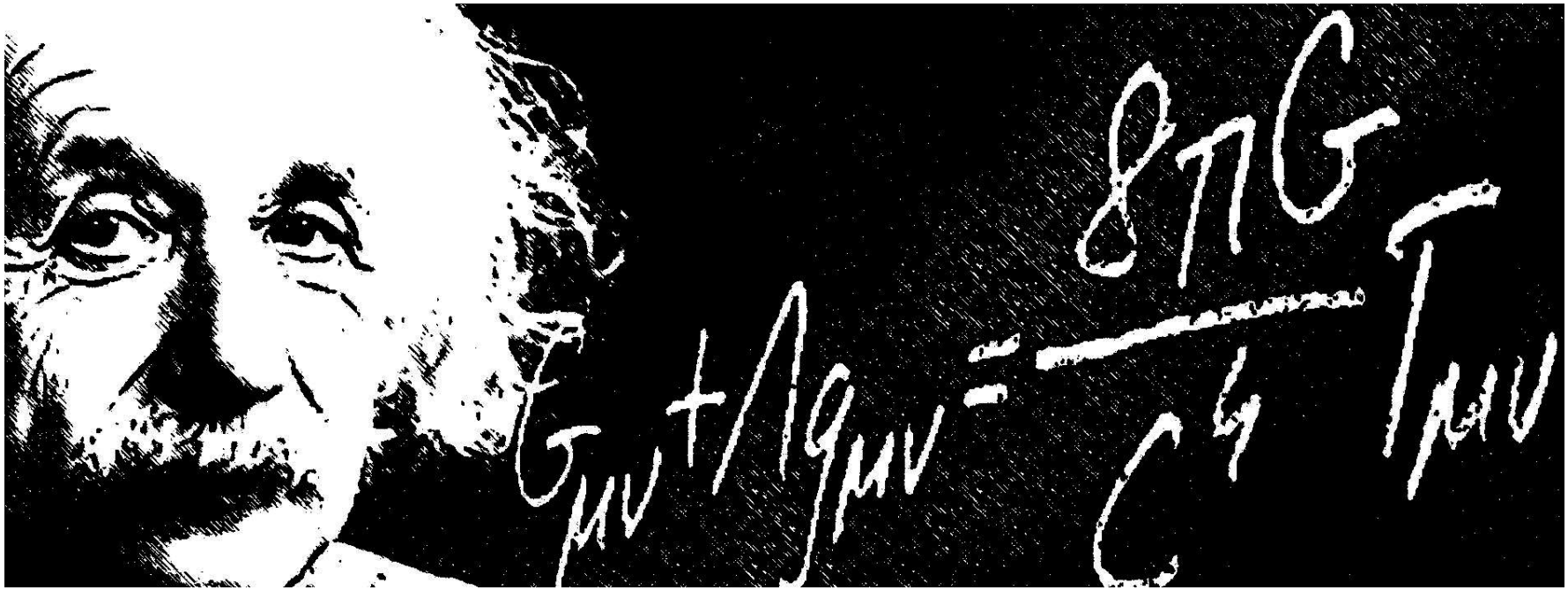


Was Einstein right?

Nils Andersson

STAG RESEARCH CENTRE

GRESHAM COLLEGE

UNIVERSITY OF Southampton

1905

Special Relativity

Speed of light is constant, the same for all observers.

- Moving clocks run slow
- Moving rods appear short
- Energy and mass are equivalent…

