The Precession of Mercury's Perihelion

Where Newton failed and Einstein succeeded.

Dan Wysocki

SUNY Oswego

QUEST 2014

Introduction

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- many models were accurate during the lifespan of the people who created them, but over long periods of time began to lose accuracy
- eventually a new model comes along which takes its place, until yet another model replaces that one

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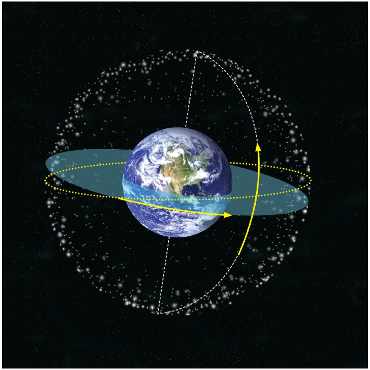
- all stars and planets move about the Earth

Celestial Sphere and Planets



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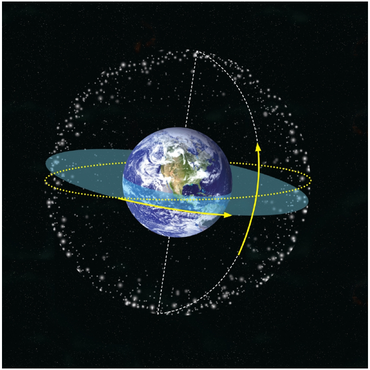

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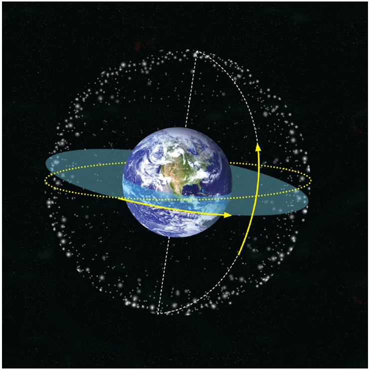

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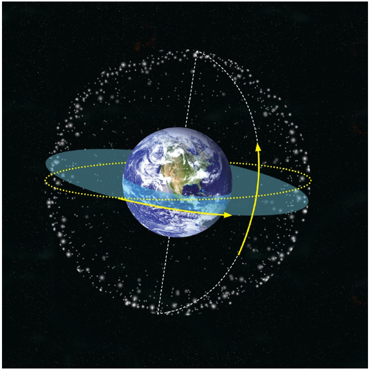

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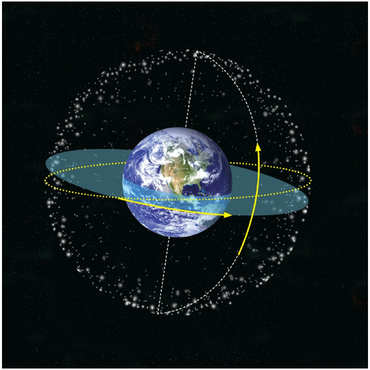

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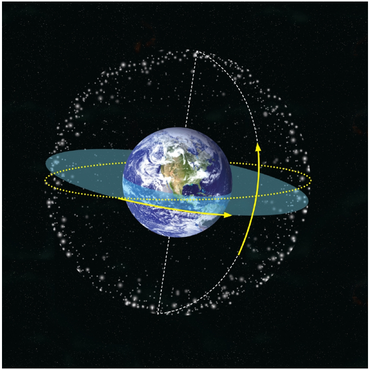

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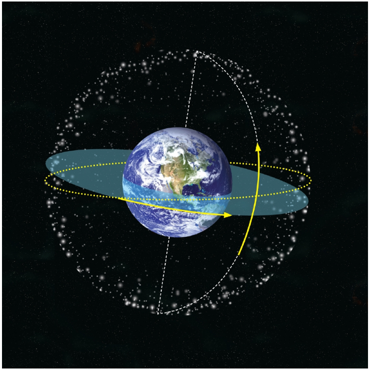

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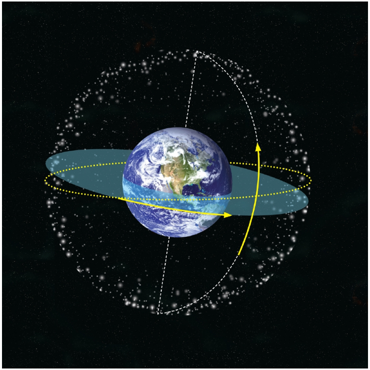

