Weighing the Universe

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Weight ≠ Mass
If you weigh 100 lb on Earth, you’d weigh:

- 17 lb on the moon
- 38 lb on Mercury
- 91 lb on Venus
- 38 lb on Mars
- 253 lb on Jupiter
- 107 lb on Saturn
- 91 lb on Uranus
- 114 lb on Neptune

Image credit: NASA
Newton and the apple tree

"The story was certainly true, but let's say it got better with the telling.”

Keith Moore, Head of Archives, Royal Society
Einstein’s spacetime continuum
"STARLIGHT BENT BY THE SUN'S ATTRACTION": THE EINSTEIN THEORY.

DRAWN BY W. E. ROBINSON, FROM MATERIAL SUPPLIED BY DR. CROMMELIN.

This Diagram shows the proportional Displacement of the Star in relation to the distance from the Sun. The amount of Displacement is exaggerated about 600 times.

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.

The Andromeda Galaxy (M31)

Newton Observations

Gravitation

Centrifugal
B R E A K I N G   N E W S!

96% UNIVERSE MISSING
What the Universe is made of:

- Dark Energy: ~ 73%
- Dark Matter: ~ 23%
- Normal matter (not giving out light)
- Normal matter that gives out light

95% of the Universe is dark!
1929

Hubble-Lemaître Law
The Expanding Universe… in Your Kitchen!
The left-over "heat" from the Big Bang:

−270.425 ºC

Signals Imply a ‘Big Bang’ Universe

By WALTER SULLIVAN

Scientists at the Bell Telephone Laboratories have observed what a group at Princeton University believes may be remnants of an explosion that gave birth to the universe.

These remnants are thought to have originated in the burst of light from that cataclysmic event.

Such a primordial explosion is embodied in the "big bang" theory of the universe. It seeks to explain the observation that virtually all distant galaxies are flying away from the earth. Their motion implies that they all originated at a single point 10 or 15 billion years ago.

The Bell observations, made by Drs. Arno A. Penzias and Robert W. Wilson from a hilltop in Holmdel, N. J., were of radio waves that appear to be flying in all directions through the universe. Since radio waves and light waves are identical, except for their wavelength, these are thought to be remnants of light waves from the primordial flash.

The waves were stretched into radio waves by the vast expansion of the universe that has occurred since the explosion and release of the waves from the expanding gas cloud born of the fireball.

In what may prove to be one of the most remarkable coincidences in scientific history, the existence of such waves was predicted at

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The fate of the Universe

Matter (visible+dark)

GRAVITY

Dark Energy

ANTI-GRAVITY

Decelerating Universes

Accelerating Universe
The end of the visible Universe

380,000 years after the Big Bang
Big Bang:
- $t = 0$
- Nucleosynthesis ($t = 3$ mins)
- Inflation ($t = 10^{-32}$ s, exponential)
- Radiation (decelerates)
- Dark matter (decelerates)
- Dark energy (accelerates)

End of the visible cosmos:
- $t = 380,000$ yrs

Events:
- $t = 380,000$ yrs
- $t = 3.8$ Bn yrs
- $t = 13.7$ Bn yrs

Time:
- $t = 10^{-32}$ s
- $t = 3$ mins
- $t = 380,000$ yrs
How old is the Universe?

Age = 13.798 billion years*

*(give or take 29 million years)
Seeing cosmic sound

Credit: Daniel Eisenstein
An ant’s perspective:

Flat (Euclidean)  Closed (spherical)  Open (hyperbolic)
The Geometry of the Universe

The three different possible geometries of the Universe.

Ref: Schneider (2006)
Einstein:

Geometry = Energy + Matter

- **Sum > 1**
  - Closed Universe
  - Big Crunch
  - Finite Universe

- **Sum = 1**
  - Flat Universe
  - Borderline Universe
  - Infinite

- **Sum < 1**
  - Open Universe
  - Sub-critical Universe
  - Infinite
Weighing the Universe

\[ \Omega_K = 0.0005 \pm 0.0060 \]

In a flat universe, this quantity would be exactly 0 equal to 0.
Quantum Fluctuations

- Relic Radiation: 380,000 years
- Dark Ages: 1 billion years
- First Stars: a few billion years
- Galaxy Formation: 13.7 billion years
- Today:
Average mass density of the Universe:

0.000 000 000 000 000 000 000 000 000 000 000 003 837 g/cm$^3$
The most amazing discoveries are still ahead of us.

THANK YOU!

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