



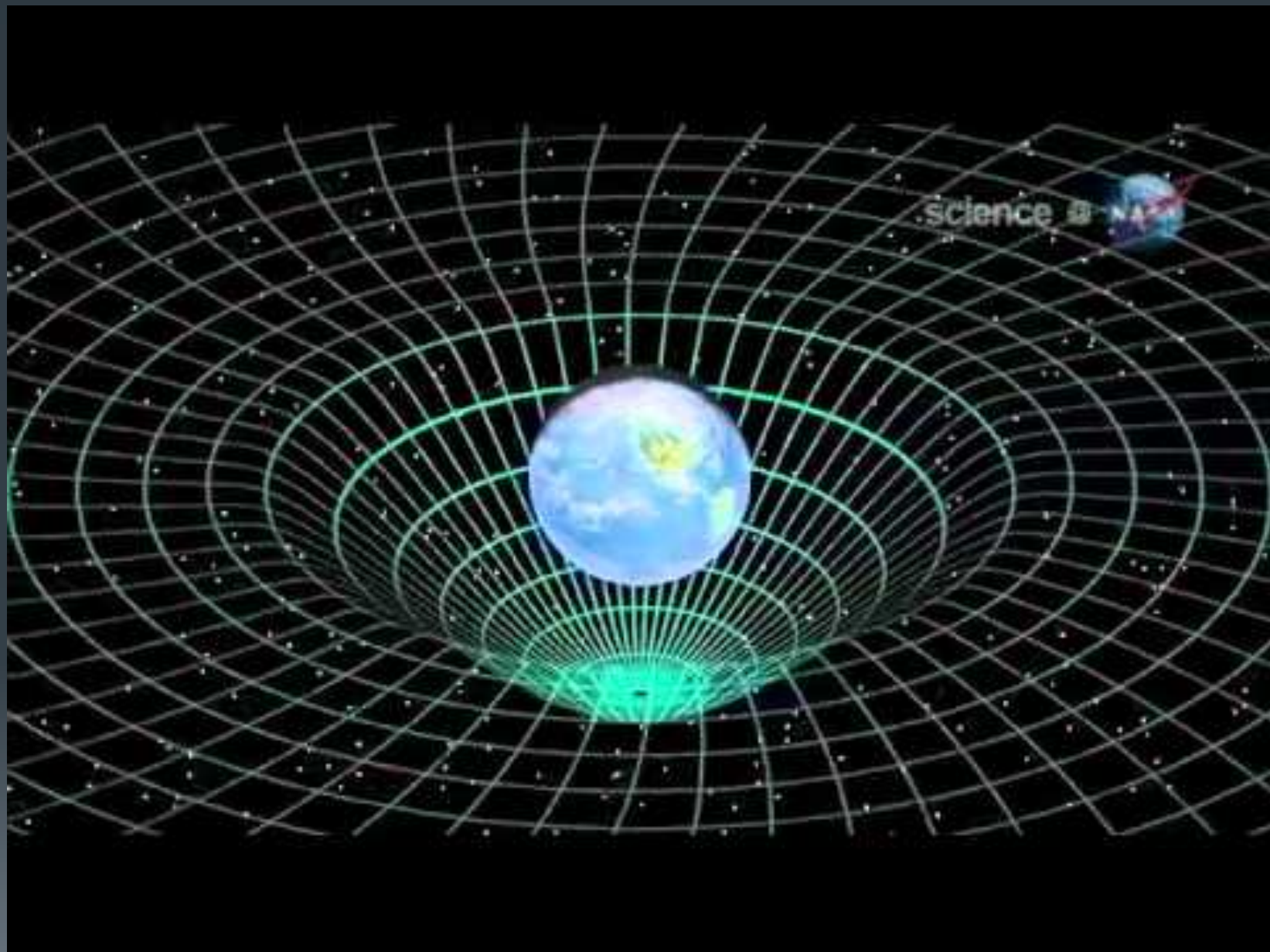
# EINSTEIN FIELD EQUATIONS (EFE)

