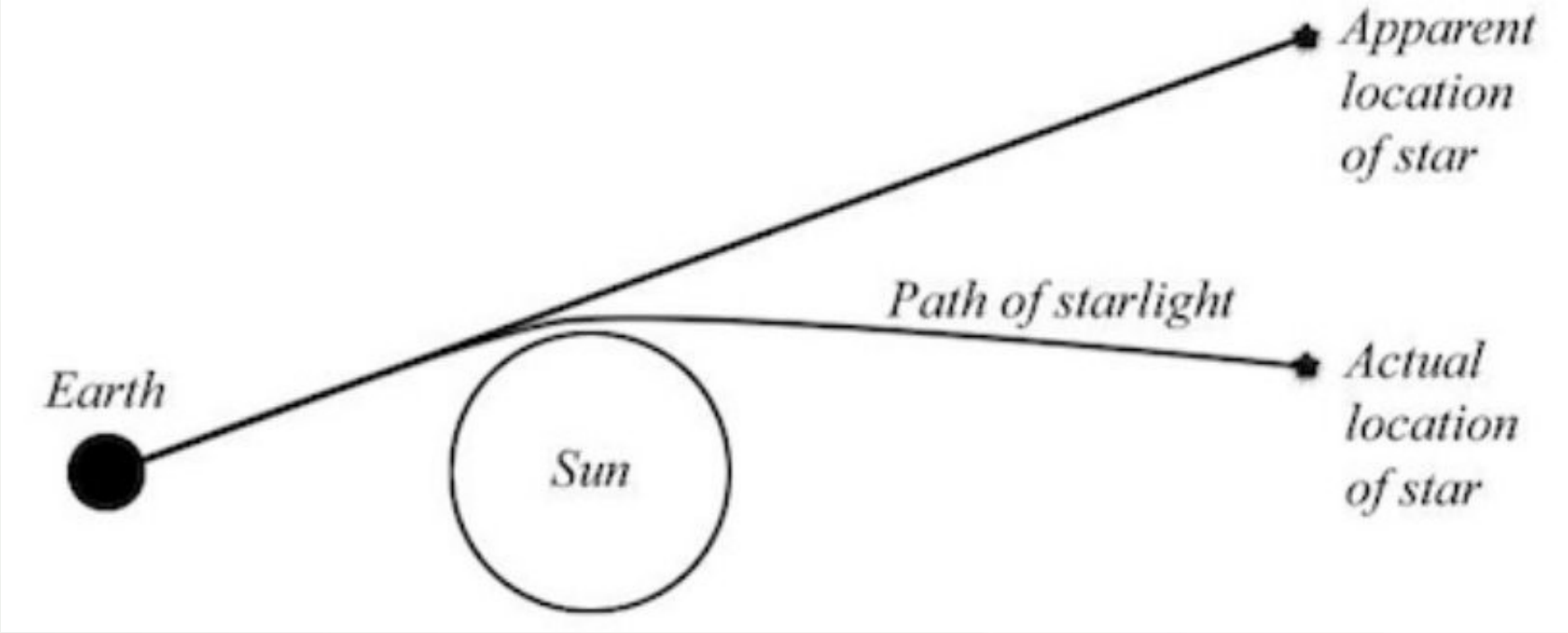
Gravitacijsko lečenje

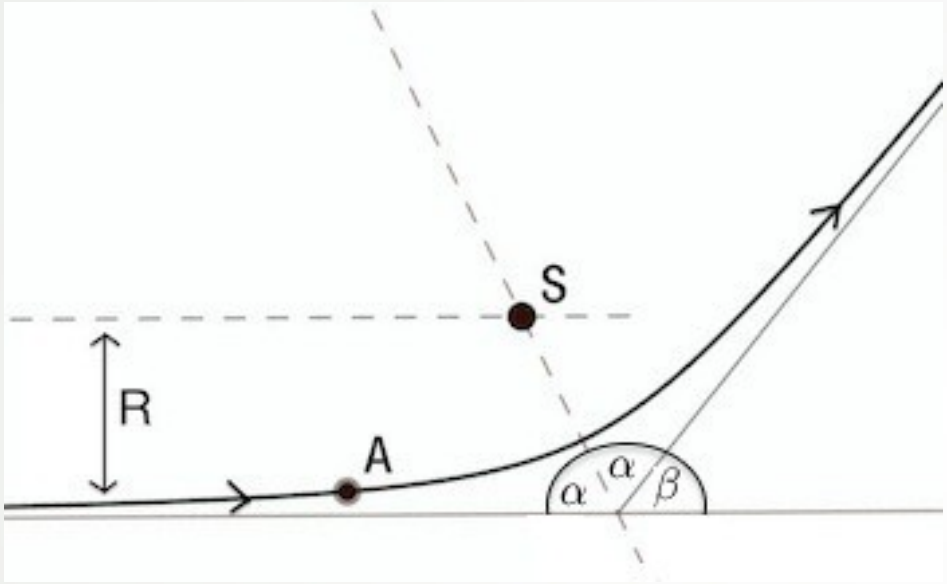
(intermezzo)

