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Albert Einstein
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Special relativity
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General relativity
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Cosmology
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Summary
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Einstein's theory of relativity

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UCL Institute of Origins

Origins

UCL has established the Institute of Origins to promote world leading research in topics related to the Origins and Evolution of the Universe. Our research themes are:

- ▶ Galaxy Evolution
- ▶ Mathematical Foundations
- ▶ Neutrino physics
- ▶ Planetary Science

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- ▶ **Albert Einstein**
    - ▶ 1905 Einstein's "Wonderful Year"
    - ▶ 1915 General relativity
- ▶ Special relativity
    - ▶ the twin problem
    - ▶ mass-energy equivalence
- ▶ General relativity
    - ▶ matter and curvature
    - ▶ black holes and wormholes
- ▶ Cosmology
    - ▶ from the big bang to today
    - ▶ dark matter, dark energy and all that

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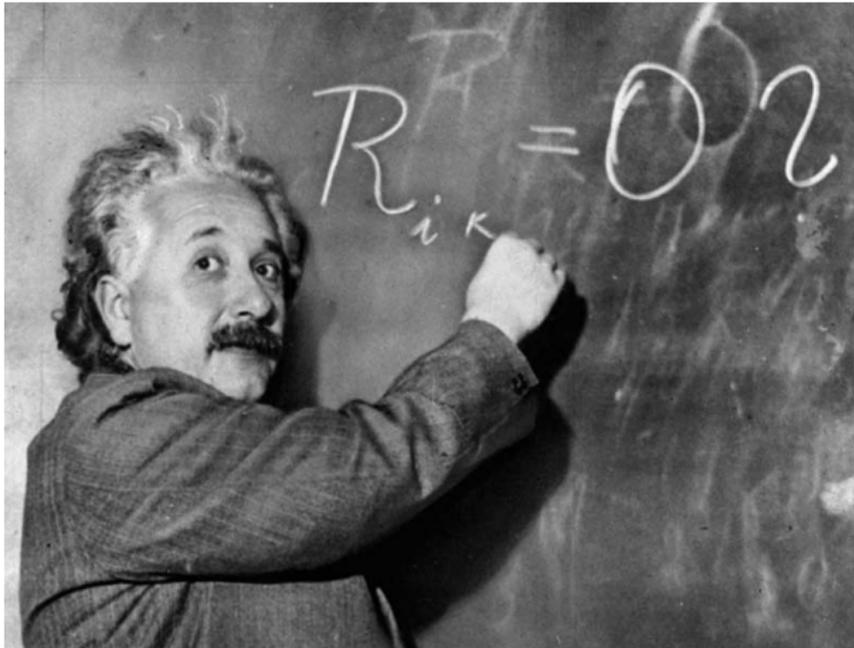○● | ○○○○ | ○○○○○○○○ | ○○○○○ | ○○○○○○○○ | ○

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Albert Einstein

Albert Einstein (1879 – 1955)

1905 – Annus Mirabilis

▶ particulate nature of light – photoelectric effect

▶ Brownian motion – confirming atomic theory

▶ electrodynamics of moving bodies – special relativity

▶ mass-energy equivalence – $E = mc^2$

Overview   **Albert Einstein**   Special relativity   General relativity   Cosmology   Summary
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1915 – General relativity

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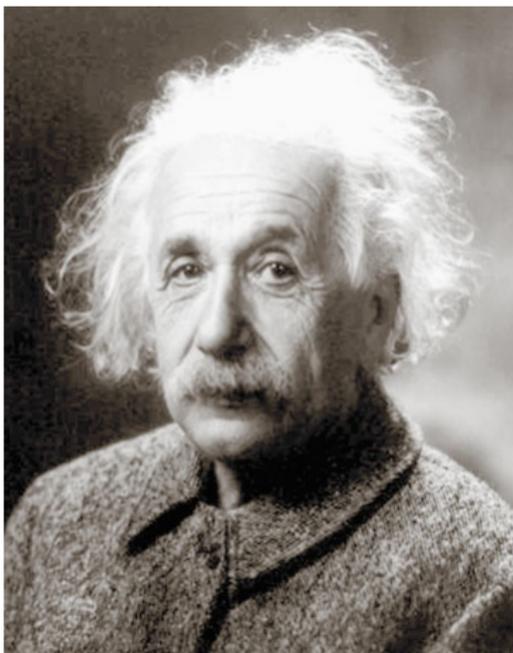Albert Einstein

