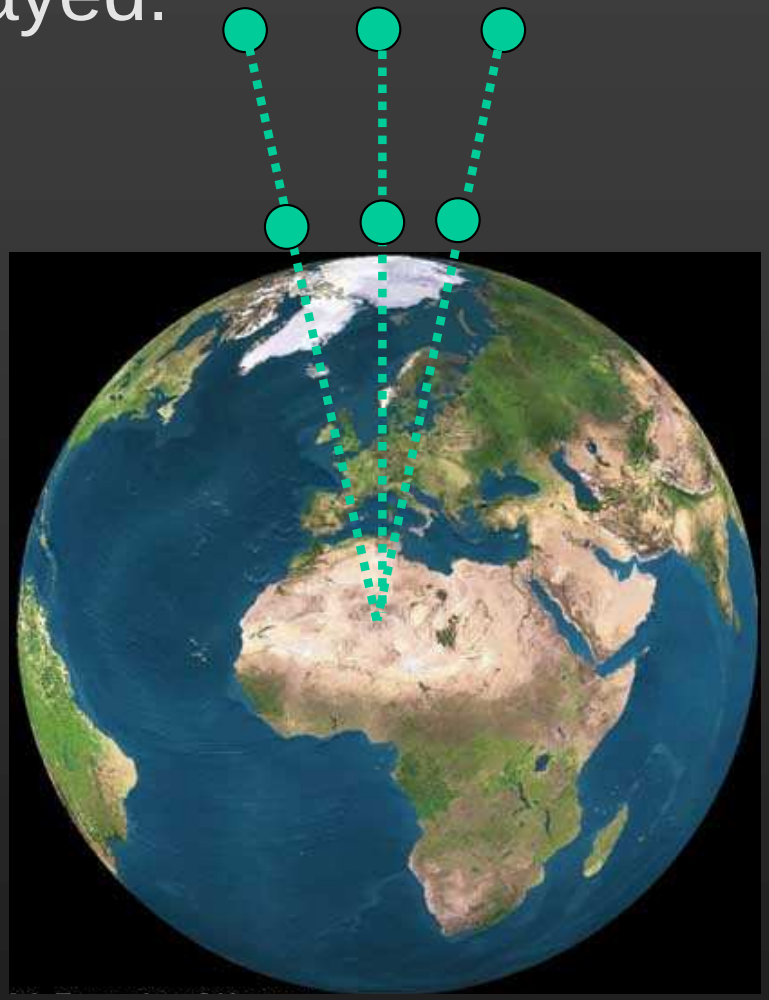
- **But: you can't get rid of gravity completely!**

  à **tidal forces betray gravity!**

  à **globally, gravity is non-uniform!**

General Theory of Relativity (1915-16)

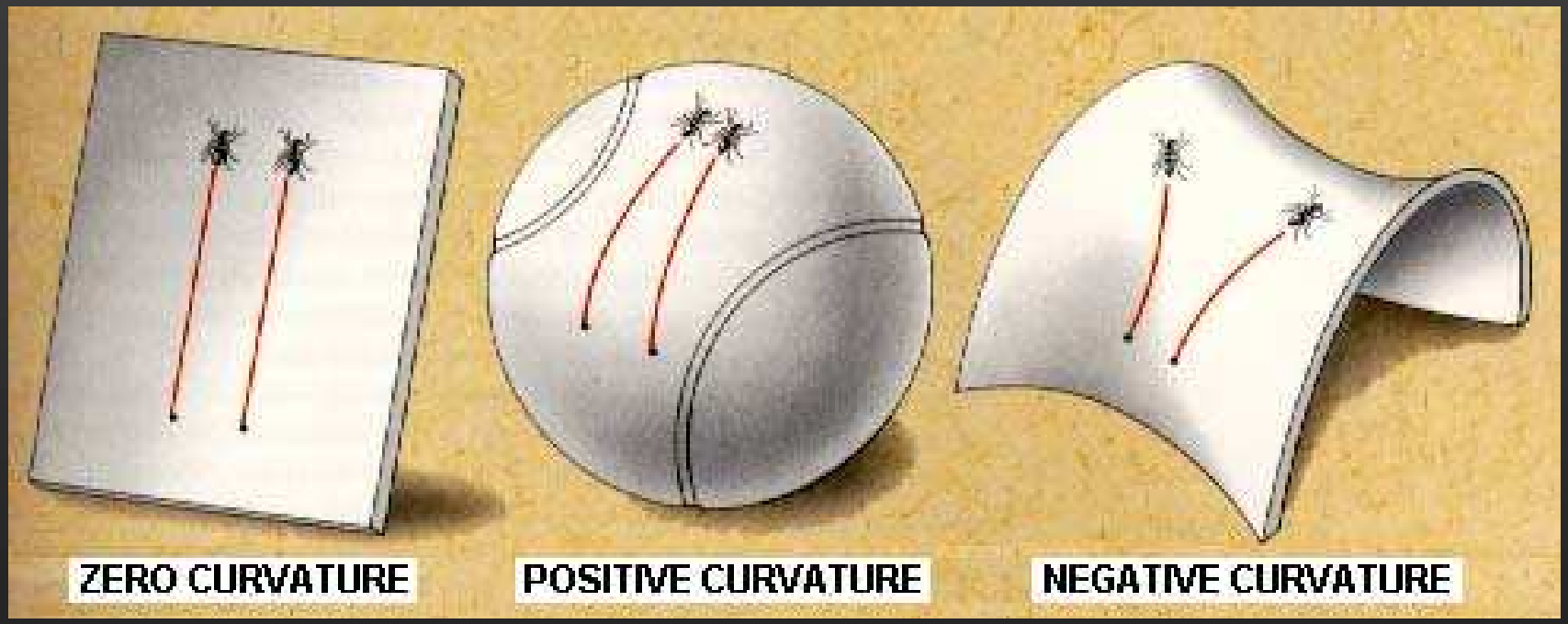
- gravity betrayed:



- gravity: neighboring particles in free-fall slowly converge (experience: `tidal forces')

General Theory of Relativity (1915-16)

- tidal effect of gravity à similar to behavior of `straight' lines on curved surfaces

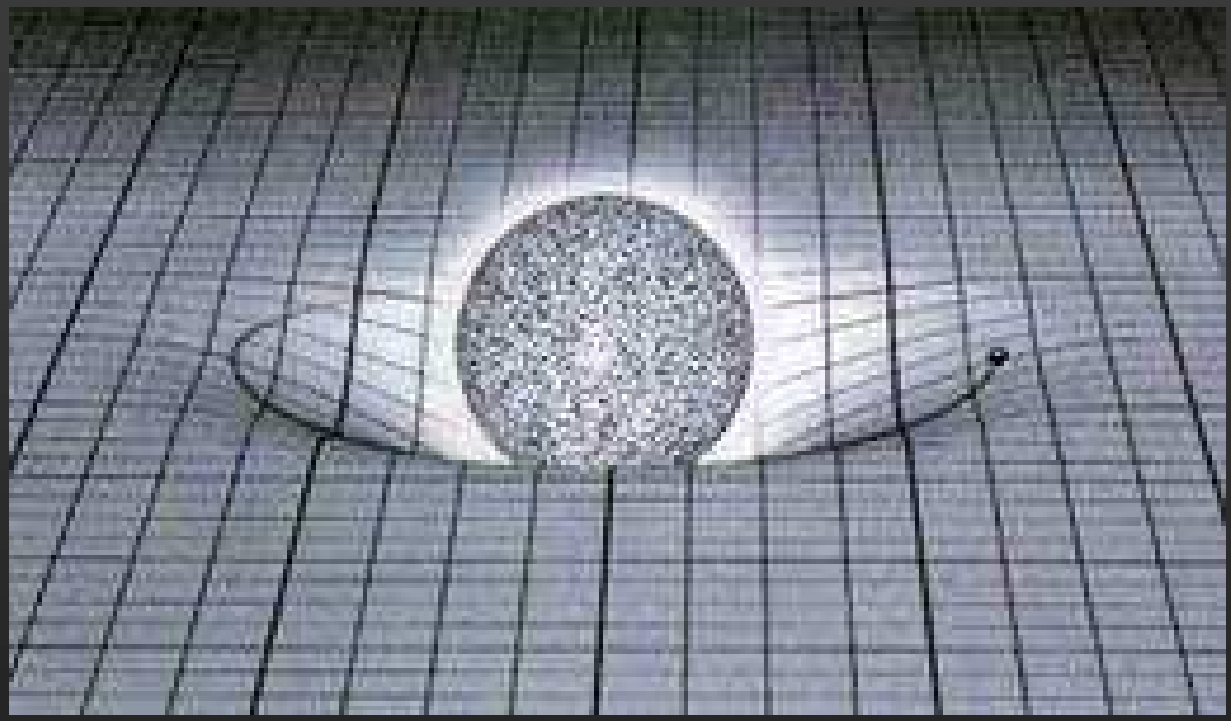


(ants are told to crawl straight ahead!)

