Tracing Shadows: How Astronomers predicted the perfect eclipse to test Einstein's theory of General Relativity

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Einstein's fame

An eclipse in 1919 made Einstein World famous almost literally overnight.

Measurements taken during an eclipse of that year had confirmed his bold prediction that light is deflected by gravity and favored his theory of General Relativity over the traditional Newtonian theory of gravity.

New York Times headline from 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.

Special Cable to THE NEW YORK TIMES.
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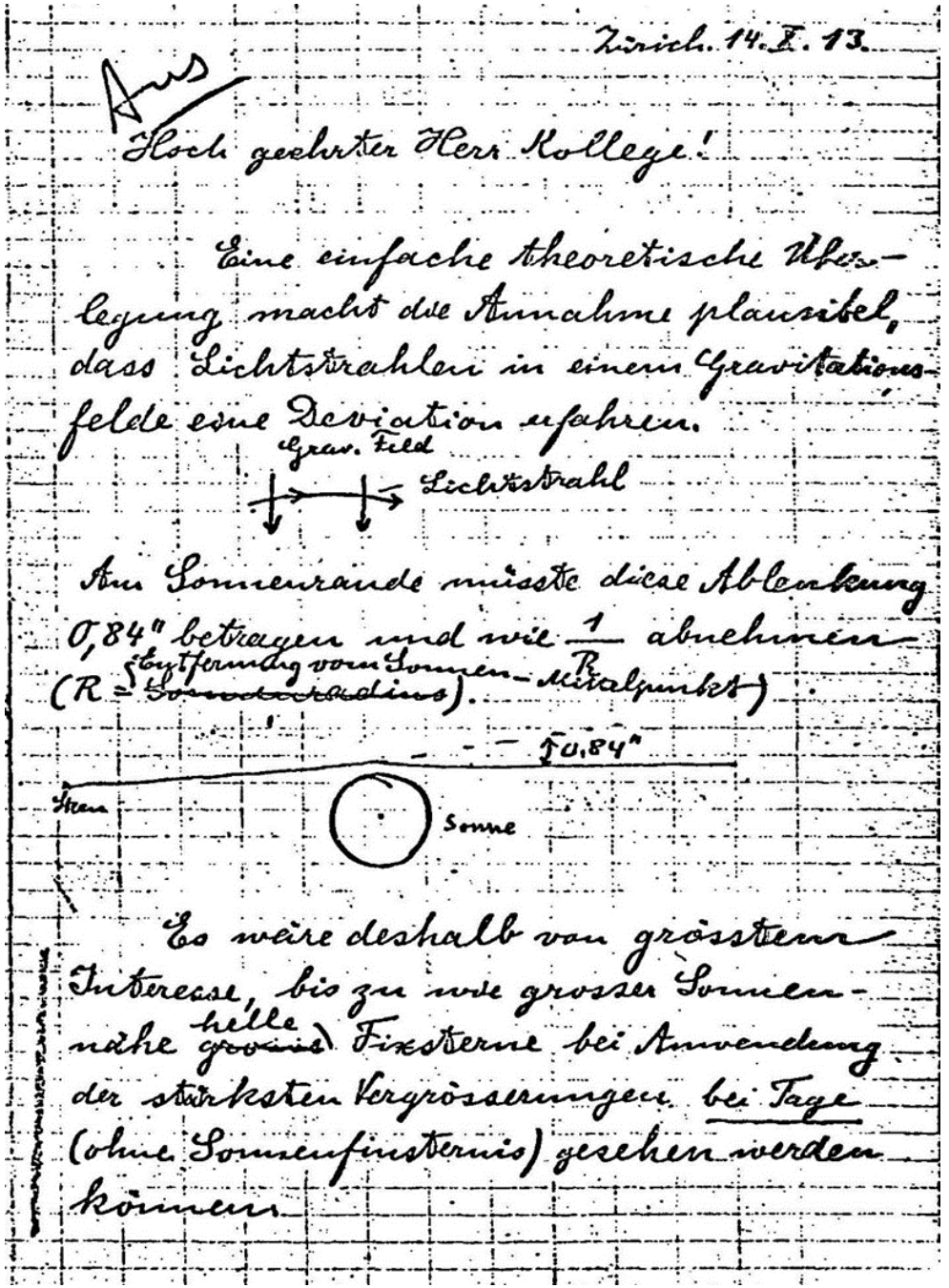
Einstein and the Eclipse

Einstein had been asking astronomers (including George Ellery Hale) to test his theory at an eclipse since 1913.

