

Stars askew in the heavens: The centenary of the 1919 eclipse expeditions



Clifford Will

University of Florida, Gainesville

Institut d'Astrophysique de Paris

GR22/Amaldi13, Valencia, 8 July 2019

Stars askew in the heavens!

Coming to a Cineplex near you!

Back to the
18th century!

Exotic
Locations!

A Race to
the Finish!

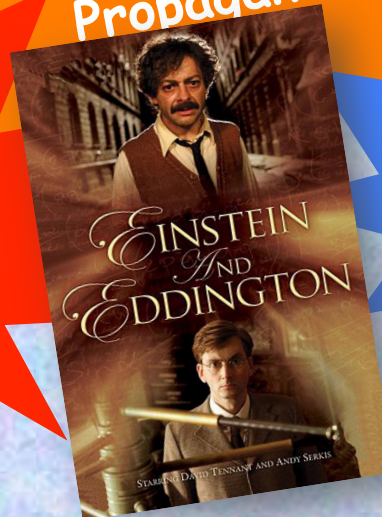
Fame and
Fortune!

Futuristic
Technology!

Racist
Propaganda!

Academy
Awards!

Black
Holes!



Gravity affects light

J. Michell (1784):

If there should really exist in nature any bodies whose density is not less than that of the sun, and whose diameters are more than 500 times the diameter of the sun, since their light could not arrive at us... we could have no information from sight; yet if any other luminous bodies should happen to revolve about them we might still [infer] the existence of the central ones....

$$1.6 \times 10^8 M_{\text{sun}}$$

P. S. Laplace (1796):

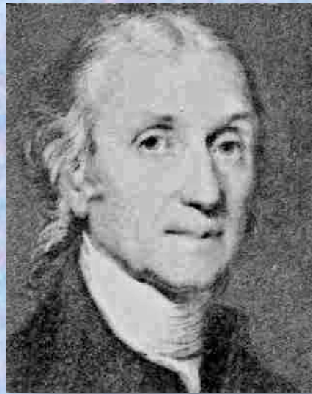
... the attractive force of a heavenly body could be so large that light could not flow out of it.



Does gravity bend light?

Henry Cavendish
(1731 - 1810)

- Hydrogen
- Measurement of G
- 1920 - publication of chemical and astronomical work



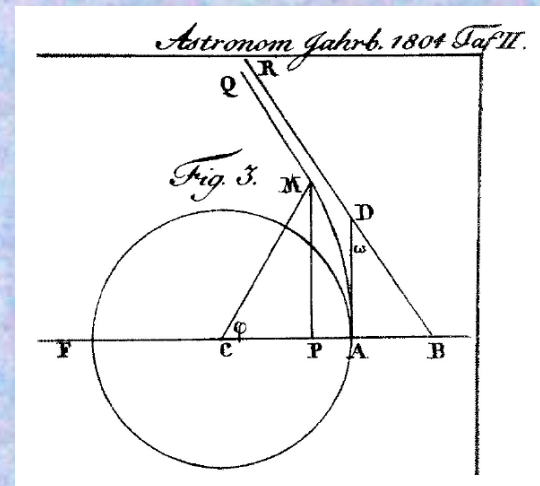
Johann Georg von Soldner
(1776 - 1833)

- Astrometry
- Geodesy
- Director, Munich observatory
- 1801 - assistant to Bode in Berlin



To find the bending of a ray of light which passes near the surface of any body by the attraction of that body:

Let s be the center of a body and a a point of surface. Let the velocity of body revolving in a circle at a distance as from the body be to the velocity of light as $1:u$. then will the sine of half bending of the ray be equal to $1/(1+u^2)$



$$\Delta\theta = \frac{2Gm/c^2 d}{1 + Gm/c^2 d}$$

CMW, Am.
J Phys. **56**,
413 (1988)

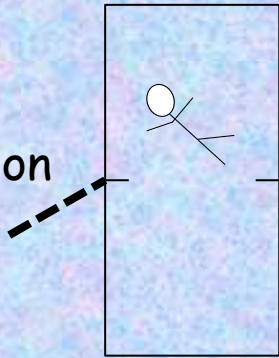
$$\Delta\theta = \frac{2Gm/c^2 d}{1 - Gm/c^2 d}$$



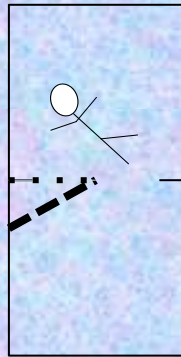
Does gravity bend light?