- Einstein's great idea: gravity is related to curvature of space! (surface = 2 dimensional space)

General Theory of Relativity (1915-16)

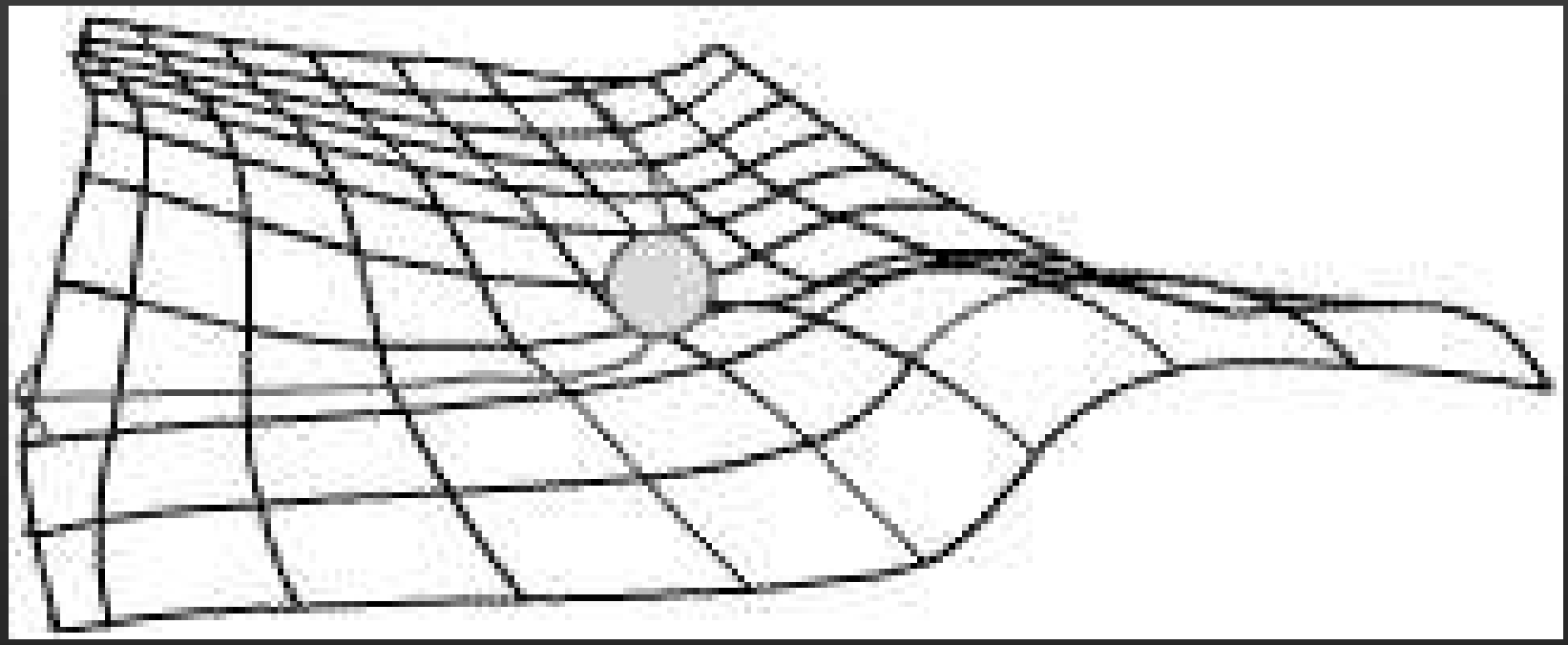
- Principle 1: “Matter tells space how to curve”



- matter creates `dimples’ in otherwise flat spacetime!

General Theory of Relativity (1915-16)

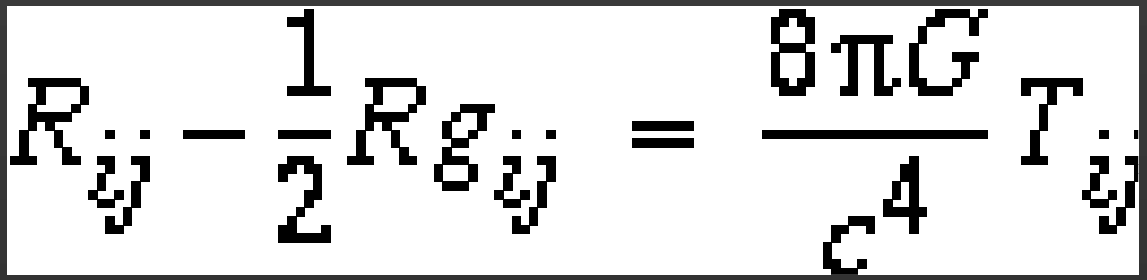
- Principle 2: “Curved space tells matter how to move”



- particles move through spacetime along paths of least resistance (technically: `geodesics’)!

General Theory of Relativity (1915-16)

- Einstein's Field equations:

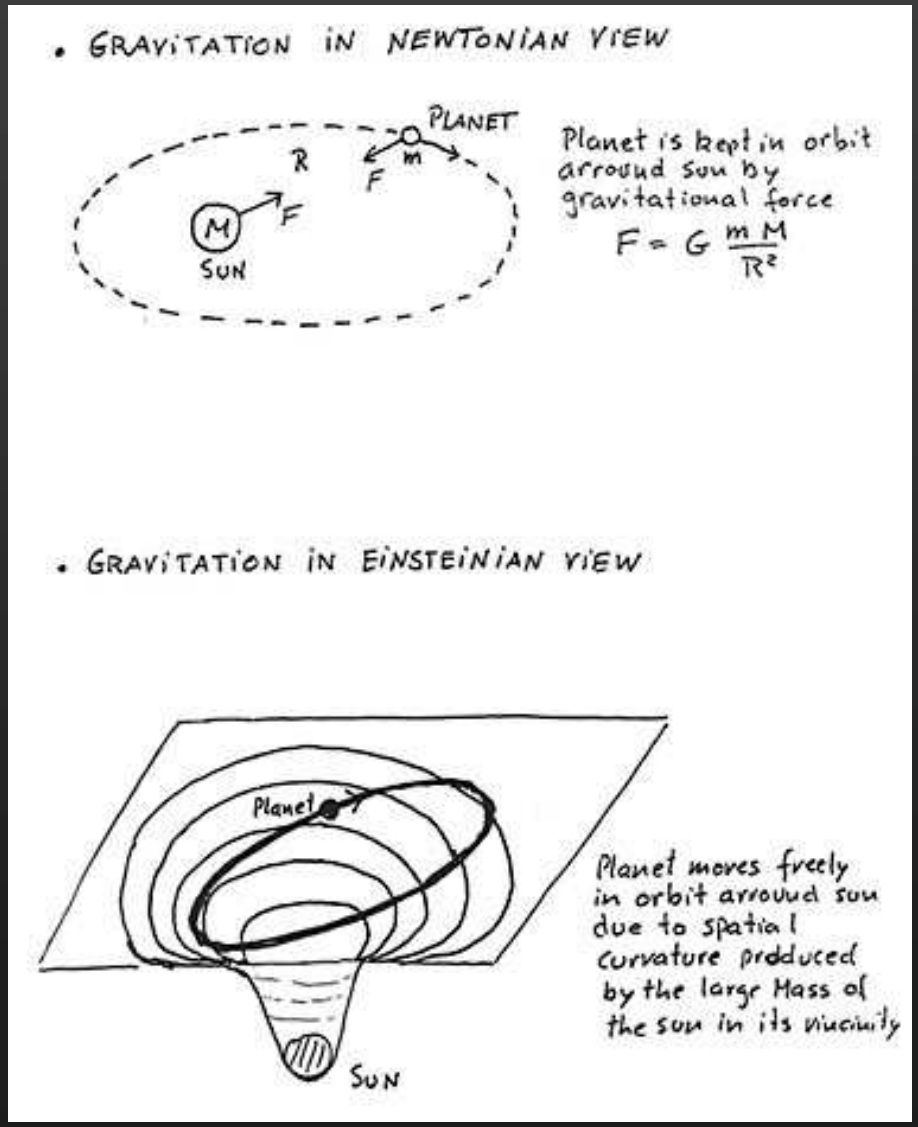


(curvature of space) (matter content)

- a `tensor equation' à *very* complicated (10 coupled non-linear differential equations)

Einstein vs Newton

- compare views on planetary motion:



Einstein vs Newton

- Old view (Newton): Gravity acts `at-a-distance'
  (i.e., speed of gravitational disturbance = infinity)
- New view (Einstein): Gravity acts via gravitational waves (`ripples in spacetime')
  (i.e., speed of gravitational disturbance = speed of light)

- try to detect them with LIGO and LISA!

LIGO Experiment (Laser Interferometer Gravitational-wave Observatory)

- tries to detect gravitational waves

General Theory of Relativity (1915-16)

- Einstein proposes 3 classical tests of GR:

