

Seminar Katedre za astronomiju
15.10.2019.

Pomračenje i revolucija: 100 godina od Edingtonove potvrde opšte relativnosti

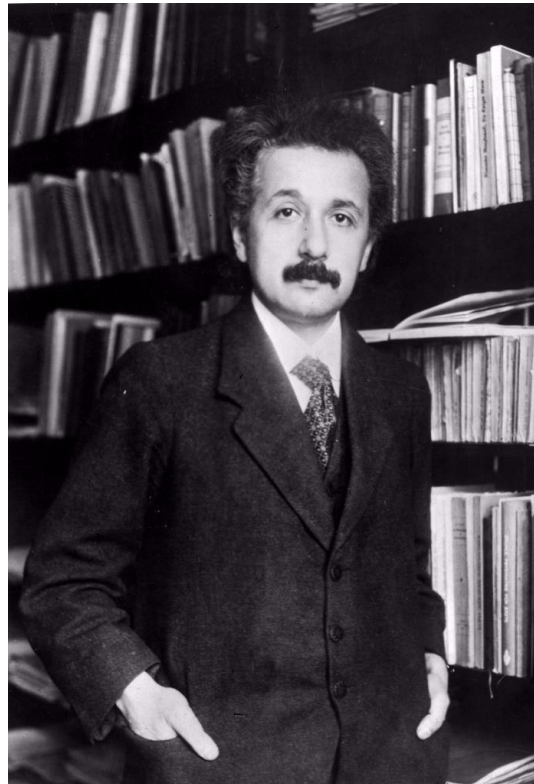
Dr Milan Stojanović

Astronomska opservatorija u Beogradu

Uvod

REVOLUCIJA

Albert Ajnštajn (1879-1955)



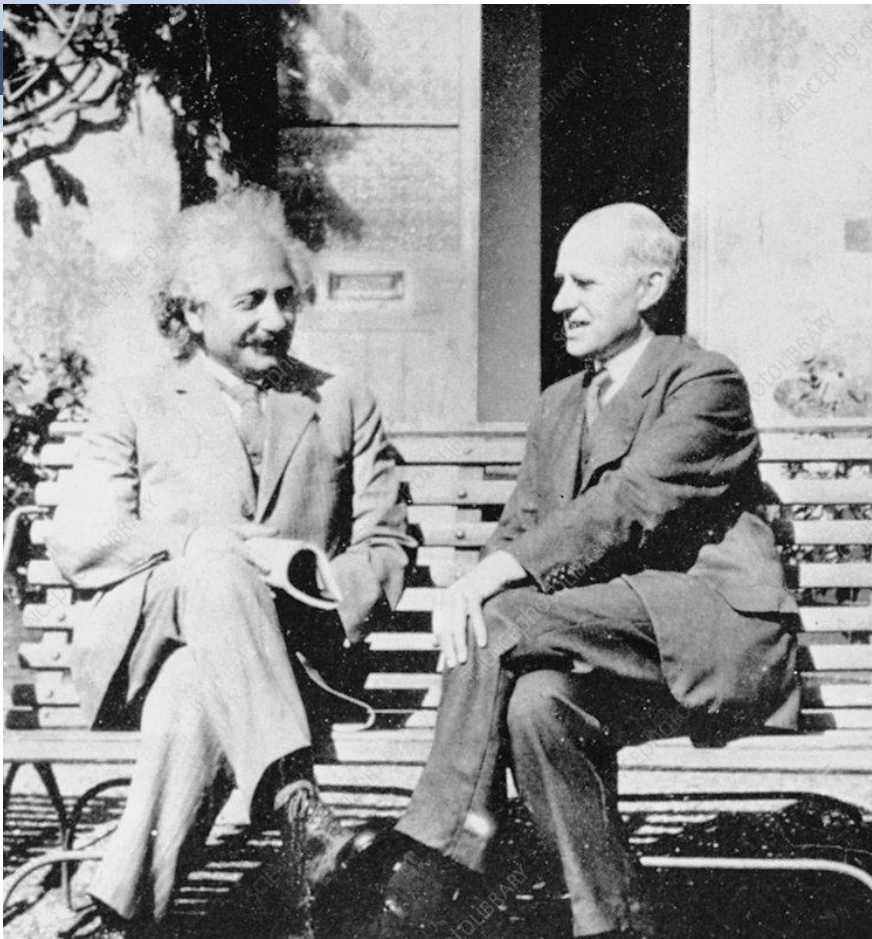
- Otac savremene kosmologije
- Osim radova o Specijalnoj i Opštoj teoriji relativnosti poznati su i rad o foto-električnom efektu (Nobel 1921), kvantnoj mehanici itd...

Slika iz 1916.