Einstein 1911

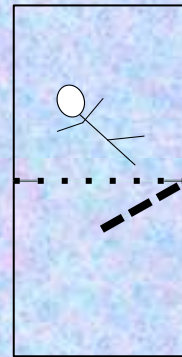
no
acceleration



(a)

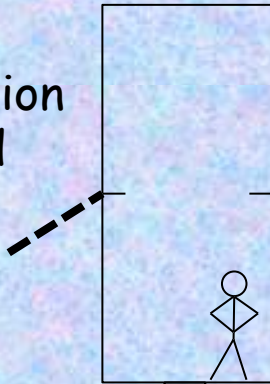


(b)



(c)

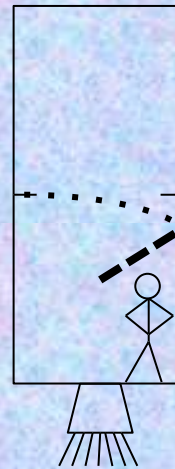
acceleration
upward



(d)



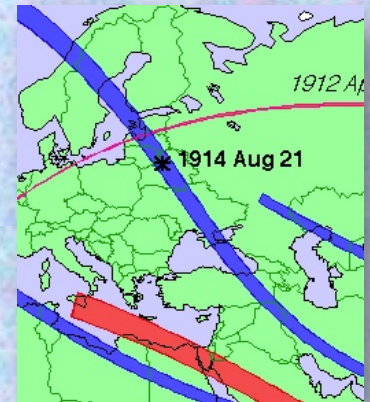
(e)



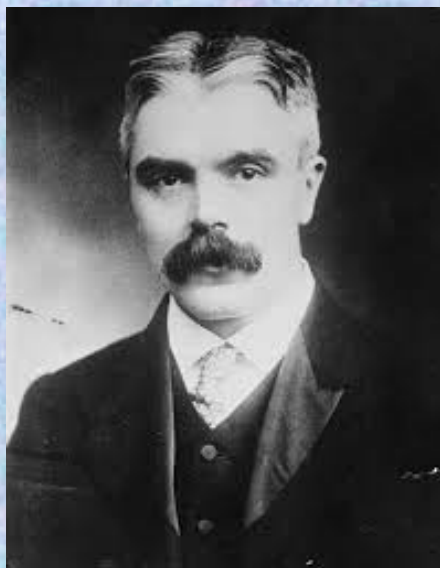
(f)



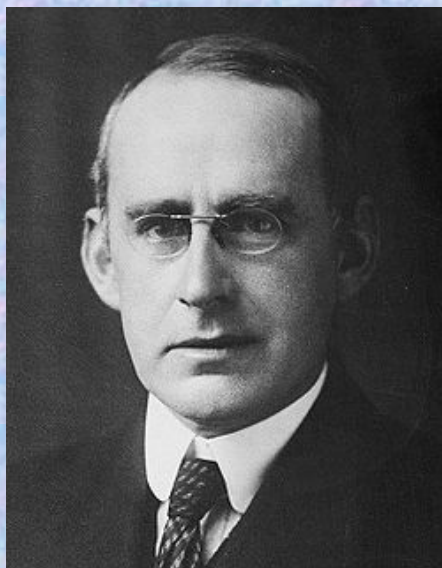
Erwin Finlay-Freundlich
(1885 - 1964)



