

Institut za fiziku
istorija nauke • epistemologija
04.06.2019.

Pomračenje i revolucija: 100 godina od Edingtonove potvrde opšte relativnosti

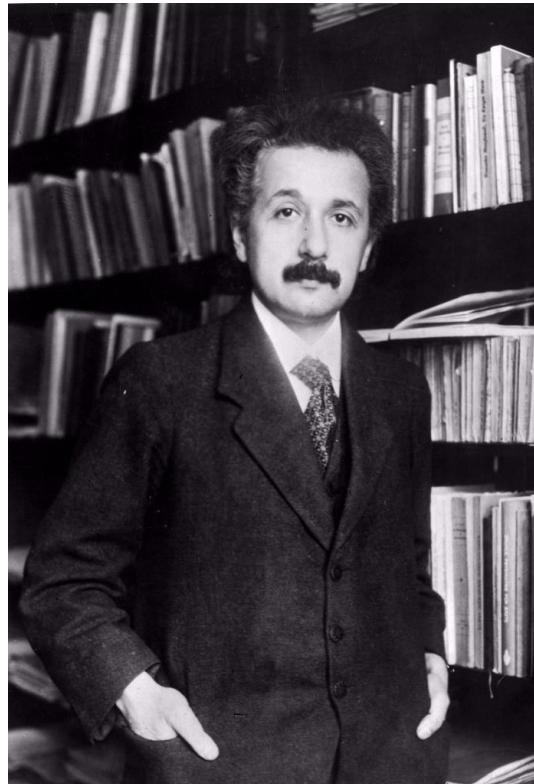
Dr Milan Stojanović

Astronomski observatorij 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.

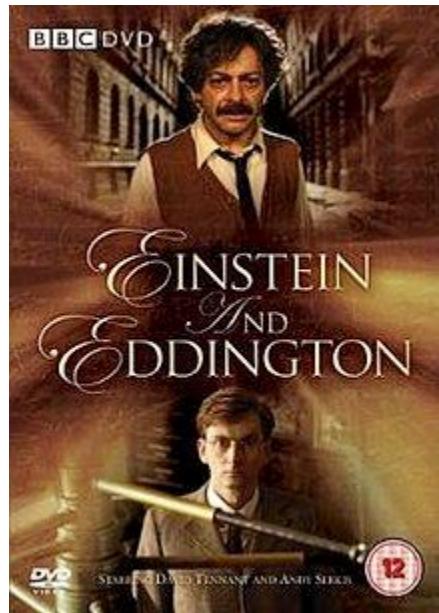
Sir Arthur Stanley Eddington (1882 –1944)

- 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 Edington u razgovoru,
snimljeno u Kembrižu 1930.



Pre Ajnštajbove revolucije

- Njutnova kosmologija – gravitacioni paradoks
- Olbersov paradoks (oko 1840) – Kosmos je daleko od stanja termodinamičke ravnoteže
- 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!