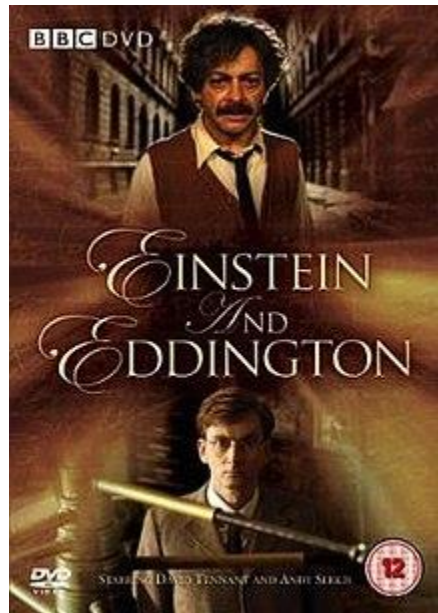
Sir Arthur Stanley Eddington (1882 –1944)

- Astrofizičar i veliki popularizator nauke
- Bavio se posmatračkom astronomijom (paralaksa 433 Eros)
- 1913. Plumian Professor of Astronomy and Experimental Philosophy - Cambridge University
- Evolucija zvezda, kosmologija...





Ajnštajn i Eddington u razgovoru,
snimljeno u Kembridžu 1930.



Pre Ajnštajnovе revolucije

■ Njutnova kosmologija – gravitacioni paradoks*

* Kerszberg, P. (1986). The Cosmological Question in Newton's Science. *Osiris*, 2, 69-106. Retrieved from <http://www.jstor.org/stable/301831>

■ Olbersov paradoks (oko 1840) – Kosmos je daleko od stanja termodinamičke ravnoteže

■ E. A. Poe (1848) – „Eureka“

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■ E. A. Poe (1848) – „Eureka“

■ Bolcman i Zermelo 1895-1896

■ Nedostaje teorija prostor-vremena...

Dva velika rada 1905. i 1915.

- Ajnštajn objavio 1905. rad o Specijalnoj teoriji relativnosti, prva revolucija u poimanju prostor-vremena.
- 1908. prostorvreme Minkovskog
- „Svi problemi su rešeni...“ Plank i Mah
- 1905-1915. „Lutanje u tami...“
- 1915. Ajnštajnov drugi rad, konačno OTR!

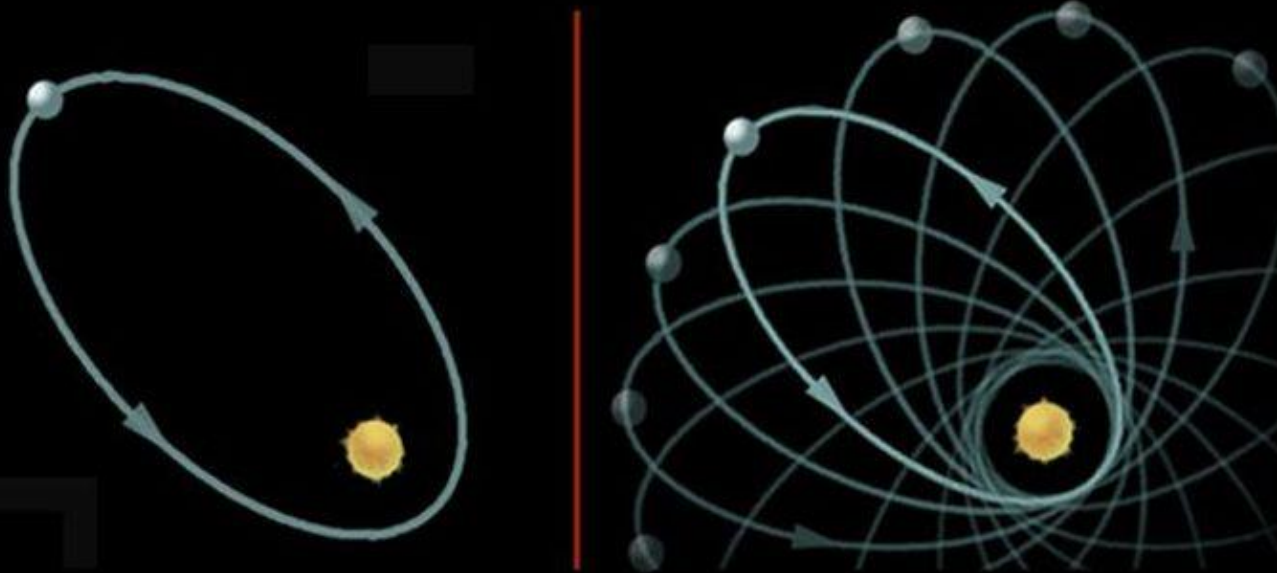
Princip ekvivalencije

- Krajem 19. veka Lord Etvaš pokazao da je inercijalna masa jednaka gravitacionoj masi.
- Glavna motivacija za OTR
- Misaoni eksperiment:

Posmatrač u kosmičkom brodu i posmatrač u kapsuli u slobodnom padu (lift) obojica u bestežinskom stanju.

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

Anomalija Merkurove orbite usled precesije



Dodatnih 43"/vek

- Njutnovski koncept prostora je apsolutan i **ravan** baš kao i prostorvreme Minkovskog u specijalnoj teoriji relativnosti!
- Nasuprot nezakrivljenom prostoru dolazi OTR.
- Najkraće rastojanje između dve tačke je geodezik!
- Putanja svetlosti – zakrivljena (geodezijska linija)
- Ovo je dokazano misaonim eksperimentom (Ajnštajn), a zatim i stvarnim eksperimentom (Edington).