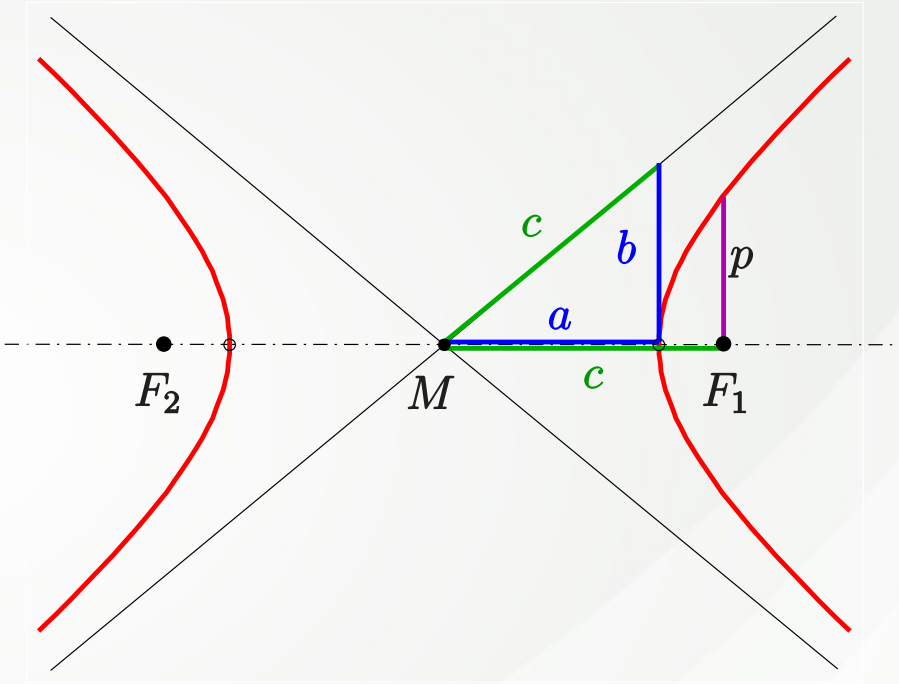
Viri: Jones, Lambourne (Chap. 1), Maoz (Chap. 6)

Newtonova in Einsteinova teorija na preizkusu



Odklonski kot (Newton)





asteroid (A) se giblje mimo Sonca (S);
kot β imenujemo *odklonski kot*,
razdaljo R pa imenujemo
vpadni parameter

$$\beta = \frac{2GM}{c^2 R}$$

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$

enačba hiperbole
a – velika polos
b – mala polos

Avtorstvo slike (desno): Ag2gaeh

Odklonski kot (Einstein)

Einsteinova enačba polja $$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

tenzor, povezan z metriko (ukrivljenost prostorčasa)

tenzor, ki opisuje porazdelitev energije in gibalne količine

Opis prostor-časa z metriko:

Minkowski:

$$(ds)^2 = (cdt)^2 - (dx)^2 - (dy)^2 - (dz)^2$$

$$(ds)^2 = (cdt)^2 - (dr)^2 - (rd\theta)^2 - (r\sin\theta d\phi)^2$$

sferni koord. sistem

Schwarzschild:

$$(ds)^2 = \left(1 - \frac{2GM}{rc^2}\right)(cdt)^2 - \left(1 - \frac{2GM}{rc^2}\right)^{-1}(dr)^2 - (rd\theta)^2 - (r\sin\theta d\phi)^2$$