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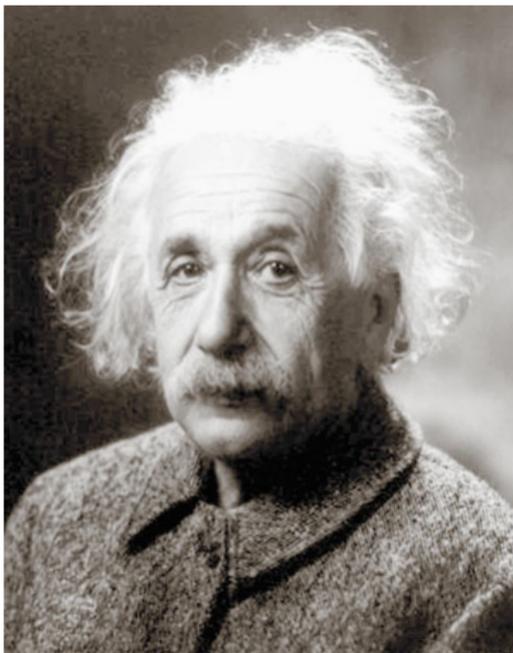- ▶ $R_{ab} - \frac{1}{2} R g_{ab} = 8\pi T_{ab}$

Albert Einstein 1947

Latter years

▶ Einstein refuses Quantum Theory

▶ subsequently refuses Quantum Field Theory

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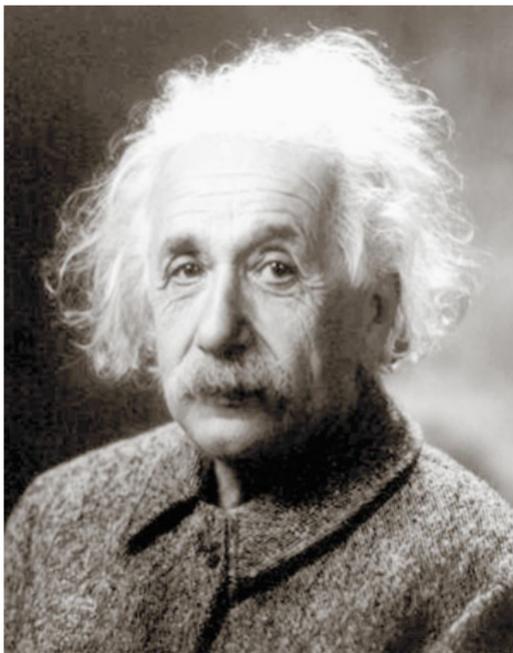- ▶ subsequently refuses Quantum Field Theory
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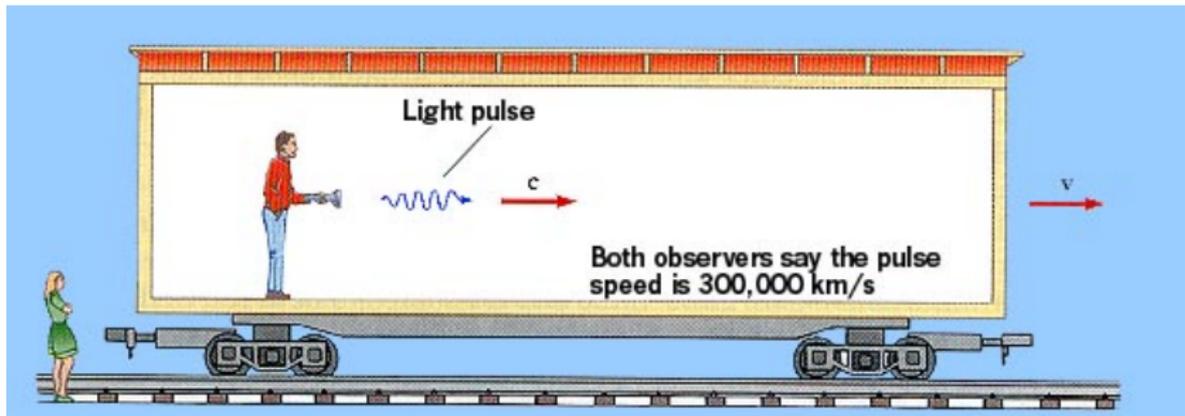- ▶ subsequently refuses Quantum Field Theory
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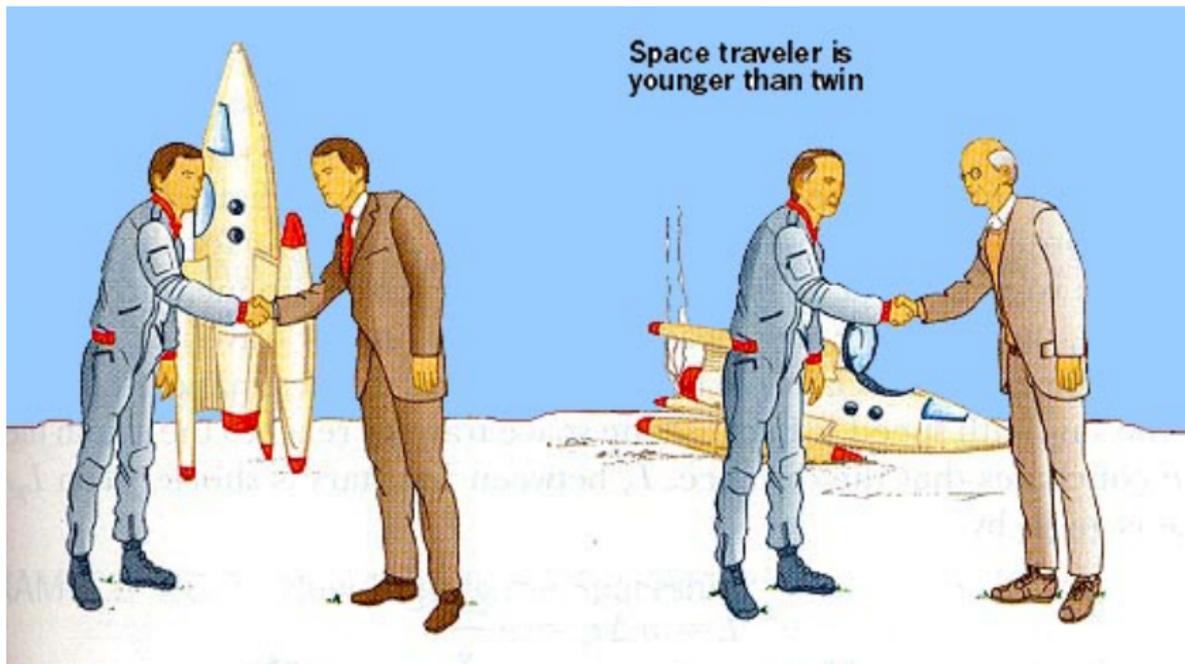Overview Albert Einstein **Special relativity** General relativity Cosmology Summary
oo   oooo   ●ooooooo   ooooo   oooooooo   o
Special relativity