The 1919 Eclipse Expedition



Sir Frank Dyson



Arthur S. Eddington



Andrew C. D. Crommelin

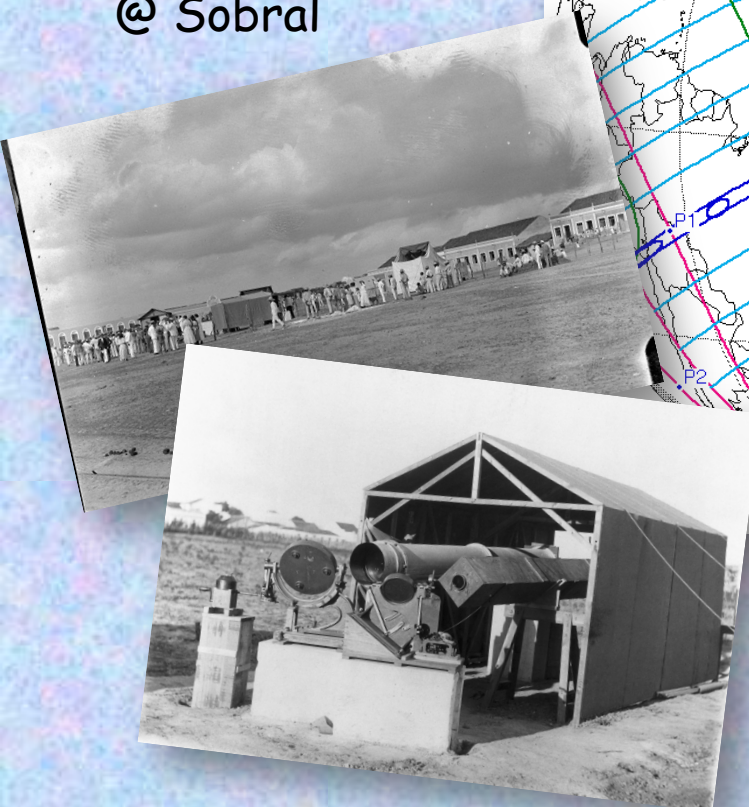
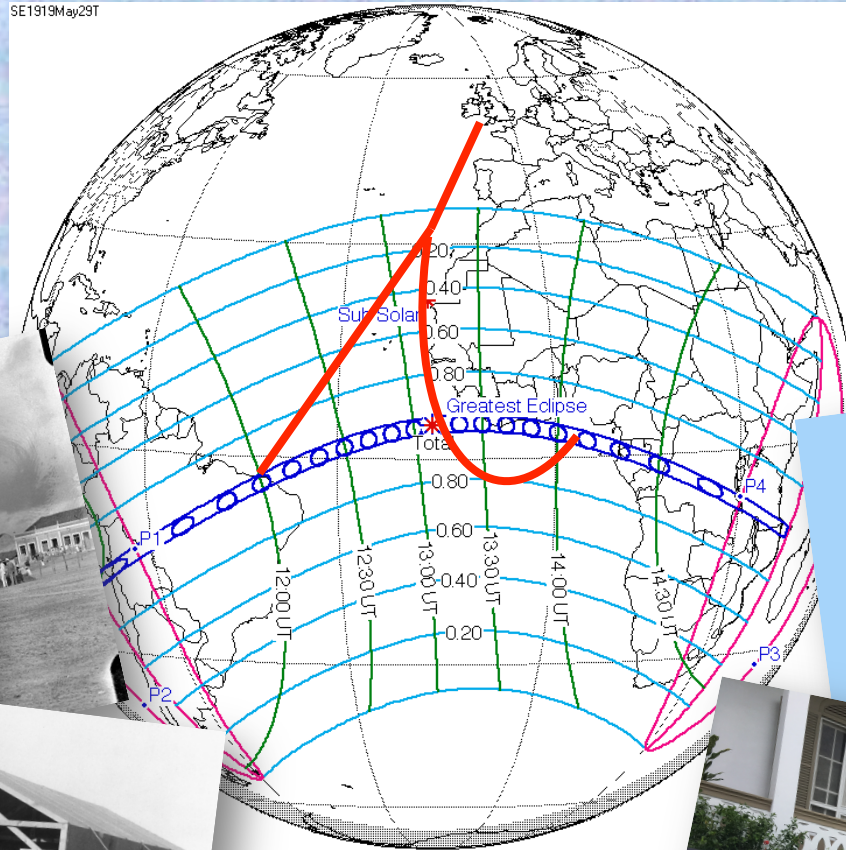
- 1916 - De Sitter sends Einstein's papers to Eddington
- 1917 - Eddington prepares report on GR for London Physical Society
- 1917 - Dyson & Eddington start planning, get £1,000 grant
- 1918 - Eddington almost drafted for WW I
- 1918 - Nov. 11 - war ends
- 1919 - April departure for Sobral and Principe