geometrija prostor-časa okrog statične, sferne masne distribucije

$$\beta = \frac{4GM}{c^2 R}$$

Potrditev splošne relativnosti

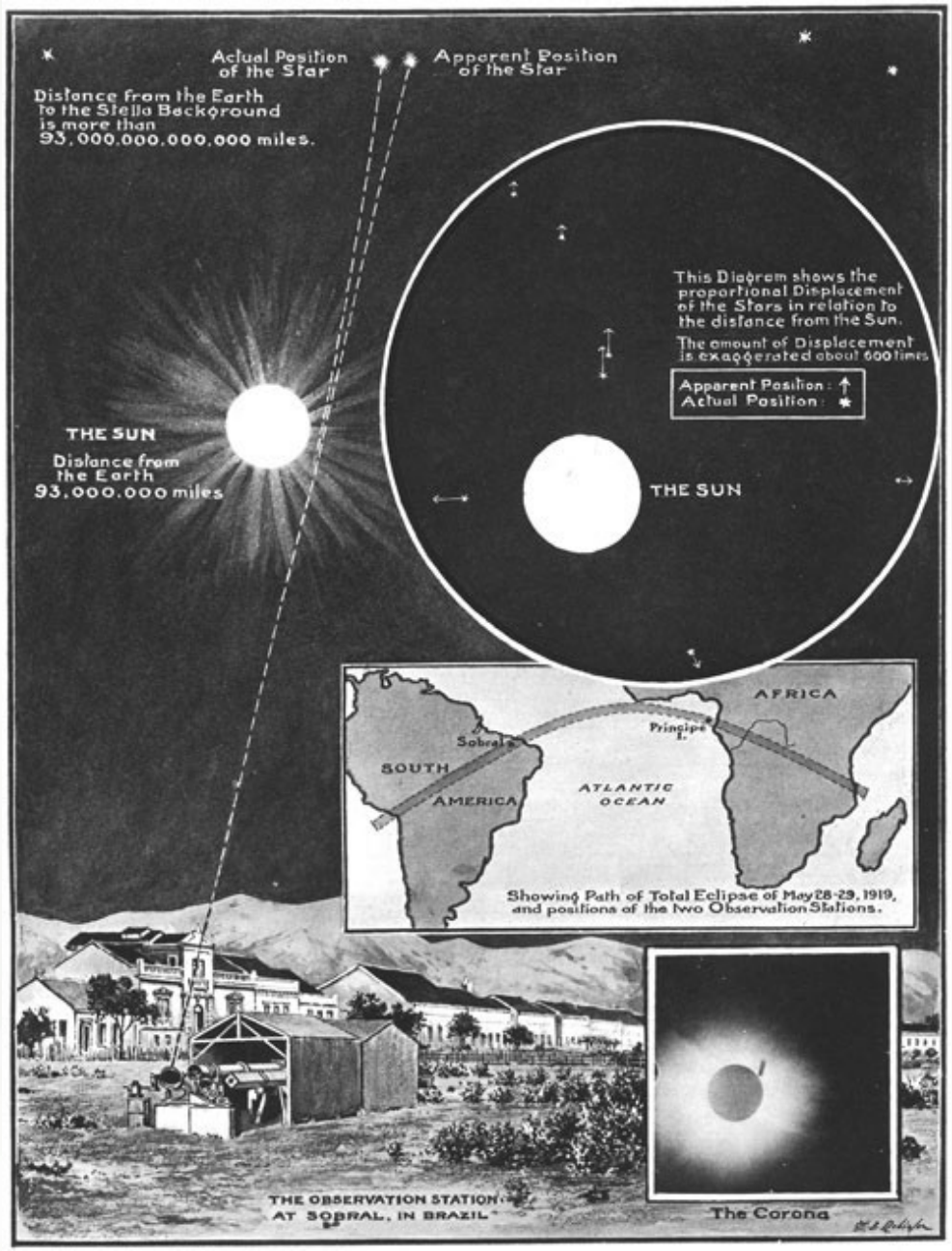
- **1919 – Eddington potrdi Einsteinovo teorijo**
- opazovanje Sončevega mrka iz otoka Principe in mesta Sobral