Image: Everett Historical/Robert Kyllo/shutterstock

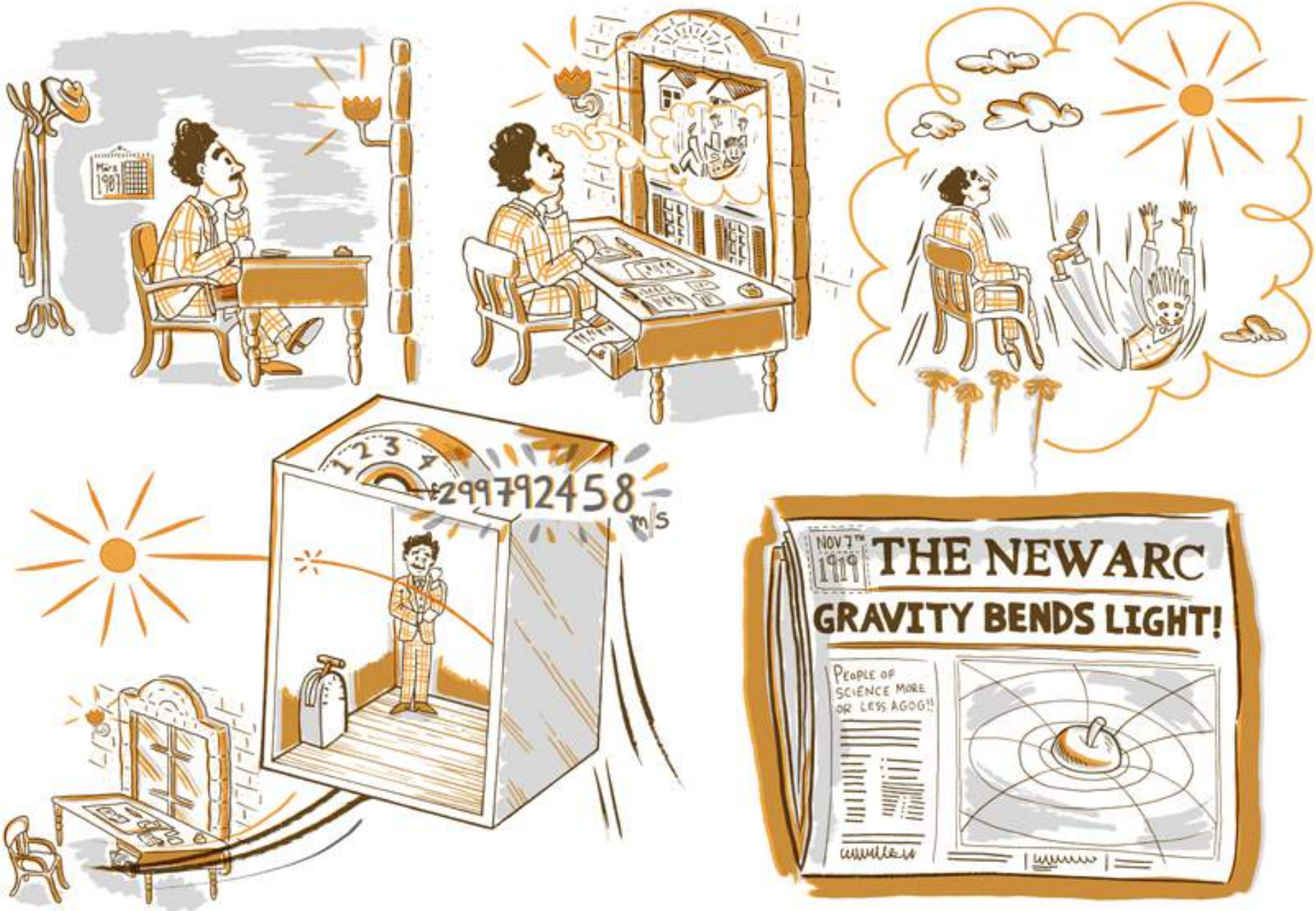


Illustration: Ollie Dean 2015

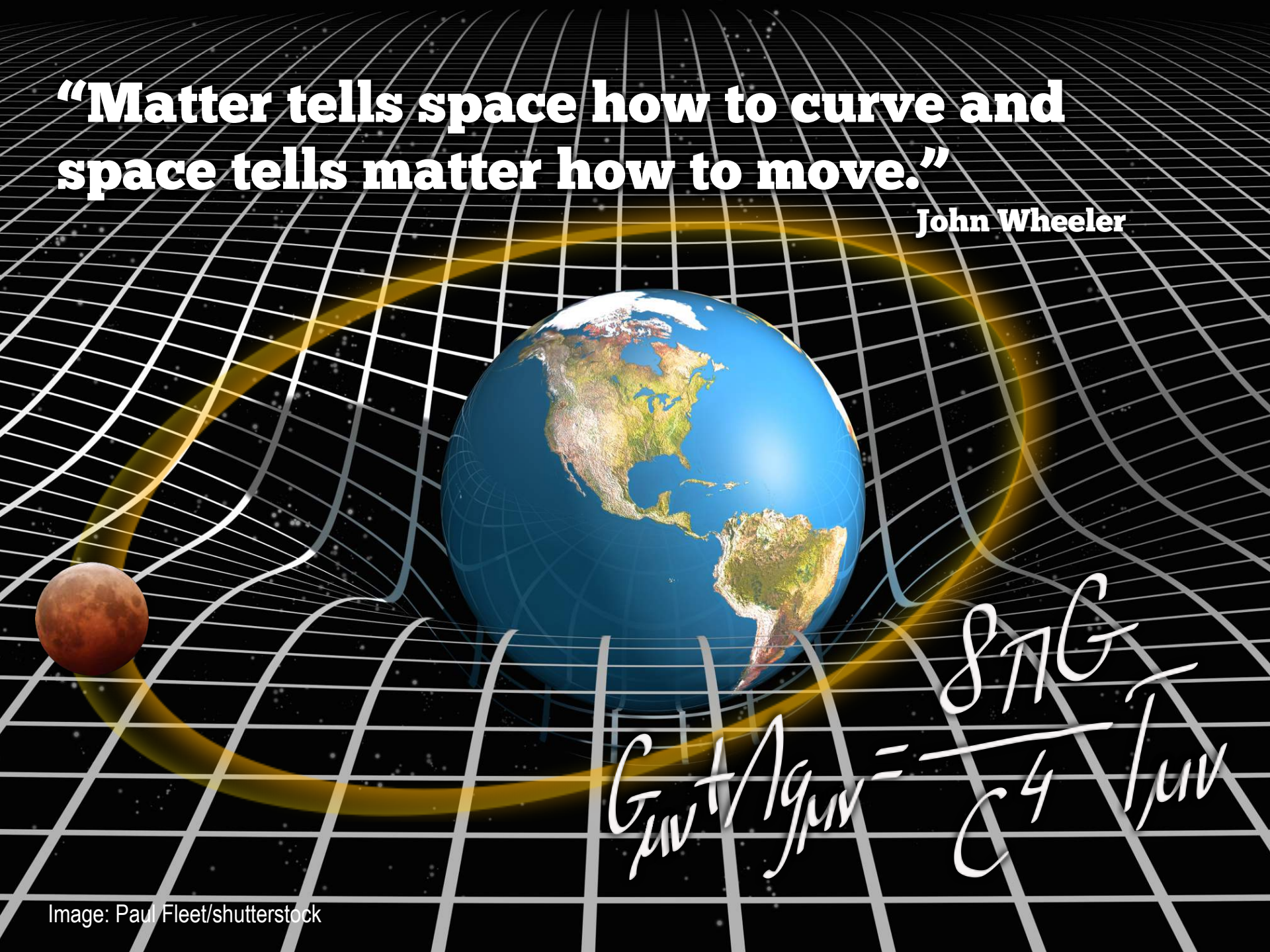


Image: Paul Fleet/shutterstock

1907

Equivalence principle

No difference between acceleration and gravity.

1915

General Relativity

Gravity is geometry.
Spacetime is curved.

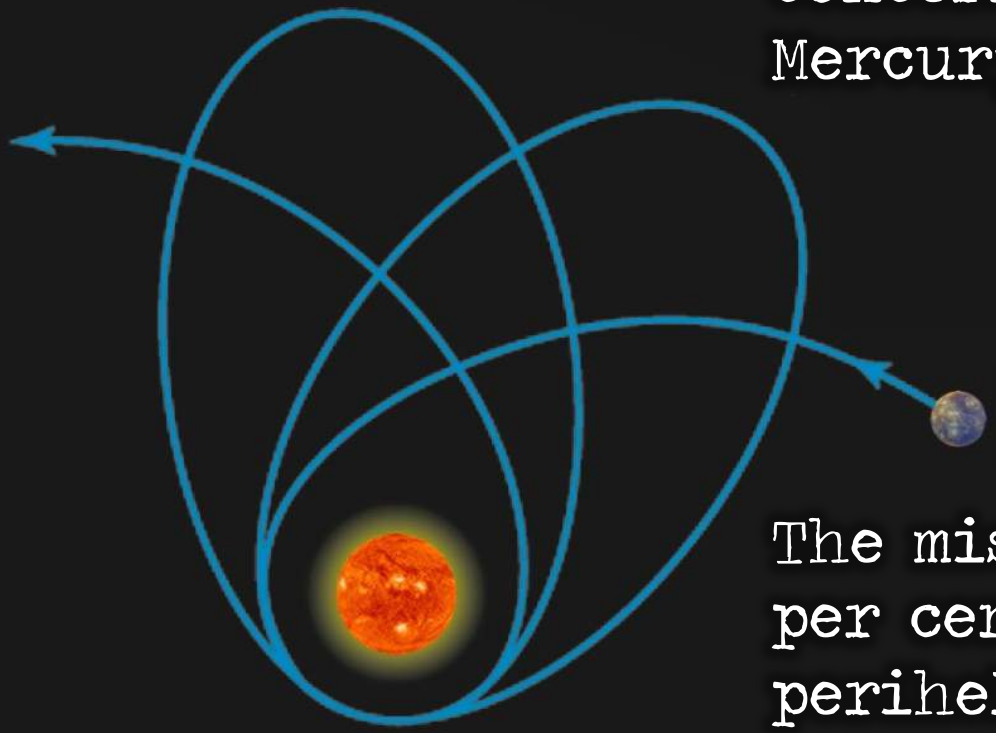
Gravity;

- moves mass
- bends light
- warps time
- makes waves
- creates black holes
- explains the cosmos

How do we know this is right?

Gravity moves mass

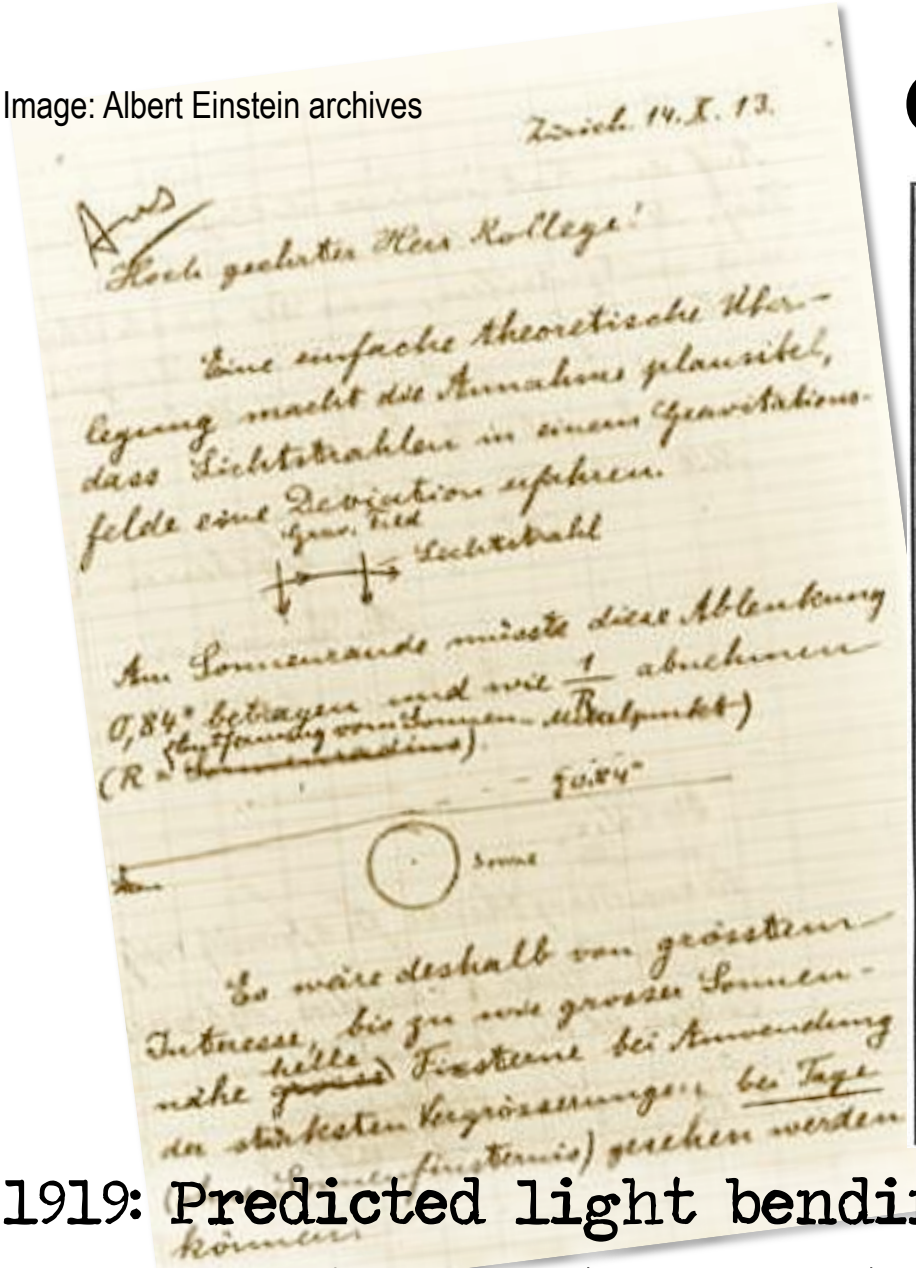
1915: Einstein revolves a long-standing problem concerning the motion of Mercury.



The missing 43 arcseconds per century in the perihelion precession is explained by relativity.

Gravity bends light

Image: Albert Einstein archives


Zürich, 14. X. 13.

Hoch geehrter Herr Kollege!