The 1919 Eclipse Expedition

Crommelin
& Davidson
@ Sobral

Eddington &
Cottingham
@ Principe



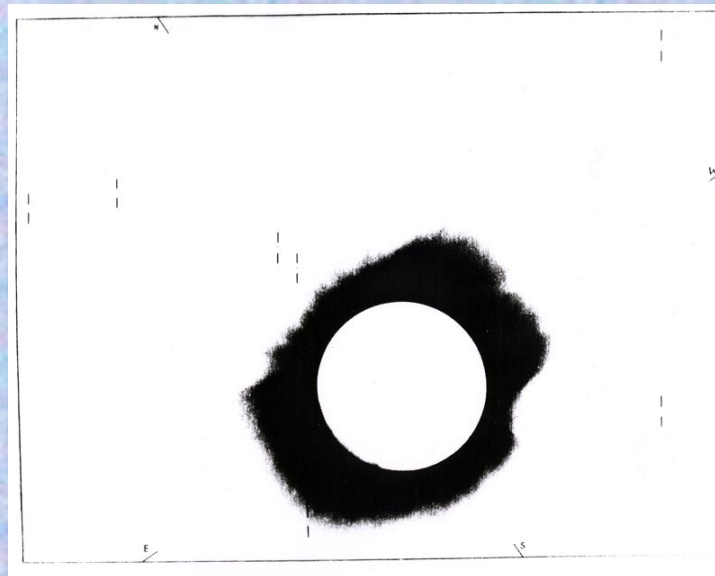
The 1919 Eclipse Expedition

The Sobral Measurements

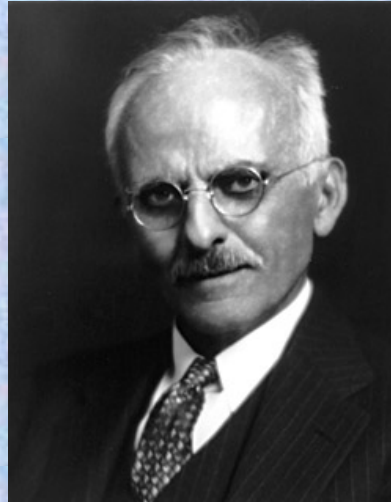
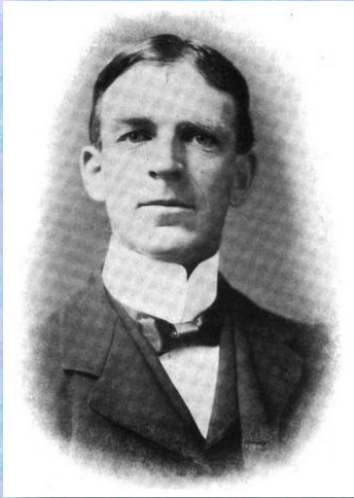
- 4" and 13" telescopes
- Cloudy weather during eclipse
- 13" changed focal length during eclipse - data not used
- 4" gave 7 plates with 7 stars each
- Comparison plates made on July 11
- Departed on July 22

The Principe Measurements

- One telescope
- Morning rain, mostly cloudy
- 2 usable plates with 5 stars each
- No comparison plates made (plates from Oxford made in Jan 1919 used instead)
- "check" plates used
- Departed on June 12, arrived Liverpool July 14

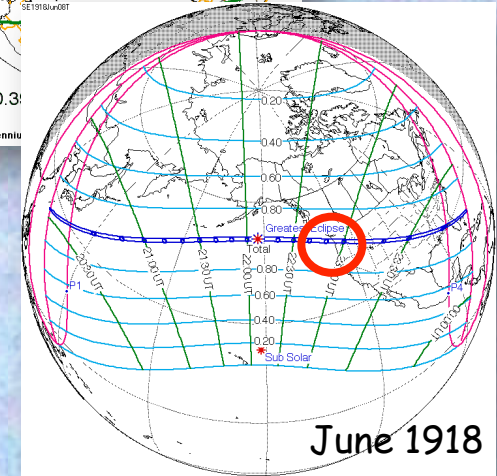
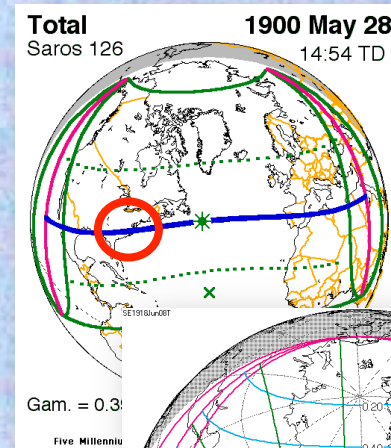


The Lick Eclipse Measurements



William W. Campbell Heber Curtis

- Anxious to beat the Brits to a GR test
- Analyzed plates from 1900 eclipse near Augusta Georgia, and a 1918 eclipse at Goldendale Washington
- Images poor; no unambiguous evidence of deflection
- Reported results at July 11 1919 meeting of the Royal Astronomical Society
- Dyson reported that Eddington might have a positive result



The 1919 Eclipse Expedition

The Sobral Measurements

- 4" and 13" telescopes
- Cloudy weather during eclipse
- 13" changed focal length during eclipse - data not used
- 4" gave 7 plates with 7 stars each
- Comparison plates made on July 11
- Departed on July 22