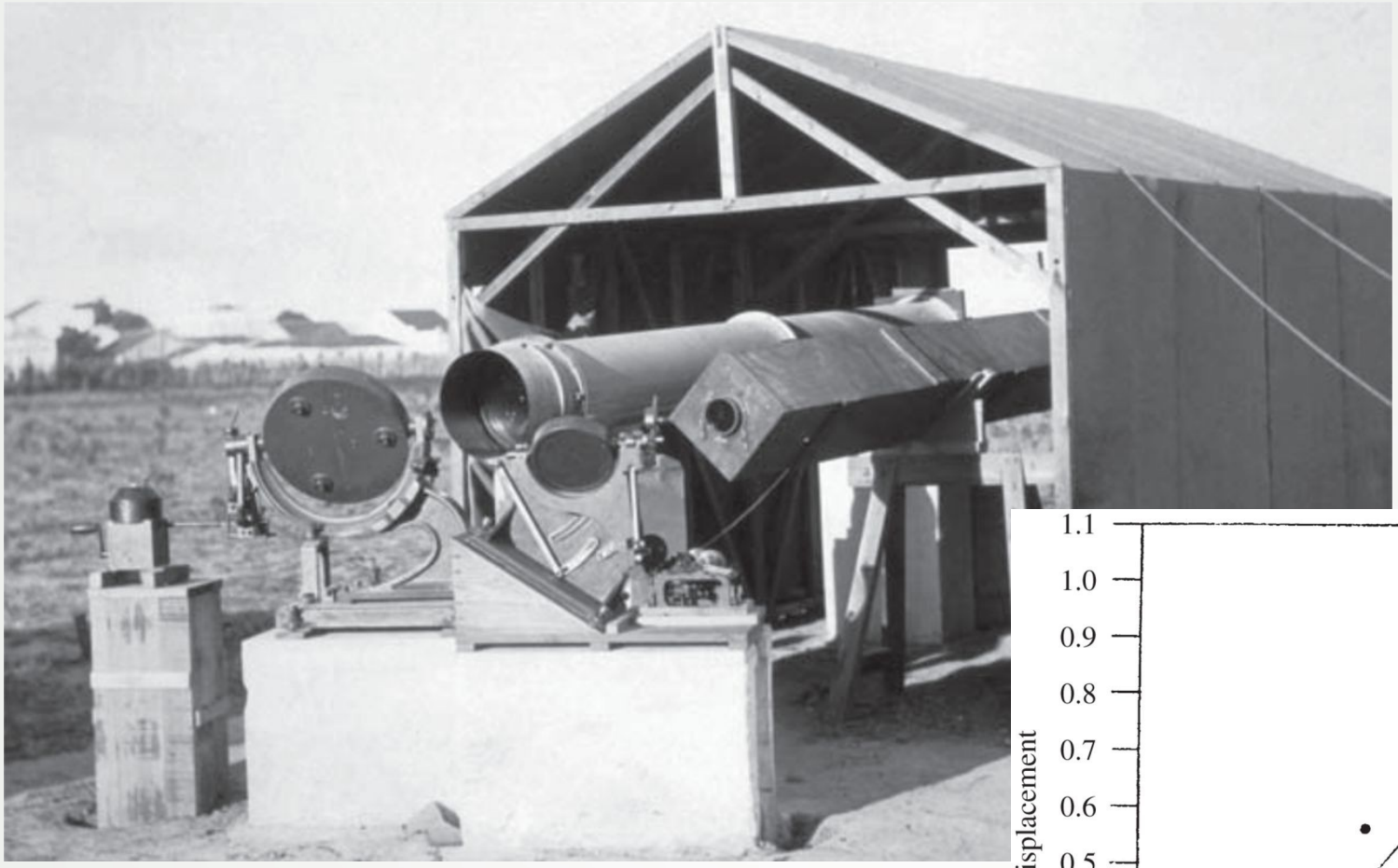
LIGHTS ALL ASKEW IN THE HEAVENS

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

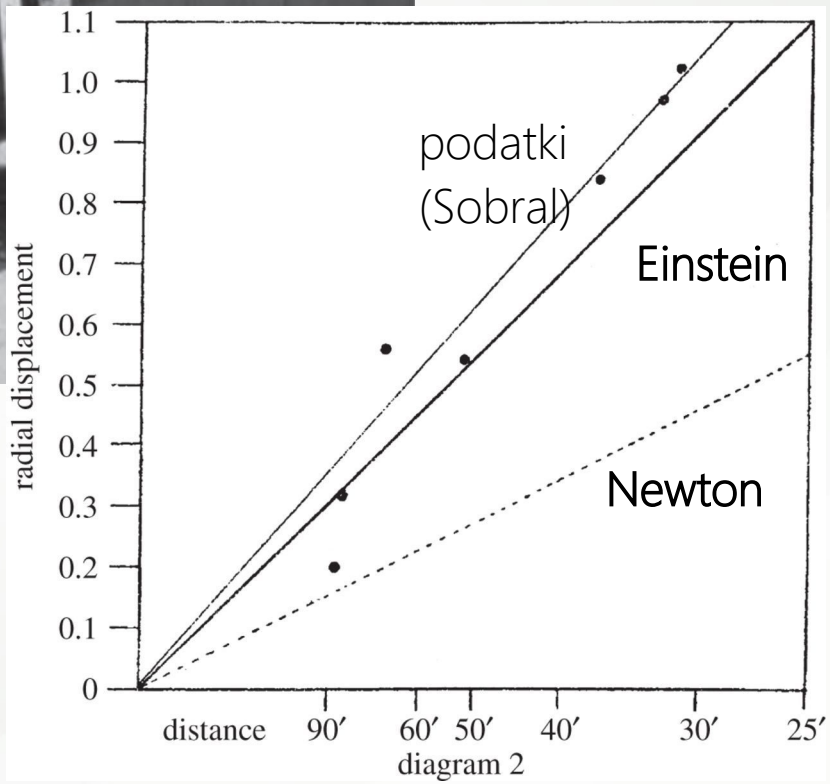
EINSTEIN THEORY TRIUMPHS

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





Postavitev teleskopov za opazovanje Sončevega mrka v mestu Sobral (Brazilija): 16-inčna leča in celostat (levo) ter 4-inčni teleskop v kvadratni cevi (desno)



rezultati za podatke iz Sobrala
(abscisna os prikazuje oddaljenost od središča Sonca)

Principe (Zahodna Afrika): **1,61 ± 0,31″**
Sobral (Brazilija): **1,98 ± 0,12″** (4-inčni teleskop)

Predlagano branje za ozadje meritev Eddingtona in njegovih sodelavcev:

Malcolm Longair, *Bending space-time: a commentary on Dyson, Eddington and Davidson (1920) 'A determination of the deflection of light by the Sun's gravitational field'*

https://royalsocietypublishing.org/doi/full/10.1098/rsta.2014.0287

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Review

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One contribution of 17 to a theme issue 'Celebrating 350 years of *Philosophical Transactions*: physical sciences papers'.

Subject Areas:
relativity, astrophysics

Keywords:
general relativity, light bending by the Sun, eclipse expedition 1919, gravitational lensing, Eddington

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The featured article can be viewed at http://dx.doi.org/10.1098/rsta.1920.0009.

THE ROYAL SOCIETY PUBLISHING

Bending space–time: a commentary on Dyson, Eddington and Davidson (1920) 'A determination of the deflection of light by the Sun's gravitational field'

Malcolm Longair

Cavendish Laboratory, JJ Thomson Avenue, Cambridge CB3 0HE, UK

The famous eclipse expedition of 1919 to Sobral, Brazil, and the island of Principe, in the Gulf of Guinea, led by Dyson, Eddington and Davidson was a turning point in the history of relativity, not only because of its importance as a test of Einstein's General Theory of Relativity, but also because of the intense public interest which was aroused by the success of the expedition. The dramatic sequence of events which occurred is reviewed, as well as the long-term impact of its success. The gravitational bending of electromagnetic waves by massive bodies is a subject of the greatest importance for contemporary and future astronomy, astrophysics and cosmology. Examples of the potential impact of this key tool of modern observational astronomy are presented. This commentary was written to celebrate the 350th anniversary of the journal *Philosophical Transactions of the Royal Society*.