He was impressed by their “pedantic precision.”

In 1917 the English Astronomer Royal, pointed out that the total solar eclipse of 1919 would be perfect for Einsteins’ test.

But how did he know?



Zürich. 14. I. 13.

Aus

Hoch geehrter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfelde eine Deviation erfahren.

grav. Field

Lichtstrahl

Am Sonnenrande müsste diese Ablenkung 0,84" betragen und wie $\frac{1}{R}$ abnehmen (R = Entfernung vom Sonnenmittelpunkt).

0,84"

Stern

Sonne

Es wäre deshalb von grösstem Interesse, bis zu wie grosser Sonnennähe helle Fixsterne bei Anwendung der stärksten Vergrösserungen bei Tage (ohne Sonnenfinsternis) gesehen werden können.

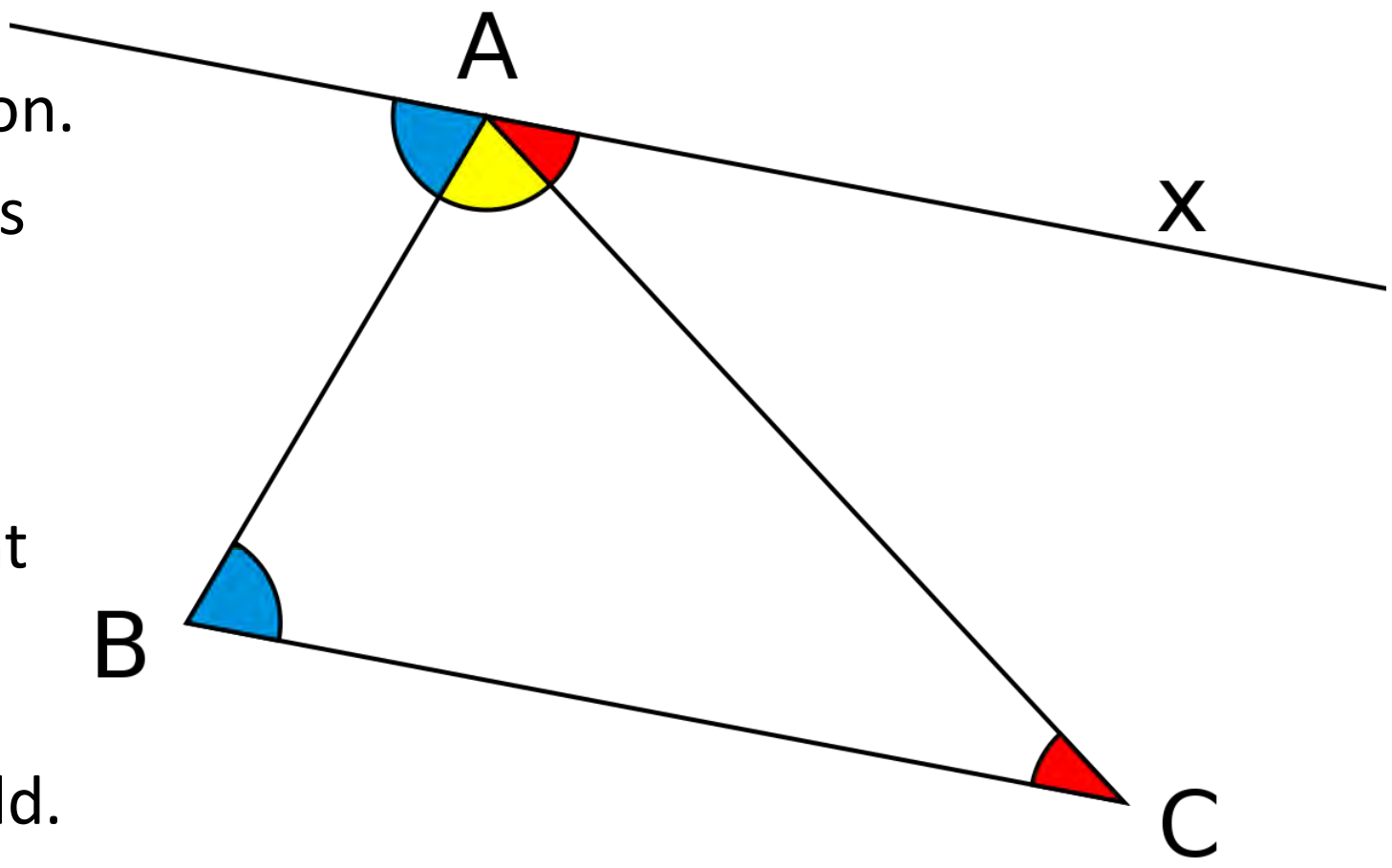
General Relativity and curvature

Einstein actually made two predictions about light deflection.

The first says that light has mass and therefore falls in a gravitational field.

