

# GENERAL RELATIVITY

## from A to Z

**Clocks** will "tick tock" at different rates if experiencing different gravities – one of the fundamentally counter-intuitive notions of general relativity (and plot points of *Interstellar*).

**Dark matter**, the not-yet-fully understood stuff believed to permeate the universe, reveals itself through its gravitational effects on the cosmos.

**Albert Einstein** presented his field equations to the Prussian Academy of Science in November 1915, sparking the general relativity revolution.

**Black holes** are predicted by the tenet of general relativity that says a sufficiently compact mass will radically transform spacetime.

**Gravity** was the missing factor of Einstein's earlier theory of special relativity. It took a decade for him to explain how gravitational effects between masses warp spacetime.

**Hubble Space Telescope** snapped an image in March 2015 that shows four points of light emanating from a distant supernova. The spots – known as an Einstein cross – provide visual confirmation of general relativity's predictions about the gravitational bending of light.

**$E=mc^2$** , the most iconic equation of all time, states that mass and energy are equivalent. It follows directly from Einstein's special relativity, which became a crucial subset of what is considered his masterpiece, general relativity.

**Frame dragging** is the idea that spacetime is elastic, and particles in it will exchange energy. That means spacetime will absorb some of the energy of a spinning particle. Research has shown that Earth is "dragging" spacetime around it as it rotates.

**Kip Thorne**, one of the world's leading experts on general relativity, was the scientific consultant for the movie *Interstellar*, which depicts astronauts aging at drastically different rates due to relativistic time dilation around a black hole.

**LIGO**, the Laser Interferometer Gravitational-Wave Observatory, is on the hunt for gravitational waves, one of general relativity's unobserved predictions. This year, the upgraded Advanced LIGO comes online and is hoped to finally get the goods.

**Imagination**, in Einstein's own words, "is more important than knowledge." Truly pioneering breakthroughs like general relativity don't often happen without a lot of it.

**Jets** come in two forms in physics. Particle jets (sprays of subatomic particles released in high-energy collisions) are dictated by special relativity, while general relativity governs astrophysical jets (surges of matter spewed from black holes and accretion discs).

**Orbits** Mercury's orbit deviates from the predictions of Newtonian physics, but Einstein's general relativity explained it without any so-called "fudge factors."

**Pioneer anomaly** When the Pioneer space probe started to slow down, it was thought Einstein's general relativity calculations might be incorrect. In fact, heat from the probe itself caused it to decelerate.

**Mathematics** Curved "non-Euclidean" geometry had been debated for centuries, but it wasn't until the 1800s that it was taken seriously. It remained simply a mathematical idea until general relativity gave it real-world application.

**Navigation** via GPS would be impossible (or extremely unreliable) if not for the nanosecond precision of satellite signals that factor in the effects of special and general relativity.

**Spacetime**, the interwoven continuum of (you guessed it) space and time, "tells matter how to move," while "matter tells spacetime how to curve," according to John Archibald Wheeler's snappy summary of Einstein's general relativity.

**T**ry, try again: Einstein often reworked previous papers, and in November 1915, he wrote four separate papers – one a week. The fourth finally computed the perihelion of Mercury's orbit correctly.

**Quantum mechanics**, the other great pillar of modern physics, doesn't quite jibe with general relativity. Their unification is considered a Holy Grail of theoretical physics.

**T**roof Einstein saw a man fall from a nearby roof onto a pile of soft rubbish. The man later said he felt no sensation of gravity while falling. That conversation, and subsequent research, led Einstein to reconsider Newtonian gravity.

**Wormholes** – predicted by general relativity equations – could create shortcuts between different places in the universe, and, some theorize, between different times.

**X-ray astronomy** looks deeper into space than typical light-absorption telescope astronomy, and is ideal for probing areas of extreme gravity, such as neutron stars and black holes.

**Unified field theory** is a term coined by Einstein to describe his fruitless attempt to combine general relativity and electromagnetism. It now broadly denotes the goal of describing all elementary particles and fundamental forces in terms of a single field (i.e. a theory of everything).

**V**erification Astronomer Arthur Eddington went to Principe, a West African island, to observe the deflection of sunlight during a solar eclipse in 1919. The measurements matched Einstein's predictions of relativity, and made Einstein a star.

**Y**outh is the time Einstein considered most fertile for discovery. He wrote: "Truly novel inventions emerge only in one's youth. Later one becomes ever more experienced, famous – and foolish."

**Z**ee, Anthony His book *Einstein Gravity in a Nutshell* opens with the lovely line: "Relativity is all about the notion that you are as good as the next guy, or to put it relatively, the other guy is as good as you."