Eksperimenti

Ajnštajnov misaoni eksperiment

- Misaoni eksperiment o liftu koji slobodno pada u gravitacionom polju.
- Putanja svetlosti u liftu koji pada?
- Različiti pogledi različitih posmatrača?
- Ishod eksperimenta **mora** biti isti za sve posmatrače!
- Zamena starog principa relativnosti...
 - ▷ Geodezici su zakrivljeni u gravitacionom prostoru,
 - ▷ Gravitacija ne može biti Njutnovska, već mora biti metrička.

“

As the sun moves in the sky toward a background star, it should bend the star's light. The star will appear to move.

A. Einstein

Ajnštajново pismo iz 1913.

- Erwin Finlay-Freundlich - 1913. prvi koji se odazvao Ajštajnovom pozivu da ispita pozicije zvezda tokom pomračenja.
- 1914. pomračenje Sunca u blizini Kijeva.
- Erwin završava u zatvoru!
- Astronomi sa Lik Opservatorije stižu u Kijev, međutim bez uspeha... (Hammond, Mitchell)
- Sreća na strani Ajnštajna?

Edington – organizacija ekspedicije 1917.

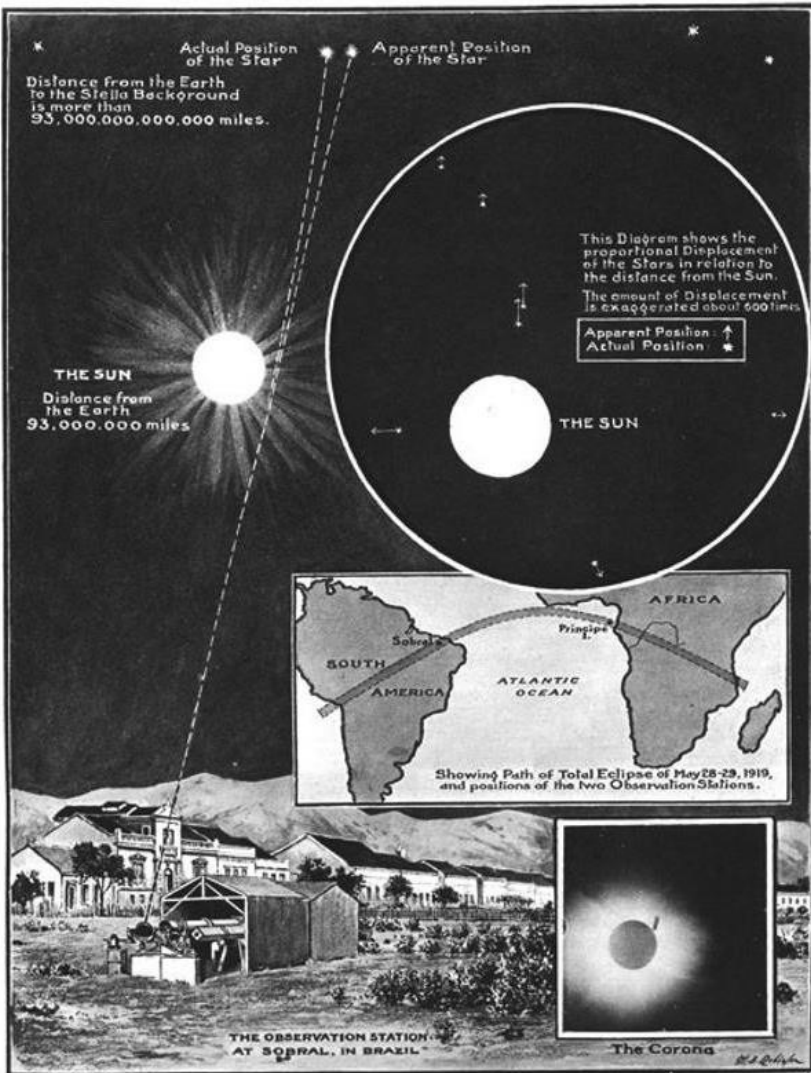
- Edington u vreme prvog svetskog rata...
- „Bitka za nauku“
- Nakon detaljnog istraživanja donosi odluku da testira OTR pomoću posmatranja pomračenja Sunca i planira datum ekspedicije.
- Najbolji uslovi 29.05.1919. godine
- Podrška Frenka Dajsona



Kraljevski astronom Frank Dajson i Artur Edington.

Uslovi

- Pomračenje trajalo nešto više od 5 minuta
- Hijade u blizini Sunca
- Tropski predeli, gde je razlika u temperaturi danju i noću bila mala
- Plan je bio da se odmah naprave i uporedni snimci
- Sobral i Principe dve lokacije sa kojih su posmatrali pomračenje



Ekspedicija Principe - Edington

- Od ukupno 16 foto ploča koje su poneli samo dve su imale upotrebljive podatke.
- Komparacioni snimci načinjeni u Oksfordu i na Principe ost.