Einstein's greatest achievement



# The Equation

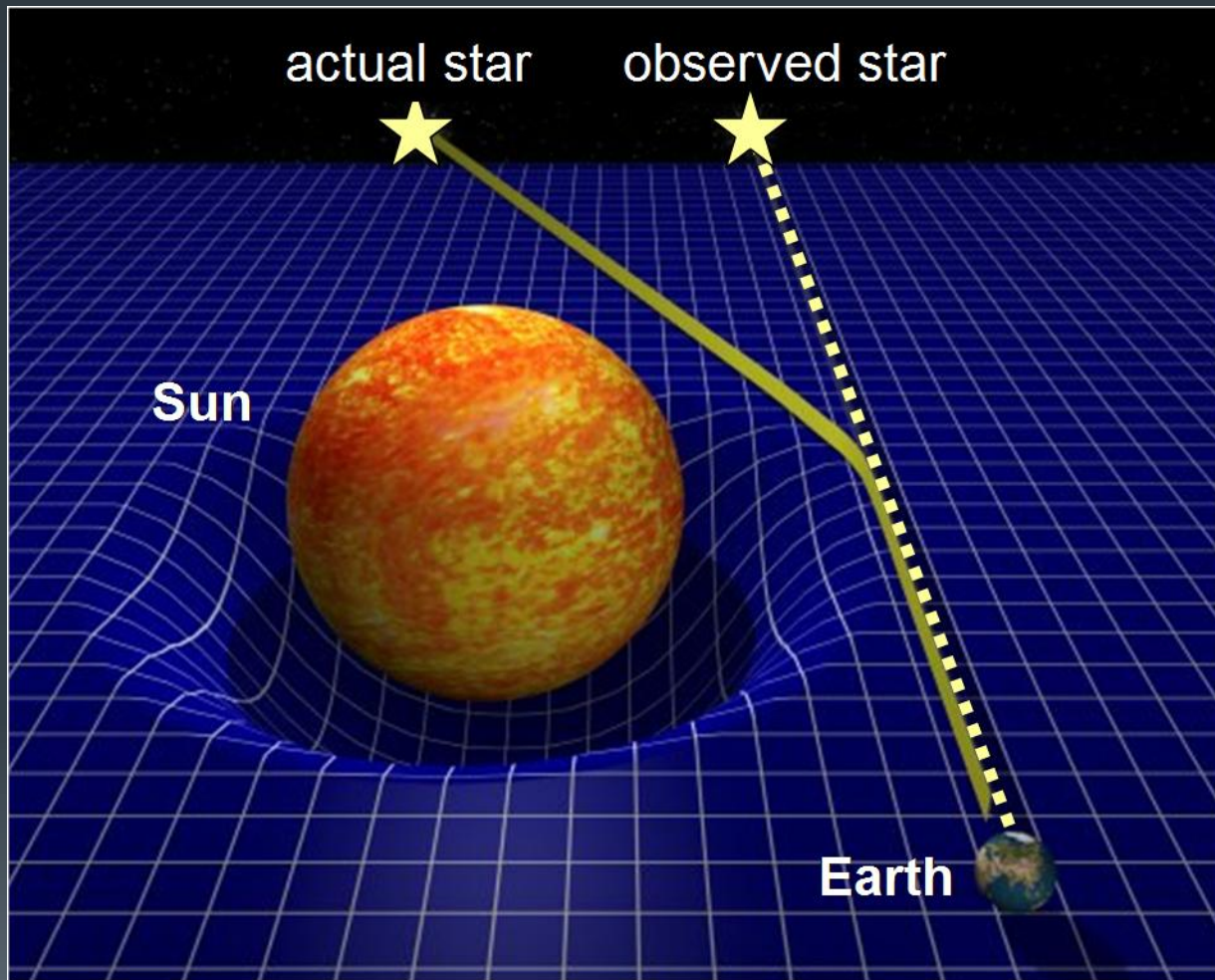
- Meaning at a glance
- Developed from 1905-1915 by Albert Einstein
- 1905-The miracle year-Einstein released special relativity and accurately explained the photoelectric effect, for which he won his Nobel Prize
- Time dilation, length contraction, speed of light, and particle nature of light