The second says that gravity distorts space, so “parallel” light rays will converge.

For instance, Thales of Miletus’ famous result will no longer hold.



Thales' eclipse, 585 B.C.

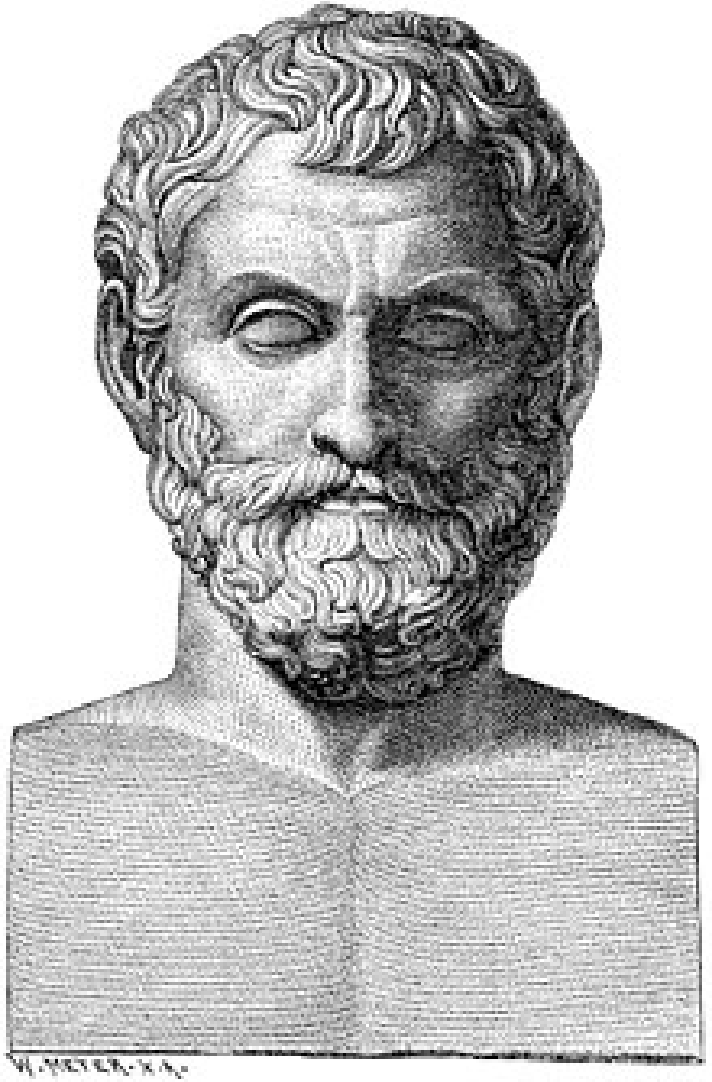
Was this the first prediction of an eclipse?

It is said to have occurred during a battle between the Medes and the Lydians, the first dateable event in world history?

No scientific theory of eclipses existed at this time.

The track of totality was NOT predicted.

"fixing for it the very year in which it actually took place" -Herodotus.



Thales of Miletus

The Saros Cycle

An eclipse can only take place when the Moon is lined up with the Sun in our sky in two different ways:

It must be at the new Moon (for a solar eclipse) or the full Moon (for a lunar eclipse). This happens every synodic month.