Speed of light in vacuum same in all inertial systems

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Special relativity

The twin problem: an apparent paradox

Space traveler is younger than twin

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Special relativity

Time dilation in special relativity

Time dilation

$$\frac{\Delta t'}{\Delta t} = \frac{1}{\sqrt{1 - v^2/c^2}}$$

- ▶ $\Delta t'$: time interval as measured by a moving observer
- ▶ v: the observer's velocity; c: denotes the speed of light
- ▶ Δt: time interval as measured by an observer at rest
- ▶ $1/\sqrt{}$-term is often called Lorentz factor

Time dilation – how does it effect us?

Time dilation
The speed of light is about $c \approx 299792458$ meters per second.
Let's compare this with the following velocities:

- ▶ speeding car at 100 mph (160 kmh or 44 meter per second)

- ▶ super sonic jet 1000 mph (1600 kmh or 444 meters per second)

- ▶ space shuttle 18000 mph (28800 kms or 8000 meter per second)

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Time dilation – how does it effect us?

Let's have a look at the numbers

$$\left(\frac{\Delta t'}{\Delta t}\right)_{\mathrm{car}} = 1.00000000000001$$

$$\left(\frac{\Delta t'}{\Delta t}\right)_{\mathrm{jet}} = 1.00000000000109$$

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Conclusion
Special relativity does not effect our everyday life!

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Special relativity

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Special relativity

Time travel – what can be done?

Into the future

The theory of special relativity, in principle, allows travelling into the future.

Into the past

Travelling into the past does not seem to work, unless time bends into, say, a circle.