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

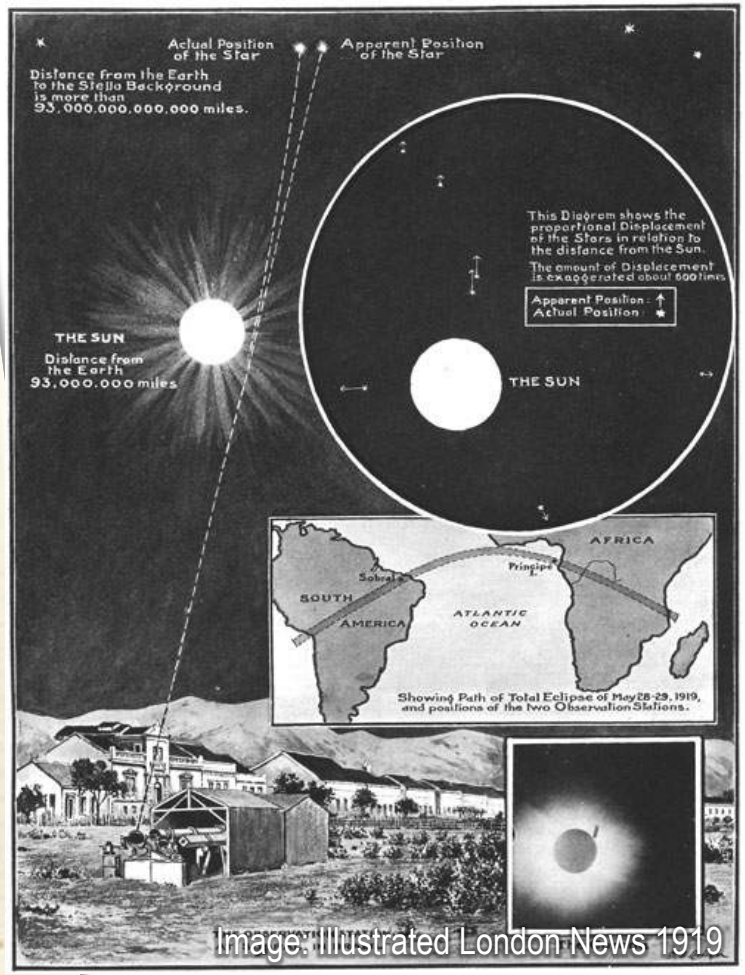
Gravitationsfeld — Lichtstrahl

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

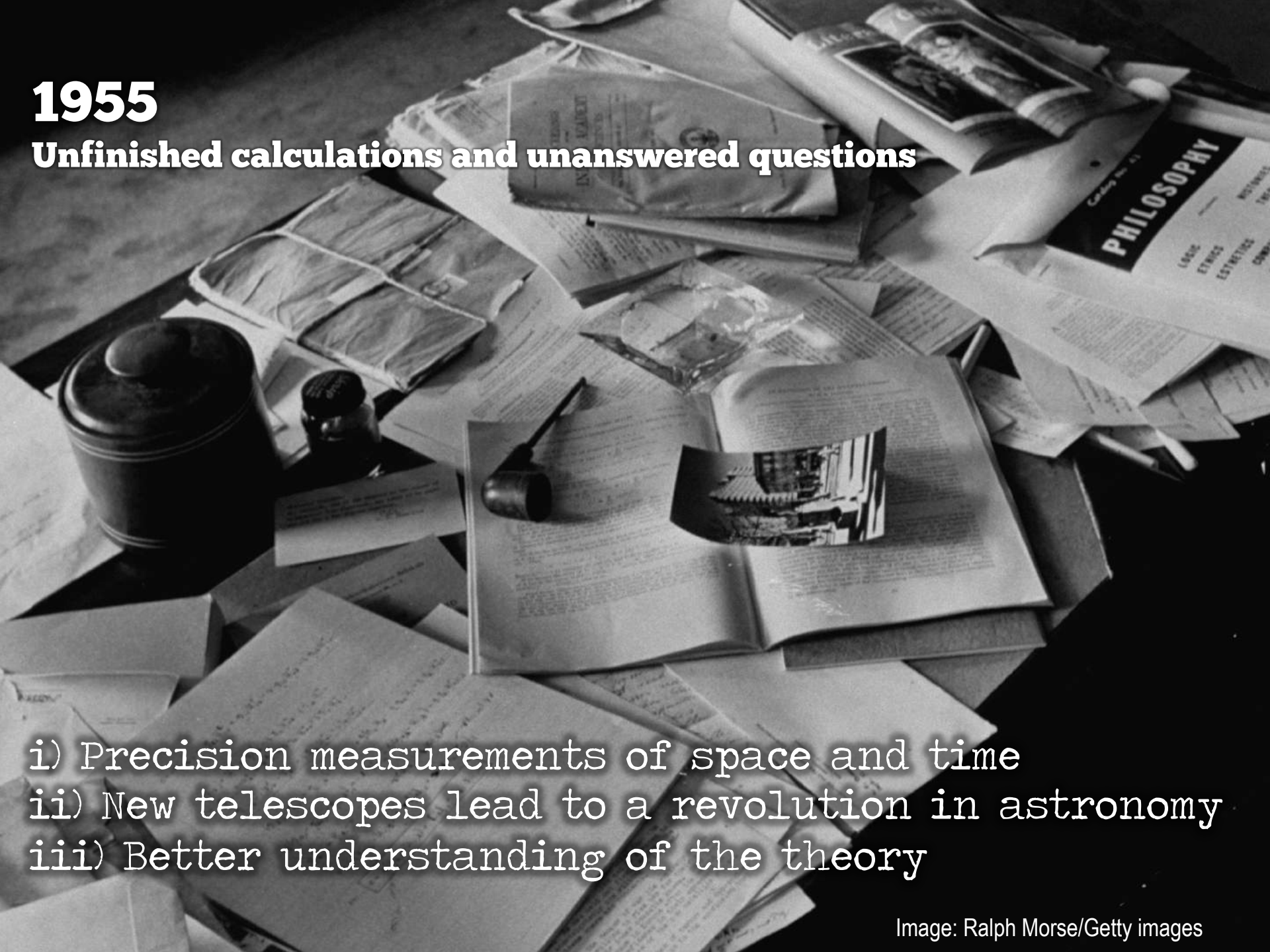
0,84"

Sonne

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



1919: Predicted light bending tested during solar eclipse, but only at the 30% level…



1955

Unfinished calculations and unanswered questions

i) Precision measurements of space and time
ii) New telescopes lead to a revolution in astronomy
iii) Better understanding of the theory

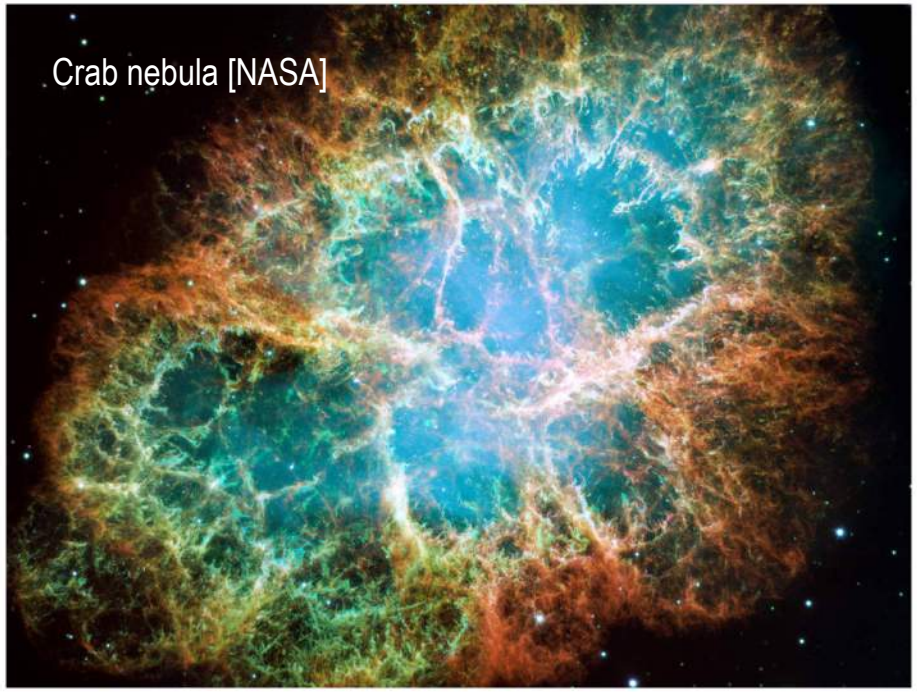
Image: Ralph Morse/Getty images

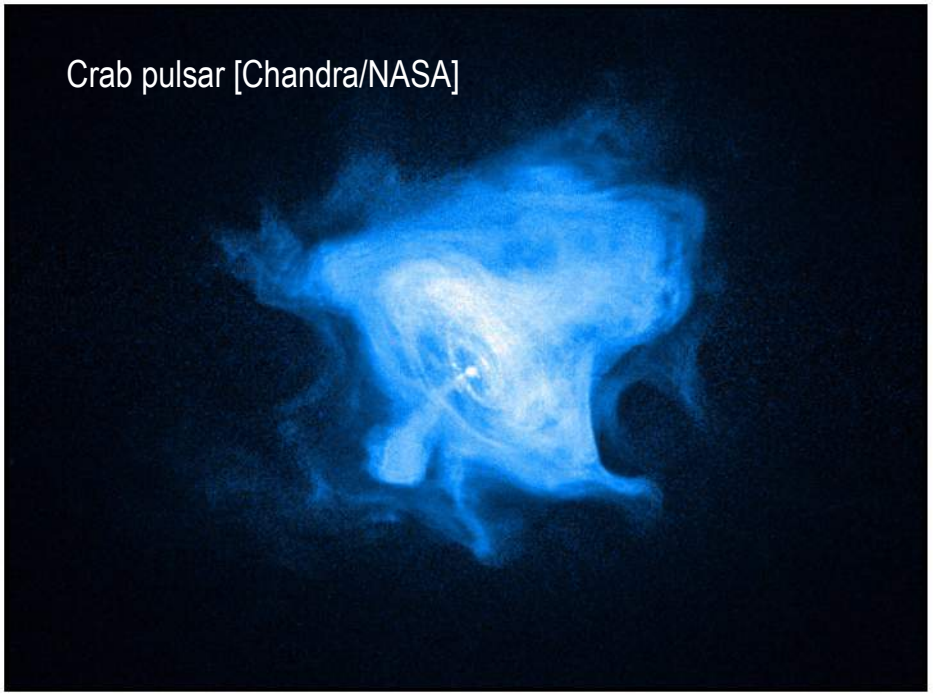
1960

A violent universe

1963: The discovery of quasars opens a window to a very different universe.