1. Einstein and bent space–time

The famous expedition to measure the deflection of the positions of stars caused by the curvature of space–time in the gravitational field of the Sun had a profound

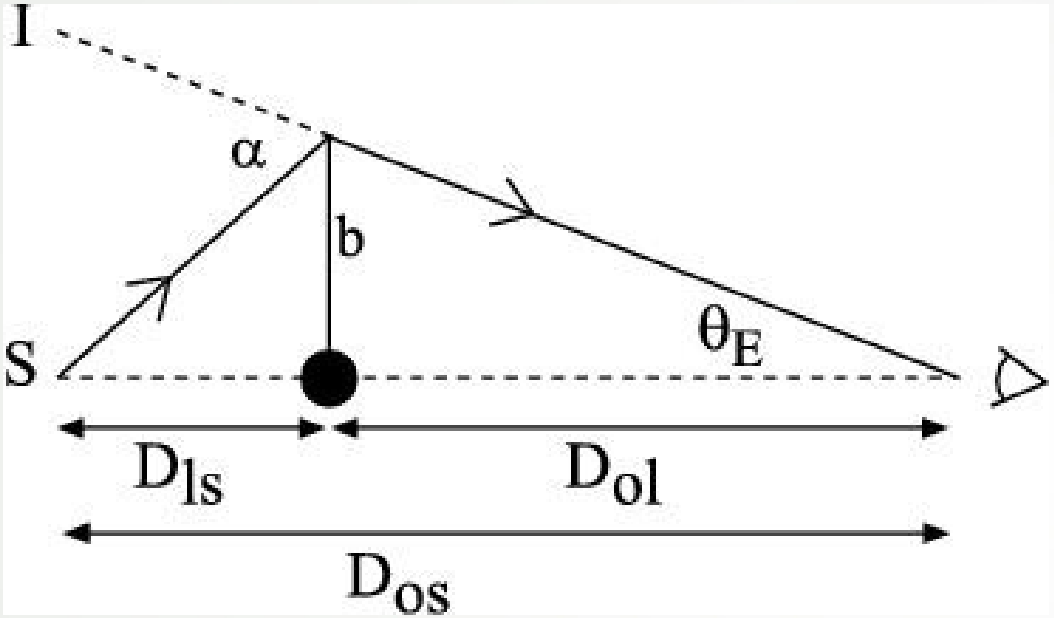
Odklonski kot

- Odklonski kot za žarek, ki gre tik mimo roba Sonca:

NEWTON: $\beta = 0.87''$

EINSTEIN: $\beta = 1.75''$

Osnove gravitacijskega lečenja



θ_E = **Einsteinov obroč**

$$SI = \alpha D_{ls} = \theta_E D_{os}$$

$$b = D_{ol}\theta_E$$

$$\alpha = \frac{4GM}{c^2 b}$$

$$\frac{4GM}{c^2}\frac{1}{D_{ol}\theta_E} D_{ls} = \theta_E D_{os}$$

S = oddaljeni izvor (angl. *source*)