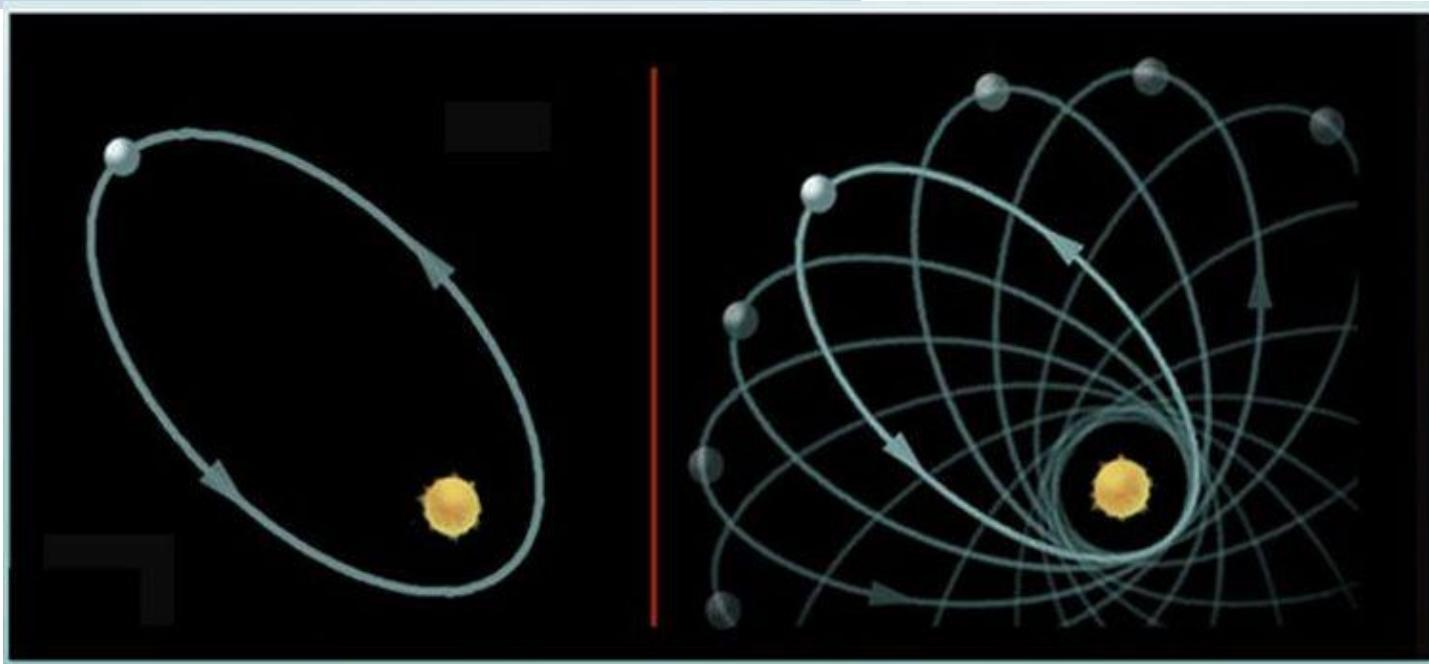
Princip ekvivalencije

- Krajem 19. veka pokazano je 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.

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

Anomalija Merkurove orbite usled precesije



Dodatnih $43''/\text{vek}$

- Njutnovski koncept prostora je apsolutan i **ravan** baš kao i prostorvreme Minkovskog u specijalnoj teoriji relativnosti!
- Nasuprot nezakrivljenom prostoru dolazi OTR.
- Najkraće rastojanje izmedju 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

Ajnštajnovo 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.

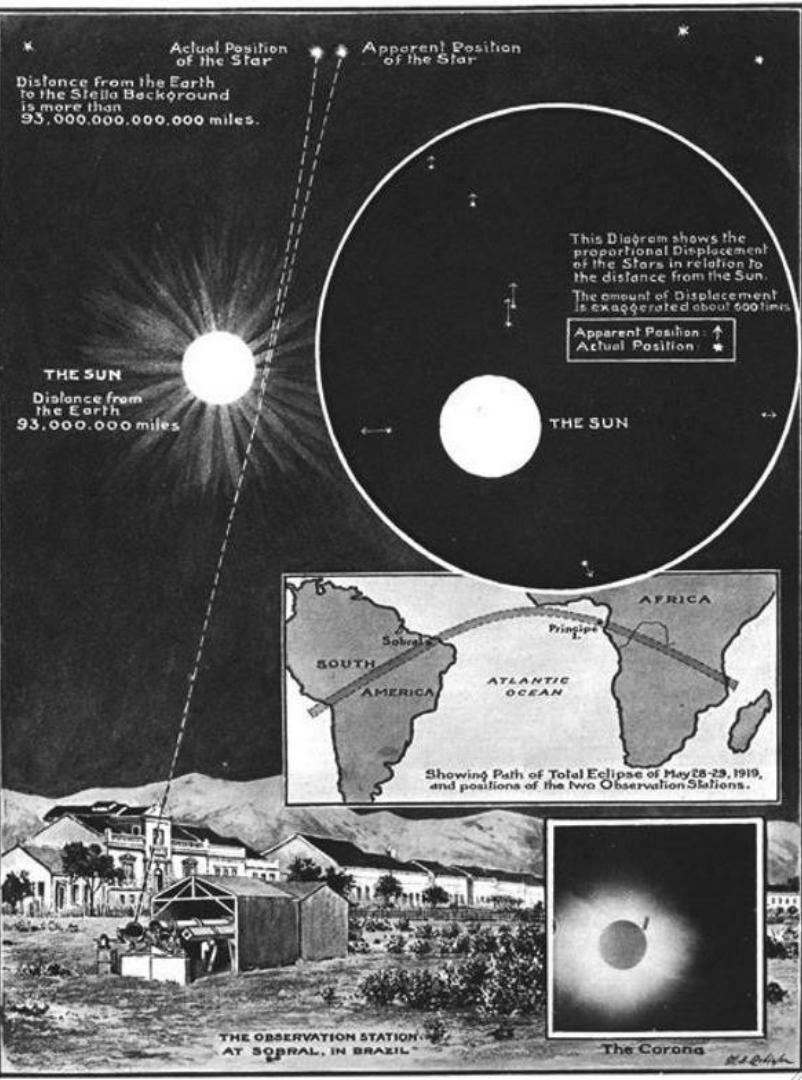
- Edington u vreme prvog svetskog rata...
- „Bitka za nauku“
- Nakon detaljnog istraživanja donosi odluku da testira OTR pomoću posmatranja pomračenja Sunca i planira datum ekspedicije.
- Najbolji uslovi 29.05.1919. godine
- Podrška Frenka Dajsona



