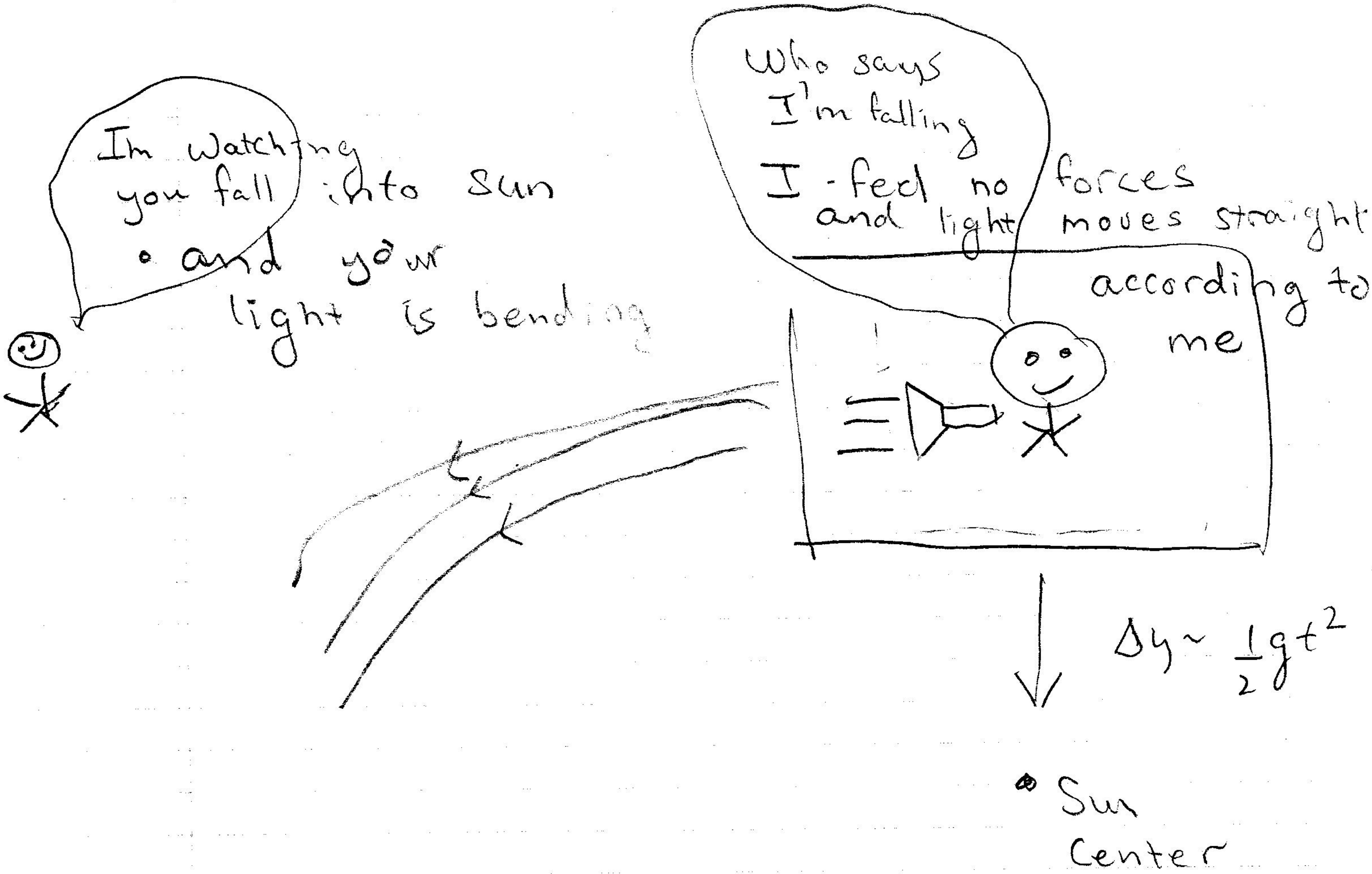
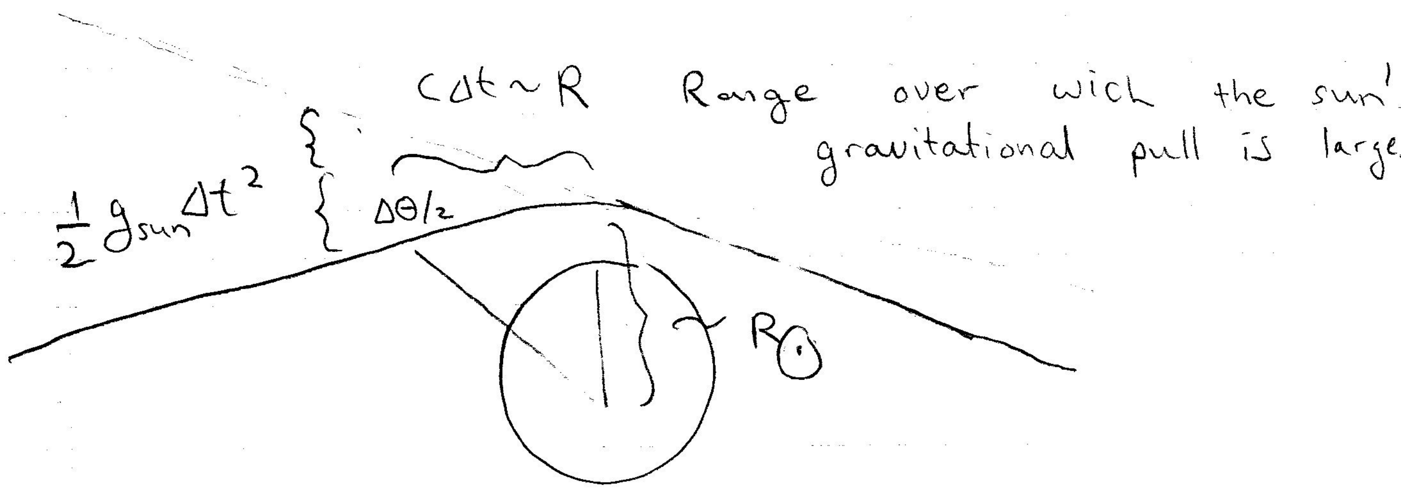