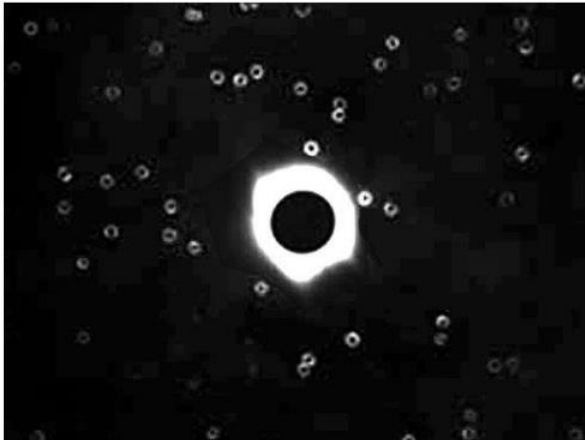


Figure 2. The 1919 eclipse. Credit: Arthur Eddington.

Ekspedicija Sobral - Dejvidson

- Nijedna od ukupno 19 foto ploča sa glavnog teleskopa nije iskorišćena zbog fokusa.
- Manji teleskop imao sve snimke uspešne.
- Komparacioni snimci načinjeni na licu mesta dva meseca kasnije.

Ekspedicija Sobral - Dejvidson

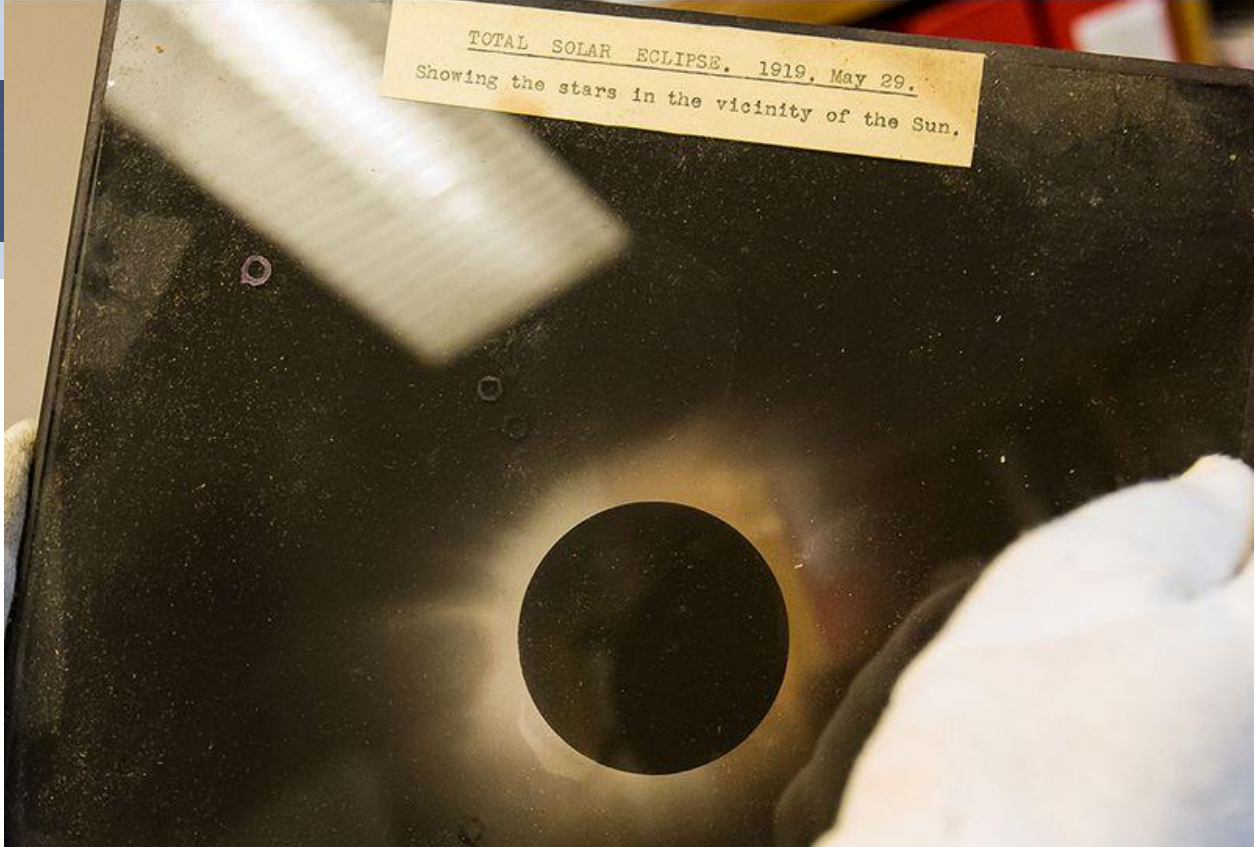


Instruments at Sobral, Brazil.

The 4-inch lens is in the square tube on the right, and the astrographic lens, chosen for its wide field of view, is in the circular tube on the left. In front of the tubes are mirrors that are driven by a mechanism that keeps the stellar images at the same position on the plates during an exposure. The mirror on the left was the chief suspect in the poor-quality astrographic-lens images produced during the 1919 eclipse. (Courtesy of the Science Museum, London.)