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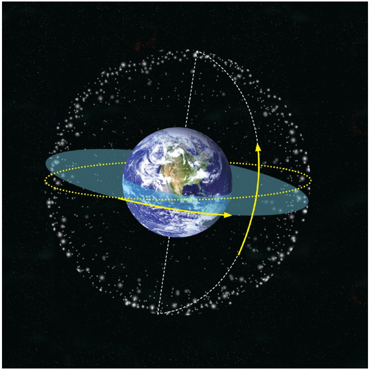

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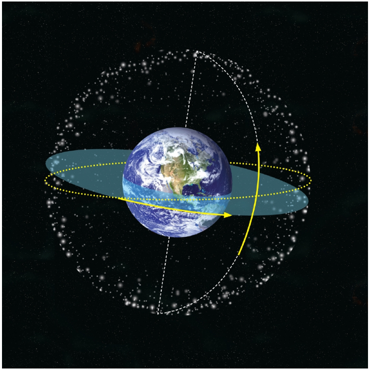

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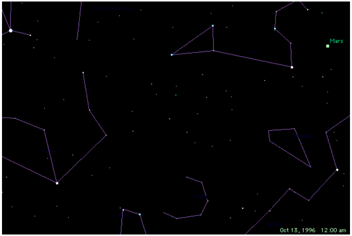
- the obvious exceptions to this rule are the 7 classical "planets", or "wanderers"
  - the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn
- these planets were thought to circle the Earth in their own paths, presumably closer to Earth than the sphere

Retrograde Motion of the Planets



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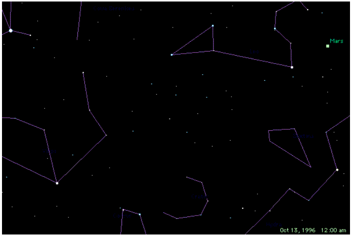

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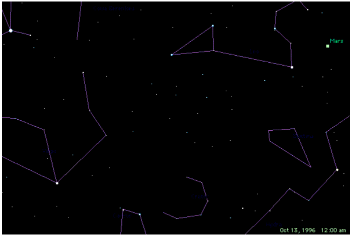

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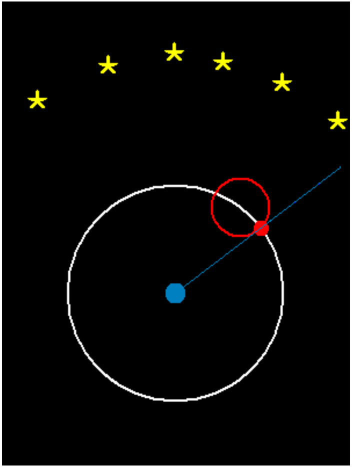
- most explanations involved "epicycles"

Epicycles



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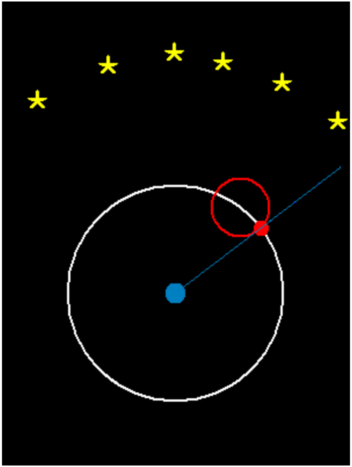

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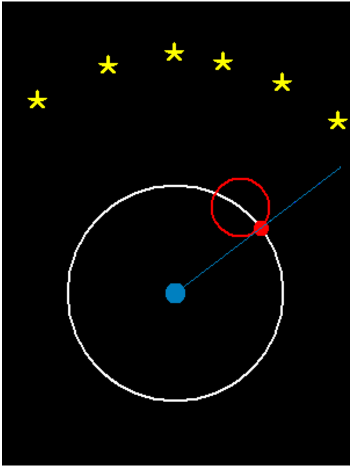

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- slowly they would go out of sync with observations

Geocentric Complexity

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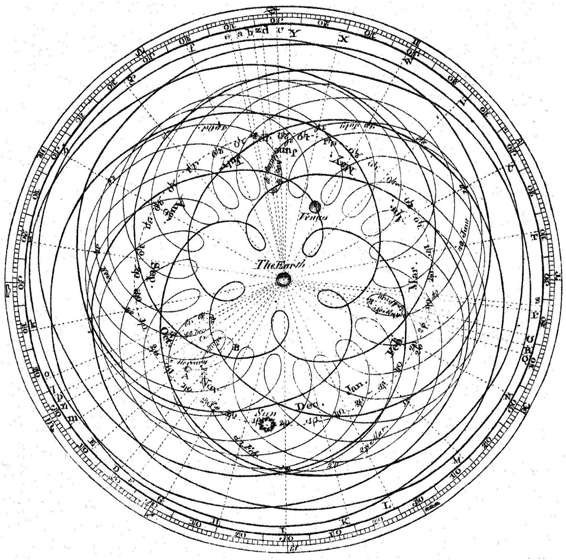