Sobral Result

$$\Delta\theta = 1''.98 \pm 0''.12$$
$$= (1.13 \pm 0.07)\Delta\theta_{GR}$$

1979 re-analysis

$$\Delta\theta_{4''} = 1''.90 \pm 0''.11$$

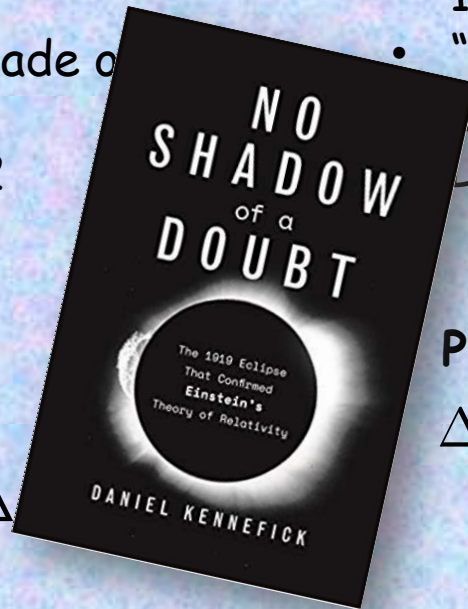
$$\Delta\theta_{13''} = 1''.55 \pm 0''.34$$

The Principe Measurements

- One telescope
 - Morning rain, mostly cloudy
 - 2 usable plates with 5 stars each
 - No comparison plates made (plates from Oxford made in Jan 1919 used instead)
 - "check" plates used
- Departed on June 12, arrived in Liverpool July 14

Principe Result

$$\Delta\theta = 1''.61 \pm 0''.30$$
$$= (0.92 \pm 0.17)\Delta\theta_{GR}$$



The 1919 Eclipse Expedition

Alfred North Whitehead:

The whole atmosphere ... was exactly that of a Greek drama... in the background the picture of Newton to remind us that the greatest of scientific generalizations was now, after more than two centuries, to receive its first modification.

London Times, Nov 7 1919

REVOLUTION IN SCIENCE

NEW THEORY OF THE UNIVERSE

**NEWTONIAN IDEAS
OVERTHROWN**

NY Times, Nov 10 1919

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.