Ekspedicije - detalji

- Dyson, F. W.; Eddington, A. S.; Davidson, C. A - Determination of the deflection of light by the Sun's gravitational field, from observations made at the total eclipse of 29 May 1919. **Philos. Trans. R. Soc. Lond. Ser. A** 1920, 220, 291–333.
- Dyson, F. W., Eddington, A. S. and Davidson, C. (1920), 'Relativity and the Eclipse Observations of May, 1919', **Nature** 106, 786–787.



A copy of a photograph of a solar eclipse taken by the English astronomer Arthur Eddington in 1919. (Niels Bohr Institute)

Mogući rezultati: 0.87" ili 1.75"

■ Dajsonovo objašnjenje Dejvidsonu:

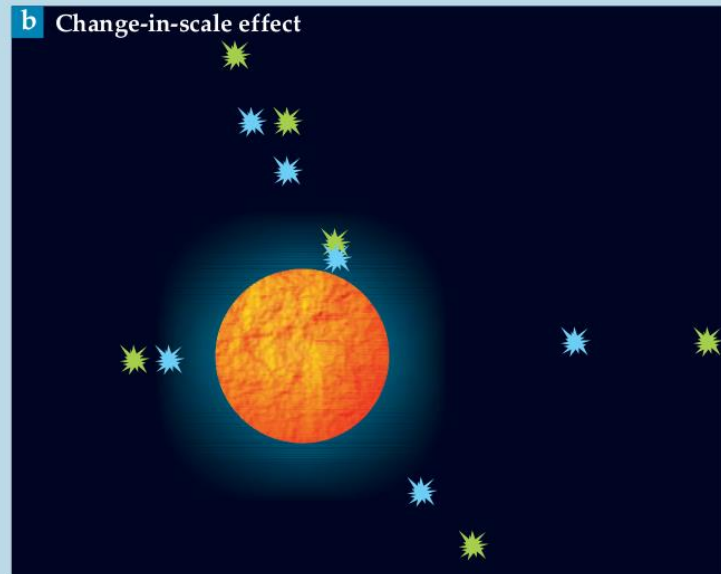
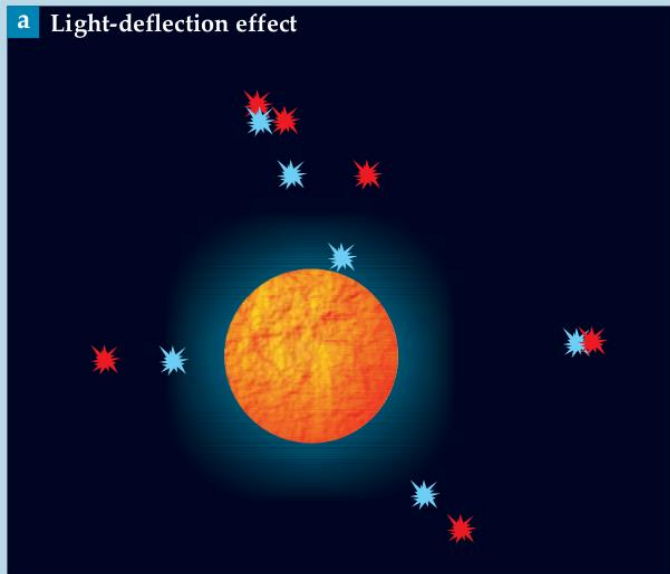
„There are three theoretically plausible results: no deflection; half deflection, which would show that light had mass, and vindicate Newton; and full deflection, which would vindicate Einstein. Gathering that the greater the deflection the more theoretically exciting and novel the result is.“

Cottingham asked: „What would happen if they obtained twice the Einstein deflection?“

“Then,” replied Dyson, “Eddington will go mad, and you will have to come home alone.”

Problemi...

„Confirmation and check plates“



Eddington - Dyson

Dear Dyson,

I was very glad to have your letter & measures. I am glad the Cortie plates gave the full deflection not only because of theory, but because I had been worrying over the Principe plates and could not see any possible way of reconciling them with the half deflection. I thought perhaps I had been rash in adopting my scale from few measures. I have now completed my definite determination of A (5 different Principe v. 5 different Oxford plates), it is not greatly different from the provisional though it reduces my values of the deflection a little. (Arthur S. Eddington to Frank W. Dyson, 3 October 1919, MS.RGO.8/150, Cambridge University Library)

Rezultati sa ekspedicija se slažu sa Ajnštajnovim predviđanjima OTR

06.11.1919.

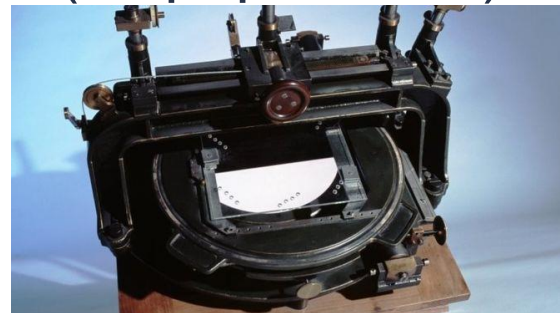
■ Sobral ekspedicija:

- ▶ 4-inch teleskop ima najveću težinu:
 $1''.98 \pm 0''.12$
- ▶ Astrograf (podaci ipak odbačeni):
 $0''.93$, odnosno $1''.52$ (sa popravkom)

■ Principe ekspedicija:

- ▶ $1''.61 \pm 0''.30$

"I knew that Einstein's theory had stood the test and the new outlook of scientific thought must prevail."