I'm watching you fall into sun
• and your light is bending
Who says I'm falling
I feel no forces and light moves straight according to me
$\Delta y \sim \frac{1}{2} g t^2$
Sun Center

Estimate:



Now use:

① $$g_{sun}(R) \sim \frac{G M_\odot}{R^2}$$

② The time over which the sun's gravity bends the light is

$$c\Delta t \sim R$$

When $c\Delta t$ is much larger than R the gravity is weak

③ $R \sim R_\odot$, our light rays skim the sun

So

So

$$\frac{\Theta}{2} \sim \frac{\frac{1}{2} g_{sun}(R) \Delta t^{\cancel{2}}}{c \cancel{\Delta t}}$$

$$\Theta \sim \frac{G m_{\odot}}{c R^2} \cdot \frac{R}{c}$$

$$\Theta \sim \frac{G m_{\odot}}{c^2 R}$$

Taking

$G = 6.6 \times 10^{-11}$ $m^3/kg\,s^2$

$m_{\odot} = 2 \times 10^{30}$ kg

$R_{\odot} = 700{,}000$ km

So

$\Theta \sim 0.43''$ arcsec

A proper General Relativistic treatment gives:

$\Theta \simeq 1.75$ arcsec

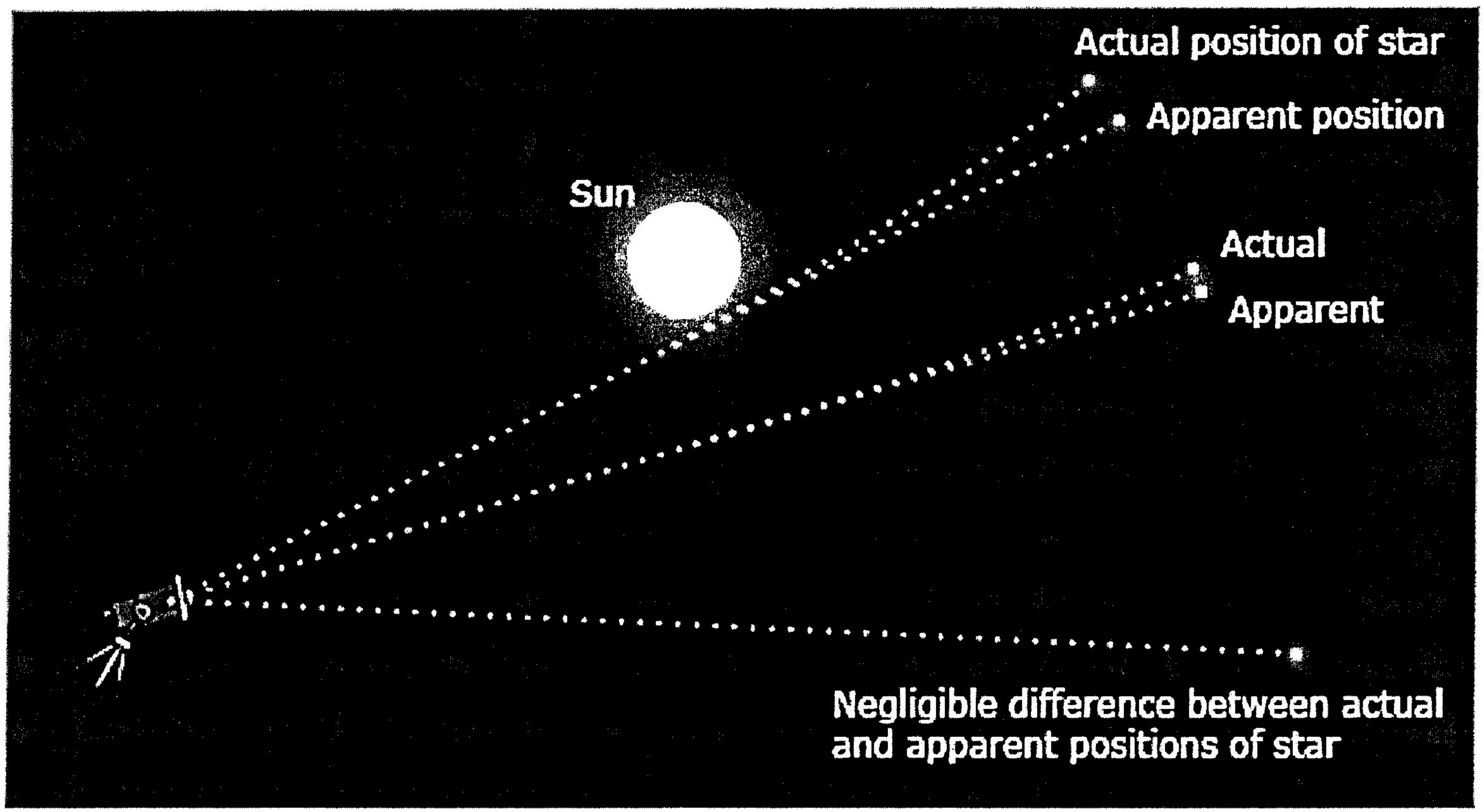
Incidentally Einstein originally predicted