# Fundamentals: Development and Context

- Space-time
- Principle of Equivalence, thought experiment
- Light bends under gravity, thought experiment
- Special Relativity and Mass-Energy Equivalence  $E=mc^2$
- Tensors
  - Scalar is tensor of rank 0
  - Vector is tensor of rank 1
  - Rank 2 tensor is combination of vectors, which EFE uses



<http://www.basicknowledge101.com/photos/2015/fig9-bend-light.jpg>



# Delving into Mathematics

- Einstein, “I admire the elegance to your method of computation, it must be nice to ride through these fields upon the horse of true mathematics while the like of us have to make our way by foot.”
- What is metric tensor,  $g_{mn}$ ?
- What is Christoffel symbol?
- What is the Ricci Curvature Tensor,  $R_{mn}$ ?
- What is Stress-Energy tensor,  $T_{mn}$ ?
- What is Cosmological Constant?
- Summary: All  $g_{mn}$  and its derivatives essentially



# What are the solutions?

- The solution is a metric tensor,  $g_{mn}$ . This will give us a coordinate system,  $ds$ , that preserves all the laws of physics.
- Simplest Solution found in 1916 by Schwarzschild for a space filled with a vacuum near a spherical mass that is non-rotating and not electrically charged
- This actually describes simple black holes and neutron stars, except most rotate
- Kerr Solution takes rotation into account.



# Implications

- Einstein and his greatest blunder
- Space is expanding!
- This seems counter intuitive to gravity
- New Cosmological constant
- Set of 16 equations can reduce to 10 solutions
- Gravity corresponds to relation between curved space and the presence of momentum, mass, and energy
- Mass/Energy curve space
- And that curved space tells that mass/energy how to move
- Geodesic



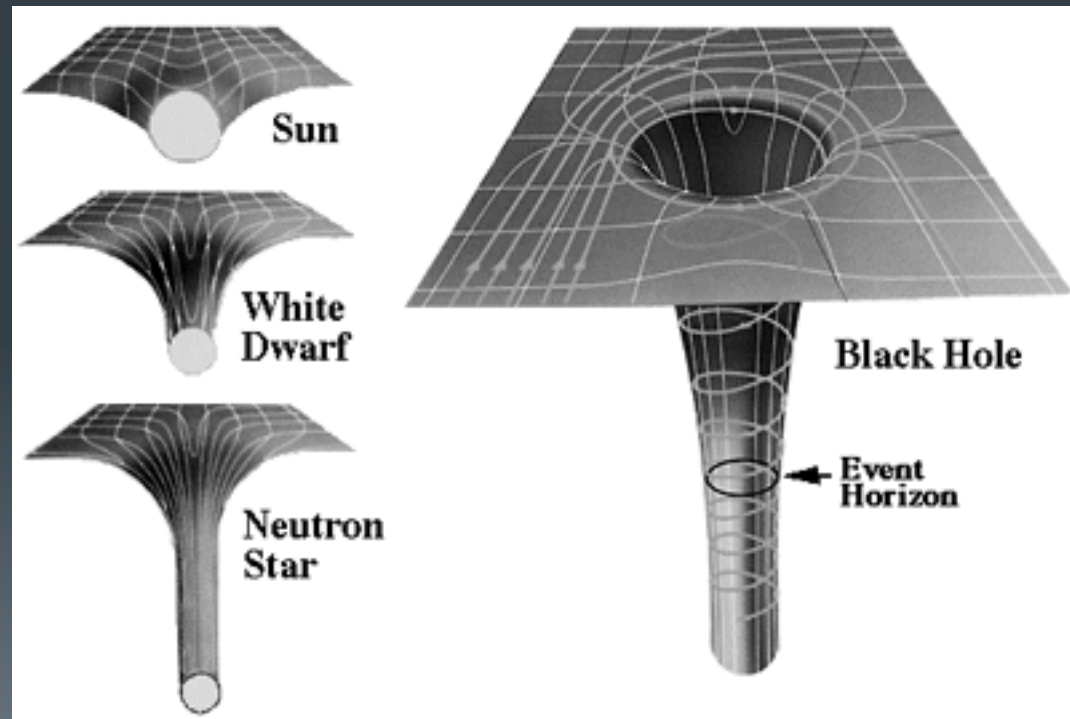


# Applications

- Prediction for Black holes, Schwarzschild radius, and other massive objects
- Gravitational Redshifts and Blueshifts of light
- Gravitational lensing, able to magnify objects behind a massive star
- Reduces to Special relativity and Newton's laws
- Predicted Gravitational waves and LIGO, binary pulsars, colliding black holes

# Where do we go from here?

- Singularity...