Provera rezultata

■ F. Dyson, *Nature* 106, 786 (1921)

If it is assumed that the scale has changed, then the Einstein deflection from the series of plates is 0.90"; if it is assumed that no real change of focus occurred, but merely a blurring of the images, the result is 1.56"; little weight is, however, attached to this series of photographs.¹¹

■ G. M. Harvey, *Observatory* 99, 195 (1979)

Instrument	1919 result	1979 result
4-inch lens	1.98" ± 0.18"	1.90" ± 0.11"
Astrographic lens	0.93"	1.55" ± 0.34"

■ S. W. Hawking, *A Brief History of Time*, New York (1988)

■ D. Kennefick, *Physics Today* 62, 3, 37 (2009)

■ P. Coles, *Nature*, 568, (2019)

“ The result was contrary to my expectations, but since we obtained it I have tried to understand the Relativity business, & it is certainly very *comprehensive*, though elusive and difficult. (MS.RGO.8/123, Cambridge University Library)

Dyson - Frank Schlesinger 1920
direktor Yale opservatorije

“ It was Dyson’s enthusiasm that got the eclipse expeditions ready to start in spite of very great difficulties. He was at that time very skeptical about the theory though deeply interested in it; and he realized its very great importance. (Hermann Weyl Nachlass, Hs 91:523, ETH-Bibliothek Zürich)

Edington - Herman Weyl 1920

Vesti, vesti.

**REVOLUTION IN
SCIENCE.**

**NEW THEORY OF THE
UNIVERSE.**

**NEWTONIAN IDEAS
OVERTHROWN.**

Copyright 1919, The Times

Can't Understand Einstein.
Special Cable to THE NEW YORK TIMES.
LONDON, Nov. 28.—The London Times in an editorial this morning on an explanation by Dr. Albert Einstein of his theory of relativity confesses that it cannot follow the details with complete certainty, and points out that even Einstein himself finds no little difficulty in making their meaning clear.
"So far as we can follow it," says The Times, "the chief result regarded as an absolute proposition, hitherto regarded as the simple majesty of the square of the distance has ceased to retain its isolated splendor as an expression of conformity between abstract thought and observation of the fabric of the universe."

The New York Times
Published: November 29, 1919
Copyright © The New York Times

Einstein's Theory

To the Editor of The New York Times
In your most interesting and article in today's Times on "Logic," discussing the Einstein theory that a theoretically straight line may be curved merely because a line of infinite Professor Newton of Yale used to mark to his classes in conic sections with regard to the axes of a parabola; that, "proceeding in a straight line to infinity in one direction, they came back to infinity in the other," this statement was always accompanied by a somewhat inscrutable smile, as though he should say: "This may seem a peculiar statement to you young gentlemen, but nevertheless is something to be reckoned with."
R. W. ARCHBALD, Yale, '71.
Scranton, Nov. 16, 1919.

The New York Times
Published: November 21, 1919
Copyright © The New York Times

**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.**

Special Cable to THE NEW YORK TIMES.
LONDON, Nov. 9.—Efforts made to put in words intelligible to the non-scientific public the Einstein theory of light proved by the eclipse expedition so far have not been very successful. The new theory was discussed at a recent meeting of the Royal Society and Royal Astronomical Society, Sir Joseph Thomson, President of the Royal Society, declares it is not possible to put Einstein's theory into really intelligible words, yet of the same kind. The new theory is

Vesti, vesti, vesti...

- *They reported Einstein triumphed over Newton, even as the portrait of Newton gazed over the proceedings...*
- *Posle The Times - 'Revolution in Science' i druge novinske agencije postupaju slično.*
- *The Daily - 'Upsetting the Universe',*
- *The Observer - 'The Baseless Fabric of the Universe',*
- *The Daily Herald - 'Bloodless Revolution',*
- *Daily Mail 'Light [had been] Caught Bending'.*

Govor predsednika RAS

Sir J. J. Thomson – 1.12.1919.

<https://doi.org/10.1098/rspa.1919.0057>

The domestic events in the history of the Society have been so numerous that I have but little time for any other subject. I cannot, however, pass over without notice the remarkable result that was announced at our first meeting this session, that the observations made at the eclipse of May 29 showed that light was deflected, when passing close to the Sun, by an amount

316 *Anniversary Address by Sir J. J. Thomson.*

which, within the somewhat wide limits of the experimental error, agreed with that predicted by Einstein.

The deflection of light by matter, suggested by Newton in the first of his Queries, would in itself be a result of first-rate scientific importance; it is of still greater importance when its magnitude supports the law of gravity put forward by Einstein, a law which has explained the long-standing difficulty of the motion of the perihelion of Mercury.