Dls = oddaljenost LEČA – IZVOR

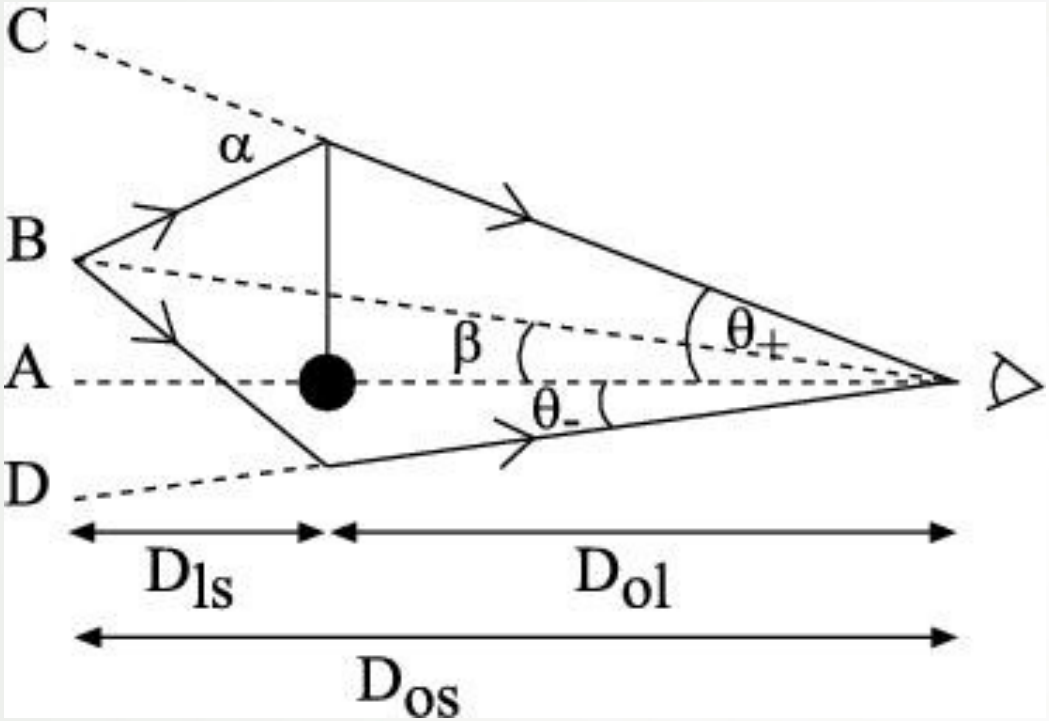
Dol = oddaljenost OPAZOVALEC – LEČA

Dos = oddaljenost OPAZOVALEC – IZVOR

$$\theta_E = \left(\frac{4GM}{c^2}\frac{D_{ls}}{D_{ol}D_{os}}\right)^{1/2}$$

enačba leče za točkasto maso

Osnove gravitacijskega lečenja



Dls = oddaljenost LEČA – IZVOR

Dol = oddaljenost OPAZOVALEC – LEČA

Dos = oddaljenost OPAZOVALEC – IZVOR

SPLOŠEN PRIMER

β = kot med izvorom (B) in lečo

θ = kot med lečo in sliko (C ali D)

$$AB + BC = AC$$

$$\beta D_{os} + \alpha D_{ls} = \theta D_{os}$$

$$\beta = \theta - \frac{4GM}{c^2}\frac{1}{D_{ol}\theta}\frac{D_{ls}}{D_{os}}$$

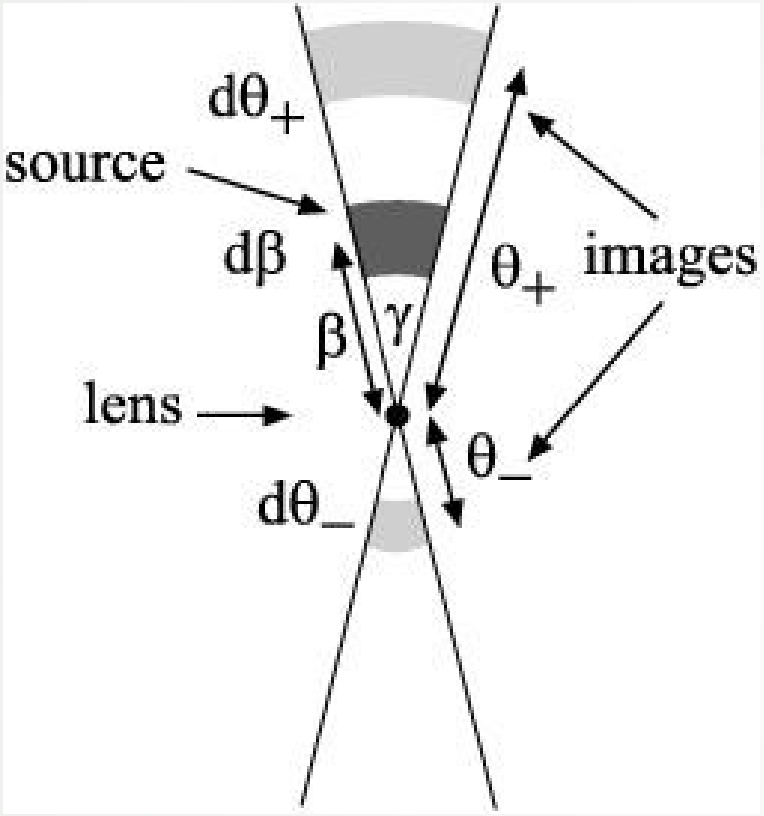
$$\theta^2 - \beta\theta - \theta_E^2 = 0$$

kvadratna enačba za točkasto maso (izvor izven osi)

Gravitacijsko lečenje s kozarcem vina

https://www.youtube.com/watch?v=vLp6CwElGP4
Perimeter Classroom Activity: Gravitational Lensing with a Wine Glass

Osnove gravitacijskega lečenja



dβ in dθ prikazujeta radialno RAZTEZANJE slike

KJE SE BOSTA POJAVILI SLIKI?

- ***povečava*** *(magnification)*

$$a_p = \frac{\theta_p \, d\theta_p}{\beta \, d\beta} \qquad a_m = \frac{\theta_m \, d\theta_m}{\beta \, d\beta}$$