It must be on the plane of the ecliptic (at a node of its orbit), which happens every Draconic month.

223 Synodic months equals 242 Draconic months.

Therefore 223 new Moons after a solar eclipse, there will be another solar eclipse in the same series. This is just over 18 years later.

The Antikythera mechanism, one of whose gears has exactly 223 teeth.

Anaxagarous

A century after Thales came a philosopher often credited with the first correct theory of eclipses.

An eclipse occurs when the Moon or the Earth passes in front of the Sun (as seen from the other) and casts its shadow upon the other body.

Pericles is supposed to have reassured Athenian troops during the Peloponnesian war that a solar eclipse was not an ill omen or portent but a purely natural phenomenon.

Anaxagoras and Pericles by Augustin-Louis Belle

Synod of Whitby, 664

A dispute between Irish and Roman monks over the dating of Easter.

The Eclipse of 664 may have exposed the inaccuracy of lunar tables used in the Easter computes.

Is this one of the earliest examples of Scientific Fraud?

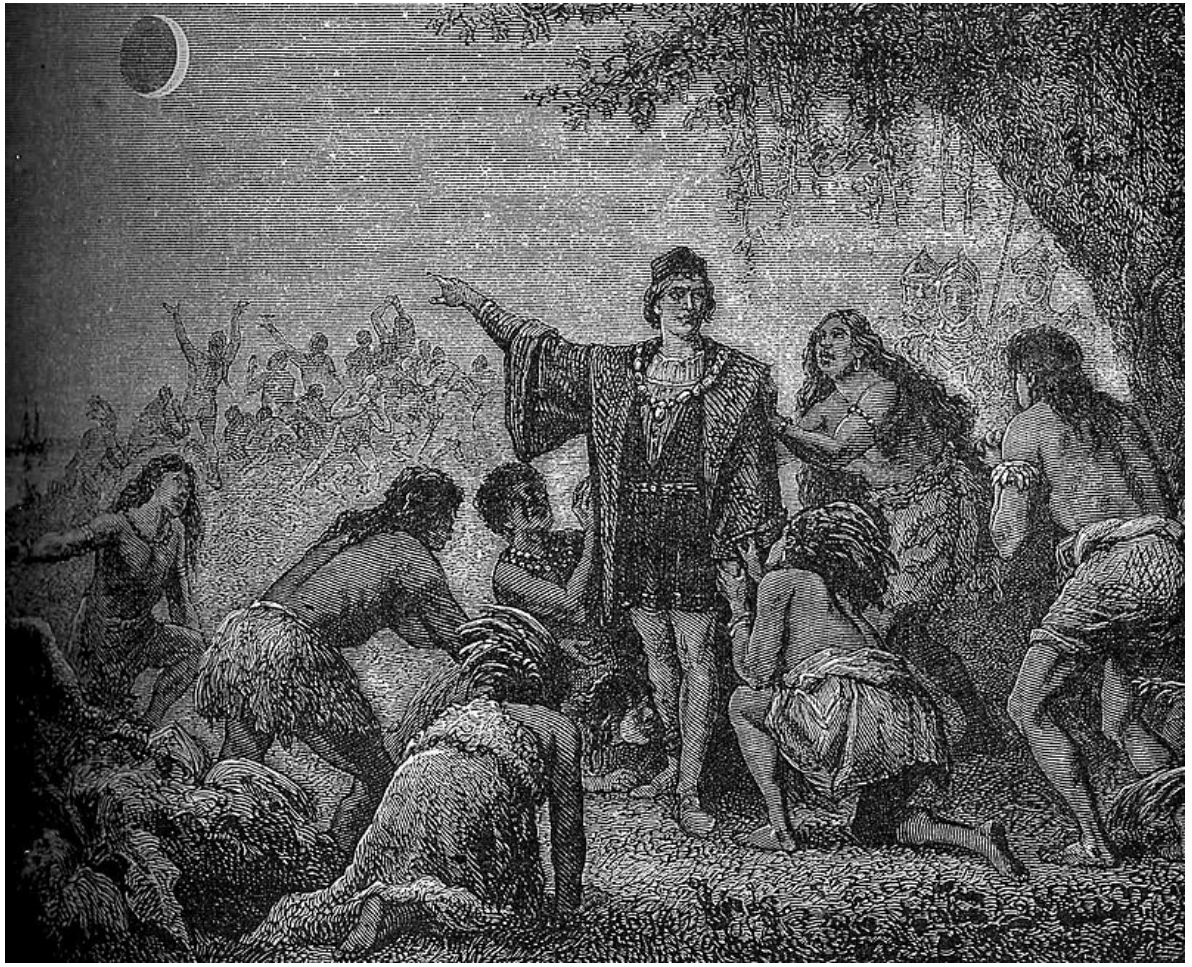
Ruins of Whitby Abbey, Northumbria
(this ruin was built many centuries later than the monastery where the Synod took place)