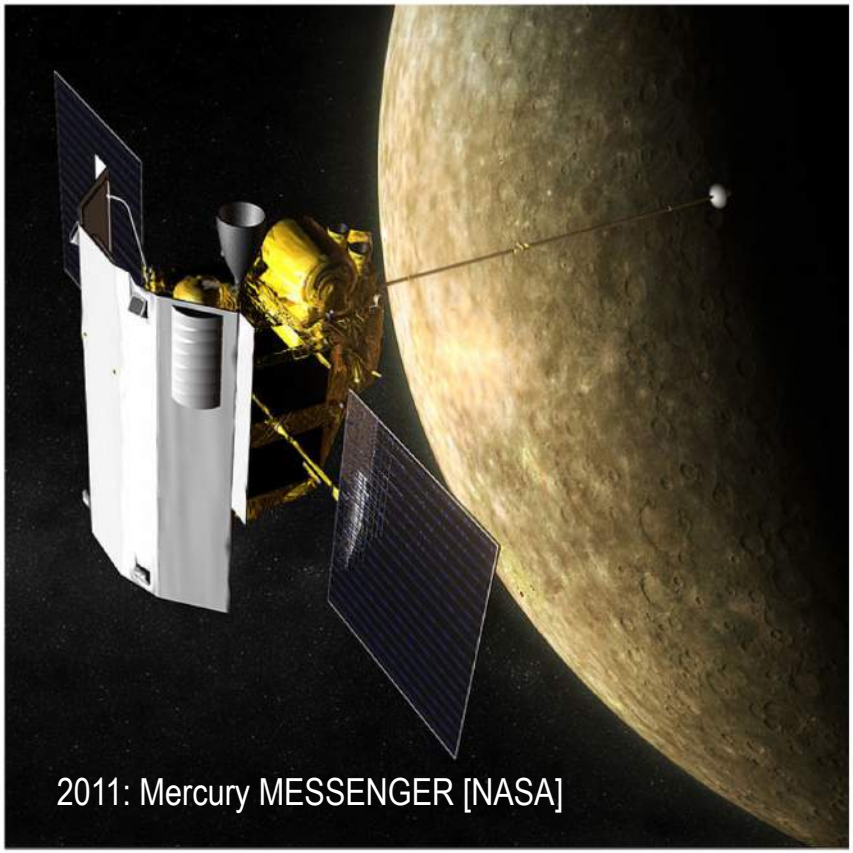
Cygnus A [NRAO]

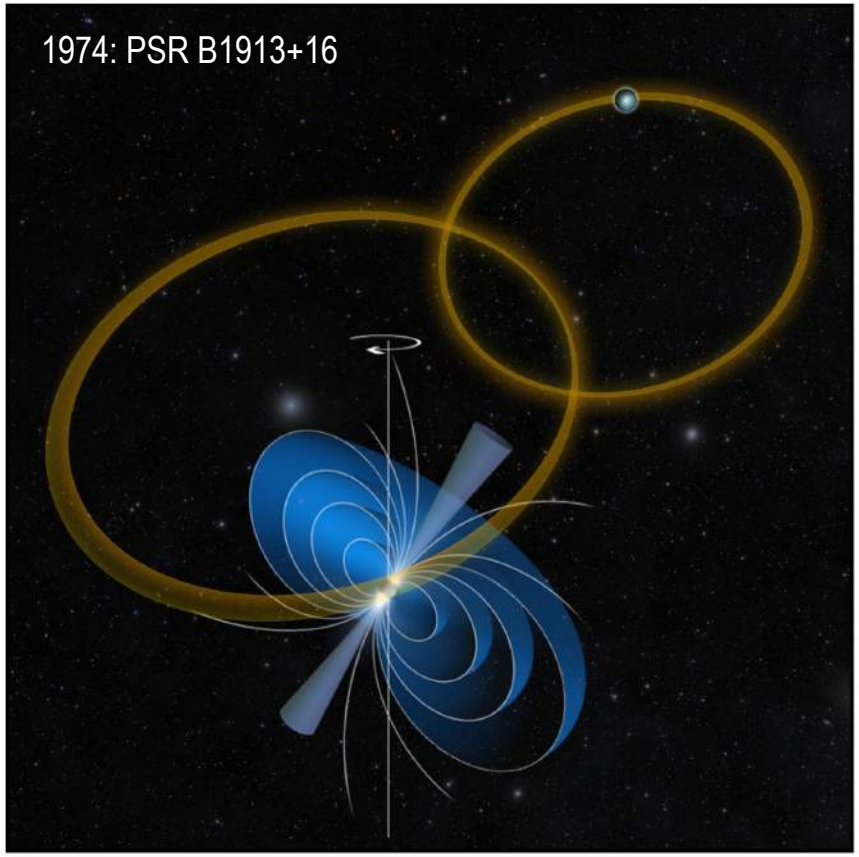

Crab nebula [NASA]


Crab pulsar [Chandra/NASA]


Artist's impression [NASA]
Stars run out of fuel and explode in supernovae.

Gravity moves mass

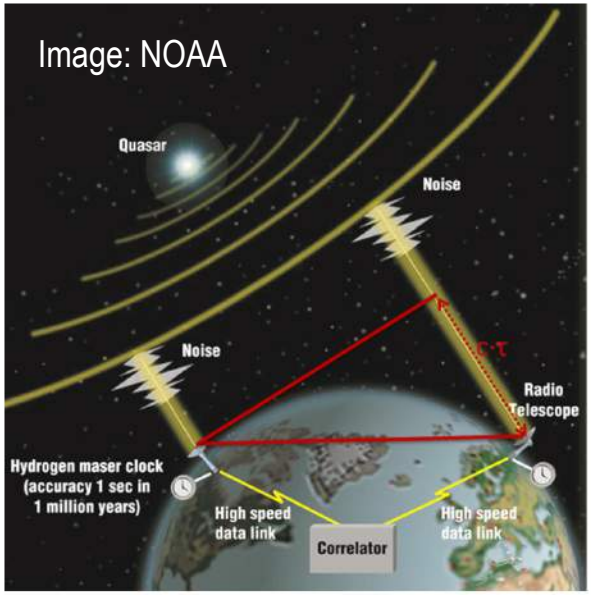




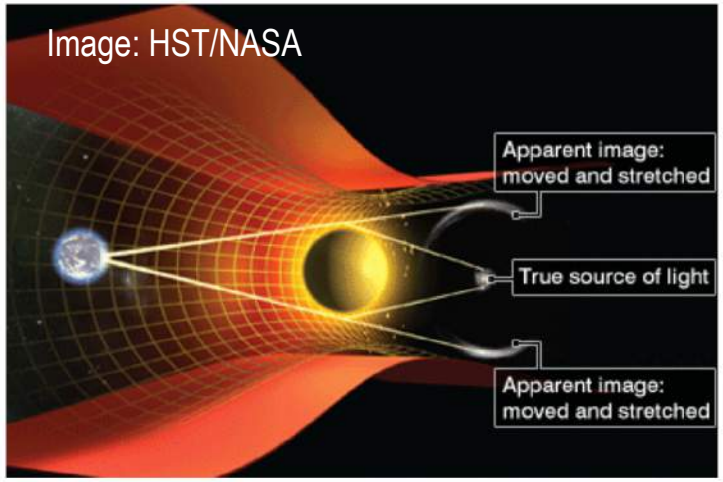
2011: Precision tracking of Mercury provides much tighter constraint.

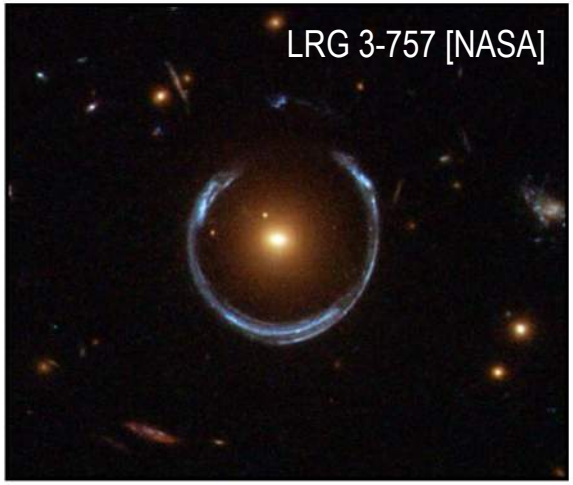
Since 1974: Theory tested in the strong gravity regime using neutron stars.