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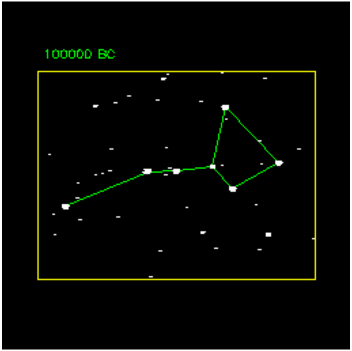

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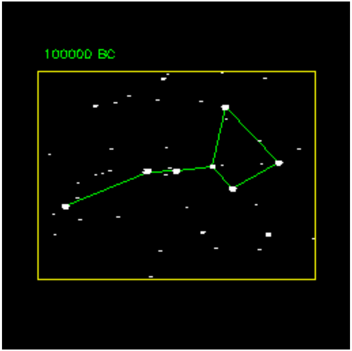

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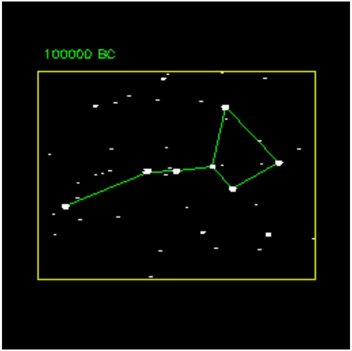

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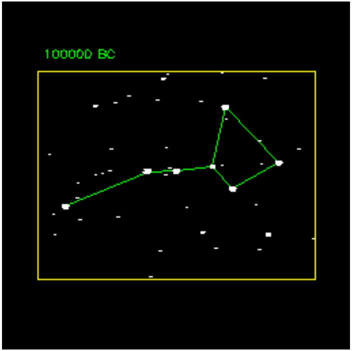

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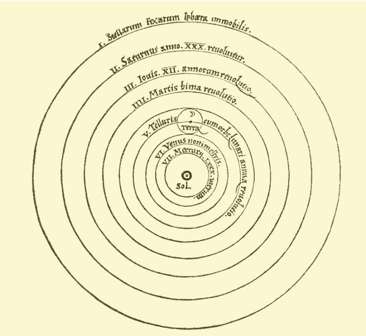
- apart from that, the stars had all drifted in seemingly random directions and speeds
- some of the brighter stars had drifted by almost an entire degree

Copernican Revolution



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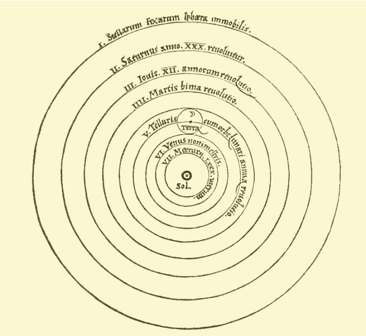
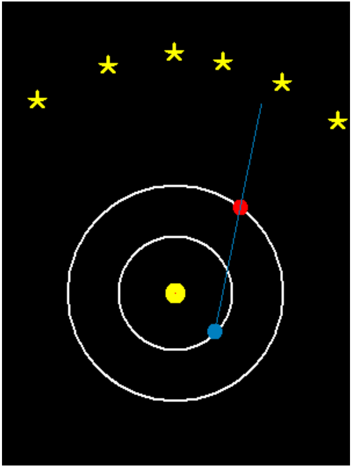


- in 1543, Nicolaus Copernicus published the first model of the Solar system which accurately put the Sun at the center, with the planets (including Earth) orbiting it
- not a perfect model, but was able to simplify the motions of the planets

Copernican Retrograde Motion



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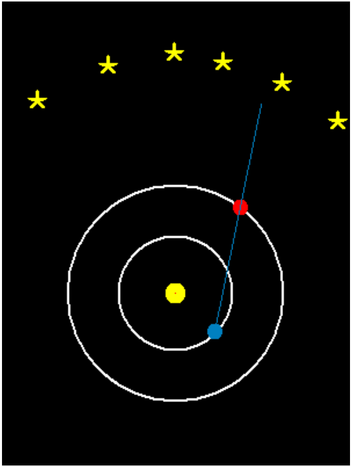