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Special relativity

Mass-energy equivalence

▶ when a flashlight emits light, it loses mass

▶ when a flower absorbs sunlight, its mass increases

▶ when a uranium nucleus splits, the mass of the remnants is less than the original mass. The difference appears as light, heat, and kinetic energy

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Special relativity

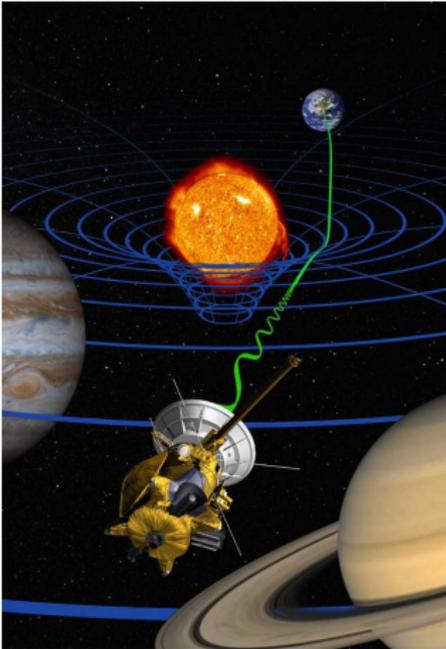# Mass-energy equivalence

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Special relativity

Nuclear explosion

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Matter and the curvature of spacetime
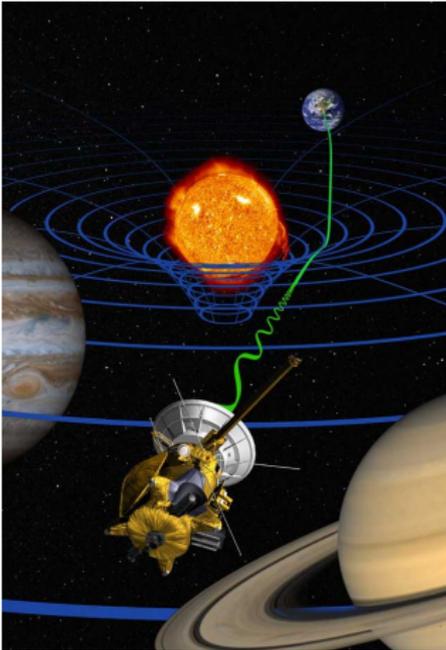

General relativity

- field equations
  $R_{ab} - \frac{1}{2}Rg_{ab} = 8\pi T_{ab}$

- properties of spacetime $=$
  properties of matter

- matter tells spacetime how to curve
  and

- spacetime tells matter how to move

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Curved spacetime
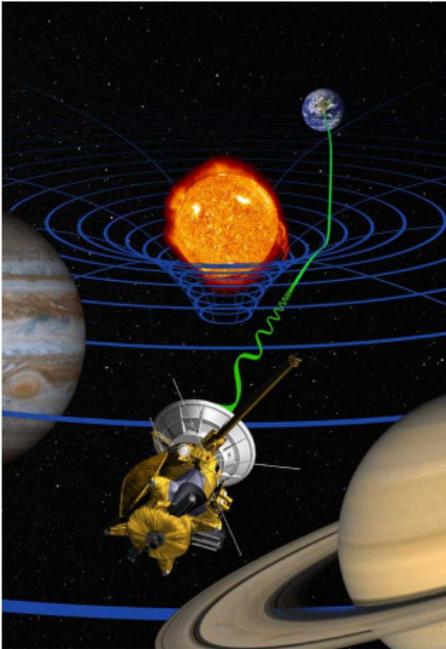
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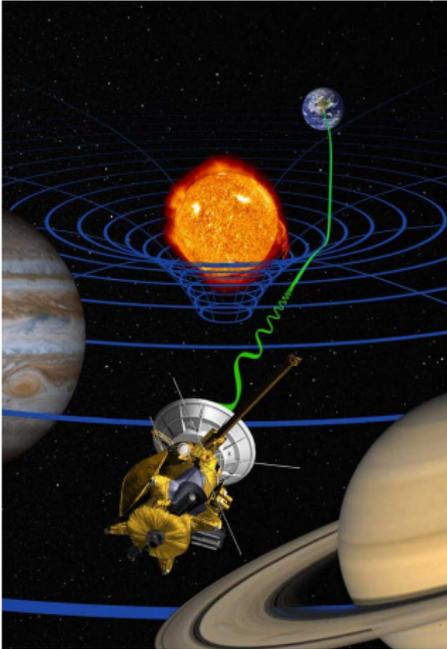