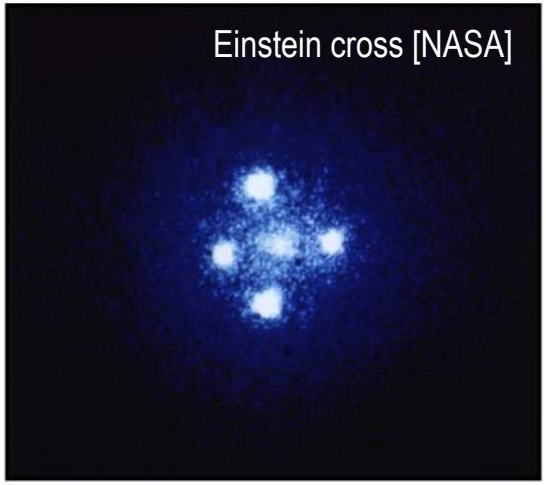
Gravity bends light

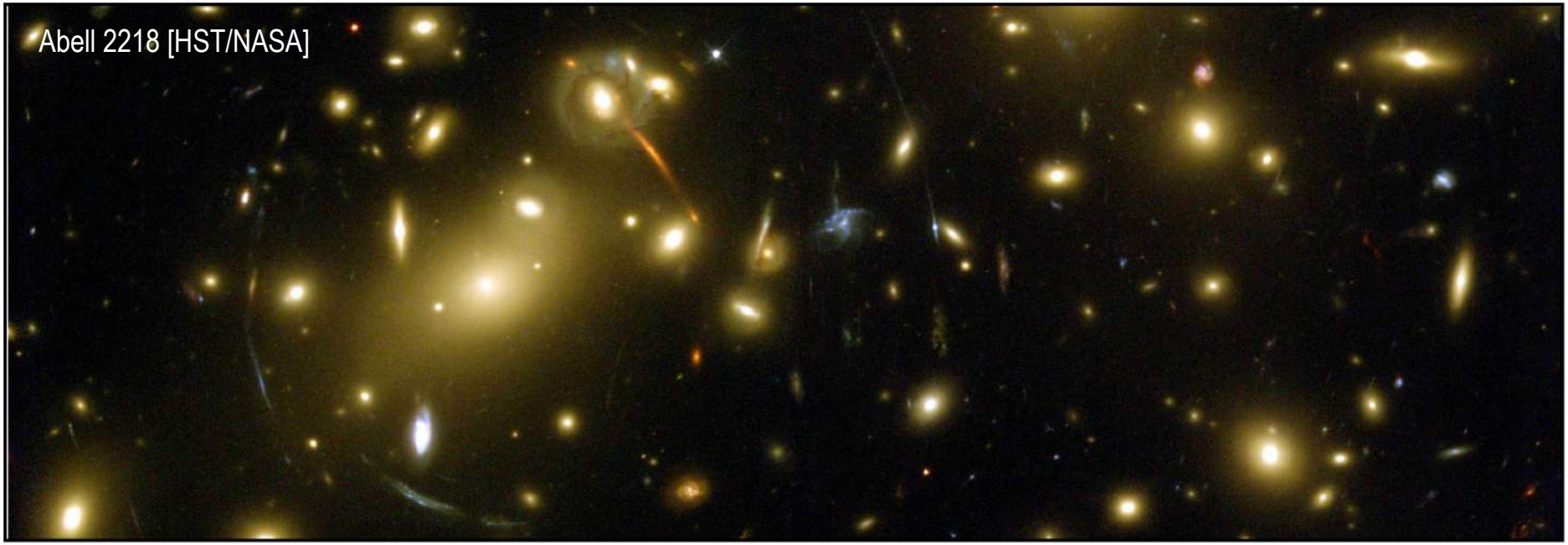


1970s: Long baseline radio interferometry allows accurate measures of light bending, testing theory at the 0.01% level.



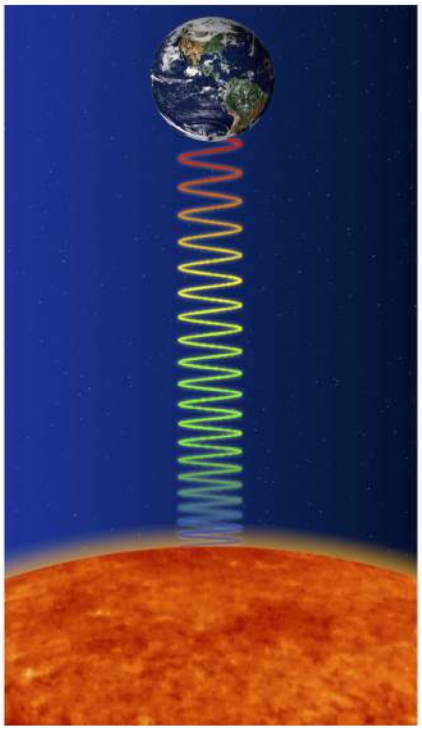


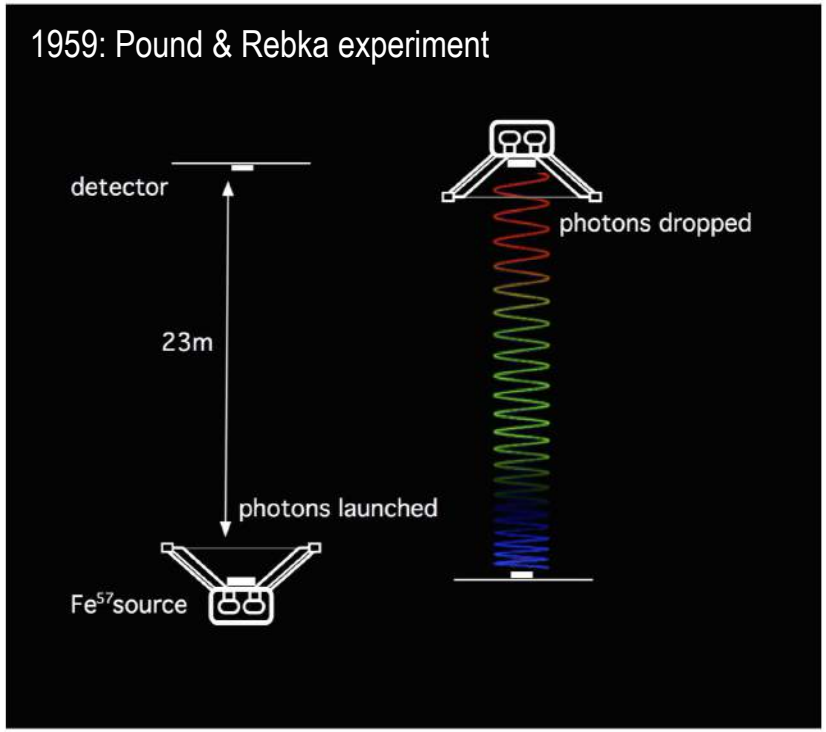


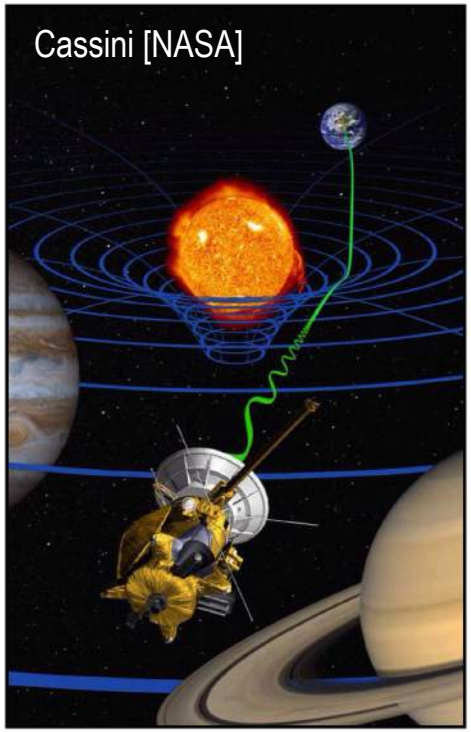


Gravitational lensing sheds light on dark matter.

Gravity warps time







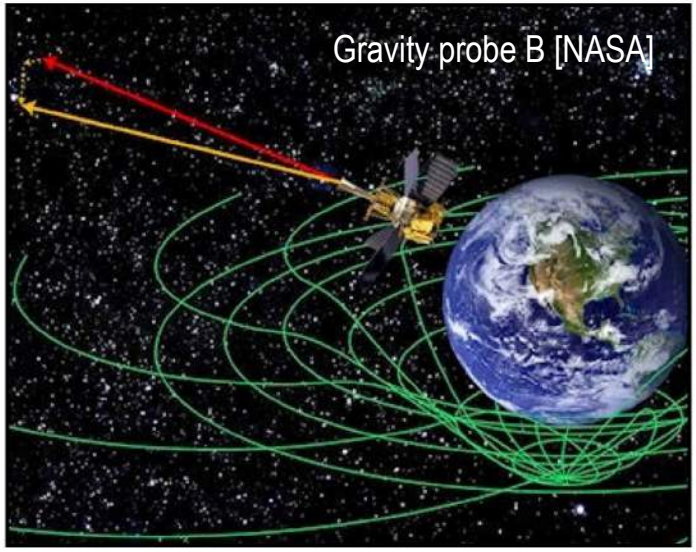
1917: Failed attempt to detect solar redshift

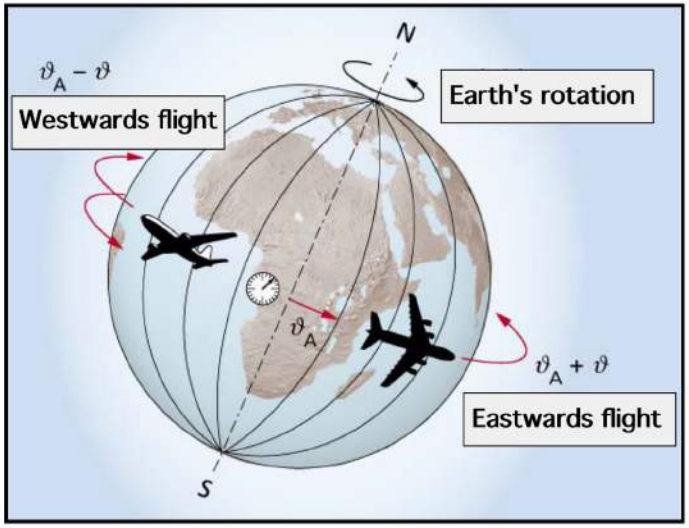
1959: First precision test measures mass of photon

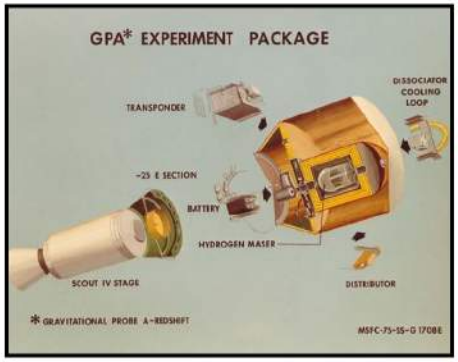
2003: Cassini tests time delay at 0.001% level