$\Theta \simeq .87$ arcsec

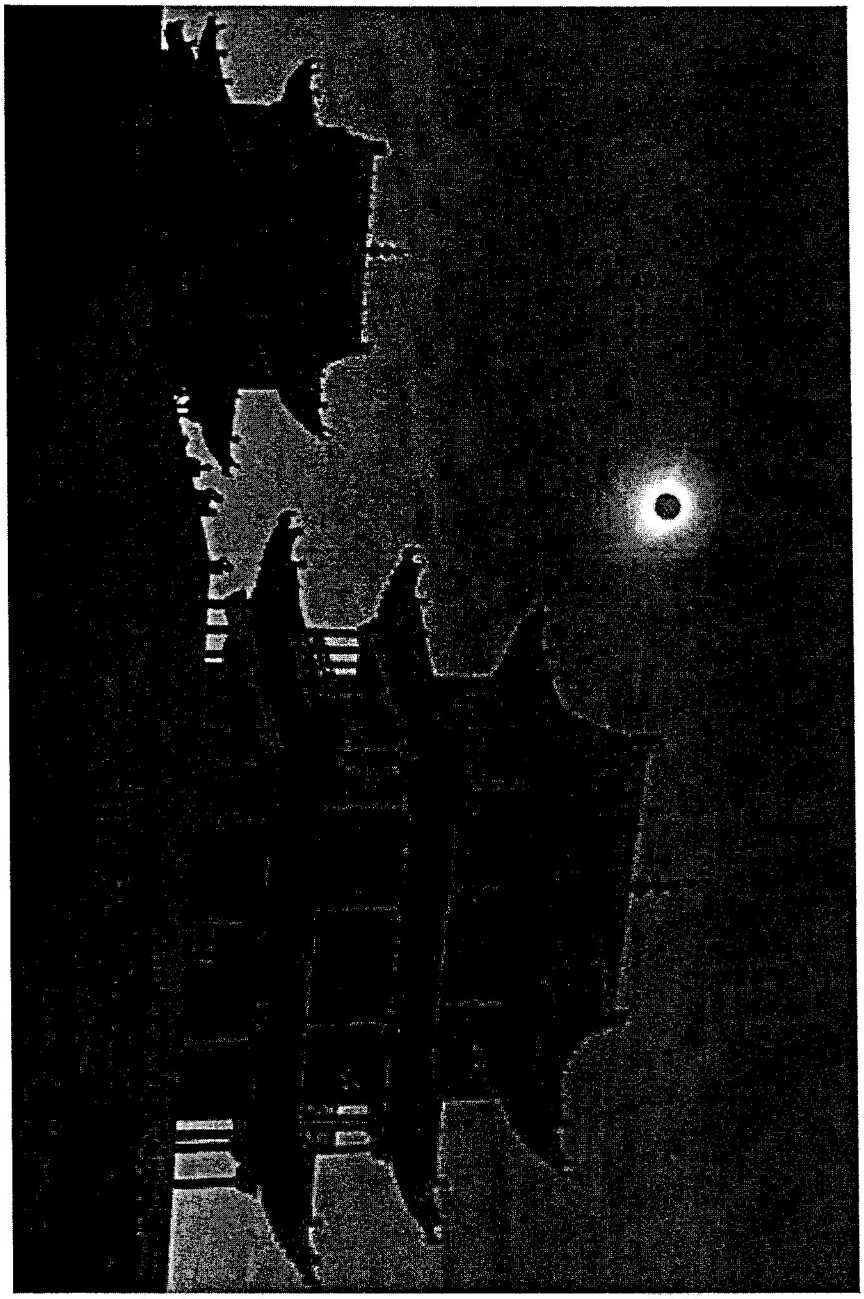
But corrected the result later (well Before the experiment in 1919)