From Adulation to Denouncement

The public Einstein

Initial US skepticism

Campbell & Trumpler 1922

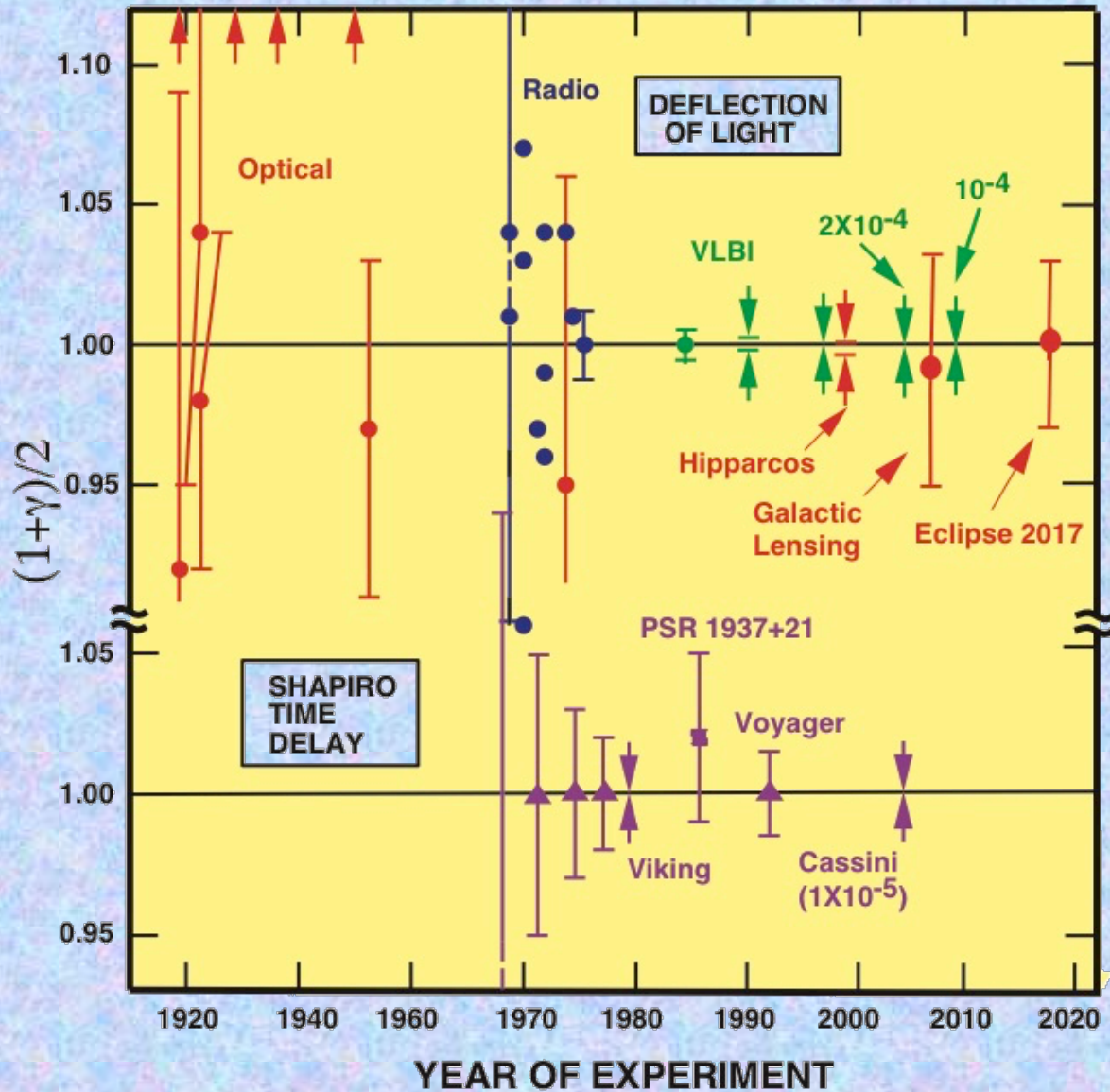
$$\Delta\theta = 1''.72 \pm 0''.11$$

German anti-relativity campaigns

- Philipp Lenard
- Nobel prize 1905
- Supported Nazi ideology
- Denounced "jewish" science such as relativity
- Reprinted von Soldner's paper in 1921



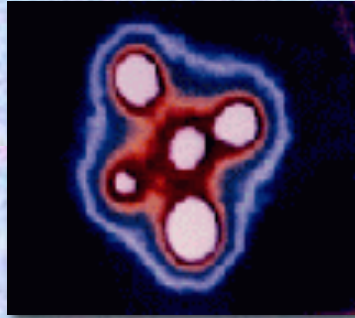
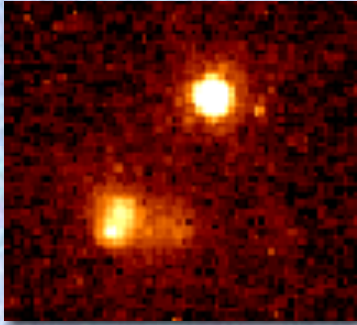
Measuring the PPN parameter γ