Columbus' Eclipse, Lunar eclipse of 1504

Columbus predicted a lunar eclipse in order to overawe and subdue the colonized people of Jamaica.

This is science in the service of colonialism, enabled by Ephemerides and Almanacs.

A young Tycho Brahe later observes the solar eclipse of 1560 and is inspired by the ability to predict astronomical events.



Halley and the Eclipse of 1715

Probably the first map showing, in advance, the track of totality of a solar eclipse was produced by Edmund Halley.

This version is an after-the-fact correction (he was wrong by 20 miles or so).

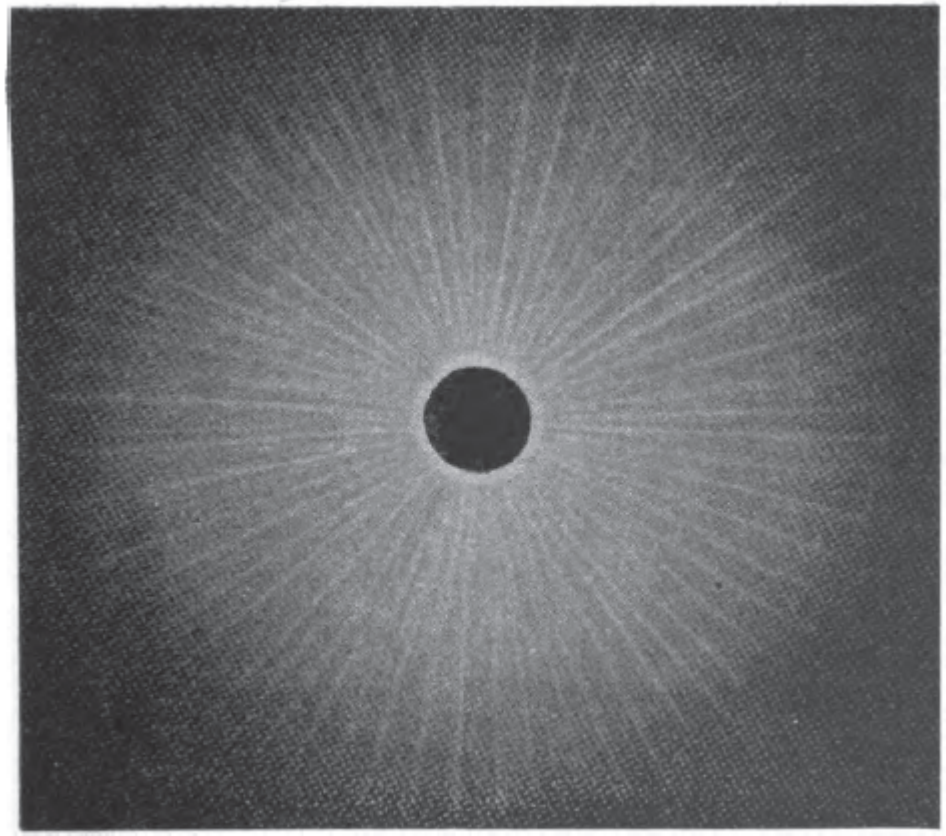
He also predicts, on this map, the eclipse track of 1724.

Tecumseh and the eclipse of 1806

Native American political leader Tecumseh and his brother, the Shawnee prophet, are said to have accurately predicted this eclipse, answering a challenge from William Henry Harrison.

Did he learn of the eclipse from an Almanac?