Measuring the bending of light

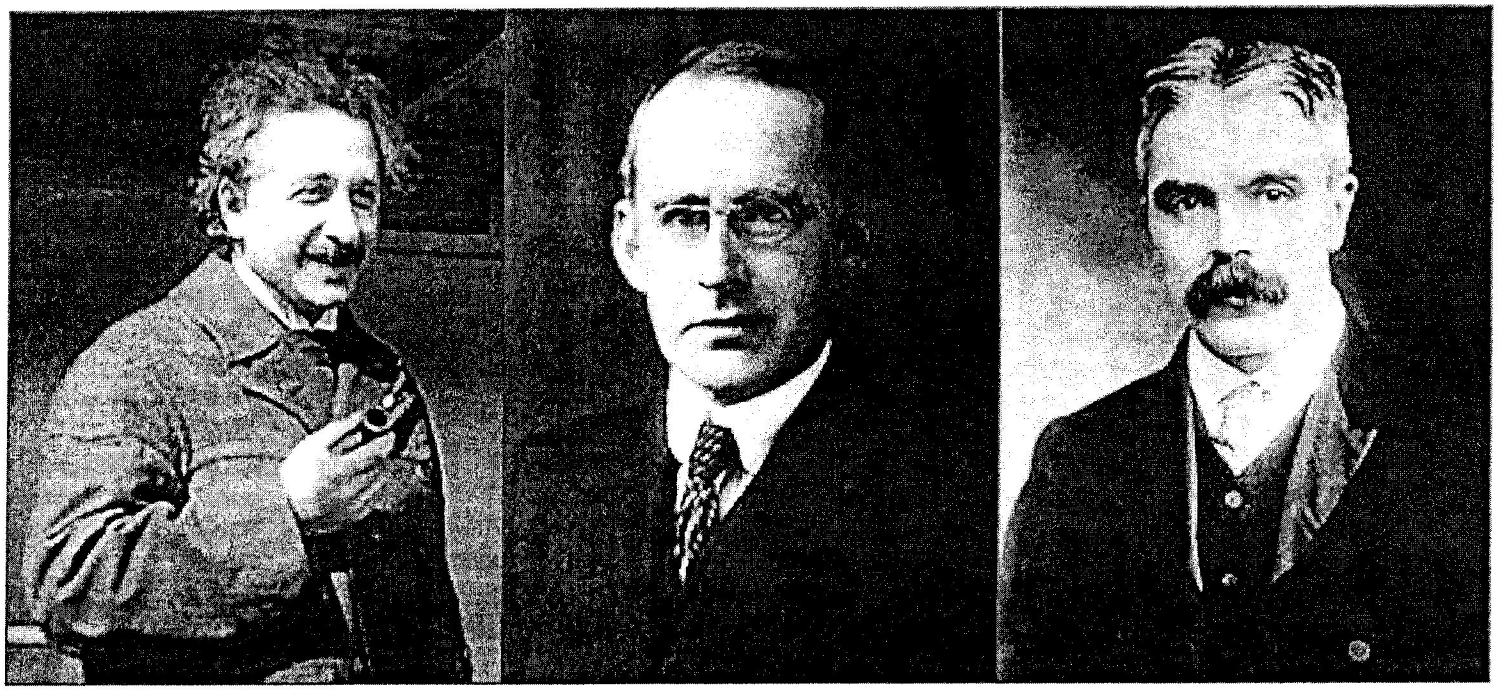
- Measure the deflection of starlight as it goes near the sun
- Compare angles between the stars during a solar eclipse, and at night at a different time of the year