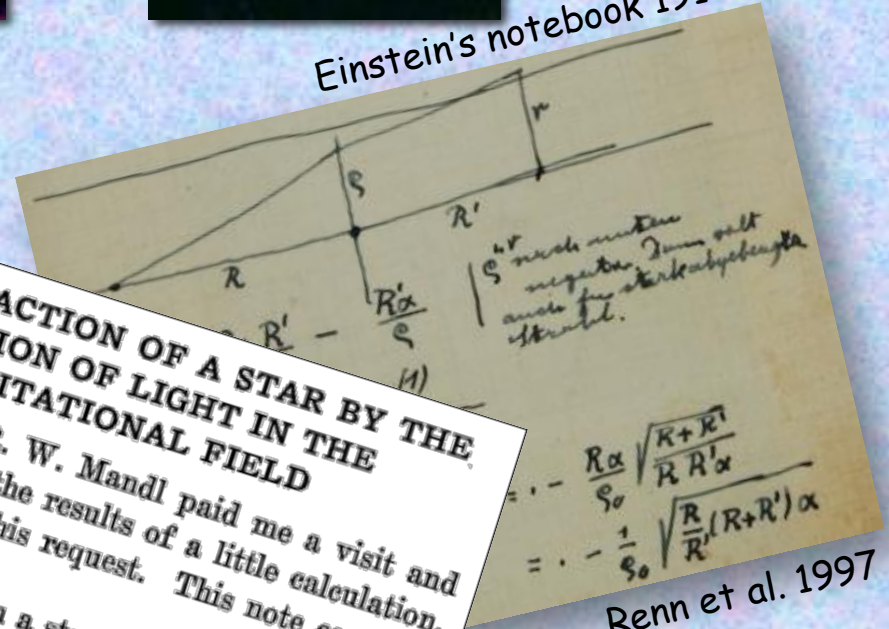
Donald Bruns in Wyoming



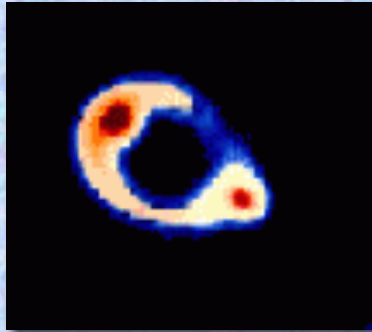
Lenses: Einstein's gift to astronomy



Einstein's notebook 1912



Renn et al. 1997



LENS-LIKE ACTION OF A STAR BY THE DEVIATION OF LIGHT IN THE GRAVITATIONAL FIELD

SOME time ago, R. W. Mandl paid me a visit and asked me to publish the results of a little calculation, which I had made at his request. This note complies with his wish.

The light coming from a star *A* traverses the gravitational field of another star *B*, whose radius is R_0 . Let there be an observer at a distance D from *B* and at a distance x , small compared with D , from the extended central line \overline{AB} . According to the general



Einstein, Science 1937: "Mandl squeezed it out of me... but it makes the poor guy happy"

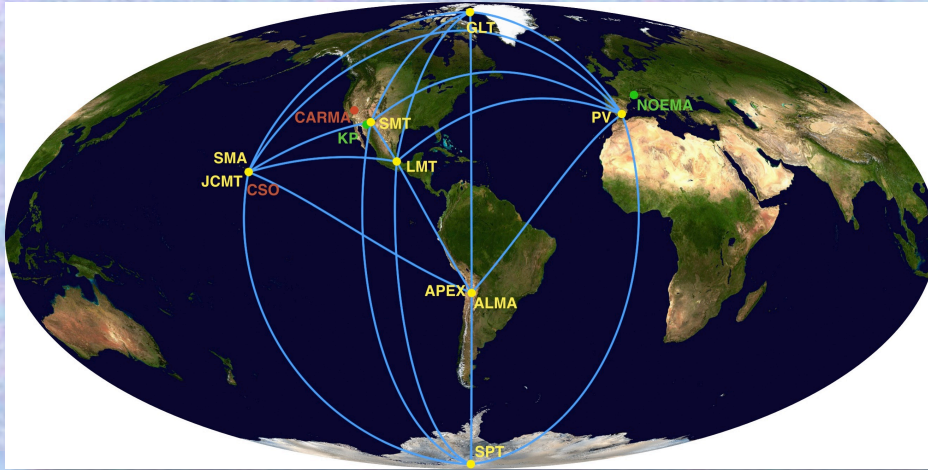


Geometry bends light: and wins an Oscar!



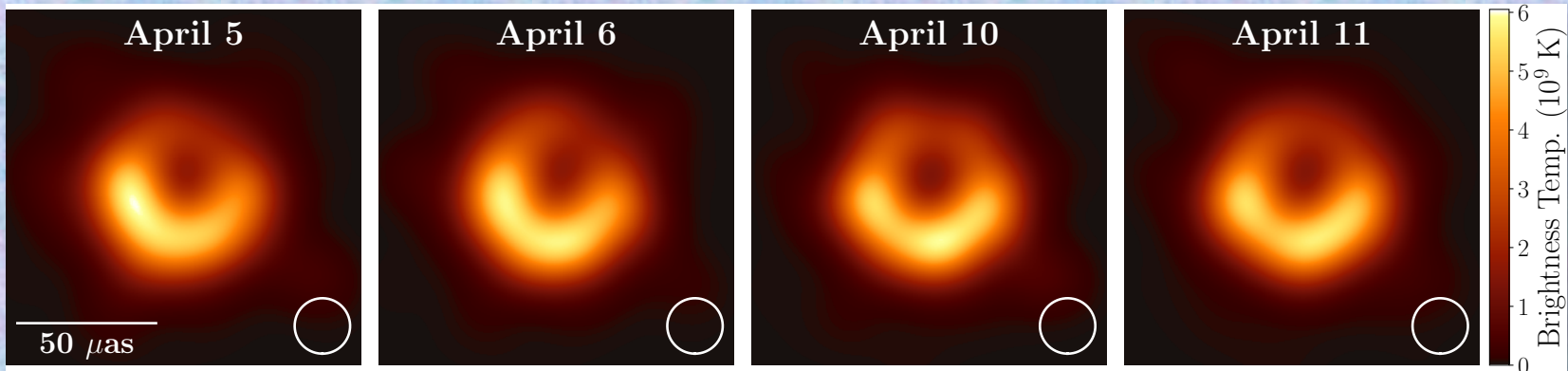
Interstellar, Paramount Pictures, Directed by Christopher Nolan
Starring: Matthew McConaughey, Anne Hathaway, Jessica Chastain, Michael Caine, ...
Image based on calculations by Kip Thorne and Double Negative Co.