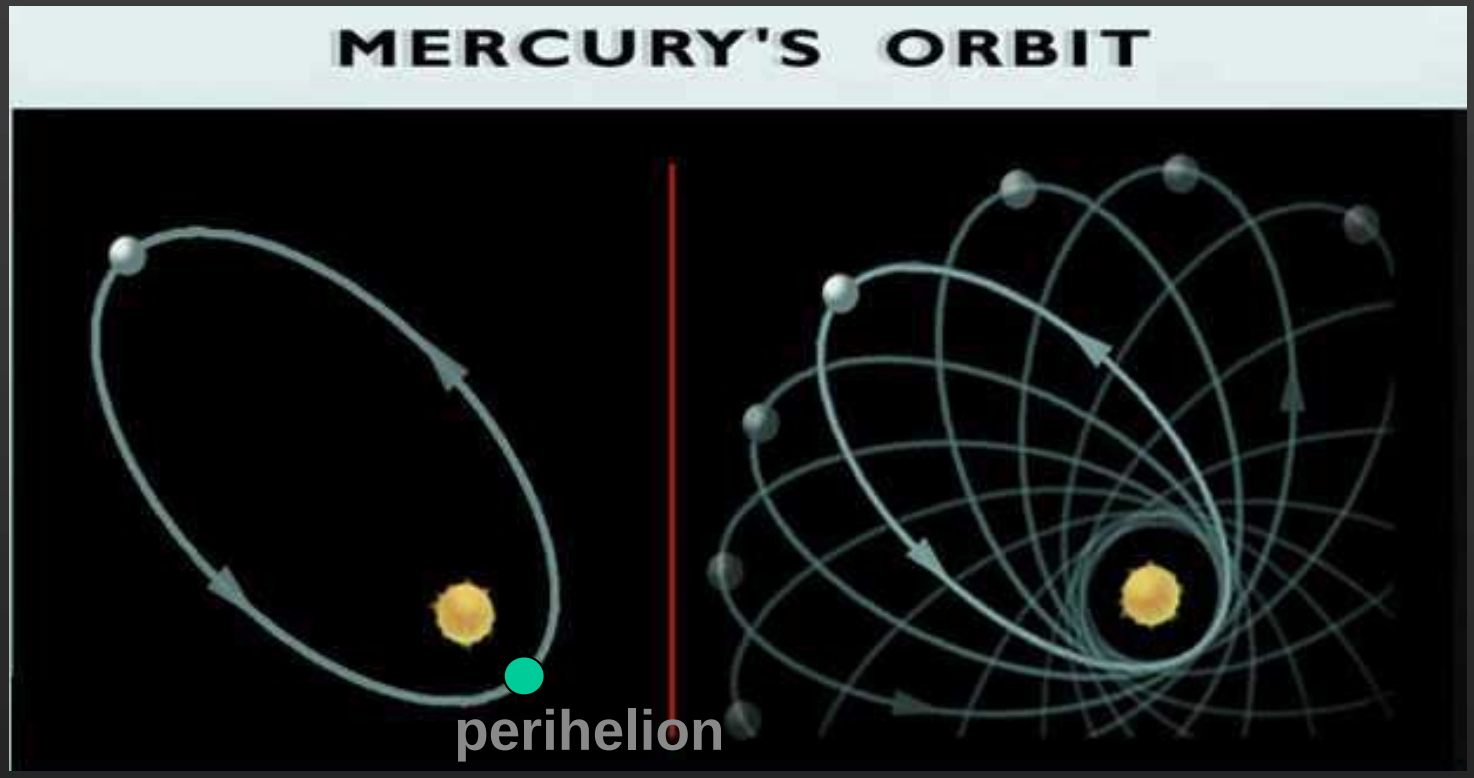
  - Successfully explain anomaly in Mercury's orbit
    (`perihelion precession')

  - Predict `gravitational redshift'
    (light escaping from massive body becomes redder)

  - Predict gravitational bending (deflection) of light!
    (most famous of the 3 tests; `experimentum crucis')

General Theory of Relativity (1915-16)

- Anomalous orbit of Mercury:

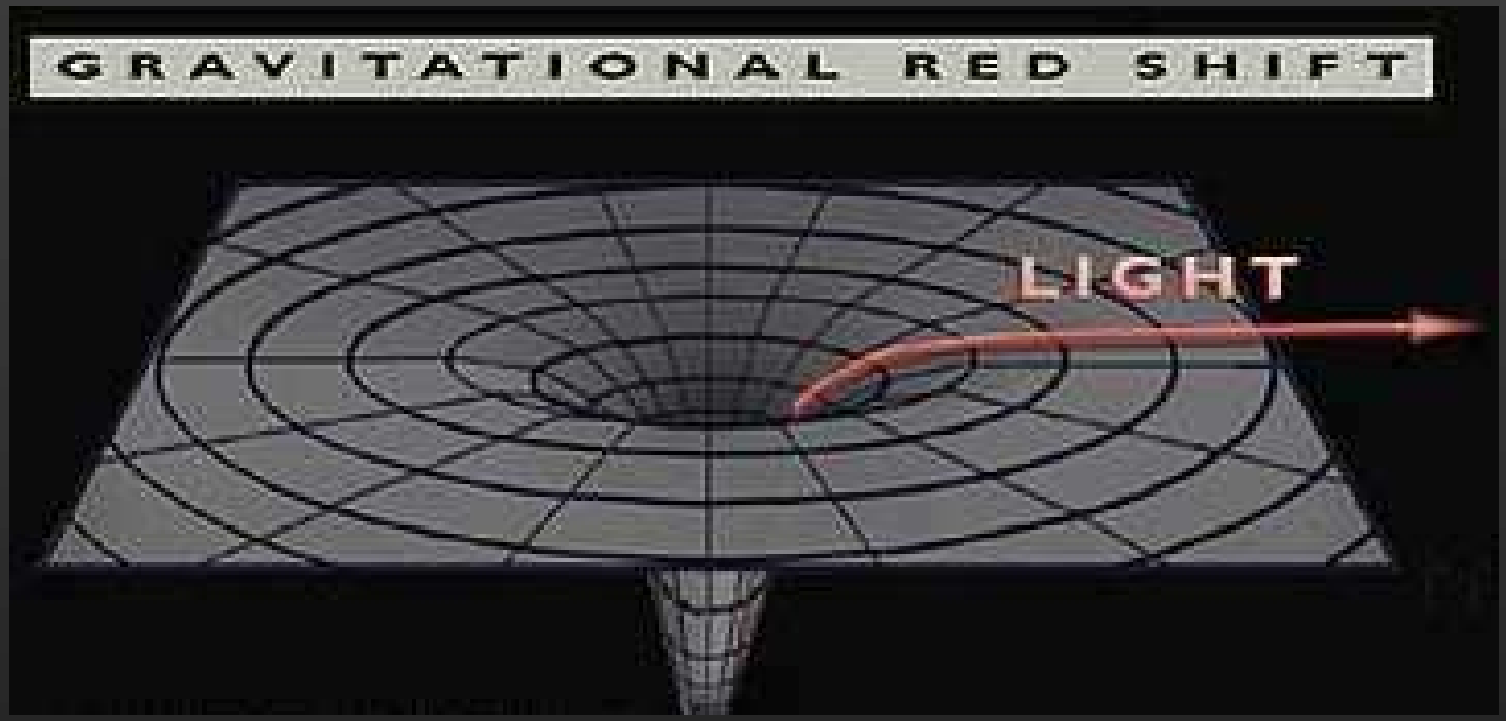


- Newton’s theory could not explained the observed shift of Mercury’s perihelion

- Einstein’s theory (GR) could!!!

General Theory of Relativity (1915-16)

- Gravitational redshift:



- Photon climbing out of gravitational well loses energy
  à less energy = lower frequence = redder color!

- was successfully measured only in 1960 (Pound & Rebka)

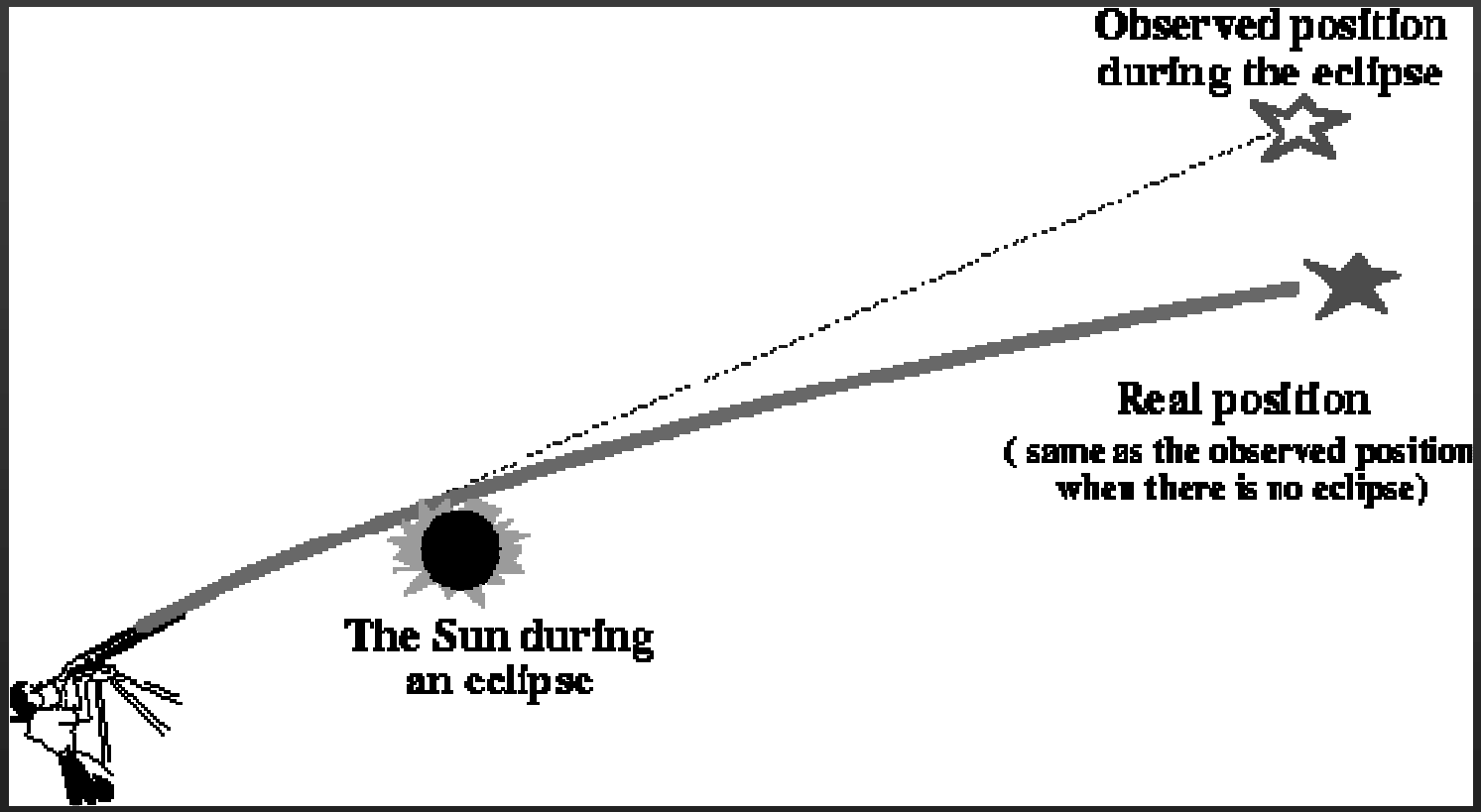
General Theory of Relativity (1915-16)