source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

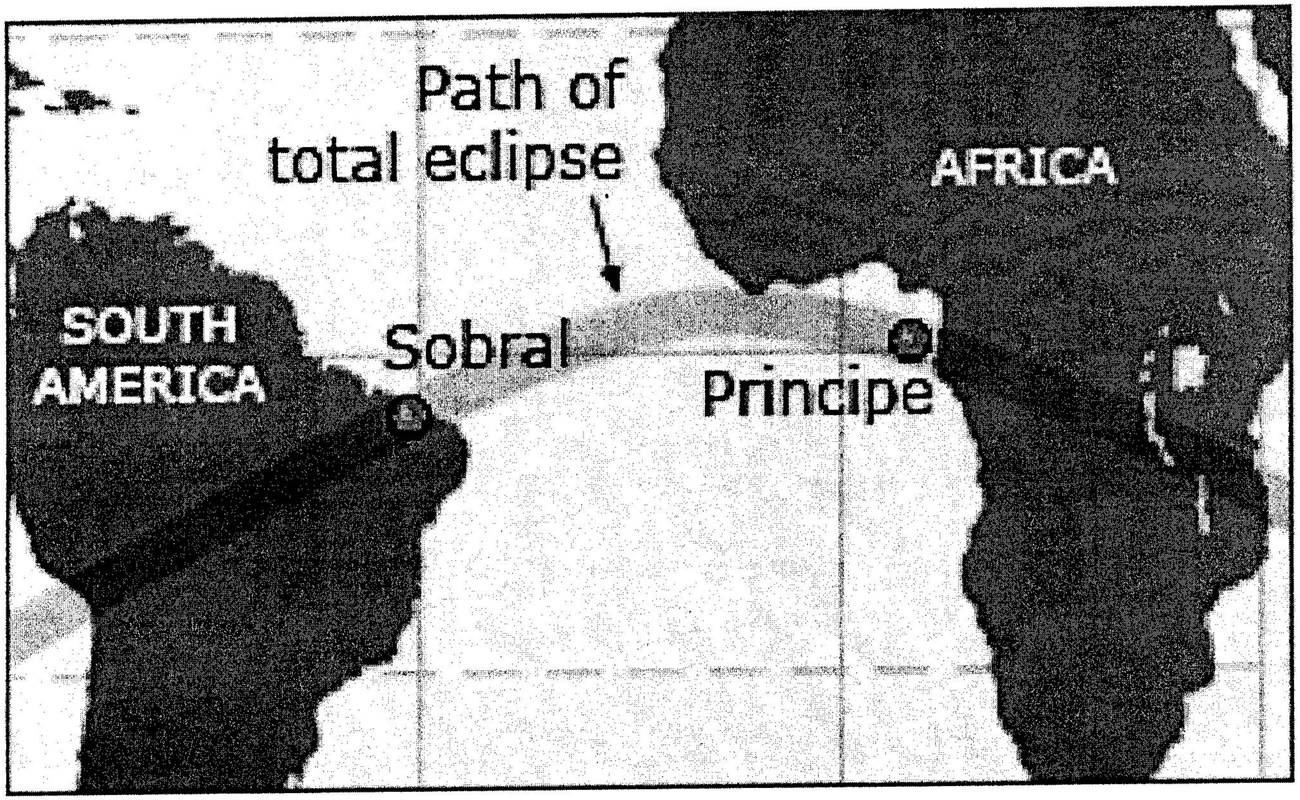


The men of the 1919 measurement – Einstein,Eddington,Dyson



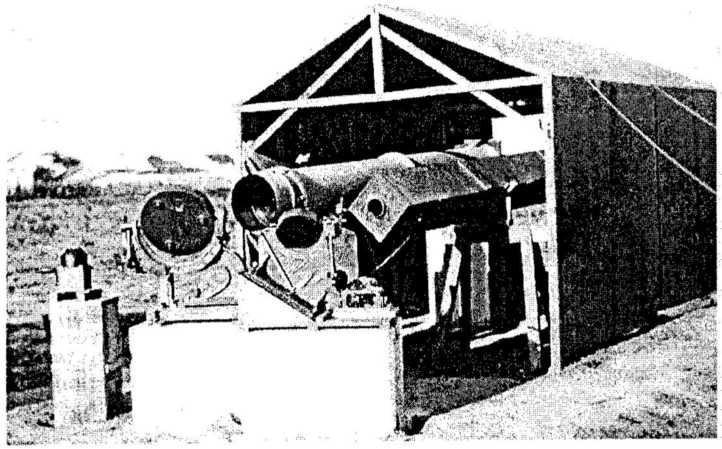
source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

Eddington and Dyson travel to the tropics at Sorbal and Principe

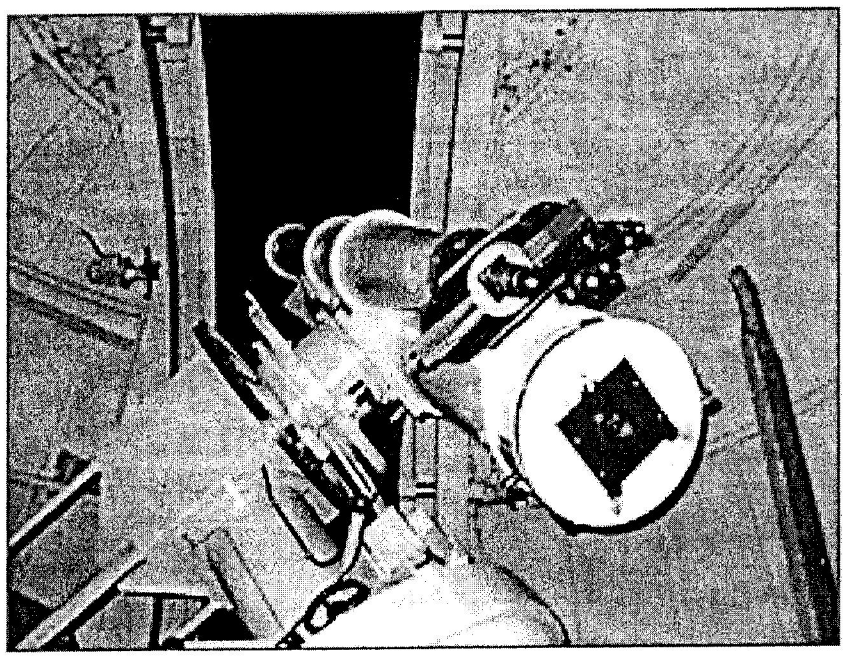


source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

. . . And set up telescopes in the Tropics and at Cambridge



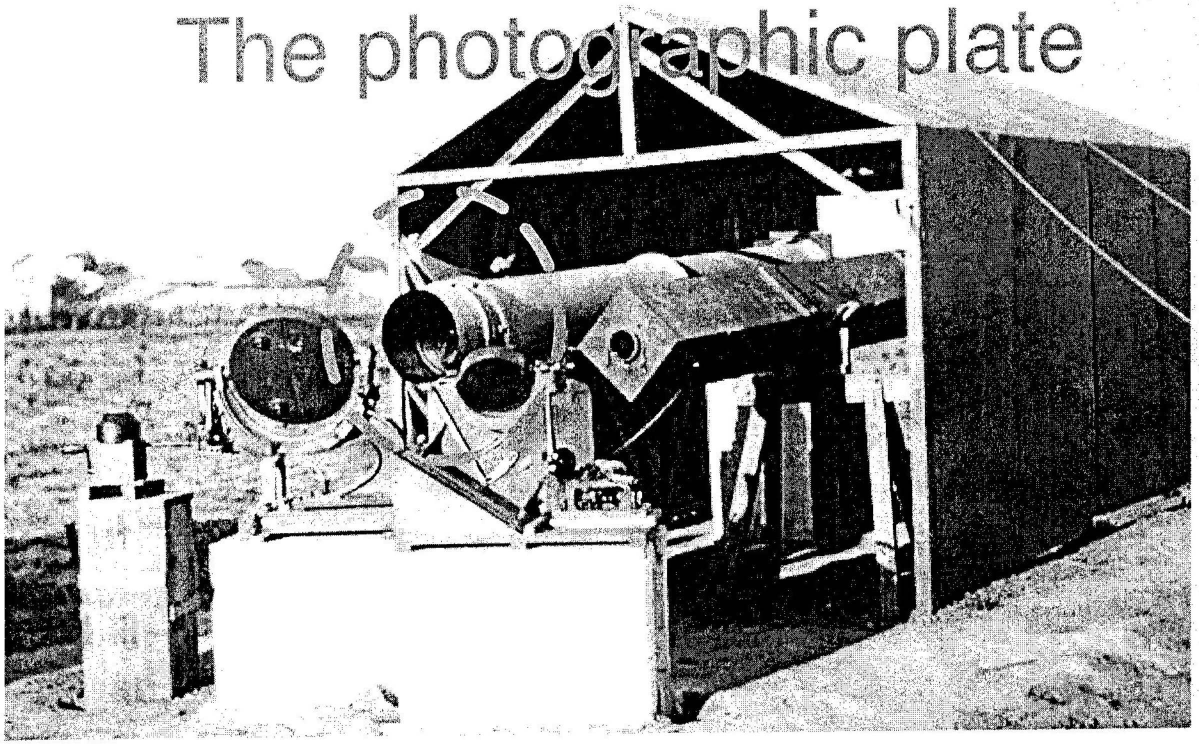
Instruments at Sobral, Brazil. The 4-inch lens is in the square tube on the right, and the astrographic lens, chosen for its wide field of view, is in the circular tube on the left. In front of the tubes are mirrors that are driven by a mechanism that keeps the stellar images at the same position on 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.)