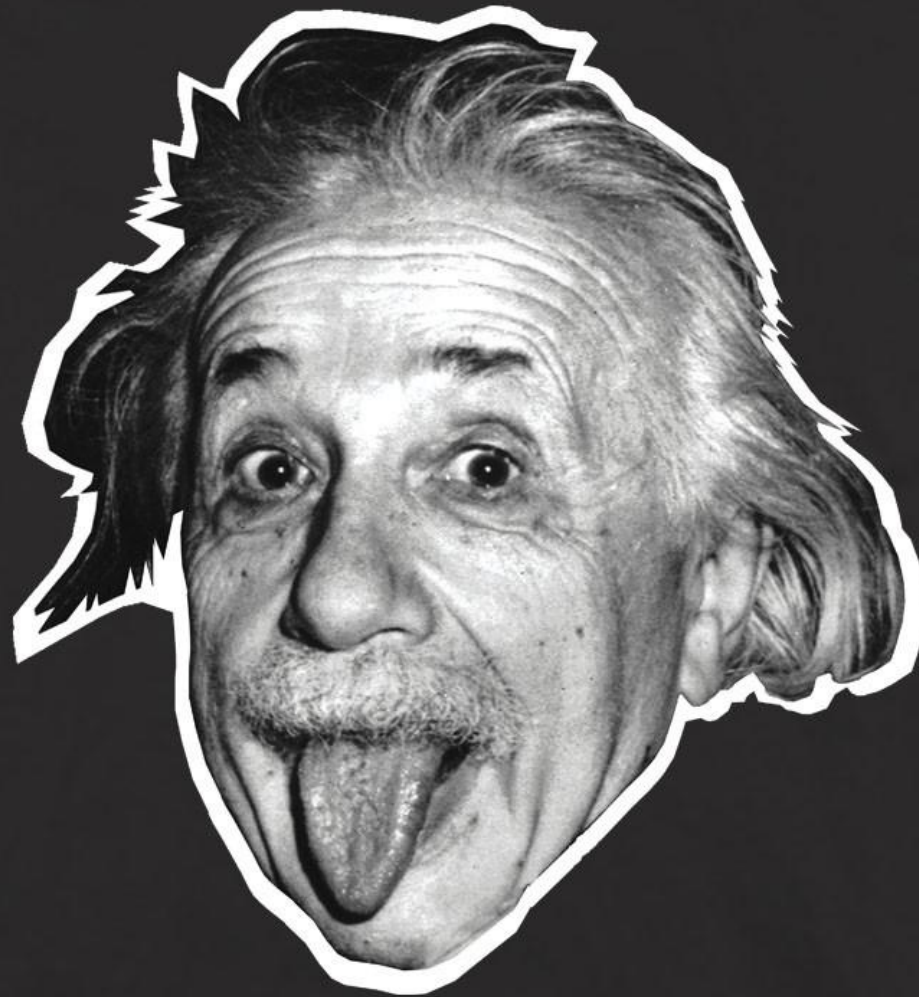




P2:

## Where do we go from here?

- Are singularities real?
- Law of Cosmic Censorship and infinite curve to spacetime
- Wormholes
- Frame shifting around event horizon
- Cosmology, Inflation
- Time travel, Some solutions contain closed timelike curves (CTC), by Godel, still not disproven





# Sources

- <https://asd.gsfc.nasa.gov/blueshift/index.php/2015/11/25/100-years-of-general-relativity/>
- Dr. Robert Eagle, [://www.youtube.com/watch?v=foRPAKAKZWx8](https://www.youtube.com/watch?v=foRPAKAKZWx8)
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- Bradley Carroll & Dale A. Ostlie, "An Introduction to Modern Astrophysics"
- Wikipedia, "General Relativity" and "Einstein Field Equations"