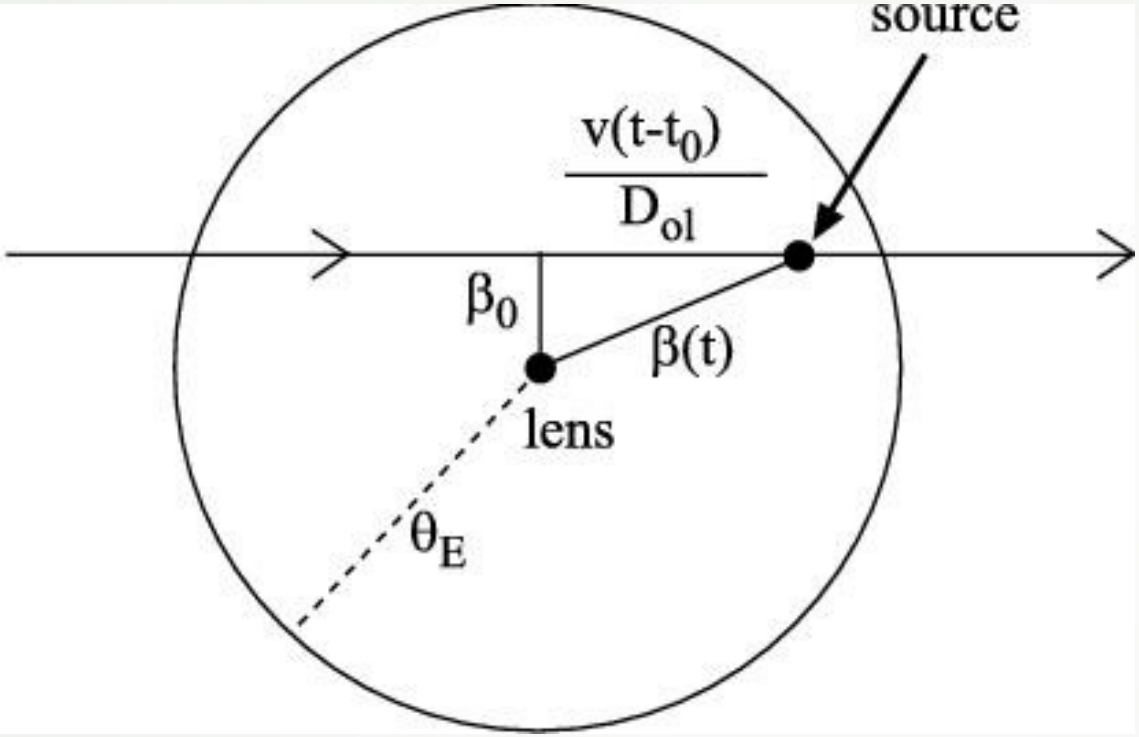
- ***ojačenje*** *(amplification)*

povečana slika bo zgledala svetlejša, ker se ohrani površinska svetlost

$$\theta^2 - \beta\,\theta - \theta_E^2 = 0$$

kvadratna enačba za točkasto maso (izvor izven osi)

Mikrolečenje



$$\beta(t) = \left[\beta_0^2 + \frac{v^2}{D_{\rm ol}^2}(t - t_0)^2\right]^{1/2}$$