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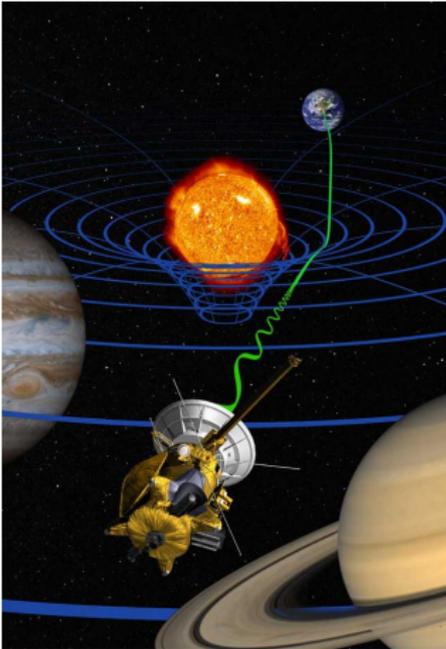- ▶ spacetime tells matter how to move

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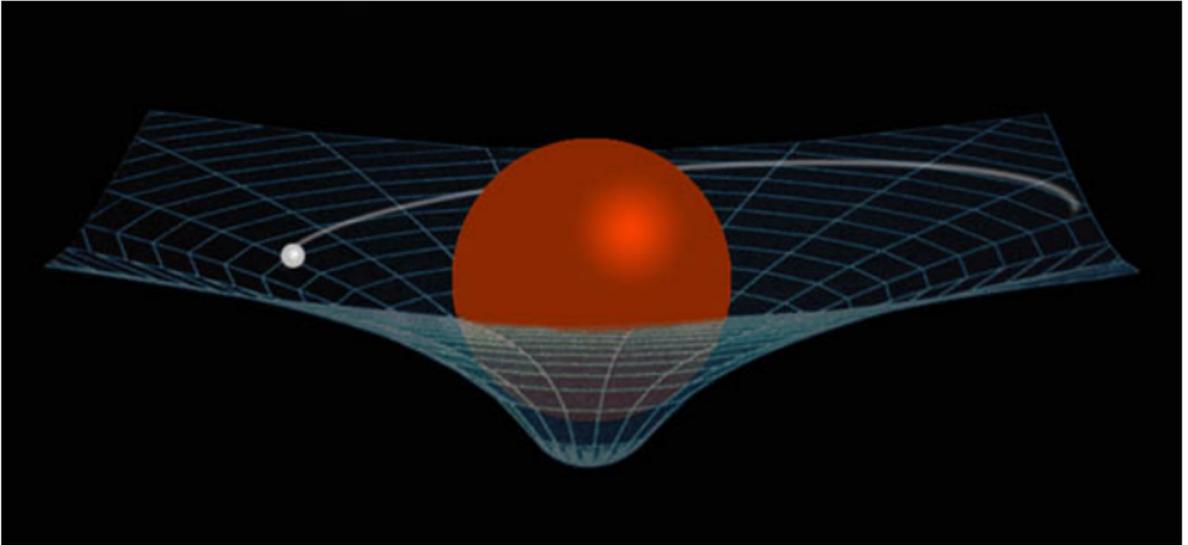
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Curved spacetime

The motion of a particle in spacetime

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Curved spacetime

Black holes

Are black holes black?

▶ black holes are such dense
  object that not even light
  can escape their
  gravitation attraction

▶ since they also attract
  other kind of matter, it is
  typically very hot near a
  black hole