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.

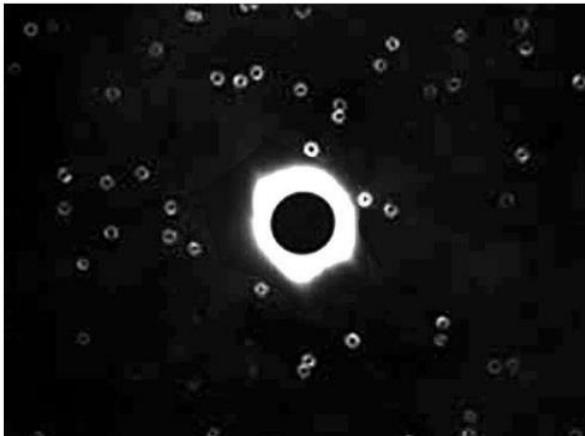


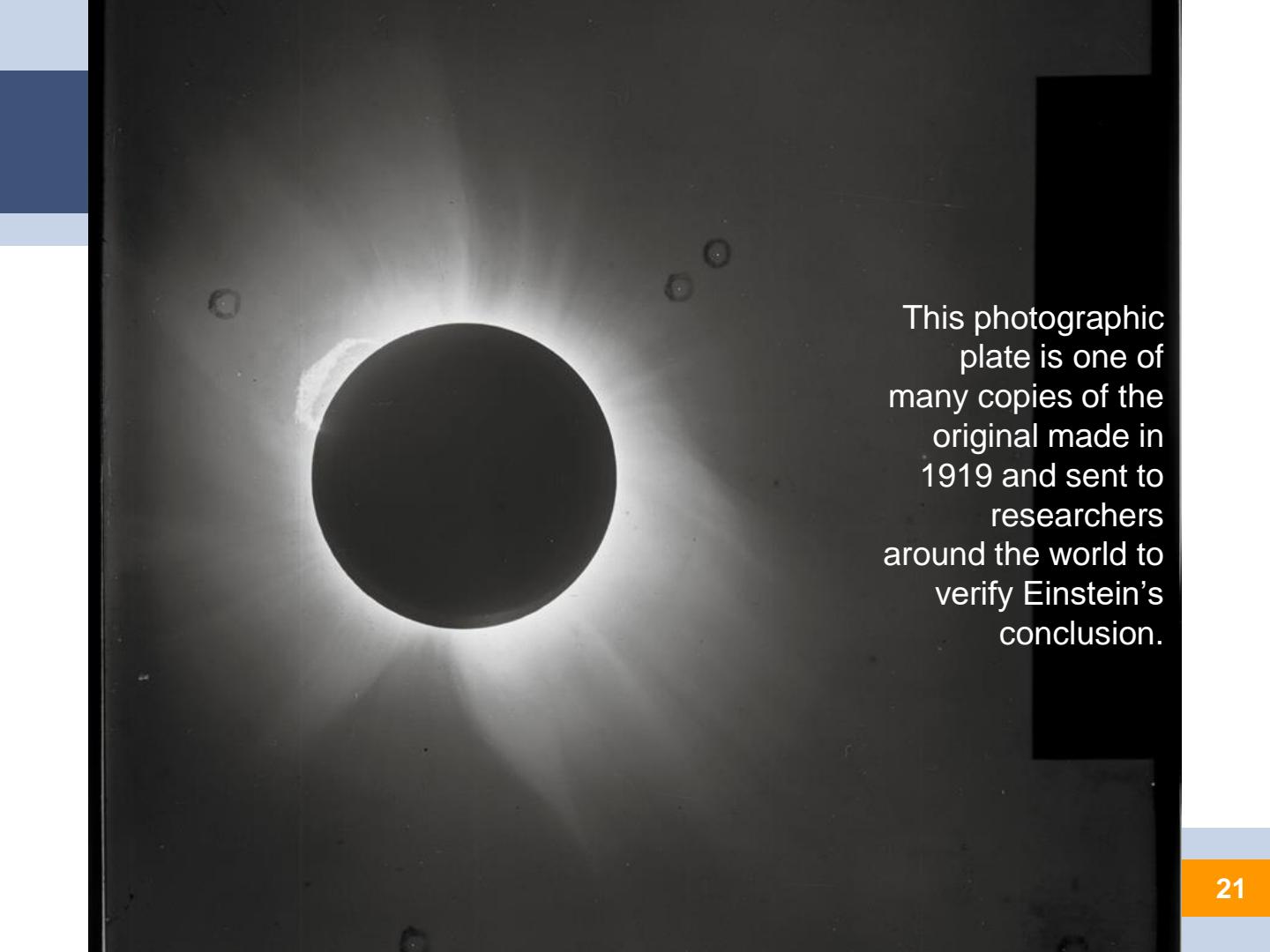
Figure 2. The 1919 eclipse. Credit: Arthur Eddington.

Ekspedicija Sobral - Dejvidson