source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

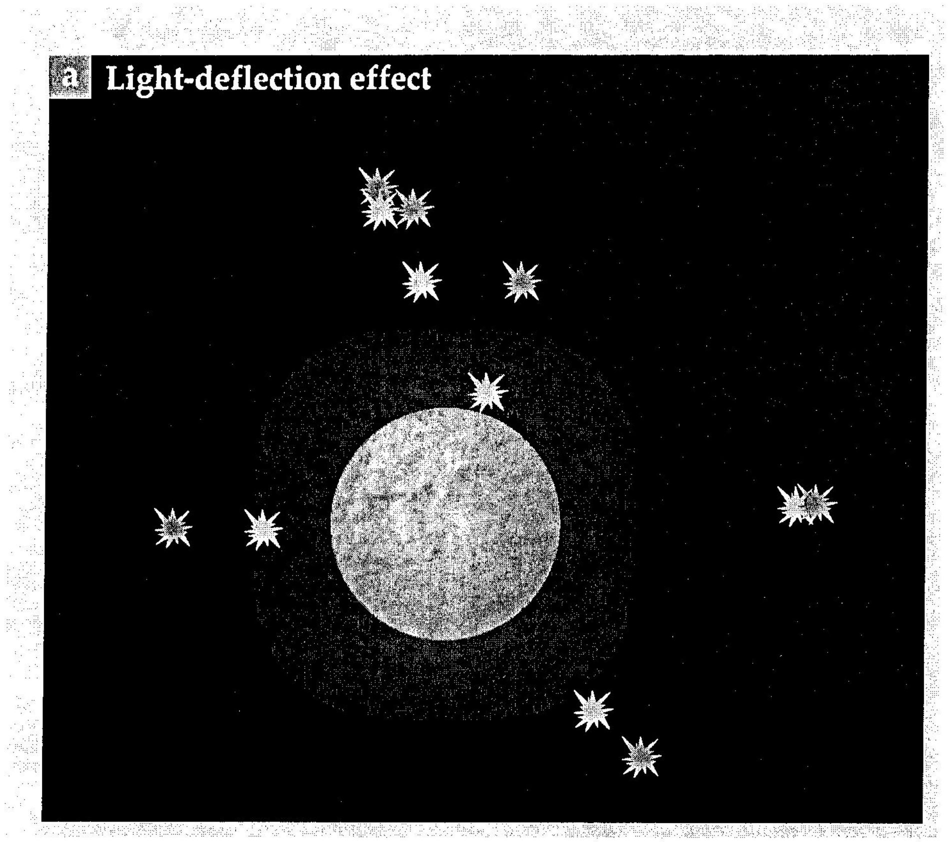
Record image on plate

The photographic plate



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.)

. . . And finally measure the deflection by reading the positions between the stars off of photographic plates with a micrometer and comparing to other plates

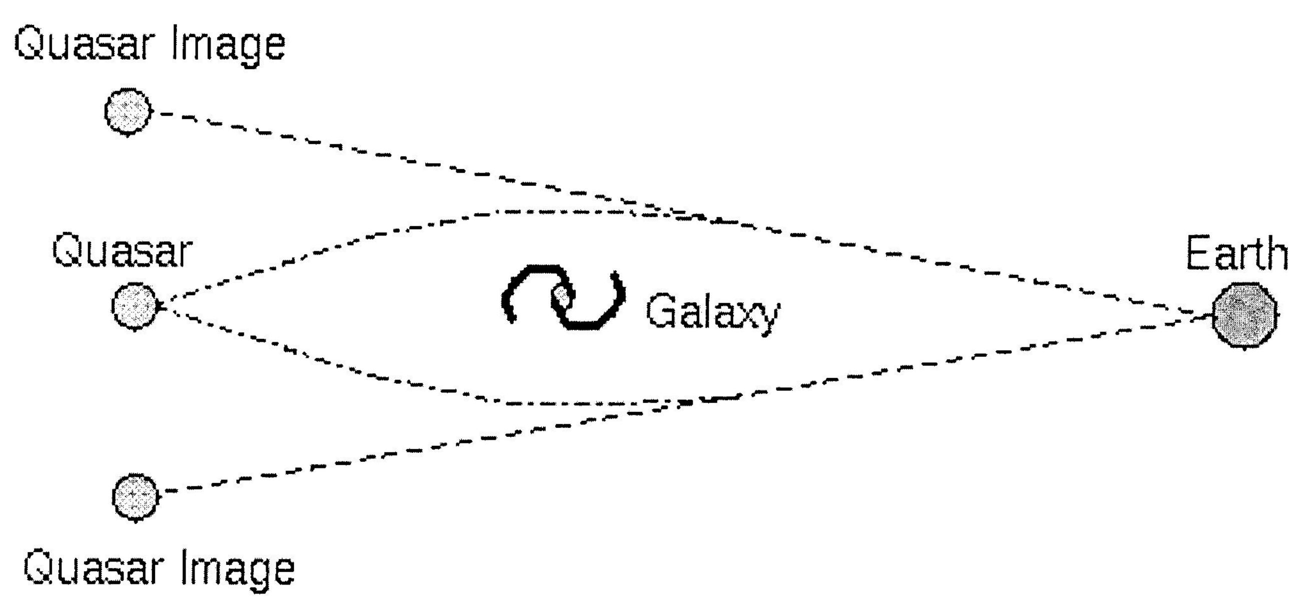


The experimetnal result agrees with Einstein's prediction of 1.7 arcsec

source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04 and Physics Today article Kennefick