▶ while the black hole
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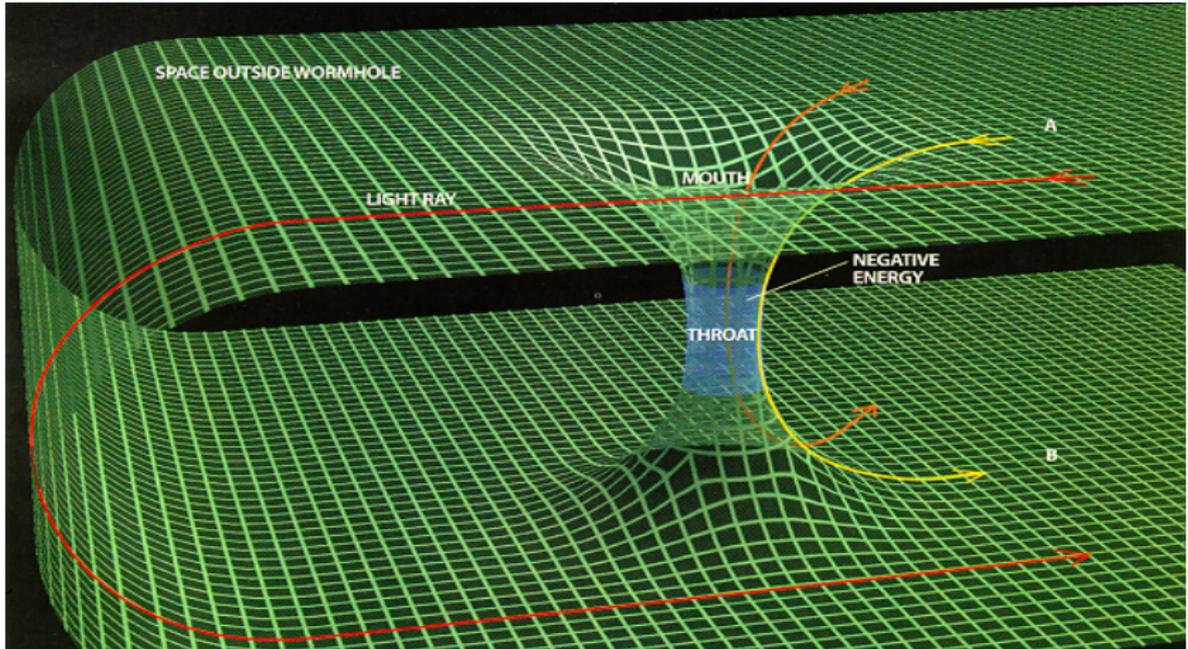▶ while the black hole indeed absorbs light, its vicinity is bright

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Black holes – a realistic image

Galactic centres
A black hole may be observed by tracking the movement of a group of stars that orbit its centre.

Wormholes in general relativity

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Cosmology

Cosmology

What does cosmology mean?

- ▶ cosmology ($\kappa o \sigma \mu o \lambda o \gamma \iota \alpha$) – cosmos and logic
- ▶ $\kappa o \sigma \mu o \zeta$ – a cosmos is an orderly or harmonious system
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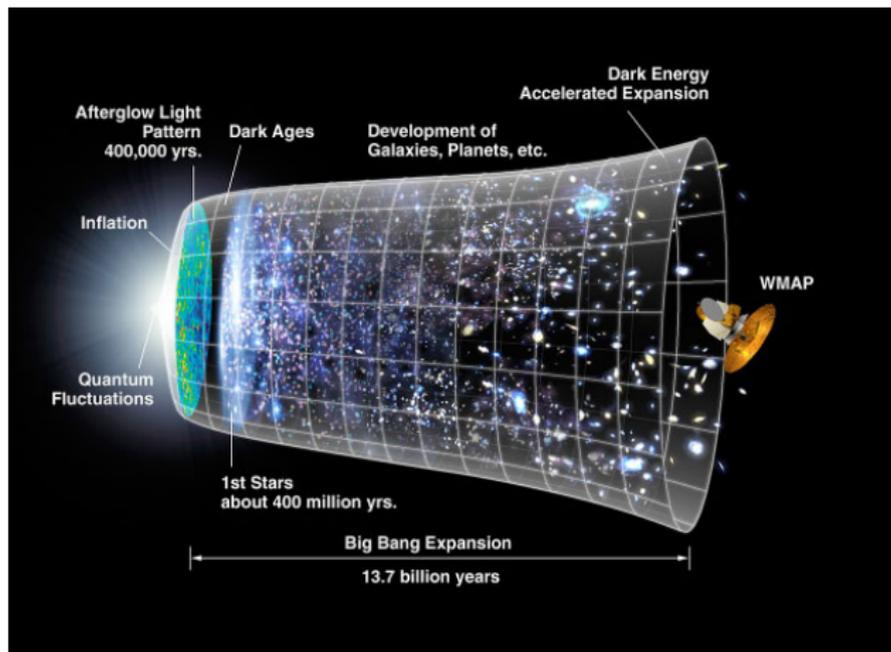
Cosmology

What does cosmology mean?