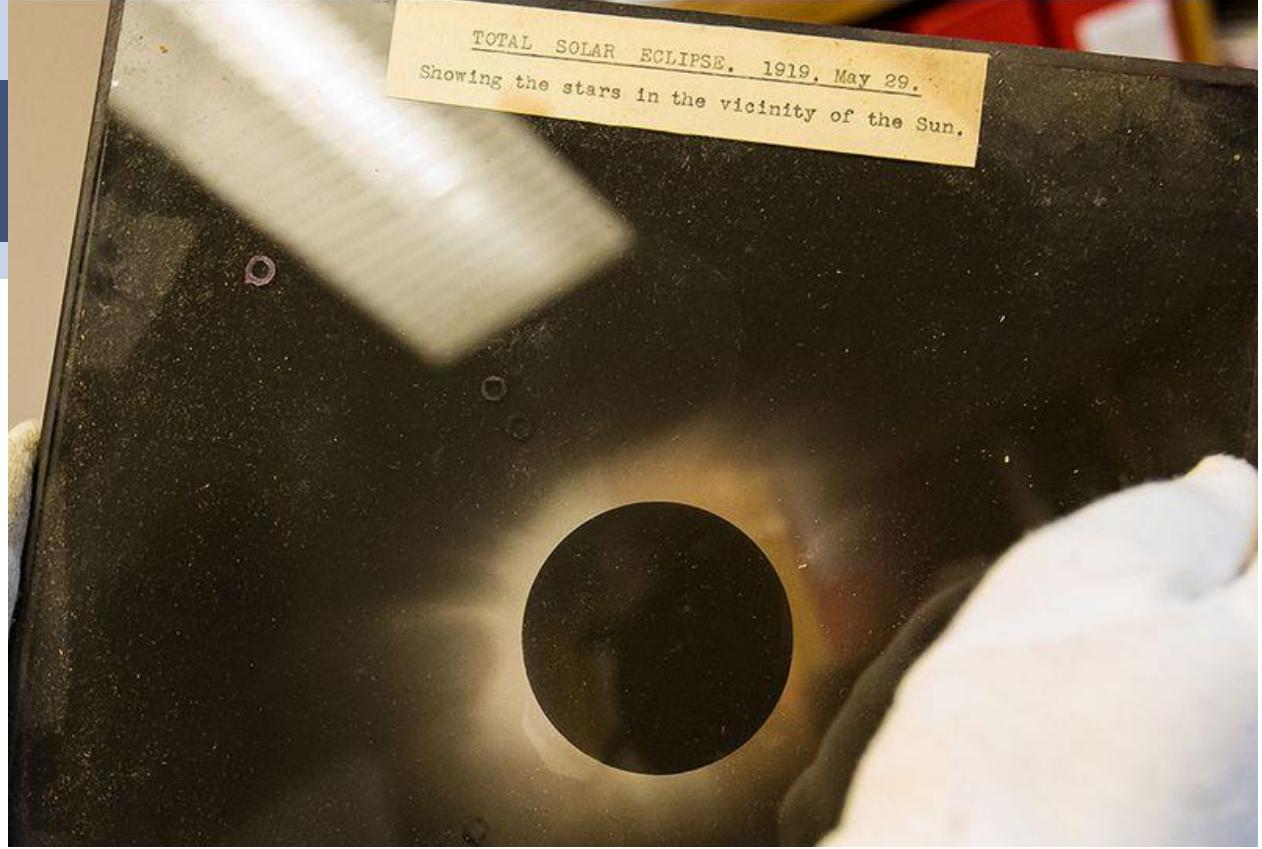
- Nijedna od ukupno 19 foto ploča sa glavnog teleskopa nije iskorišćena zbog fokusa.
- Manji teleskop imao sve snimke uspešne.
- Komparacioni snimci načinjeni na licu mesta dva meseca kasnije.