Spanish astronomer Ferrer coined the term corona after observing the eclipse from upstate New York, an early example of an eclipse expedition.



THE CORONA OF 16th June 1806 (FERRER)

Bessel and the eclipse of 1836

An annular solar eclipse was predicted to have a track whose edge ran very near the observatory at Konigsberg, Prussia.

Friedrich Bessel was moved to improve the calculation of such tracks, in order to know in advance whether he could see the annular eclipse from his observatory.

This was the eclipse where Bailey's beads were first observed.

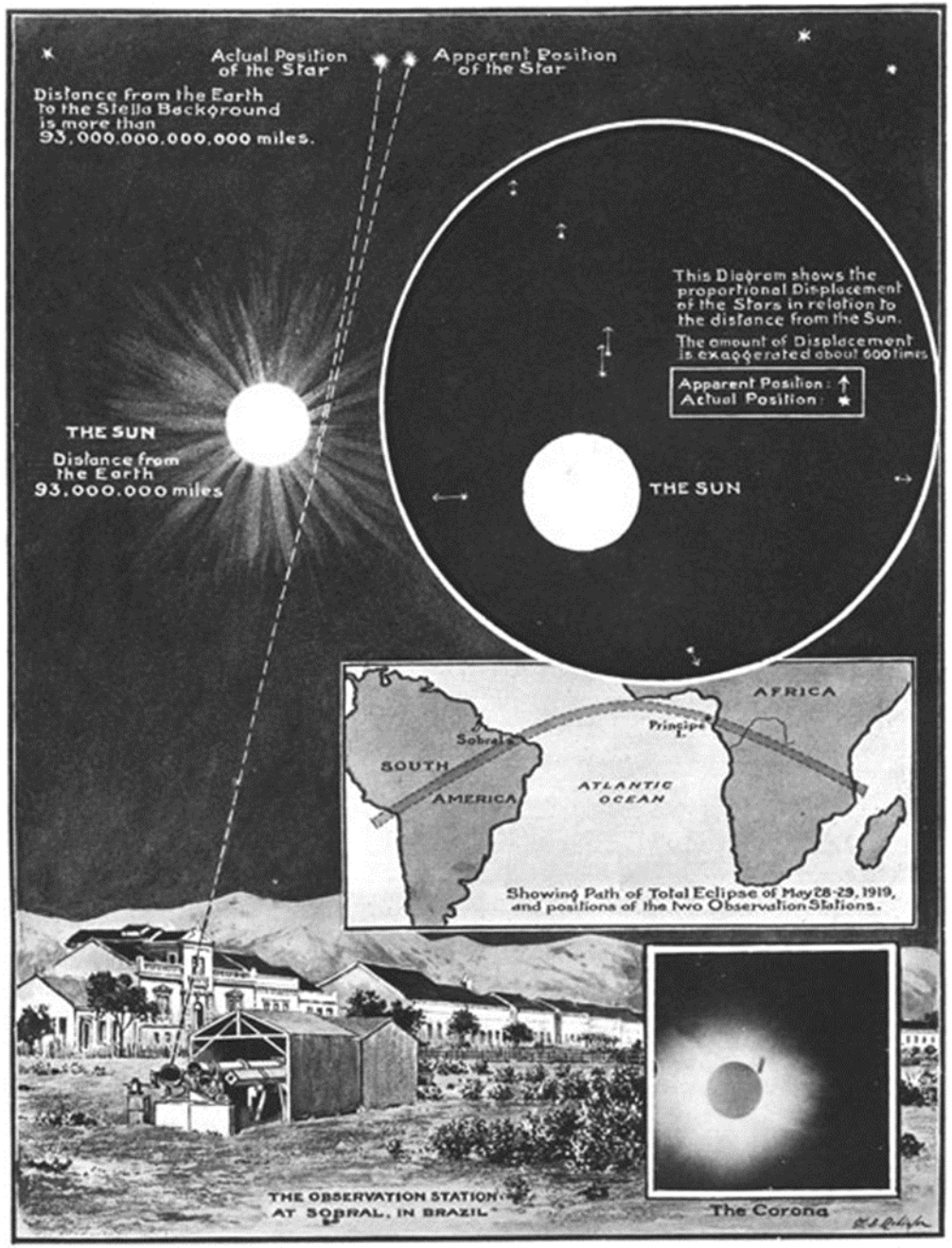
Dyson and the 1919 eclipse

By 1919 Astronomers had been mounting eclipse expeditions for decades.