- Einstein Tower: built to measure gravitational redshift

- built by Erich Mendelsohn (1921; expressionism)

General Theory of Relativity (1915-16)

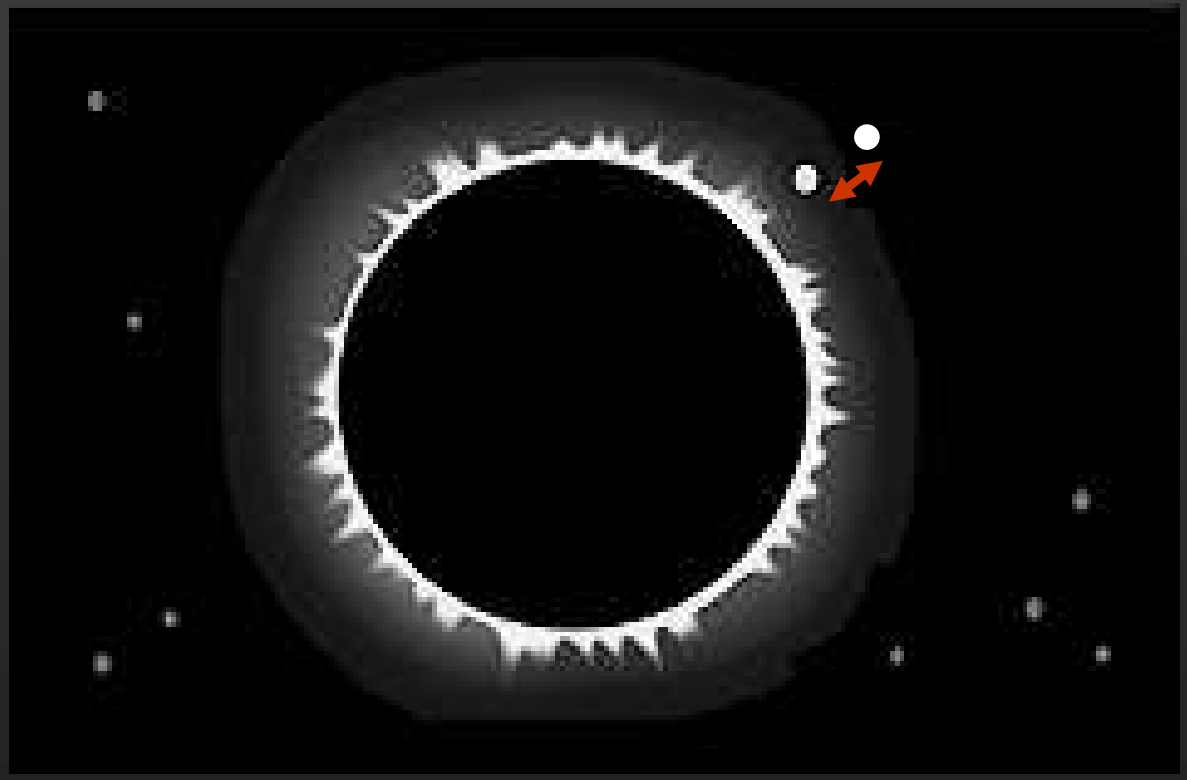
- Bending of light-rays:



- Prediction: Sun's gravity deflects light from distant stars!

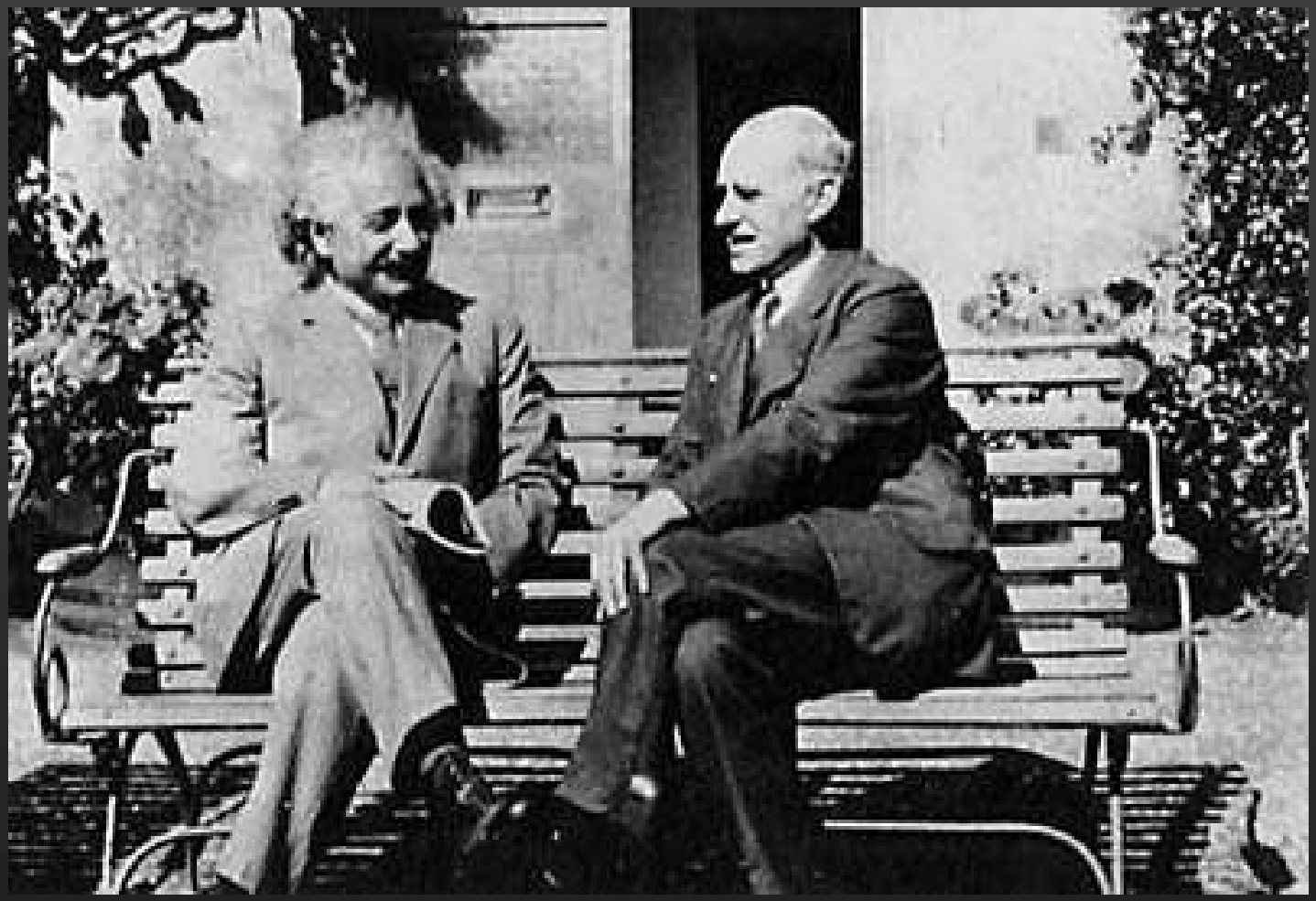
General Theory of Relativity (1915-16)

- Observe bending of light during Solar eclipse!



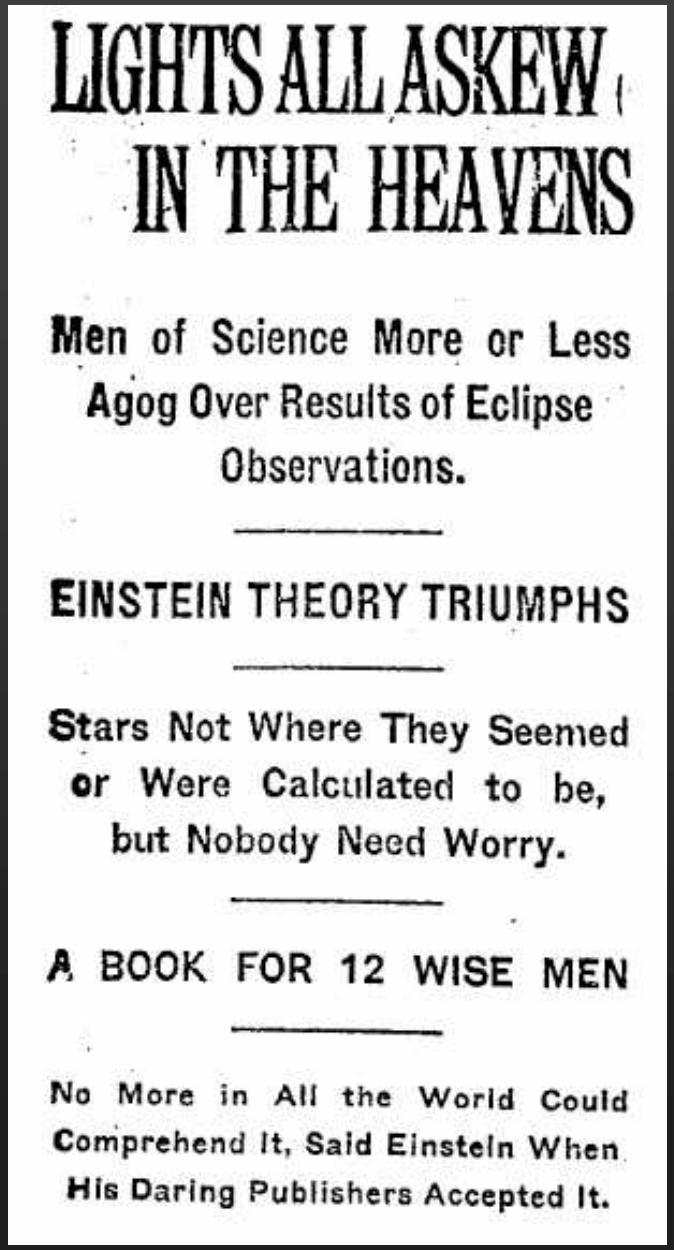
- Einstein’s prediction: Stars shifted by 1.75”

Eddington’s Eclipse Expedition (1919)



- Eddington’s observation confirms Einstein’s theory!