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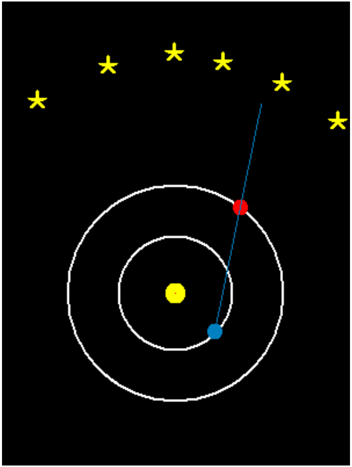

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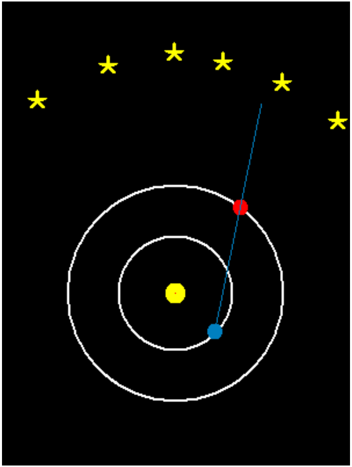

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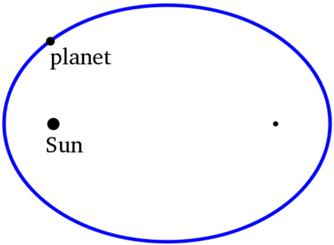
- same effect as passing a car on the highway
  - both cars are moving forward, but the slower car appears to be moving backwards

Kepler's Laws



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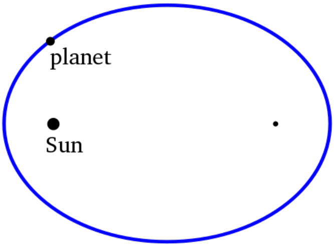

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- corrects Copernicus' false assumption that orbits are circular, when they are in fact elliptical

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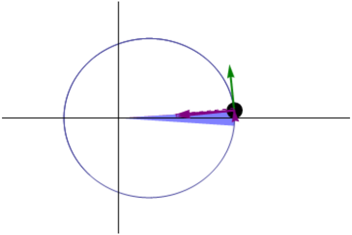
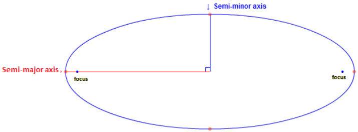
$$\mathrm{r} = \mathrm{r}_0 \frac{1+\varepsilon}{1+\varepsilon\cos\phi} \tag{1}$$

Kepler's Second and Third Laws





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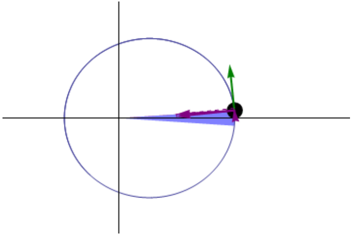

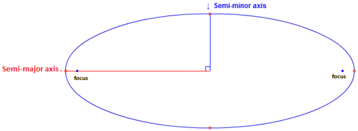

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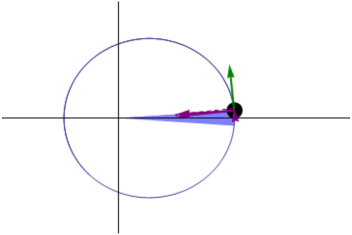

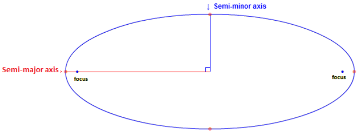

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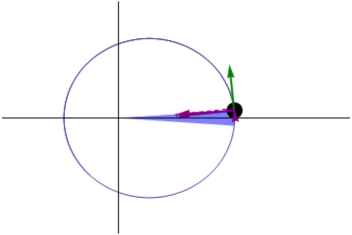

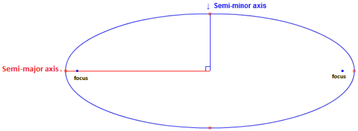

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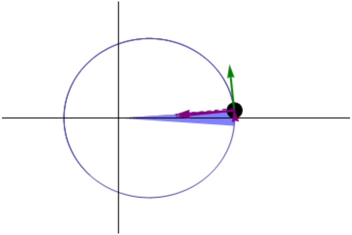