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Cosmology

Cosmology

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Beyond the big bang

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Cosmology

Afterglow light pattern – the cosmic microwave background radiation

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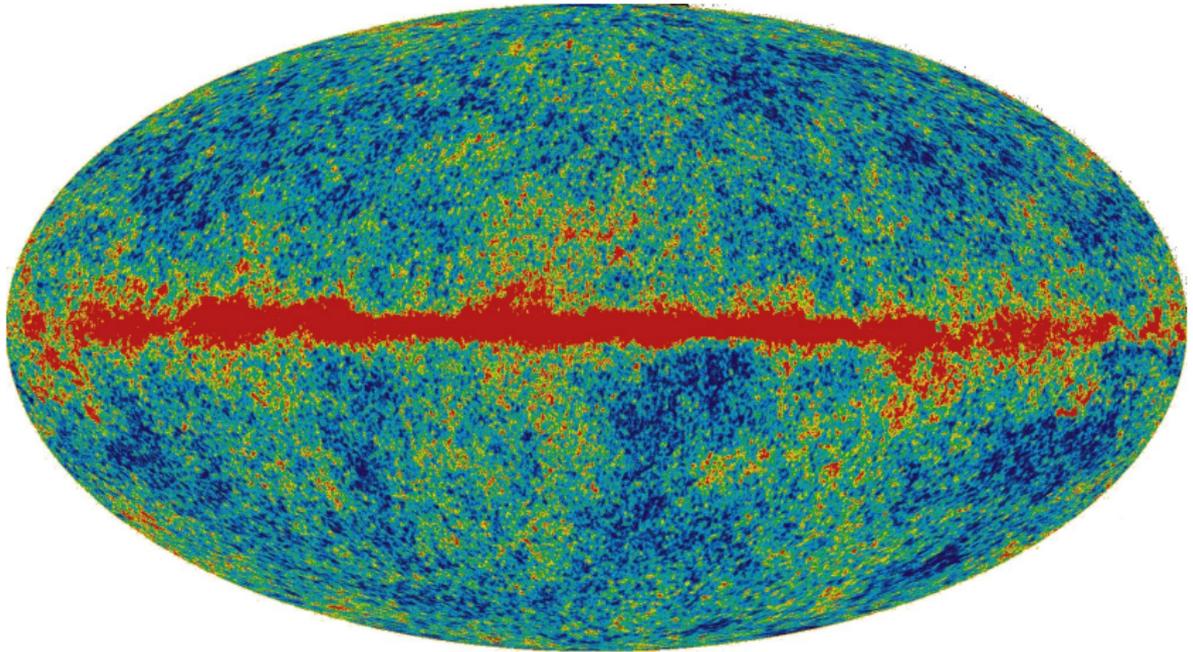
Cosmology

The energy content of our Universe

Dark matter

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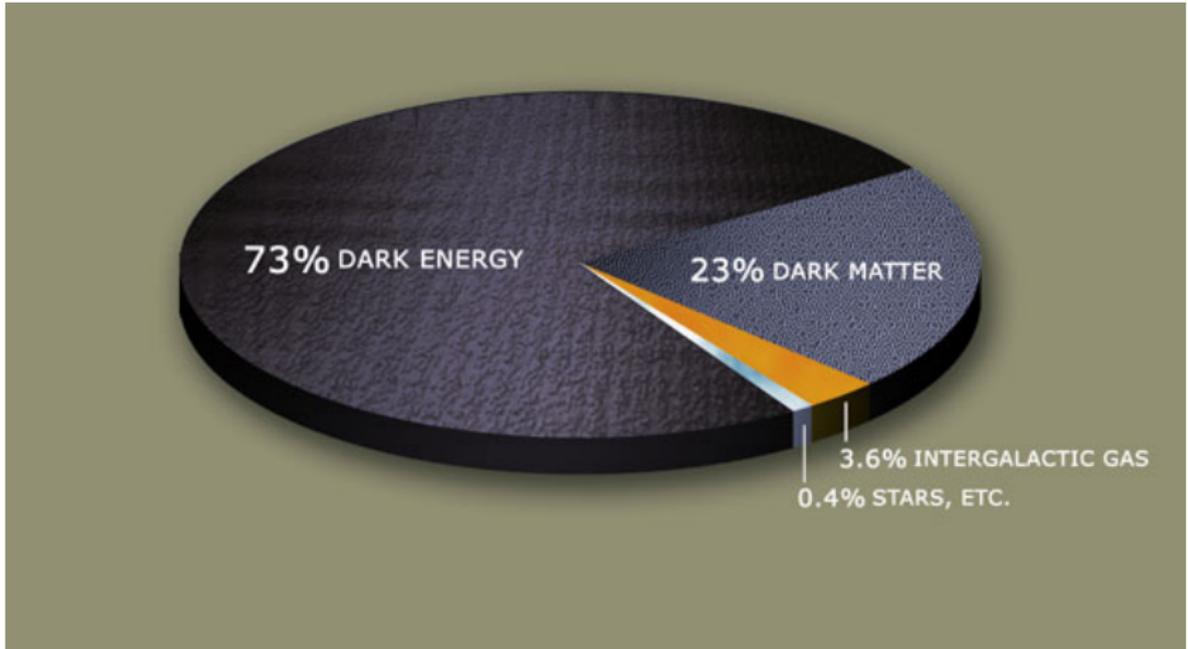
What dark energy is not!