After 1919: Einstein the Legend



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.

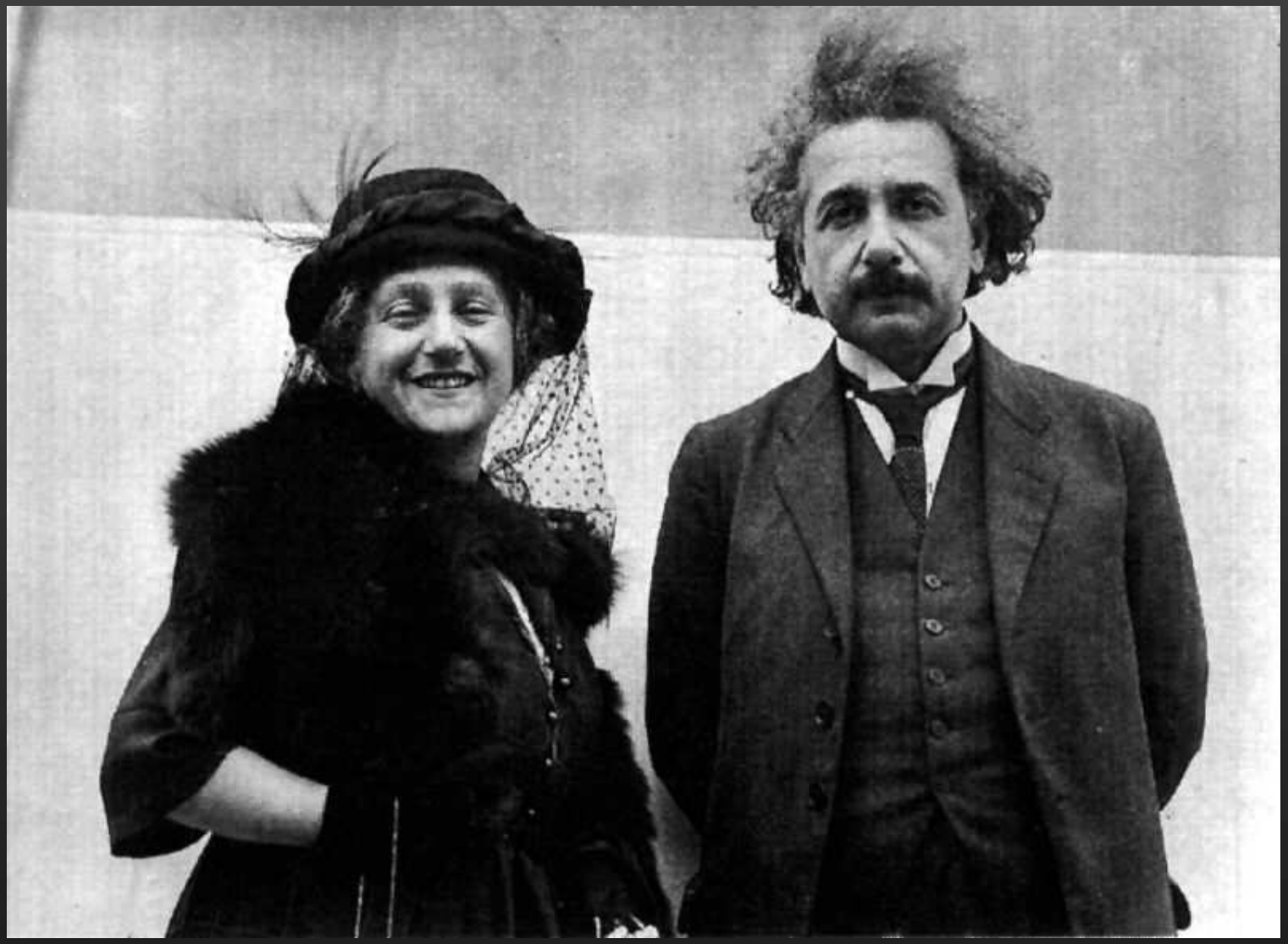
A BOOK FOR 12 WISE MEN

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

(New York Times)

- Einstein becomes world-famous!
- travels the globe
- hobnobs with high-society
- begins to exert significant influence in politics

1919: Divorce and 2nd Marriage



- marriage with his cousin Elsa Einstein (1919-36)

Einstein visits America

- Einstein at City Hall, New York (1921)

Einstein visits America

- Chaplin to Einstein: “People love me, because they understand *everything* I say, and they love you, because they understand *nothing* of what you say…”

Einstein’s Favorite Recreational Spots

- his beloved summer house in Caputh (near Berlin)

- many famous and powerful visitors

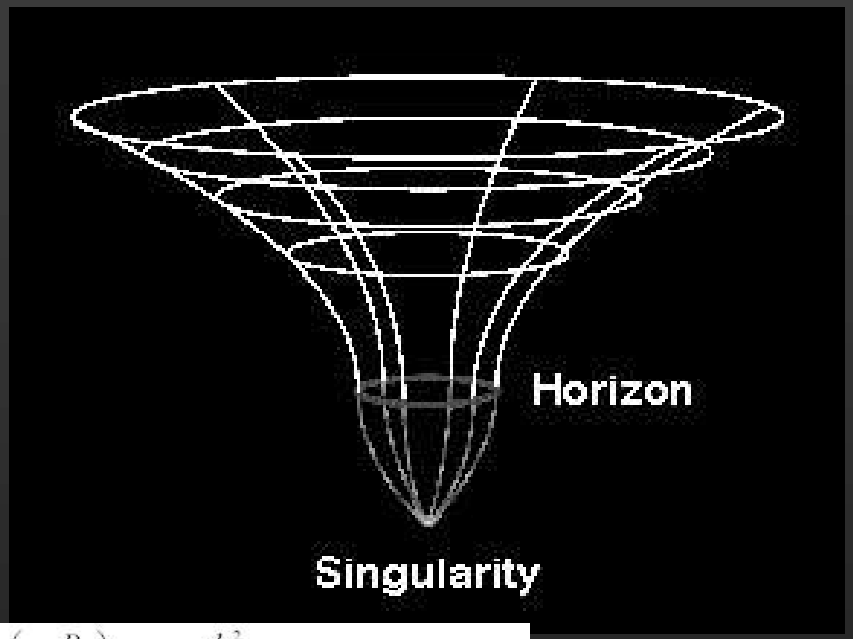
Einstein’s Favorite Recreational Spots

- Island of Hiddensee (Germany’s `Martha’s Vineyard’)

Solving Einstein's Equations of GR

- 1916: Karl Schwarzschild predicts black holes

Karl Schwarzschild (1873-1916)



$$ds^2 = -\left(1 - \frac{R_G}{r}\right) dt^2 + \frac{dr^2}{\left(1 - \frac{R_G}{r}\right)} + r^2 (d\theta^2 + \sin^2\theta \, d\phi^2)$$

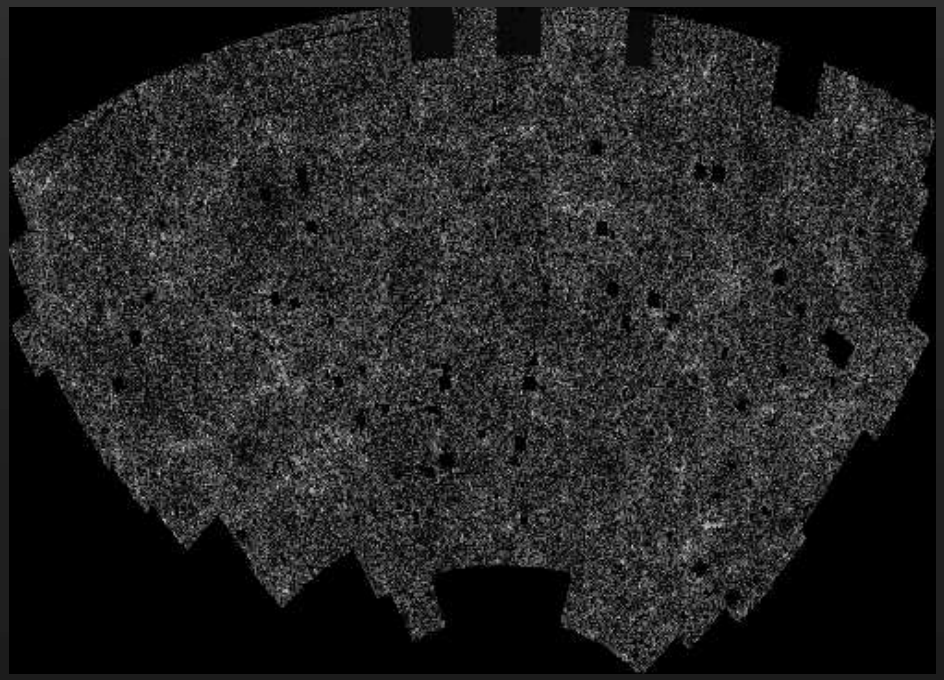
$$r_s = \frac{2GM}{c^2}$$

`Schwarzschild radius'