Someone had to do the calculations, using Besselian elements to find the eclipse path and project it on a map.

In 1919 that person was Arthur Hinks, who was both an astronomer and a geographer.

Dyson realized that the 1919 eclipse was important for its duration and its rich field of stars (the Hyades cluster).



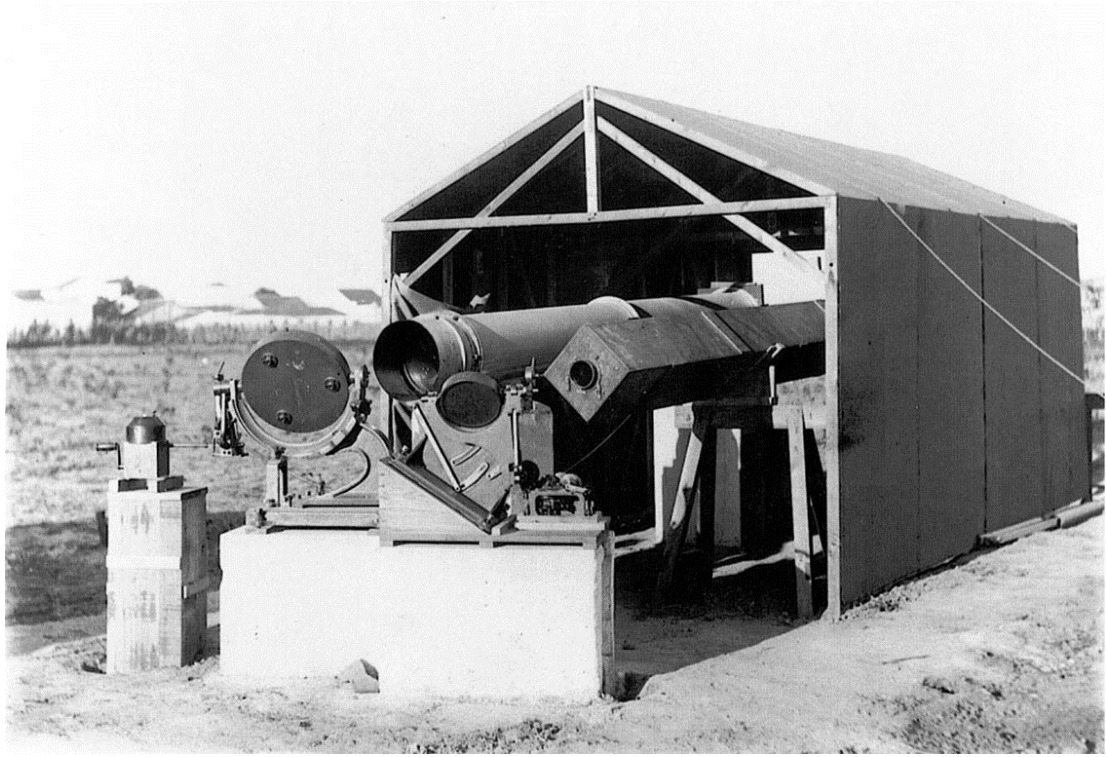
May 29, 1919

Some recent commentators have claimed that Dyson's colleague Arthur Stanley Eddington was biased in favor of Einstein's theory and that their results did not reliably contradict Newton's theory.

This is completely false, as modern re-analysis of their work proves.

It is noteworthy that subsequent eclipse did not improve on the precision of 1919.

The reason is straightforward, an eclipse does not provide opportunities for repetition of the experiment, and so it is no possible to profit from one's experience.



Instruments used at Sobral, Brazil in 1919

Foiled by fate

You can know when and where the eclipse is going to happen, but that doesn’t mean you will make it there, or that the weather and your equipment will cooperate when you do.

If something does go wrong, there are no do-overs.

Repetition and learning from one’s mistakes are bedrocks of science, and often impossible under eclipse conditions.

Charles Davidson and Frank Dyson preparing for an eclipse in 1927