On Einstein's Law the velocity of light passing through a field of gravitational attraction depends upon the gravitational potential, and diminishes as the potential diminishes. Thus the gravitational field round the Sun acts like a refracting atmosphere, the refraction diminishing as the distance from the Sun increases.

Though there are some hundreds of theories of gravitation Einstein's is the only one which has predicted a result which has been verified by experience. On Einstein's, as on several other theories, changes in gravitational attraction

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Another interesting consequence of Einstein's theory is the minuteness of structure which it demands from matter. The electron has a radius of 10^{-13} cm., carried our notions of the minuteness of constituents of the Universe far beyond those associated with atomic theory, but the size of the centres of disturbance, which in Einstein's theory are associated with matter, bears to the size of the electrons the same proportion as the size of the smallest particle visible under a powerful microscope to that of the Earth itself.

I am afraid that the termination of the war has not brought to an end the difficulties in the way of scientific research in this country. Not the least of these is the difficulty and expense of procuring apparatus. It is surprising that under these circumstances the Government should not have taken more steps to remove the obstacles in the way of the importation of philosophical instruments. Another very real difficulty is that the large increase in the number of students in our universities has greatly increased the educational requirements of many of our most active workers, and so diminished the time available for research.

The demands of war required large quantities of substances which were previously only obtainable in small quantities and at great expense. Prominent among these is helium, which can now be procured in quantities which, measured by Laboratory standards, is unlimited. Such supplies of helium put cryogenic research on a new footing and render possible investigations which promise to be of the greatest importance to many branches of Science. It is greatly to be regretted that in this country, where the birthplace of cryogenic research, we have no adequately equipped laboratory.

We must now proceed to the presentation of the Medals.

SPACE TIME

AND

GRAVITATION

AN OUTLINE OF THE GENERAL
RELATIVITY THEORY

BY

A. S. EDDINGTON, M.A., M.Sc., F.R.S.

PLUMIAN PROFESSOR OF ASTRONOMY AND EXPERIMENTAL
PHILOSOPHY, CAMBRIDGE

CAMBRIDGE

AT THE UNIVERSITY PRESS

1920

PROLOGUE

WHAT IS GEOMETRY?

A conversation between—

An experimental PHYSICIST.

A pure MATHEMATICIAN.

A RELATIVIST, who advocates the newer conceptions of time and space
in physics.

Rel. There is a well-known proposition of Euclid which states that “Any two sides of a triangle are together greater than the third side.” Can either of you tell me whether nowadays there is good reason to believe that this proposition is true?

Math. For my part, I am quite unable to say whether the proposition is true or not. I can deduce it by trustworthy reasoning from certain other propositions or axioms, which are supposed to be still more elementary. If these axioms are true, the proposition is true; if the axioms are not true, the proposition is not true universally. Whether the axioms are true or not I cannot say, and it is outside my province to consider.

Phys. But is it not claimed that the truth of these axioms is self-evident?

Math. They are by no means self-evident to me; and I think the claim has been generally abandoned.

Phys. Yet since on these axioms you have been able to found a logical and self-consistent system of geometry, is not this indirect evidence that they are true?

Math. No. Euclid’s geometry is not the only self-consistent system of geometry. By choosing a different set of axioms I can, for example, arrive at Lobatchewsky’s geometry, in which many of the propositions of Euclid are not in general true. From my point of view there is nothing to choose between these different geometries.

Rel. How is it then that Euclid’s geometry is so much the most important system?

Vrlo brzo ponovljen eksperiment

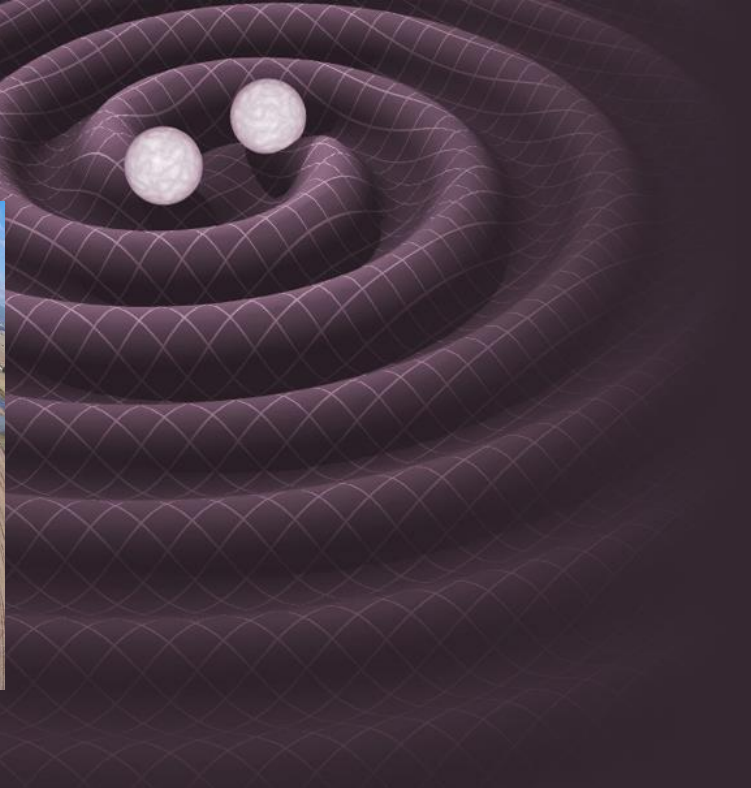
- Astronomi sa opservatorije Lik potvrdili su OTR, tj. isto ono što je prvi uradio Edington 1922. prilikom posmatranja pomračenja Sunca u Australiji i 1923. u Meksiku.

