# General Relativity short intro & history

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# **General Theory of Relativity**



# **General Theory of Relativity**

**Black holes** 

#### INTERSTELLAR

# **Albert Einstein**



# **Albert Einstein**





#### **SOLVAY CONFERENCE 1927** ON ELECTRONS AND PHOTONS

A. PICARD E. HENRIOT P. EHRENFEST Ed. HERSEN Th. DE DONDER E. SCHRÖDINGER E. VERSCHAFFELT W. PAULI W. HEISENBERG R.H FOWLER L. BRILLOUIN

P. DEBYE M. KNUDSEN

W.L. BRAGG

M. PLANCK

H.A. KRAMERS

P.A.M. DIRAC A.H. COMPTON

TON L. de

L. de BROGLIE

N. BOHR

I. LANGMUIR

Mme CURIE

H.A. LORENTZ

A. EINSTEIN

P. LANGEVIN

Ch.E. GUYE

C.T.R. WILSON

M. BORN

ILSON O.W. RICHARDS

Color by Sanna Dullaway 🎽 🔿

## What is General Relativity?

- what does it have to do with?
  - theory of <u>gravity</u> based on *equivalence principle* (happiest thought of his life)
  - generalize special relativity to <u>non-inertial frames</u> & include gravity
  - revolutionized our notion of spacetime
- what phenomena does it deal with?
  - <u>gravitational field</u>: lensing, time delay, GPS, relativistic effects, gravitational waves, black holes ...
  - <u>cosmology</u>: history of the universe and its fate

# **Equivalence Principle**

- gravity vs inertial force:  $m_g$  vs m
- can you tell the difference in diagram A?
- <u>free-fall</u> in diagram B
- can you come up with GR with EP?





## **Brief History of Einstein**

- 1879~1896:
  - born in Ulm, Germany, grew up in München
  - Gymnasium in Germany until 1894
  - **<u>failed</u>** at entrance exam of Polytechnikum in Zurich
  - Matura in Kantonsschule Aarau
- 1896~1900: ETHZ
  - <u>diploma</u> in math & science
  - met Mileva in the class
  - liked <u>free style</u> in Polytechnikum
  - hated old lectures, got 1 out 6



# 1900~1909 Patent Office

- no academic jobs (poor grade, no class attendance)
- patent office in Bern in 1902
- 1905: Annus Mirabilis
  - photoelectric effect
  - **Browninan motion**
  - PhD <u>molecular size</u> in <u>UZH</u>
  - <u>special relativity</u>
  - $\underline{E = mc^2}$
- 1907: Equivalence principle
- "der glücklichste Gedanke meines Lebens"
  - start working on general relativity
  - only to finish in 8 years





### **World-Famous Professor**

- 1909~1911: Ass. Prof. UZH (CHF 4500)
  - only 3 semesters, *bad* lectures
- 1911: Full Prof. Prague (CHF 9100)
- 1912~1914: Full Prof. ETHZ
  - world famous, but *bad* lecturer
  - field equation already *completed*, but rejected by Einstein
  - great help from Grossmann
- 1914~1933: Full Prof. Berlin
  - no teaching (he hated)
  - to be with his cousin
  - <u>1916 general relativity</u>
  - <u>1922 Nobel prize</u>





#### Institute for Advanced Study

- 1933~1955: Princeton, NJ
  - newly established institute, no teaching obligation
  - every winter from 1930, then 1933 not returned
  - work on unified theory of everything
  - died in 1955



# • gravitational lensing: *light deflection* by mass (or curved spacetime) Einstein's general theory of relativity suggests

Hubble Measures Deflection of Starlight by a Foreground Black Hole

Real star position

Observed star position



- precession of Mercury: *deviation* from Newtonian gravity
- already precisely observed
- Vulcan in ~1850: gravitational perturbations (like a prediction for Neptune in ~1840)





- Hulse-Taylor pulsars: *decay* of orbit due to gravitational wave emission (<u>weak field</u>)
- Nobel Prize in Physics in 1993 (indirect detection)



#### **Gravitational Wave Polarization**

• **Spin-2** polarization, generated by time-varying *quadrupolar* moment



gravitational waves: direct *detections* of gravitational wave

#### • <u>Nobel Prize</u> in Physics in 2017

LIGO (Laser Interferometer Gravitational-wave Observatory) is the world's largest gravitational wave observatory. LIGO consists of two laser interferometers located thousands of kilometers apart, one in Livingston, Louisiana and the other in Hanford, Washington. LIGO uses the physical properties of light and of space itself to detect gravitational waves. It was funded by the US National Science Foundation, and it is managed





by Caltech and MIT. Hundreds of scientists in the LIGO Scientific Collaboration, in many countries, contribute to the astrophysical and instrument science of LIGO. There are also other gravitational wave observatories in the world, including Virgo in Italy and GEO 600 in Germany.

Figure 9 LIGO Hanford and LIGO Livingston. Credit: Caltech/MIT/LIGO

- strain  $h \sim 10^{-22}$  produce  $\Delta L = 10^{-17}$  cm change in LIGO
- found BHs that we did not know!





Updated 2020-05-16 LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern



- initial perturbation generation in early Universe
- seed for *life* from *quantum fluctuations*



# **Upcoming Surveys**

DARK ENERGY SPECTROSCOPIC INSTRUMENT

- ground-based surveys:
  - Dark Energy Spectroscopic Instrument
  - Large Synoptic Survey Telescope
  - Square Kilometer Array
  - CMB Stage-IV
- space-based missions:
  - Euclid
  - Wide-Field Infrared Survey Telescope



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