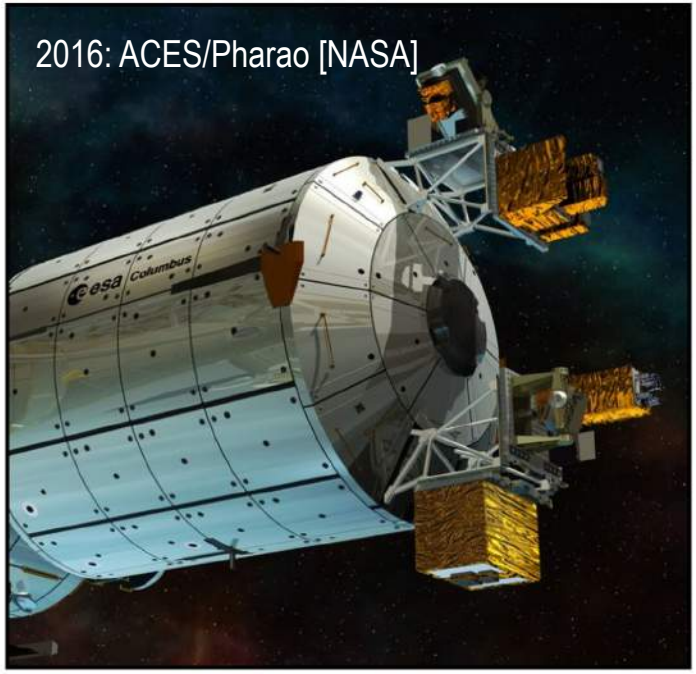

1971: Hafele & Keating
[TIME magazine]


Gravity probe A [NASA]

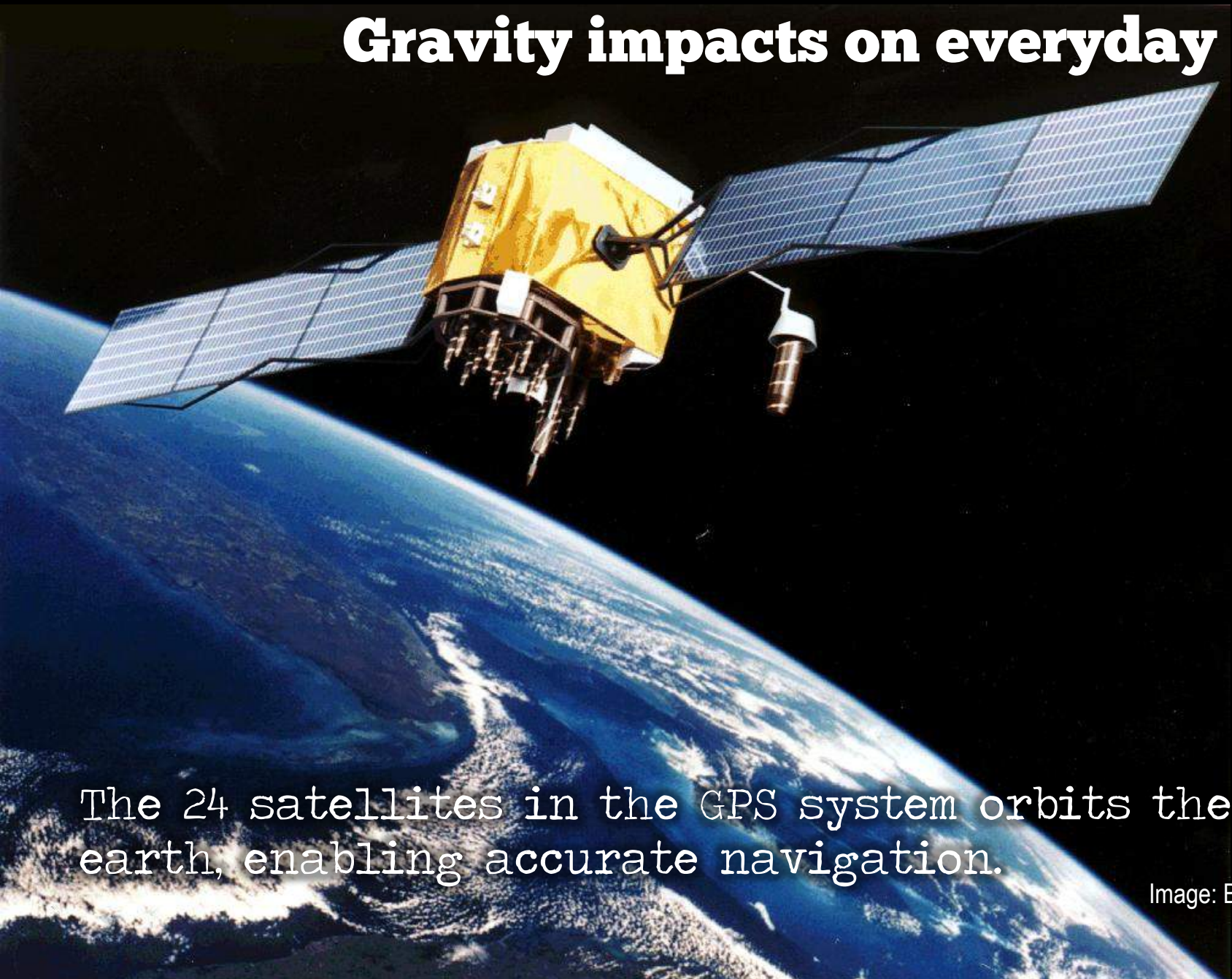

Gravity probe B [NASA]


N
$\vartheta_A - \vartheta$
Westwards flight
Earth's rotation
ϑ_A
$\vartheta_A + \vartheta$
Eastwards flight
S


GPA* EXPERIMENT PACKAGE
TRANSPONDER
DISSOCIATOR COOLING LOOP
-25 E SECTION
BATTERY
HYDROGEN MASER
SCOUT IV STAGE
DISTRIBUTOR
* GRAVITATIONAL PROBE A-REDSHIFT
MSFC-75-SS-G 1708E


2016: ACES/Pharao [NASA]
esa Columbus

Gravity impacts on everyday life



The 24 satellites in the GPS system orbits the earth, enabling accurate navigation.

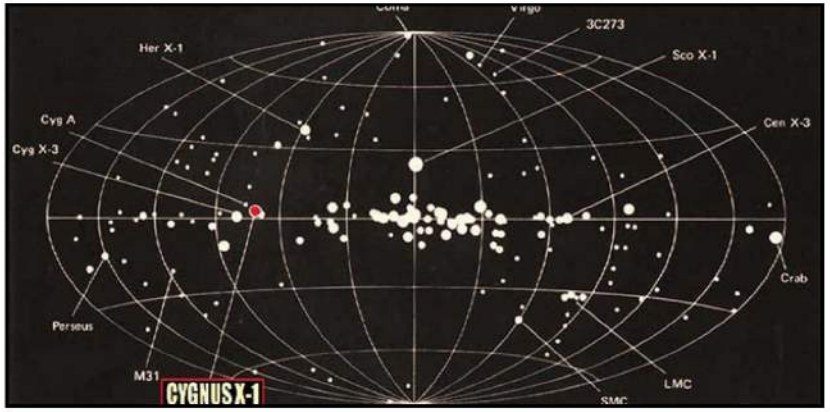
Image: Boeing

Gravity creates black holes

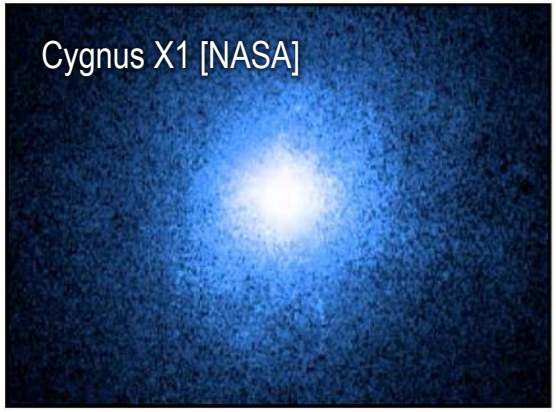
A massive star collapses forever while spacetime wraps around it like a dark cloak.

Image: Mark Garlick/Getty images

Uhuru satellite [NASA]

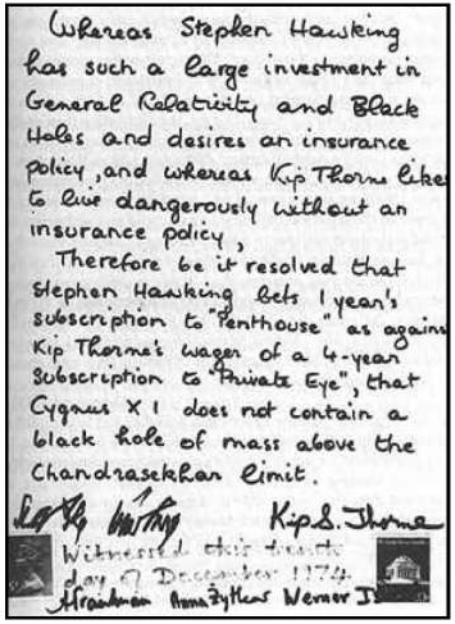


Cygnus X1 [NASA]



Artist's impression [NASA]

Black holes shine in x-rays as they devour binary partners.