Gravitational Lensing in Observational Astronomy

- light from distant quasars bends around intermediate galaxy



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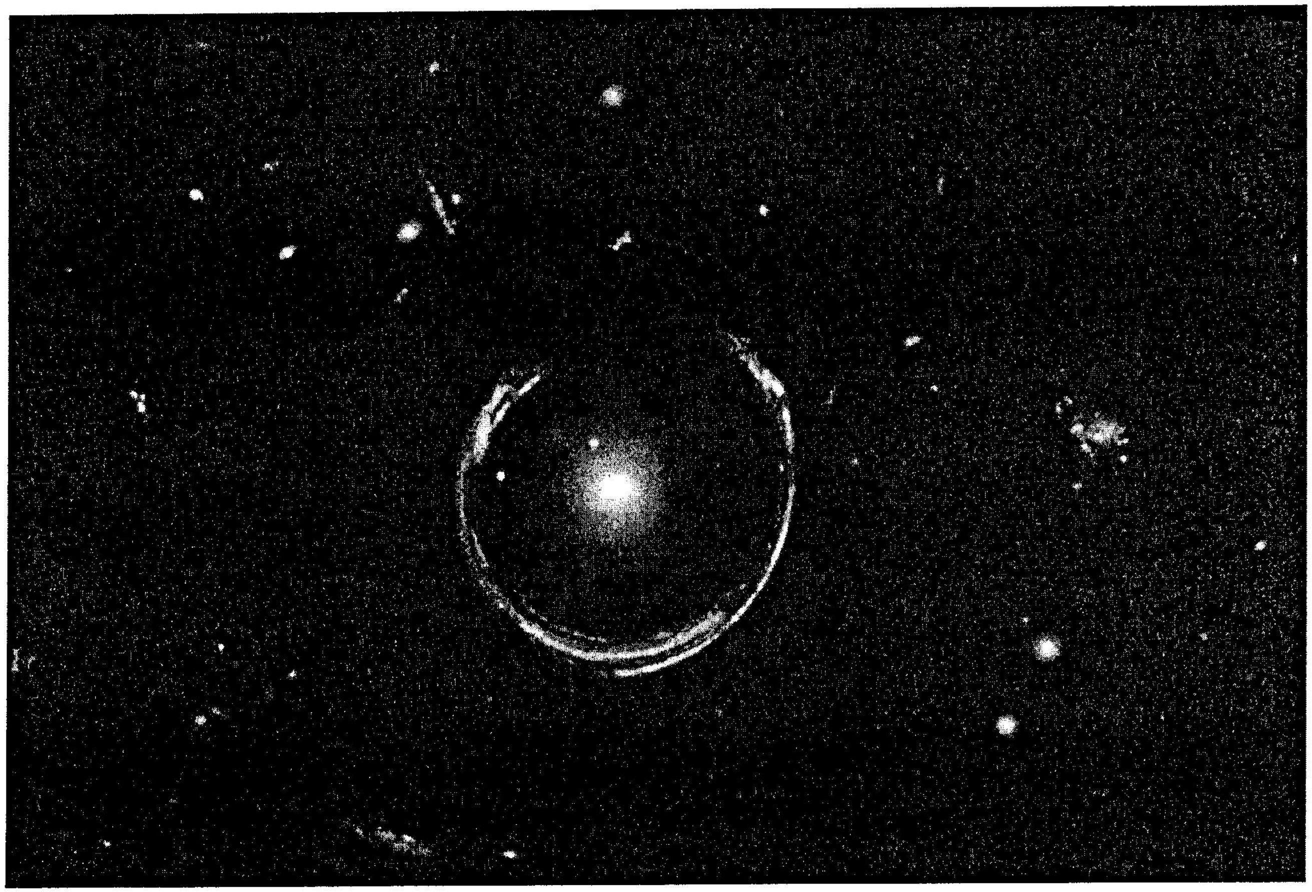
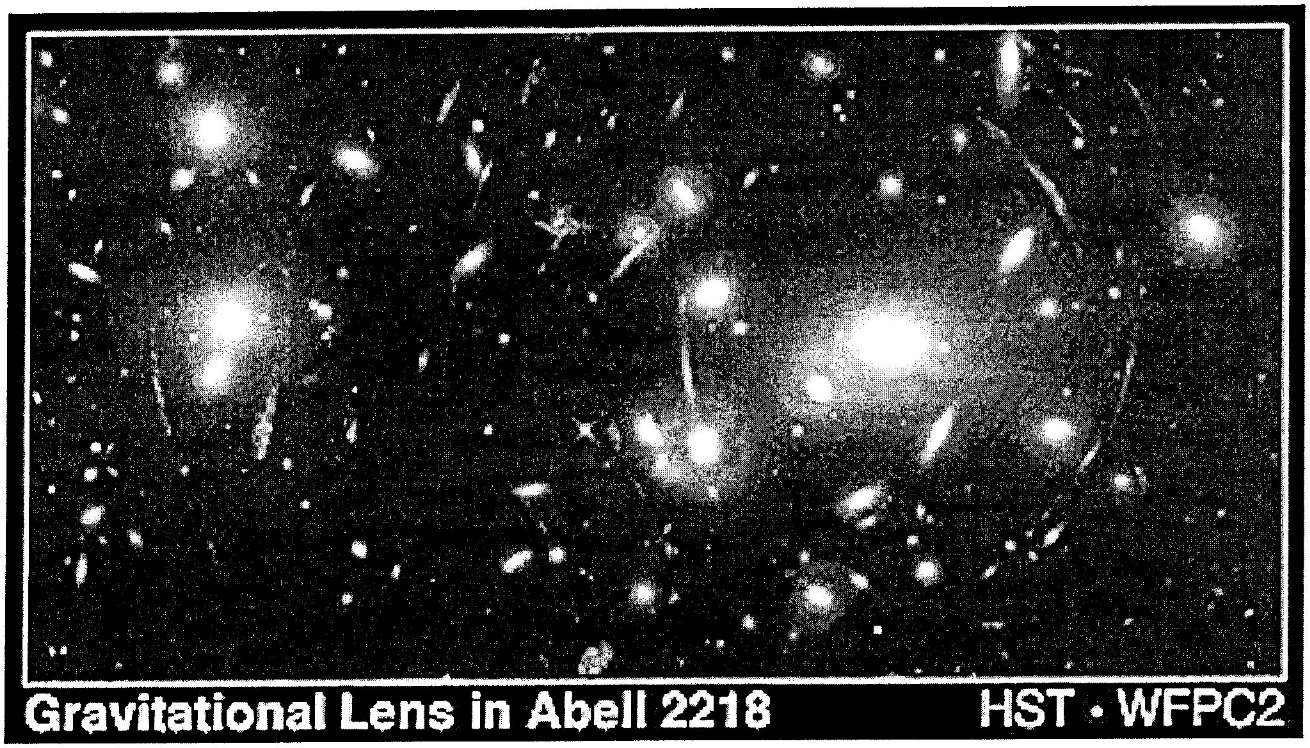
Gravitational Lensing in Observational Astronomy