Solving Einstein's Equations of GR

- 1917: Einstein constructs model of the universe that is eternal and static

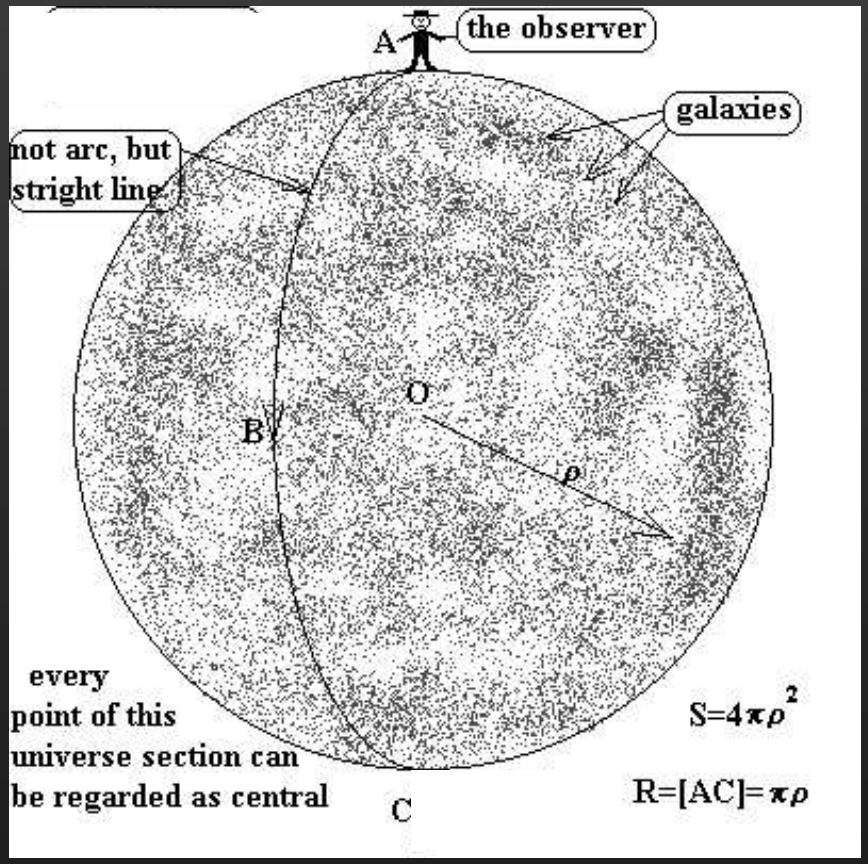
- begin by postulating **`cosmological principle'**: "Universe looks everywhere the same!" (homogeneity and isotropy)



- today, we know this is an excellent approximation, but in 1917, it was merely an inspired guess!

Solving Einstein's Equations of GR

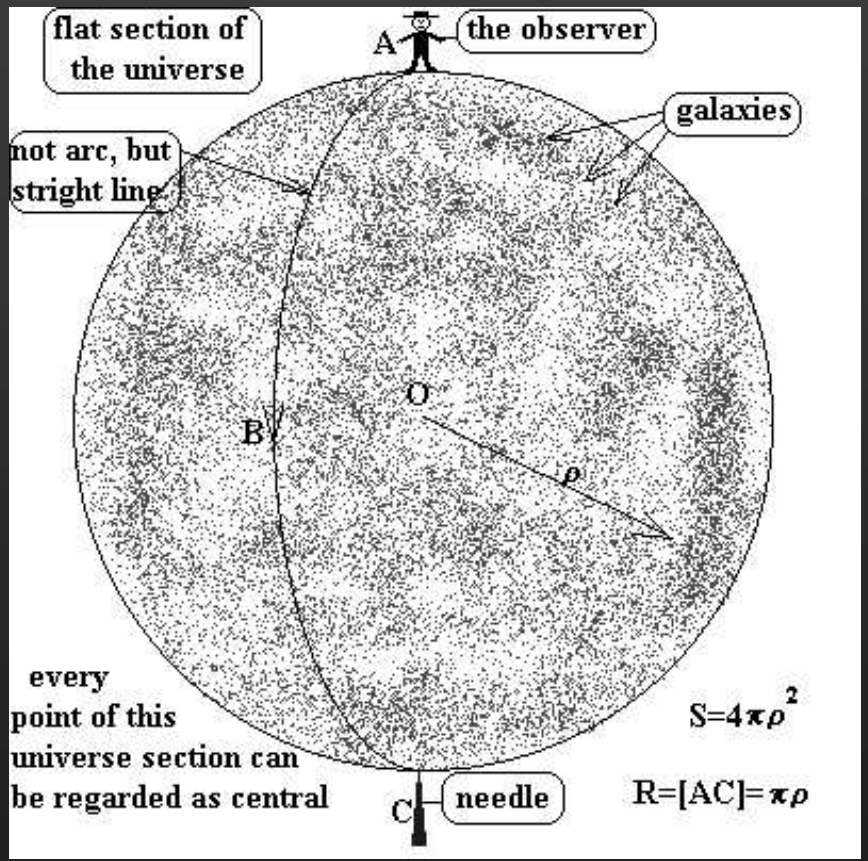
- 1917: Einstein constructs model of the universe that is eternal and static



- finite but without boundary

Solving Einstein's Equations of GR

- Big problem: model is not stable!



- equations predict collapse à that seems at odds with observations of a static universe (=Milky Way)

Einstein's `Greatest Blunder'

- The cosmological constant:

$$R_{ij} - \frac{1}{2} R g_{ij} = \frac{8\pi G}{c^4} T_{ij} + \lambda g_{ij}$$

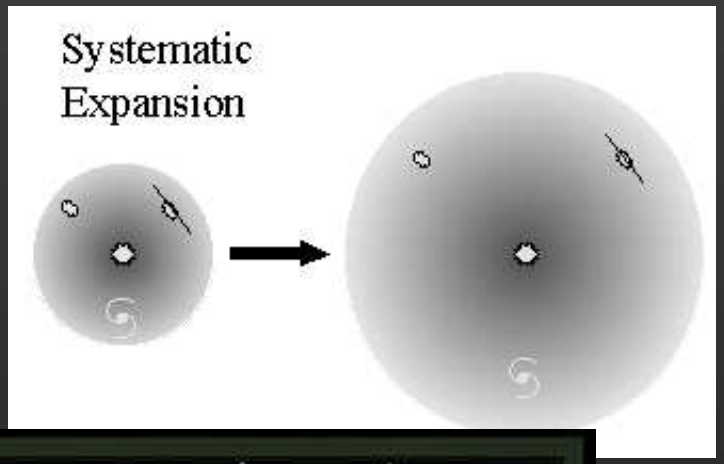
(curvature of space) (matter) (cosmological constant)

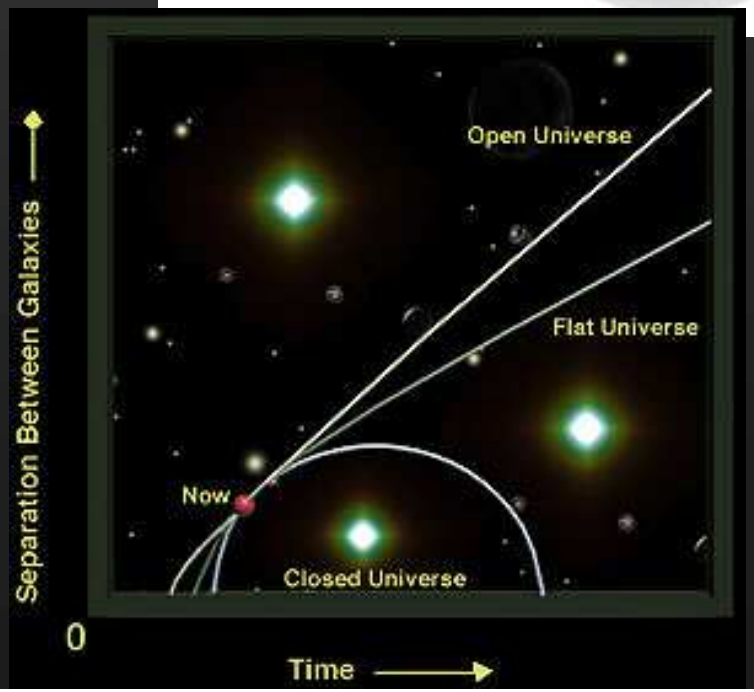
- cosmological constant (lambda) acts as anti-gravity
  (physically: *very* weird stuff, having negative pressure)

Solving Einstein's Equations of GR

- 1922: an expanding universe (GR without cosmological constant)

Alexander Friedmann
(1888-1925)





Escape from Germany (1932)

- Dec. 10, 1932: Einstein and Elsa depart from Berlin for a visit to U.S.
- Jan. 30: Hitler comes to power
- Einstein (being Jewish) never sets foot into Germany again

Einstein’s Favorite Recreational Spots

- his beloved summer house in Caputh (near Berlin)

- many famous and powerful visitors

Einstein in Princeton (1933-55)