What dark energy could be – the cosmological constant

The cosmological field equations of general relativity

$$R_{ab} - \frac{1}{2}Rg_{ab} + \Lambda g_{ab} = 8\pi T_{ab}$$

properties of spacetime + a cosmological constant = matter

The field equations with cosmological matter

$$R_{ab} - \frac{1}{2}Rg_{ab} = 8\pi T_{ab} - \Lambda g_{ab}$$

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Christian G. Böhmer   University College London

Einstein's theory of relativity

What dark energy could be – the cosmological constant

The cosmological field equations of general relativity

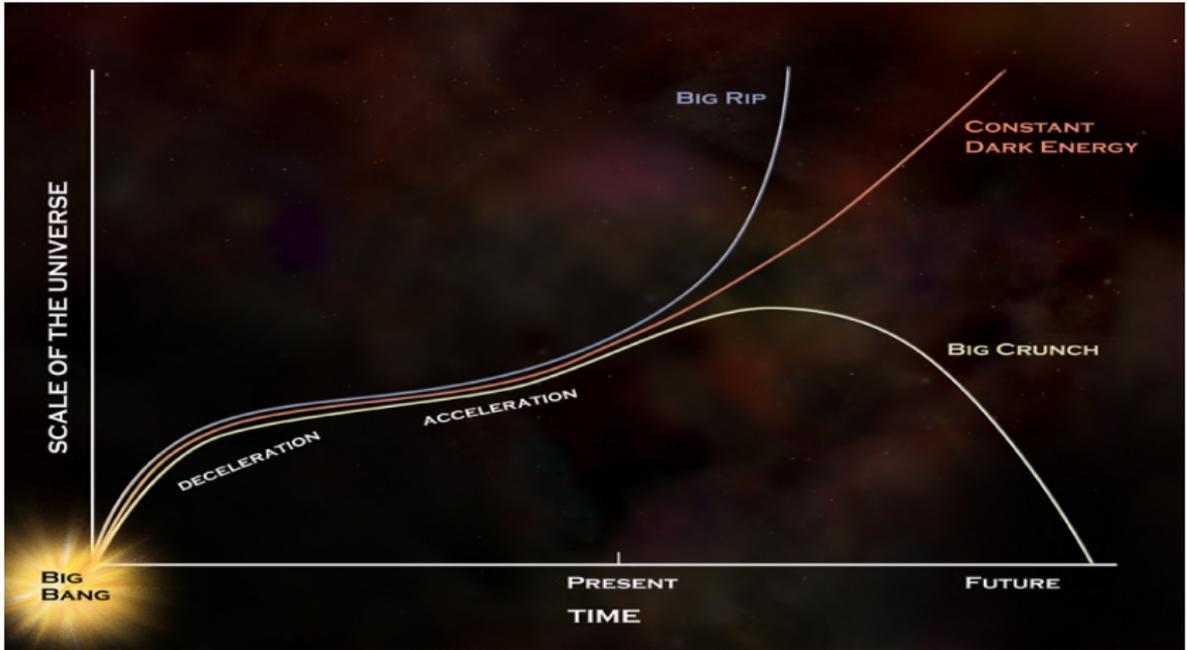$$R_{ab} - \frac{1}{2}Rg_{ab} + \Lambda g_{ab} = 8\pi T_{ab}$$

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Possible future of the Universe

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Summary

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- ▶ Special relativity and general relativity are fascinating subject areas.

- ▶ Special relativity is full of paradoxes that can be solved.

- ▶ General relativity is more or less understood.

- ▶ Cosmology is about 96% non-understood.

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Albert Einstein
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Overview
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