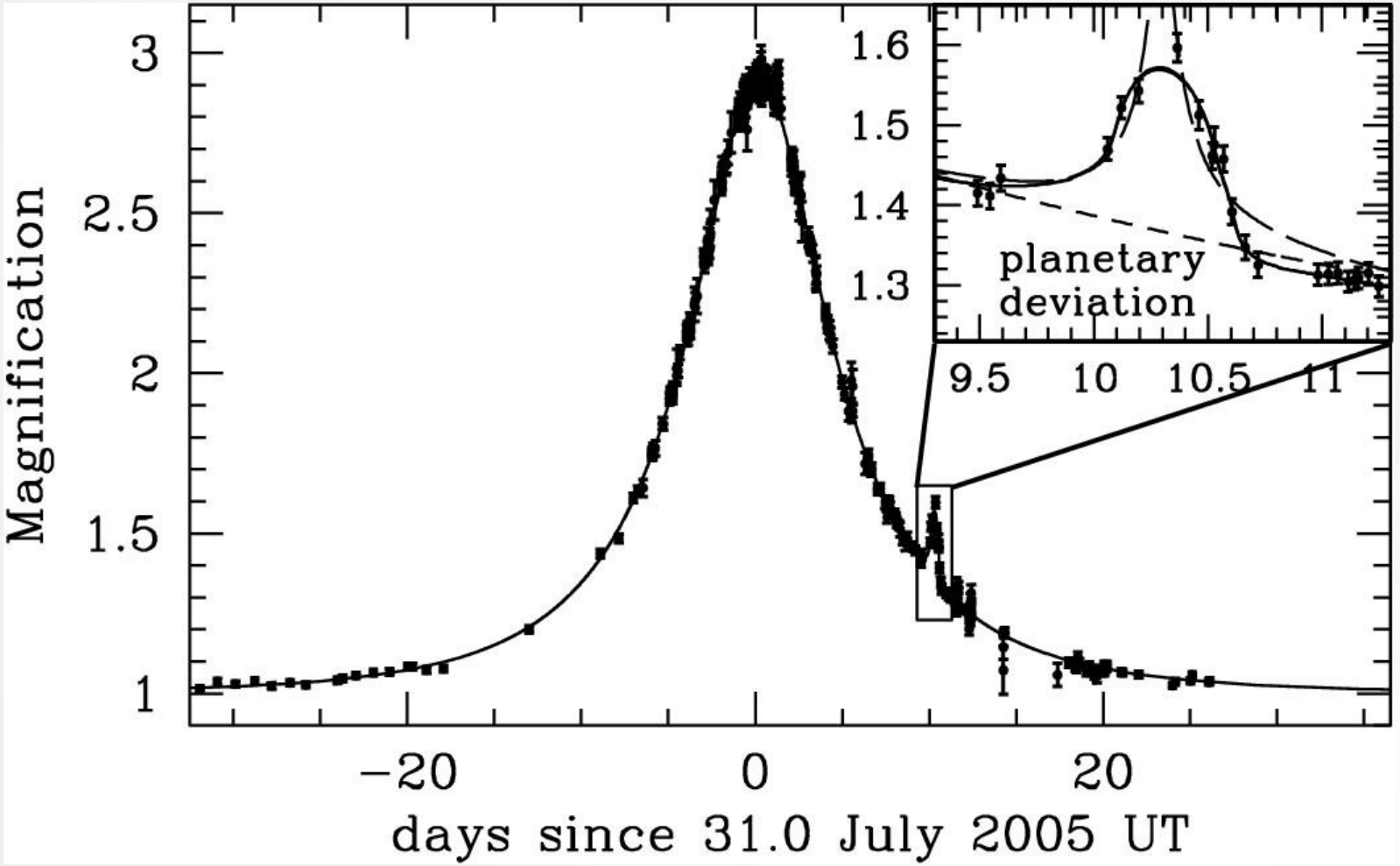
Osnove gravitacijskega lečenja

video: ***Single Lens Microlensing***
http://www.astronomy.ohio-state.edu/~gaudi/movies.html

Eksperiment mikrolečenja v Velikem Magelanovem oblaku

Prvi predlog: Paczynski, 1986

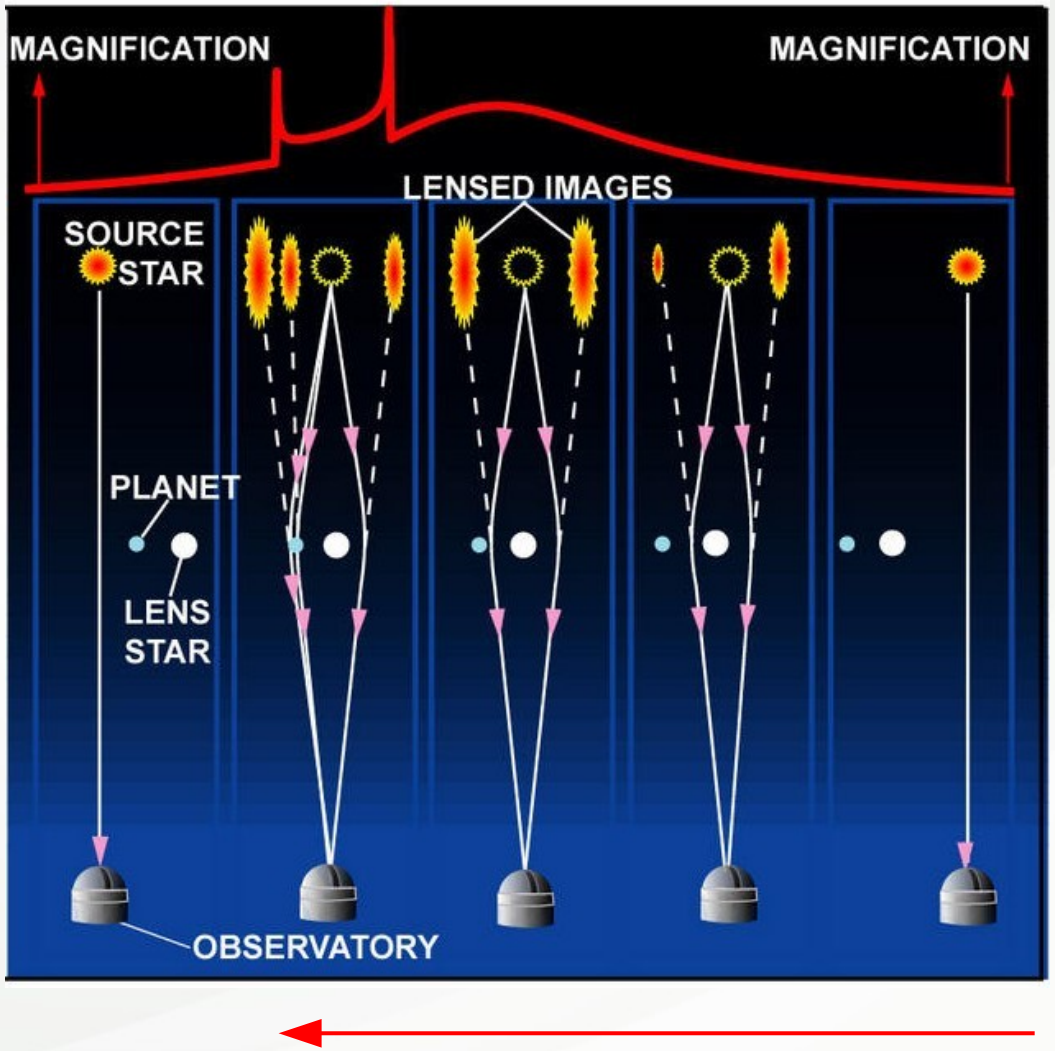
Osnove gravitacijskega lečenja



Osnove gravitacijskega lečenja

video: ***Planetary Microlensing***

http://www.astronomy.ohio-state.edu/~gaudi/movies.html



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