source – Wikimedia

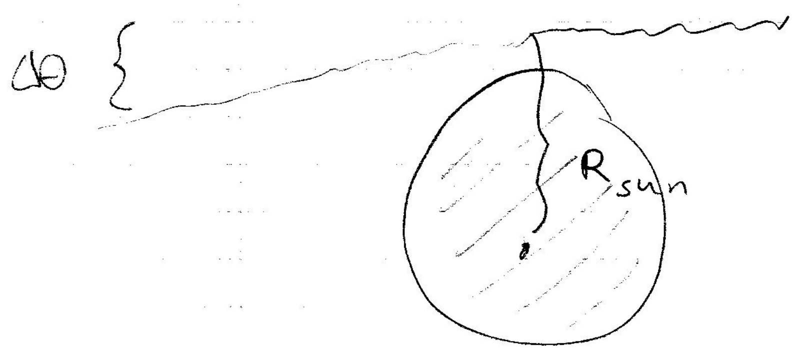
More Pictures



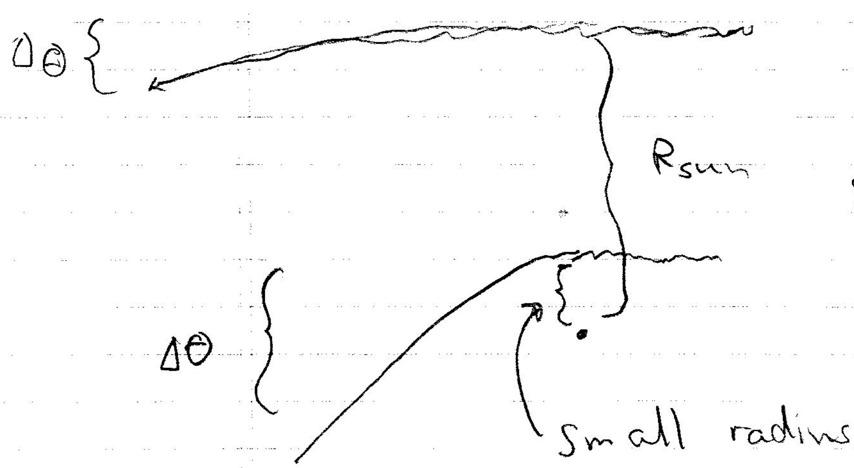
source – Wikimedia

Black Holes

Imagine you could contract the sun to a small point.



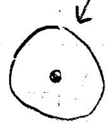
Then, as Newton taught us the force is the same.



Further, the deflection of light at a given radius is the same.

But, you can send the light much closer to the force center.

The angle gets larger. Eventually, when the radius is smaller than a certain radius R_{sch} = Schwarzchild Radius, the angle becomes of order 90° and the light doesn't escape



R_{sch}, light can not escape from this inner circle

Let's estimate the Schwarzchild radius

From before:

$$\Delta\theta \sim \frac{GM}{c^2 R}$$

deflection

how close we get to sun

We can estimate the Schwarzchild radius by setting the angle to

$$90^\circ = \frac{\pi}{2} \text{ rad}$$

So

$$\frac{\pi}{2} \sim \frac{GM}{c^2 R_{sch}}$$

$$R_{sch} \sim \frac{GM}{c^2 (\pi/2)}$$

Actual General Relativistic Corrections show that

$$\boxed{R_{sch} = \frac{2GM}{c^2}}$$