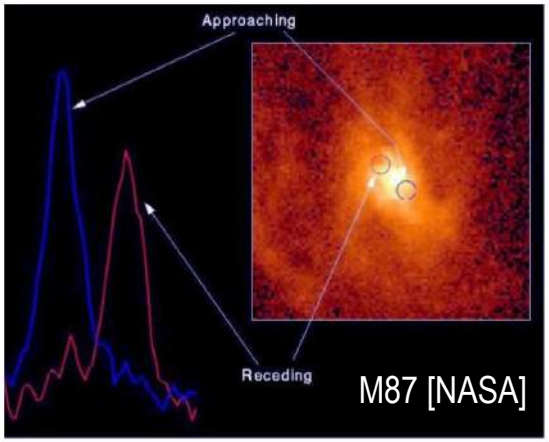
Whereas Stephen Hawking has such a large investment in General Relativity and Black Holes and desires an insurance policy, and whereas Kip Thorne likes to live dangerously without an insurance policy,

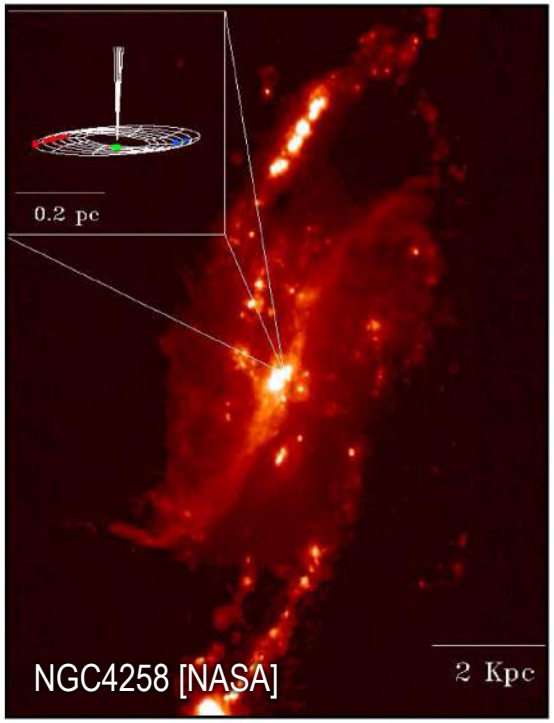
Therefore be it resolved that Stephen Hawking bets 1 year's subscription to "Penthouse" as against Kip Thorne's wager of a 4-year subscription to "Private Eye", that Cygnus X 1 does not contain a black hole of mass above the Chandrasekhar limit.

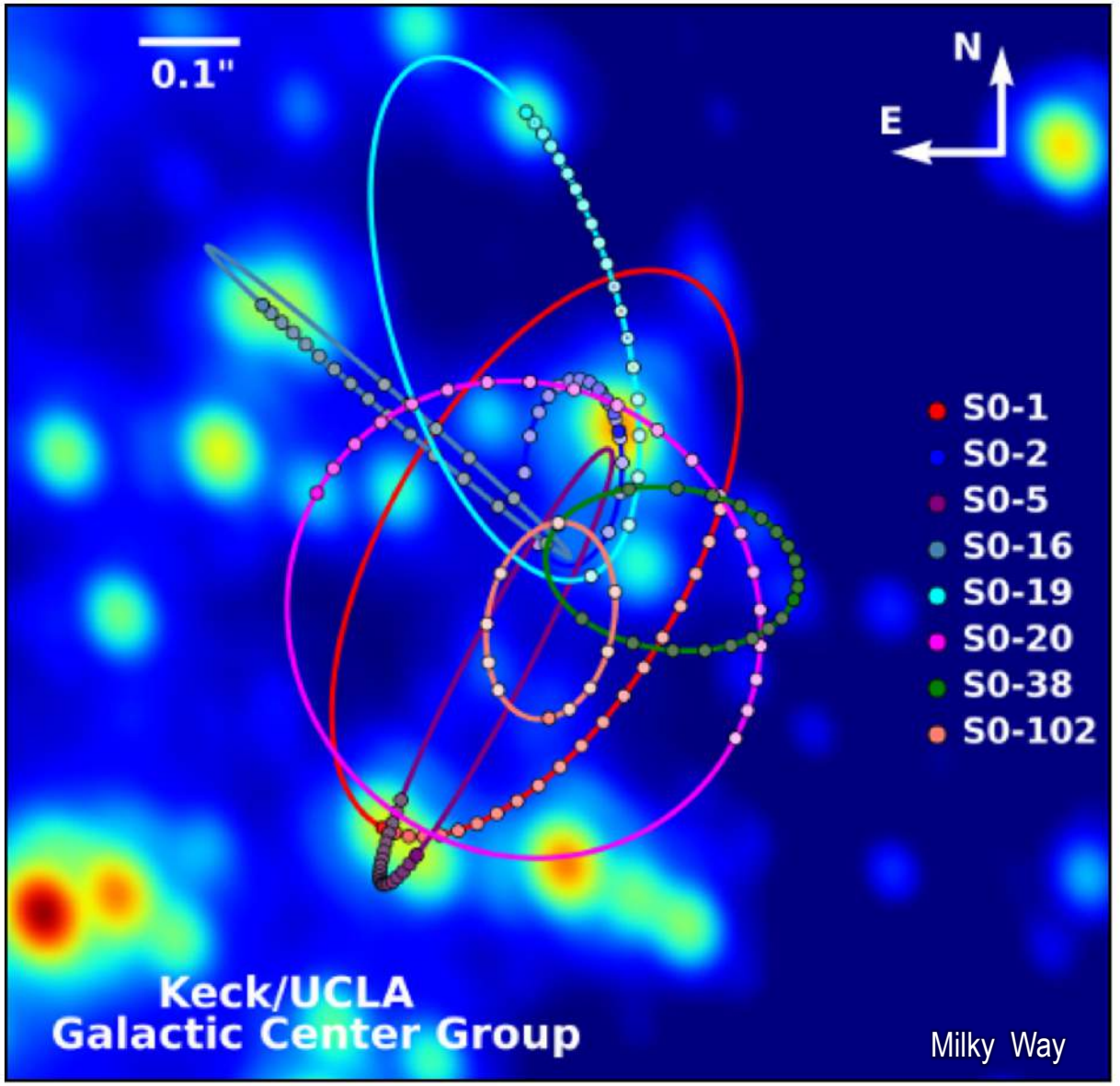
Kip S. Thorne

Witnessed this twenty-fifth day of December 1974

Werner Israel



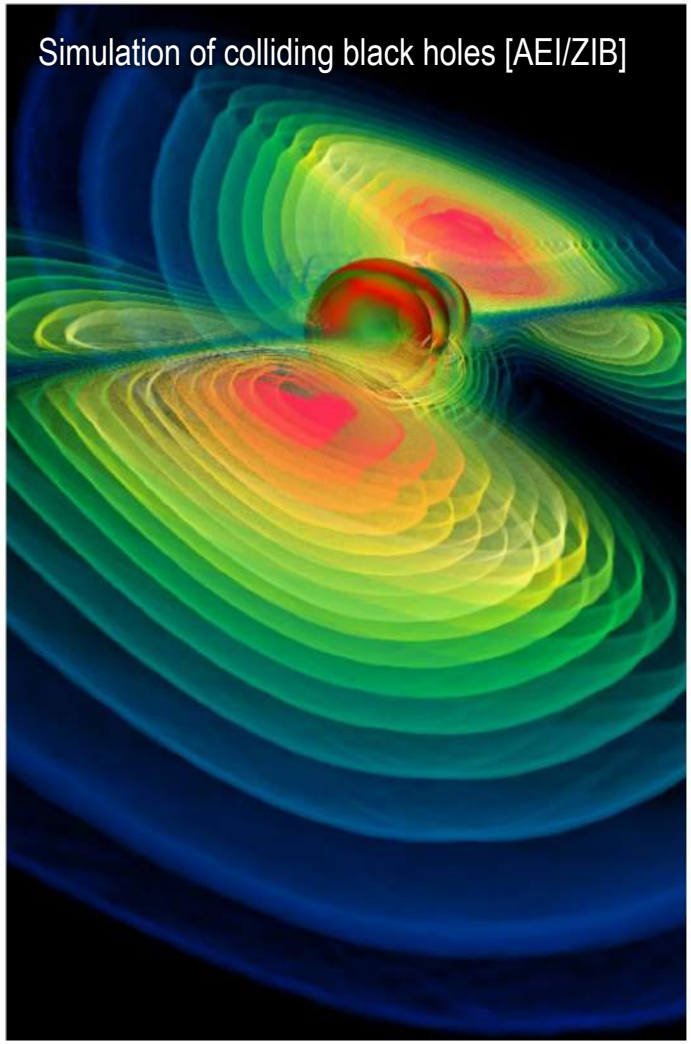




Massive black holes lurk at the centre of many galaxies, including our own Milky Way…

Gravity makes waves

Gravitational waves are generated
when massive bodies are accelerated.



Gravitational waves have proved elusive, but a new generation of detectors should soon catch them.