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.



This photographic plate is one of many copies of the original made in 1919 and sent to researchers around the world to verify Einstein's conclusion.



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.“

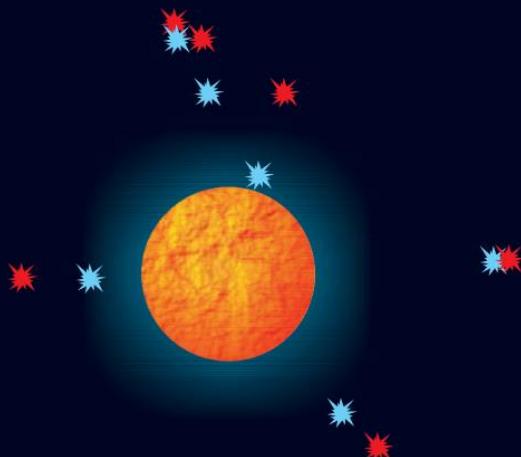
Cottingham asked: „What would happen if they obtained twice the Einstein deflection?“

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

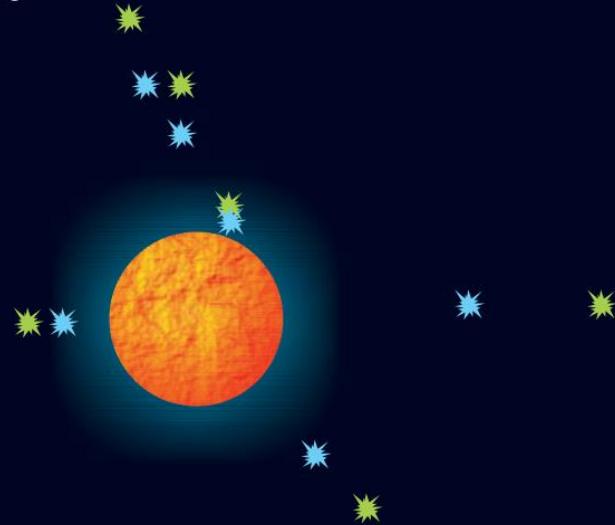
Problemi...

„Confirmation and check plates“

a Light-deflection effect



b Change-in-scale effect



Edington - 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)

06.11.1919.