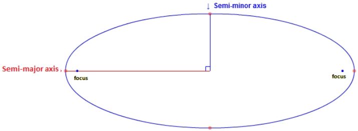

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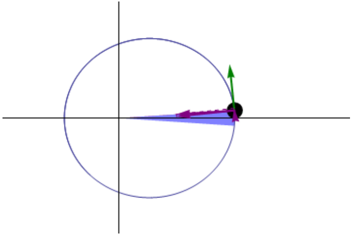

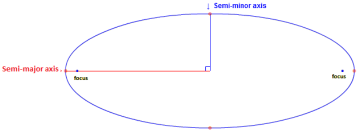

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$$\frac{P^2}{a^3} = c \tag{3}$$

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$$\mathbf{F} = \mathrm{G}\,\frac{\mathrm{m}\,\mathrm{M}}{\mathrm{r}^2}\,\hat{\mathbf{r}} \tag{4}$$

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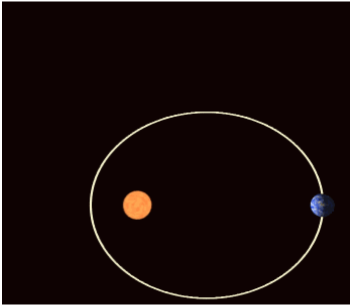
$$\frac{P^2}{a^3} = \frac{4\pi^2}{\mathrm{G}\,\mathrm{M}} \tag{6}$$

Orbital Precession



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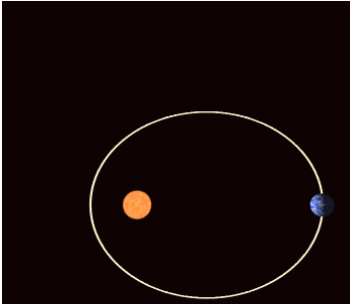

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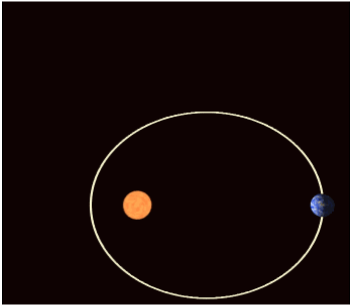

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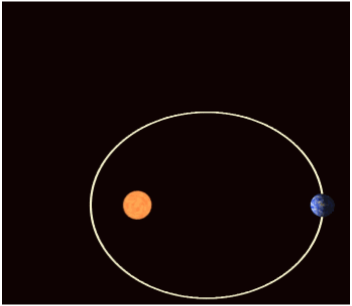

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- Newton's law of gravity predicts this, while Kepler's laws do not

Newtonian Precession Predictions

Planet	$(\delta\dot{\psi})_{\mathsf{obs}}$	$(\delta\dot{\psi})_{\mathsf{th}}$
Mercury	$575.19''$	$532.08''$
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Table: Precession rates in arc-seconds per century

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- error for the other planets can be explained by imprecision of measurements, but Mercury's is too large
- mystery puzzled physicists for many years

Corrections to Newtonian Gravity

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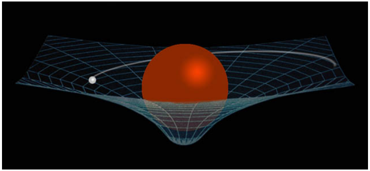
- a new explanation was in order

General Relativity



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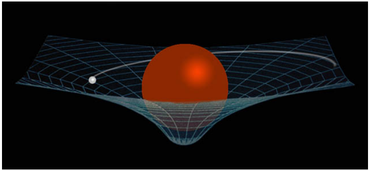

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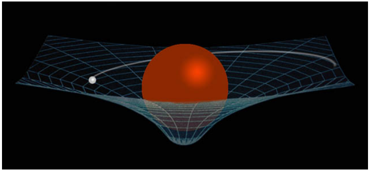

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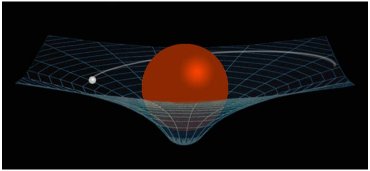

- Einstein formulated his general theory of relativity in 1916
- rejected the notion that gravity was a force
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- the planets aren't travelling in a curved path around the Sun, the space around the Sun is itself curved

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- using general relativity, we can adapt Newton's law of gravity to be more precise

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- this is exactly the amount that was missing from Newtonian predictions
- this was one of the first things that Einstein calculated to test his theory out

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- given enough time, those flaws will become apparent
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- sometimes a completely new approach is needed to be successful

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Questions?