- professor at newly founded
  Institute for Advanced Study

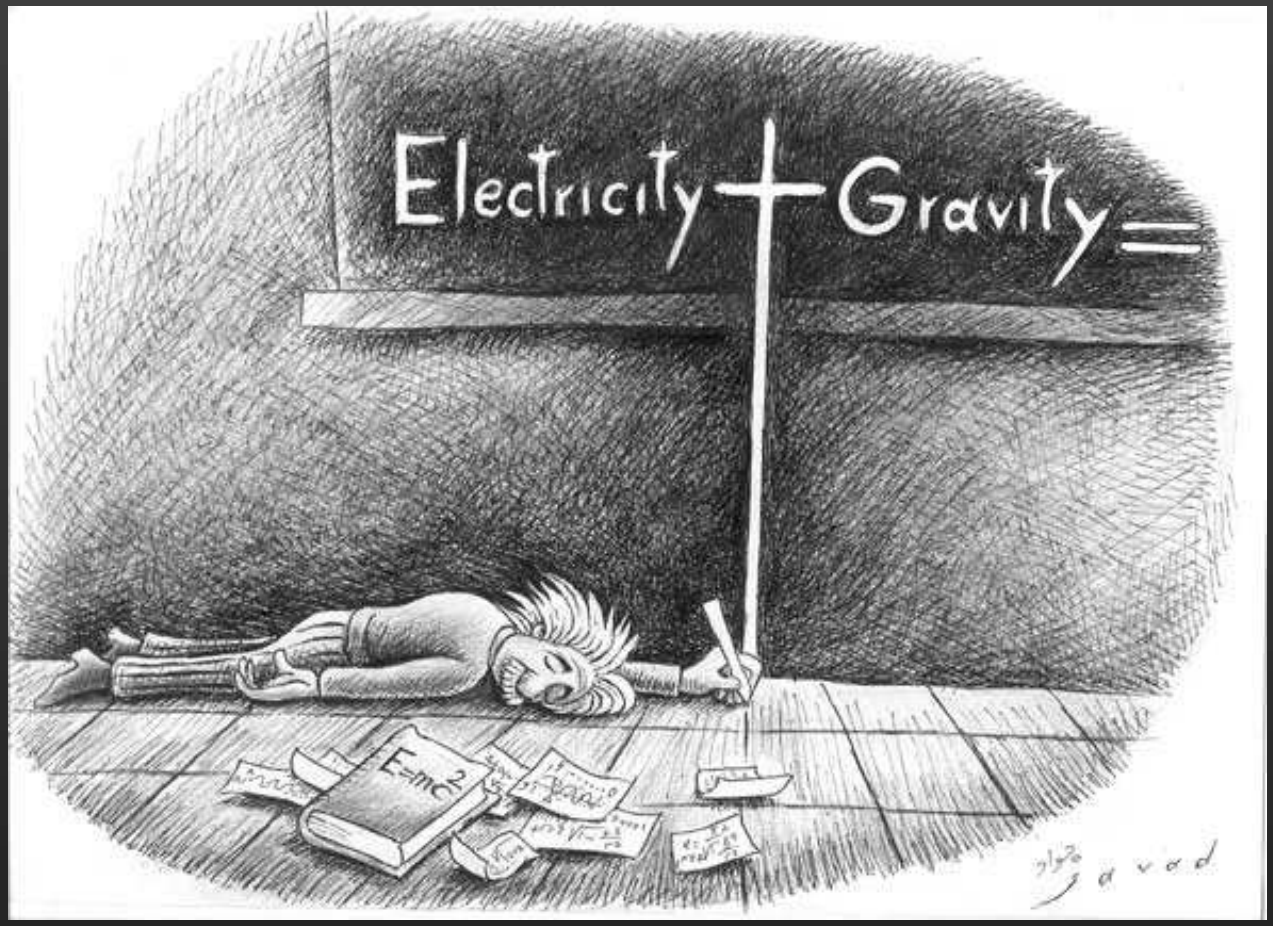
Einstein in Princeton (1933-55)

- 112 Mercer Street: his private house

Einstein in Princeton (1933-55)

- 1940: Einstein becomes an American

Einstein in Princeton (1933-55)

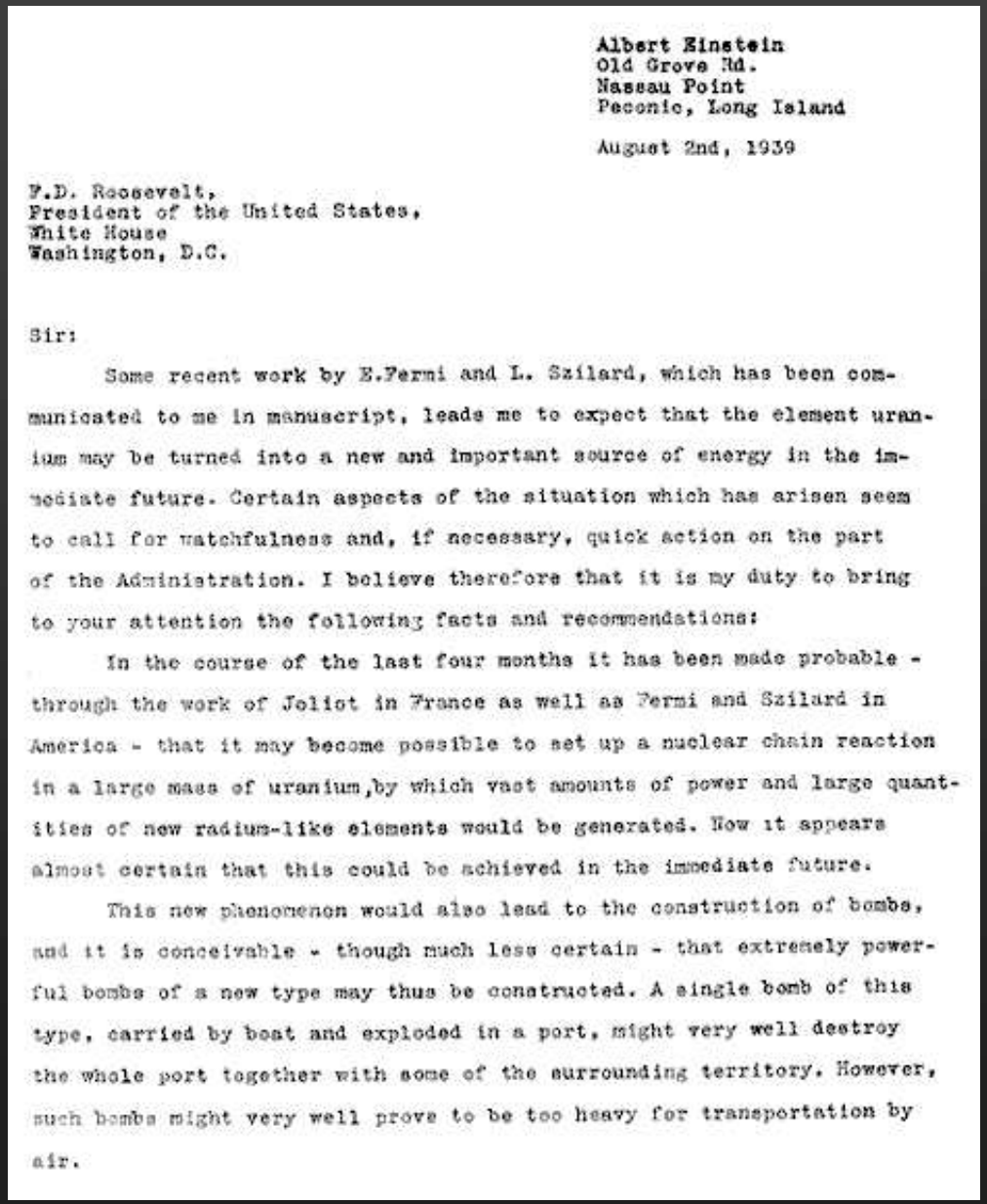


- failure to find `unified field theory'
  (i.e., gravity + electromagnetism)!

Einstein and the Bomb

- 1939: Fellow émigré Leo Szilard (Hungary) warns Einstein of possible Nazi bomb effort

Einstein and the Bomb



Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

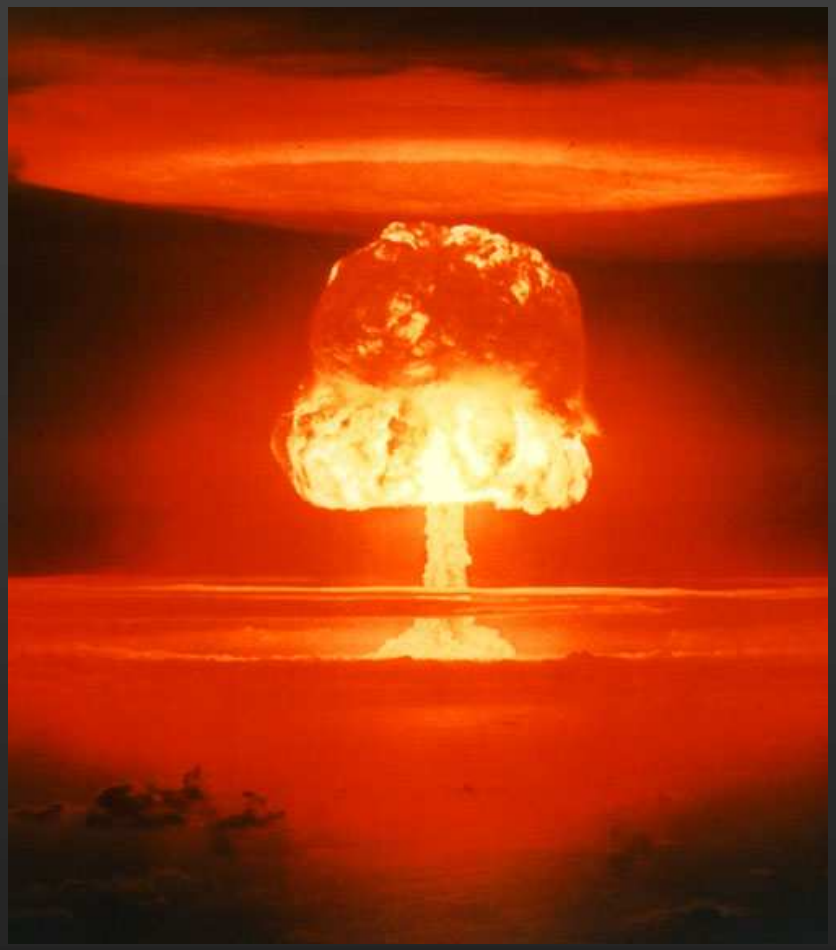
Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