Rezultati sa ekspedicija se slažu sa Ajnštajnovim predviđanjima OTR

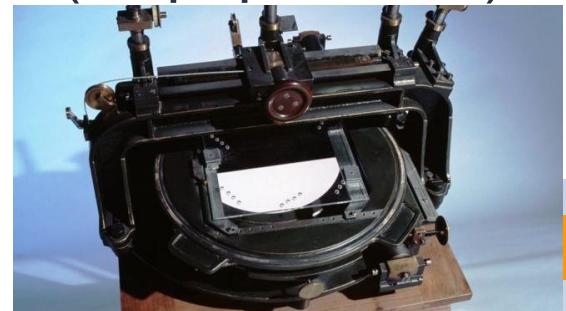
■ Sobral ekspedicija:

- ▶ 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	$1.98'' \pm 0.18''$	$1.90'' \pm 0.11''$
Astrographic lens	0.93"	$1.55'' \pm 0.34''$

■ 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.
in LONDON, Nov. 28.—The London Times
in an editorial this morning on an ex-
planation by Dr. Albert Einstein on an ex-
planation of relativity confesses that it
cannot follow the new theory and implications of his
theory of relativity. The new details and implications of the new theory 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 appears to be
that gravitation, hitherto regarded as
an absolute proposition, becomes relative.
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 observa-
tion of the fabric of the universe."

The New York Times

Published: November 29, 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.

To the Editor of THE NEW YORK TIMES,
In your most interesting article in today's TIMES on "Einstein's Theory of Light," you say: "Euclid would hardly have imagined that a theoretically because a straight line of logic, curved merely because a straight line of logic, curved." This reminds me of a remark which I made to my professor Newton of Yale used to make in his classes in conic sections with regard to his axes of a parabola, that "one direction in which they came from another." This statement was always accompanied by a smile, as though to you young gentlemen, as though to you young gentlemen, as though he should say: "This may seem a peculiar statement to you young gentlemen, but nevertheless it is something to be reckoned with." ARCHIBALD, Yale, '71.

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

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 at the same time there is no

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

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

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

I am afraid that the termination of the war has not brought to an end all 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 rather surprising that under these circumstances the Government should have removed all 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 work of many of our most active workers, and so diminished the time they can devote to research.

The demands of war required large quantities of substances which previously were only obtainable in small quantities and at great expense. Prominent among these is helium, which can now be procured on a large scale, 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 of the branches of Science. It is greatly to be regretted that in this country, the birthplace of cryogenic research, we have no adequately equipped cryogenic 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

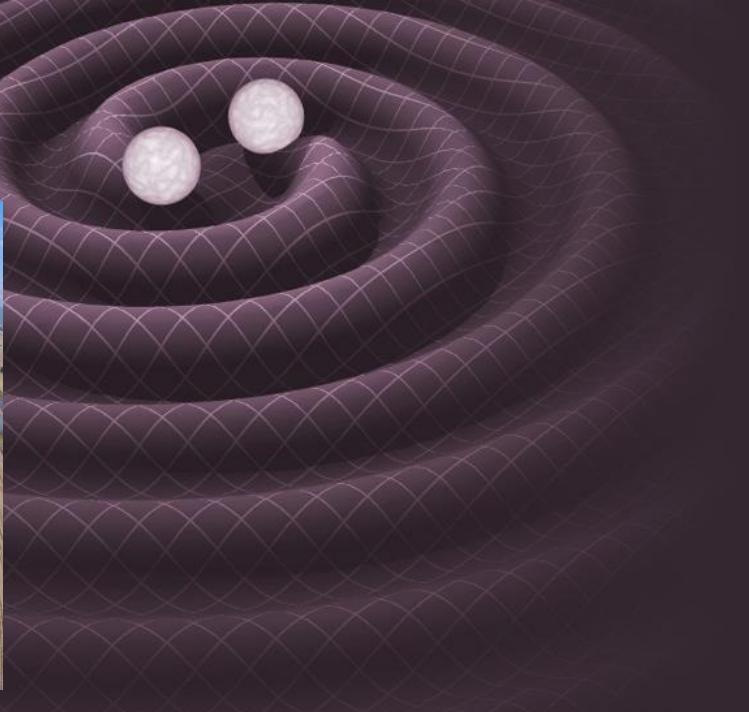
- Astronomi sa opservatorije Lik potvrdili su OTR, tj. isto ono što je prvi uradio Edington 1922. prilikom posmatranja pomračenja Sunca u Australiji i 1923. u Meksiku.

