

Einstein's Theory of General Relativity — is: MORE PYTHAGORAS!

Cartesian: $ds^2 = dx^2 + dy^2 + dz^2 - dt^2$ an option → Spherical-polar: $ds^2 = dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2 - dt^2$
GR needs *more than* numbers! **GR** needs new mathematical entities that are SQUARE ARRAYS of numbers:

$$g_{\nu}^{\mu} = \begin{pmatrix} g_1^1 & g_1^2 & g_1^3 & g_1^4 \\ g_2^1 & g_2^2 & g_2^3 & g_2^4 \\ g_3^1 & g_3^2 & g_3^3 & g_3^4 \\ g_4^1 & g_4^2 & g_4^3 & g_4^4 \end{pmatrix} = e.g., \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

General Relativity is $4 \times 4 = 16$ coupled equations.
GR gives us **Cosmology**: **1** is Newton's gravitation; the three 1's are Pressure. (AND, **GR** gives us **Black Holes**)

Einstein's **idea** was that **Newton's Law of Universal Gravitation** might be a result of spacetime being **curved** (*somehow!*) by the presence of masses *e.g.* the **Sun**—resulting in Earth **circling** the Sun. The great man created **GR** in 1916, in wartime Germany. Here it is:

$$\text{spacetime-curvature} \rightarrow R_{\nu}^{\mu} - \frac{1}{2} g_{\nu}^{\mu} R (+ g_{\nu}^{\mu} \Lambda) = \frac{8\pi G}{c^4} T_{\nu}^{\mu} \leftarrow \text{Mass \& Energy}$$

Mass & Energy is conserved: its derivative is zero. Observations today say we must *add in* a constant: Λ
spacetime-curvature $R_{\nu}^{\mu} - \frac{1}{2} g_{\nu}^{\mu} R$ is *also* conserved (in the same sense) ← took Einstein **work** to find it!

Λ *NOW* dominates **cosmology**: a length ℓ of *space-itself* is **exploding** (*even as you read this*): $\ell(t) \propto e^{\sqrt{\frac{\Lambda}{3}}t}$
 Einstein himself was **never** able to find **even one-single-solution** for those famous Field Equations! He **DID** *calculate manually* what they predicted for the precession of the planet Mercury: **and it agreed with observation!** **and:** it did **not** agree with the **Newtonian prediction!** Einstein had heart palpitations for a week! He *published!* His greatest triumph!
 Einstein's 1915 paper was in a German physics journal—which arrived at a German soldier, **Karl Schwarzschild**, on the Eastern Front. (I knew Karl's son!) And, Karl **found** a solution!

THIS is the famous Schwarzschild Solution:

$$ds^2 = + g_1^1 \frac{dr^2}{\left(1 - \frac{2m}{r}\right)} + g_2^2 r^2 d\theta^2 + g_3^3 r^2 \sin^2\theta d\phi^2 - g_4^4 \left(1 - \frac{2m}{r}\right) dt^2$$

— **CURVED PYTHAGORAS!** —

Karl's solution is for the case of a SINGLE POINT-MASS causing the curvature. In 1917, the idea of **huge point masses** was ridiculous—but white dwarf stars were found, and then neutron stars were found ... and then, at last, **black holes were found**. The galaxy M87 has, in its center, a **point mass** of **6 billion** solar masses! **Empty** spacetime, around that point!

r is *your distance from* the **point mass**. For a 20-solar-mass black hole, $m = \sim 20$ miles. Now, notice **what happens** as you **fall in**: when the moment comes that **r** falls to **40** miles, the first term (+) **changes over to TIME (-)** but, is, nevertheless, still — your *fall-direction!*
Why can't you get out of the black hole? **It's only because you cannot go back in TIME!**

The possibility of Black Holes in our universe was predicted :
 by **Pythagoras**, Albert Einstein, and Karl Schwarzschild!

Our **discovery** of **black holes** **proves** that our **universe** runs on ... **SIMPLE mathematics!**