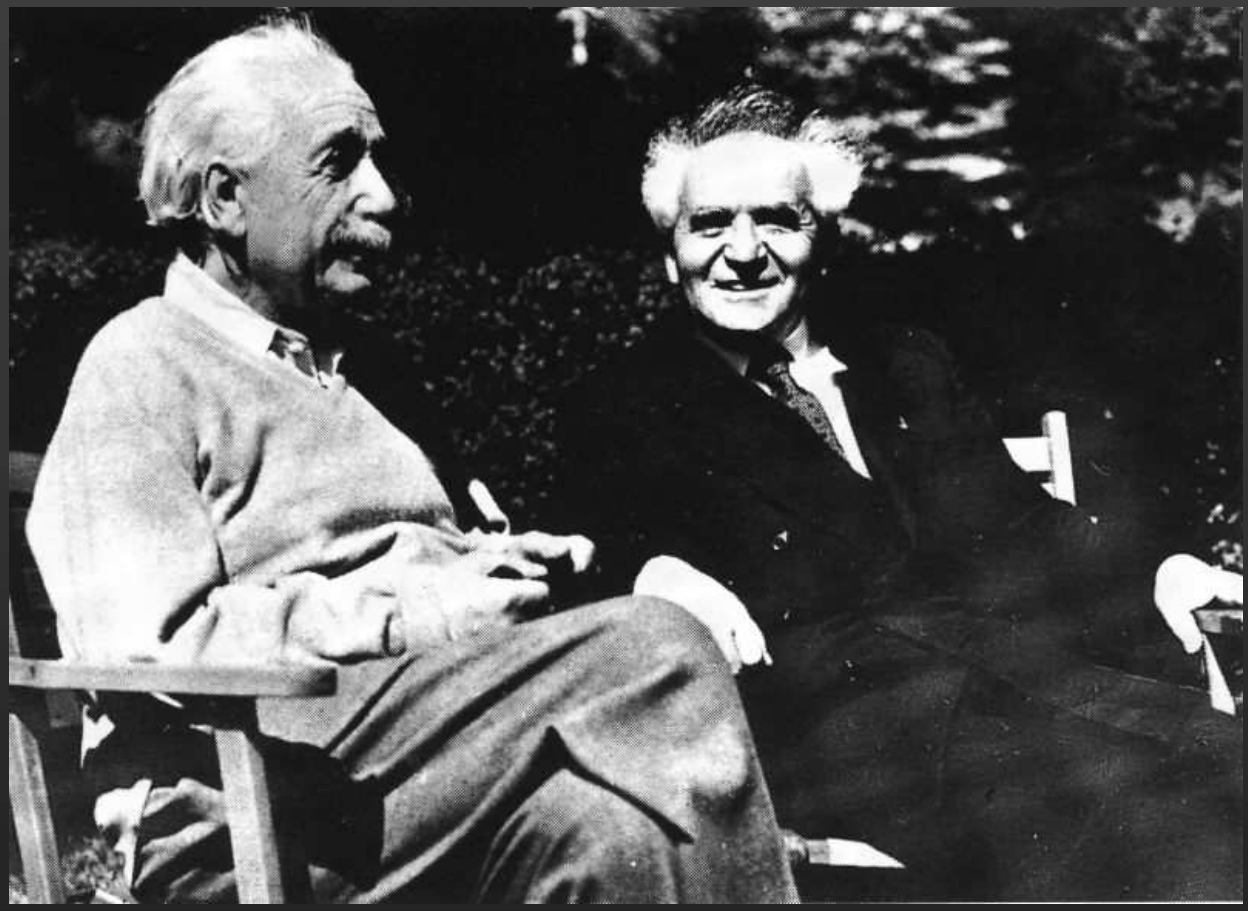
- Letter to FDR
- E warns president about Nazi bomb
- setting `Manhattan project' into motion

Einstein and the Bomb



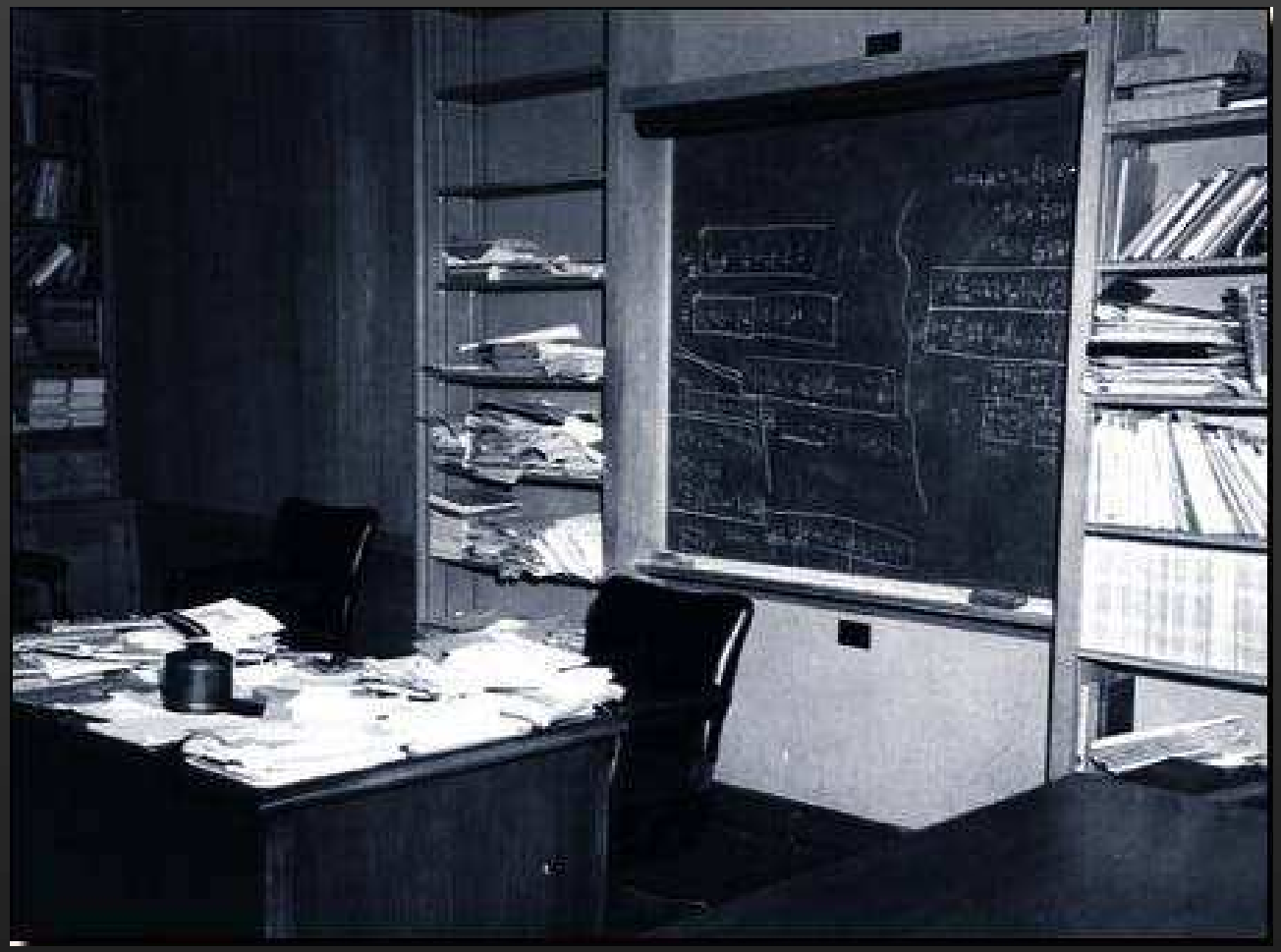
- Hiroshima bomb: 1 gram of uranium

Einstein and the Foundation of Israel



- Ben Gurion offers Einstein Presidency of Israel
  - à Einstein declines (1st Israeli president: Chaim Waizmann)

1955: Journey's End



- dies in Princeton hospital, his body is cremated the same day, and his ashes scattered at undisclosed place

Einstein (part 2)

- Later Life:
  - 1914-32: Professor in Berlin
  - 1919: Divorce and 2nd marriage
  - 1932: Emigration to U.S. (Princeton)
  - 1933-55: Professor at Institute for Advanced Study
  - 1939: Letter to FDR about atomic bomb
  - 1955: Dies in Princeton

- General Theory of Relativity (1915):
  - new theory of gravity
  - gravity=curved space
  - Einstein model of universe (1917): static and closed
  - needs to introduce cosmological constant (`Biggest Blunder')
  - 1922: Friedmann finds expanding solution of GR equations