Umesto zaključka

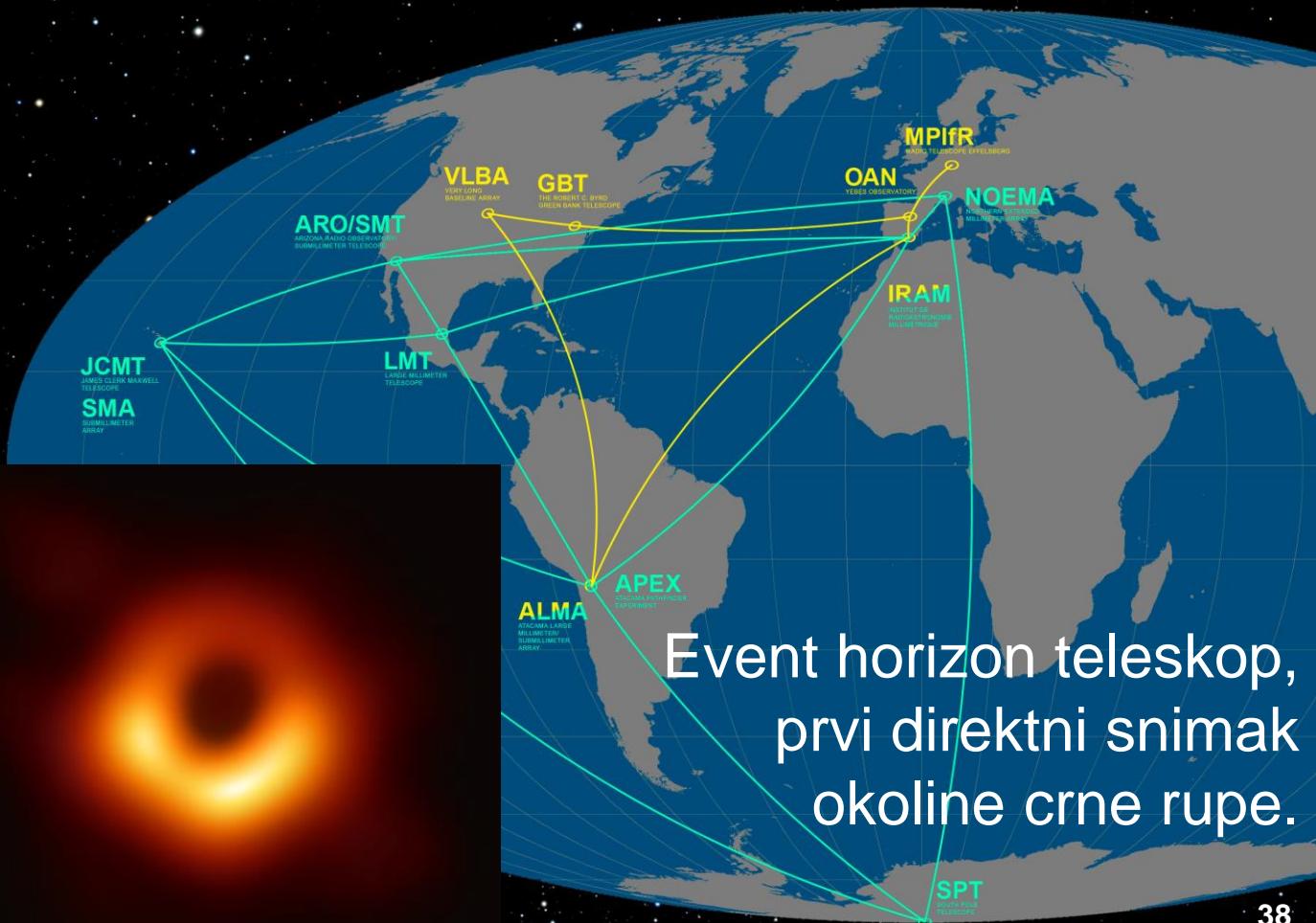
„Vek Ajnštajna“

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



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. Edington