Gravity explains the cosmos

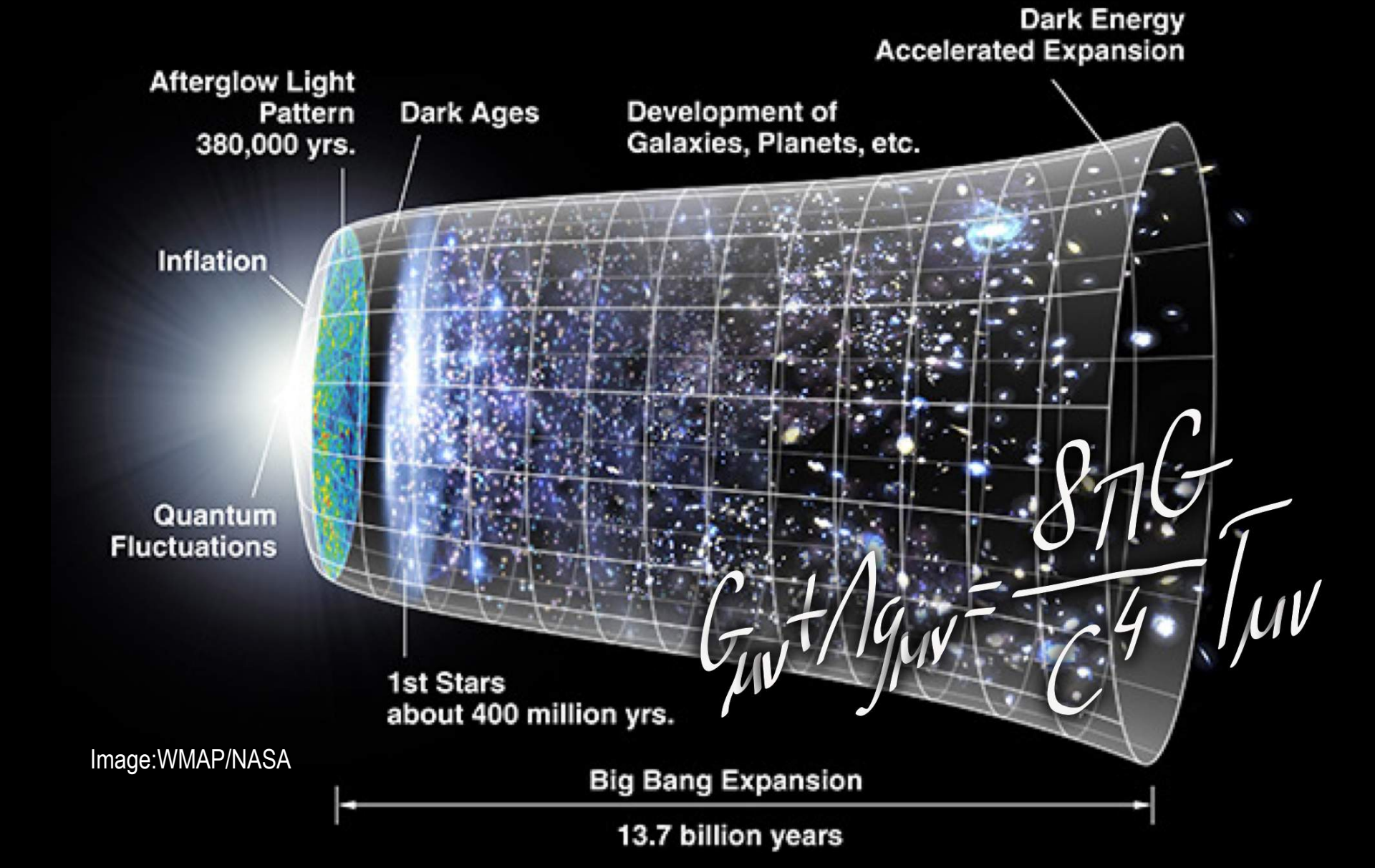
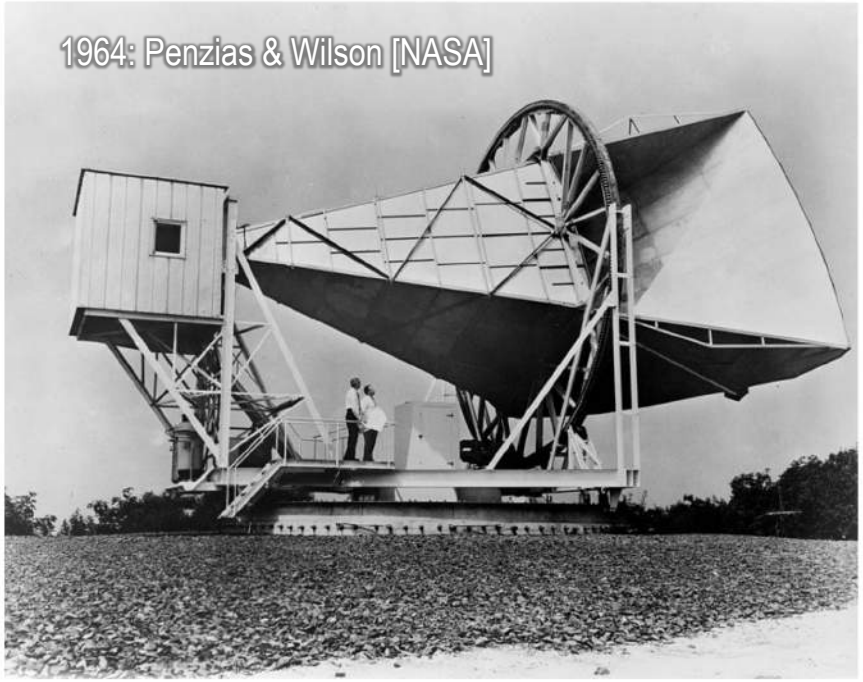


Image:WMAP/NASA



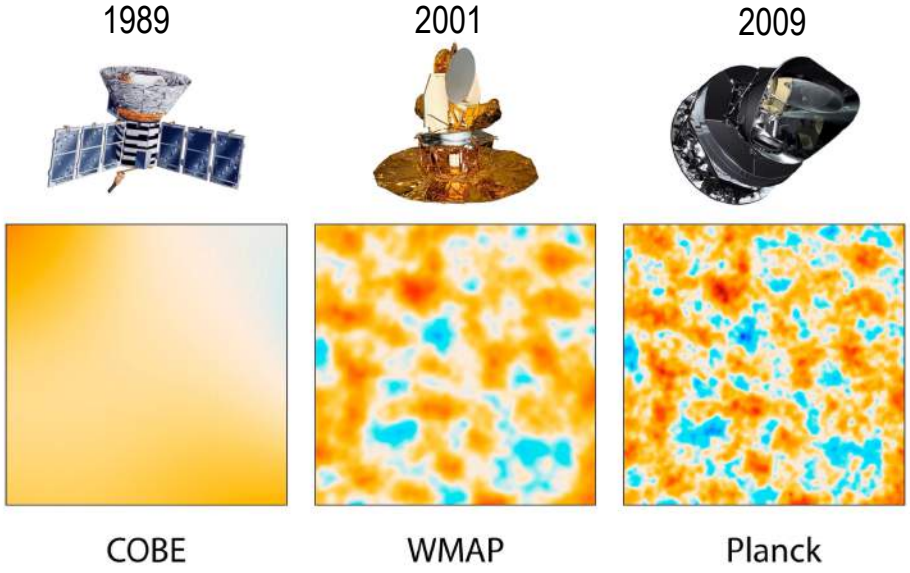


Image: NASA

2014

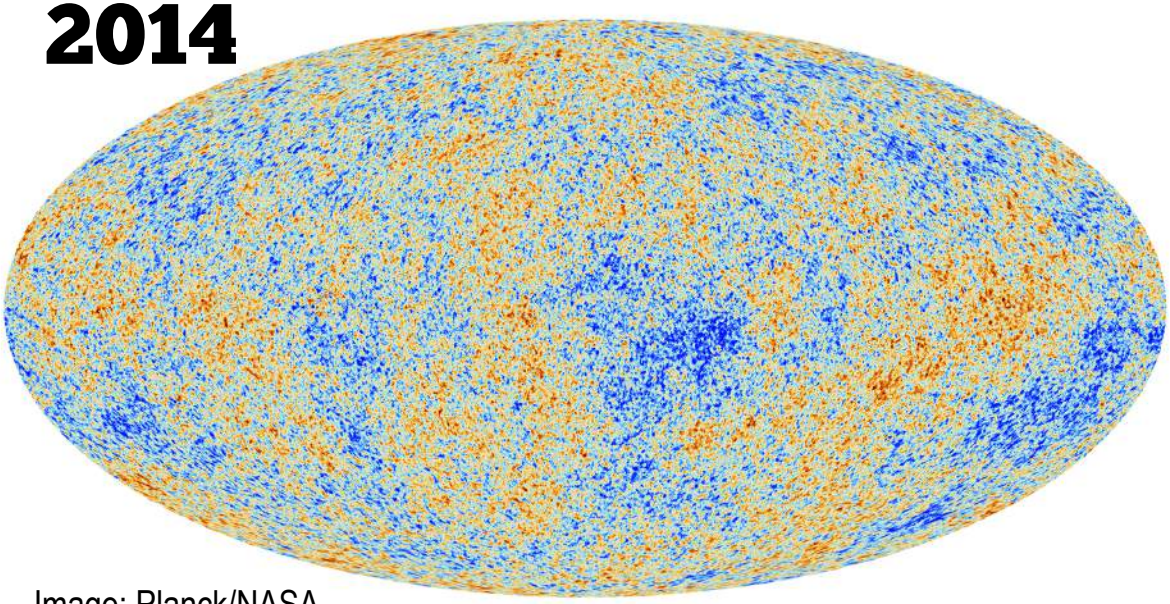


Image: Planck/NASA

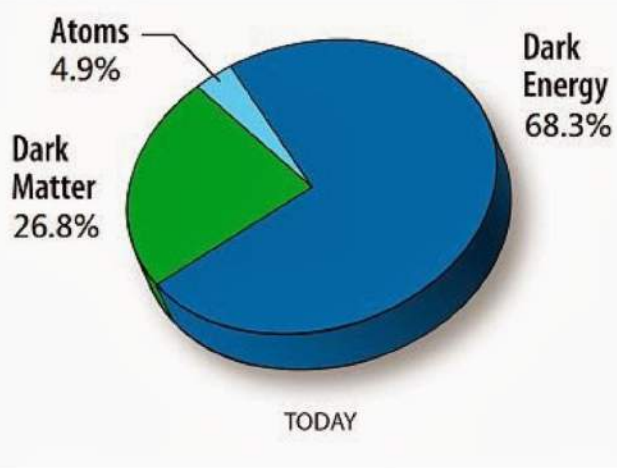


Image: Planck/NASA

2015

After 100 years of relativity

General Relativity has been tested in numerous ways - over a wide range of scales - always passing with flying colours.

The theory clearly explains what we see …

… but there are still questions:

- Are the black holes we see those of Einstein's theory?
- How do we understand the dark energy?
- Can we reconcile relativity with quantum theory?