Geometry bends light: Black hole shadows



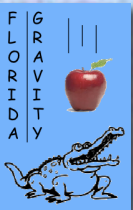
Event Horizon Telescope (EHT)

- mm wavelength
- horizon scale angular resolution at SgrA* and M87



The black hole in M87

See Heino Falcke's talk on Friday



Principe: May 29, 2019

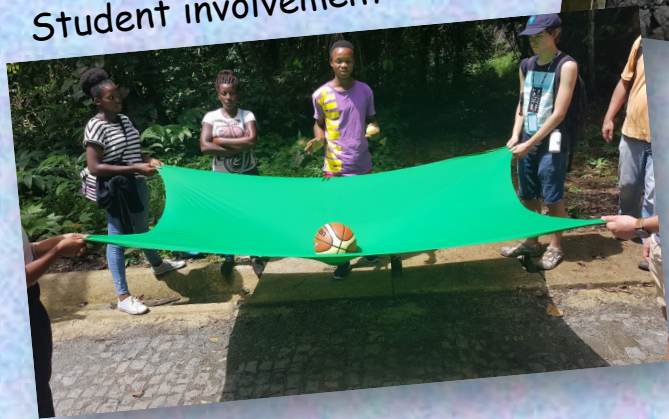
Welcome to Principe



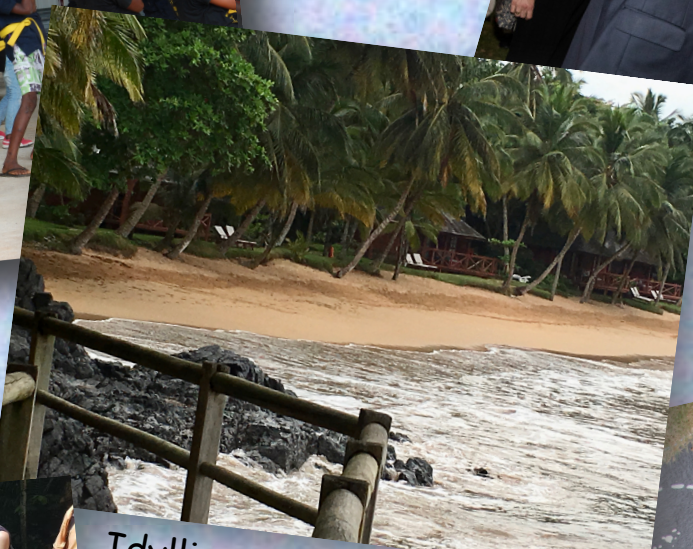
President of Portugal



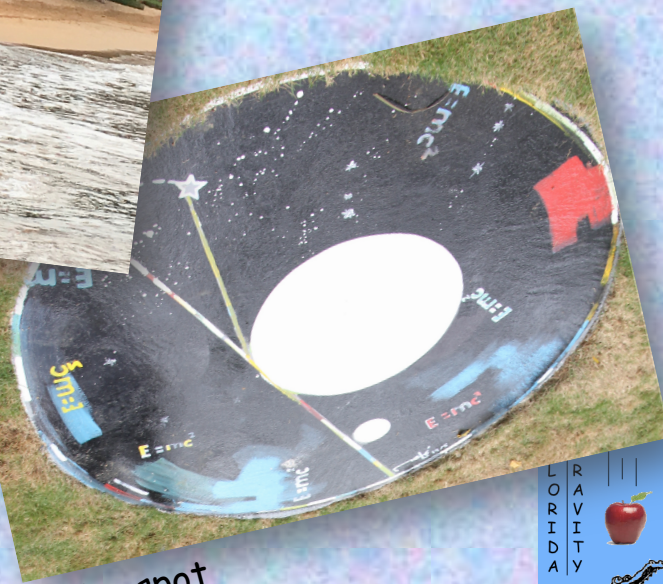
Student involvement



Idyllic surroundings



The spot



Sobral: May 29, 2019

Celebrating the moment



Einstein and friends



The 4" coelostat back in Sobral



Commemorative plaque