Umesto zaključka

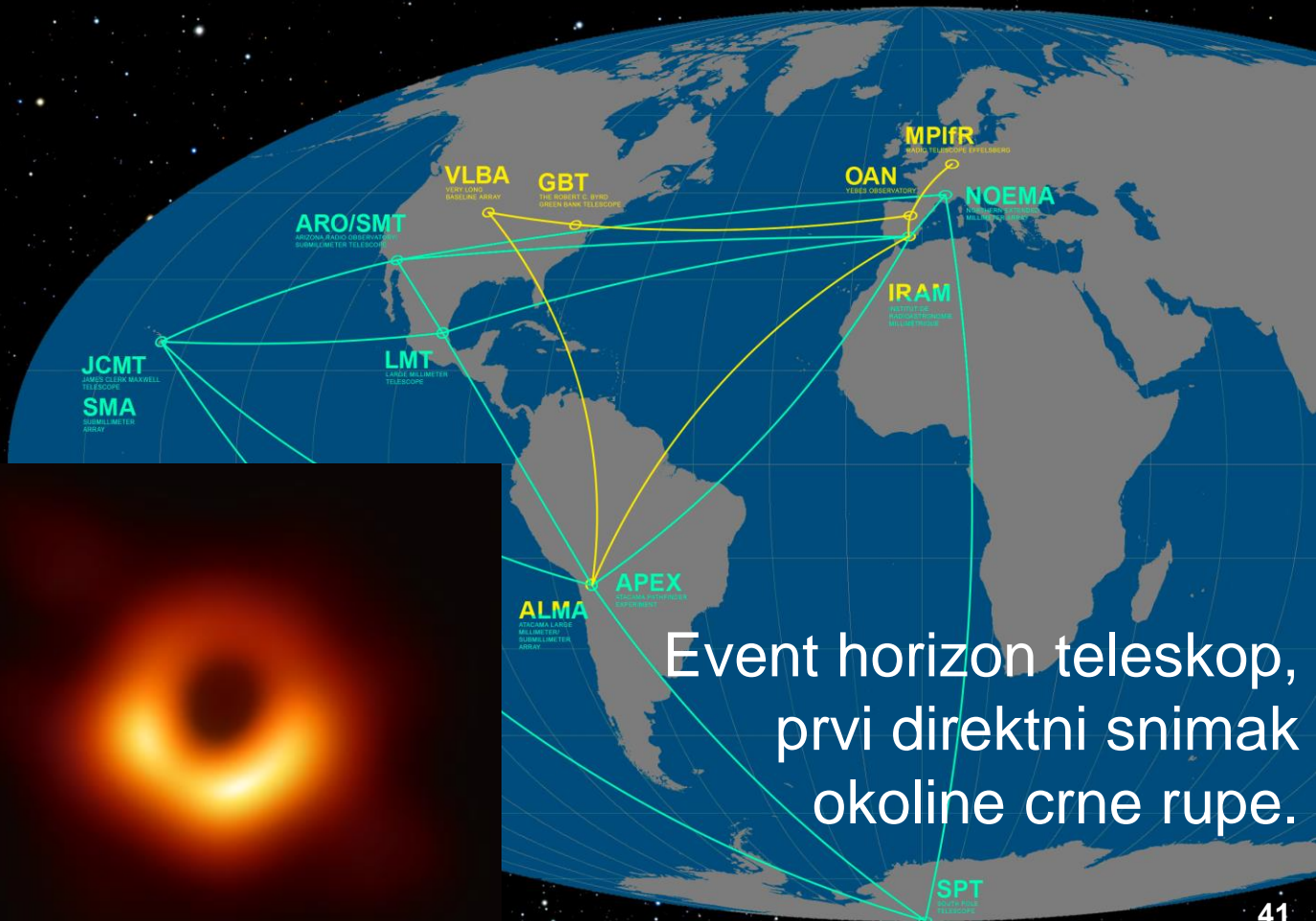
„Vek Ajnštajna“

Gravitational lensing
in galaxy cluster
Abell S1063,
showcasing the
bending of starlight
by the presence of
matter and energy.
Image credit: NASA,
ESA, and J. Lotz
(STScI)





- Poinkare 1905 i Ajnštajn 1915. diskutuju o gravitacionim talasima.
- Gravitacioni talasi potvrđjeni 2015. - LIGO



Event horizon teleskop,
prvi direktni snimak
okoline crne rupe.



Hvala na pažnji!



*Oh leave the Wise our measures to collate
One thing at least is certain, LIGHT has WEIGHT,
One thing is certain, and the rest debate —
Light-rays, when near the Sun,
DO NOT GO STRAIGHT.*

A. S. Eddington