# Astromechanics: gravity

Astronomy 101
Syracuse University, Fall 2018
Walter Freeman

October 4, 2018

*"Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things."*

–Newton, *Rules for methodizing the Apocalypse*
(n.b.: "apocalypse" also means "revealing")

*"We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances."*

–Newton, *Philosophiae Naturalis Principia Mathematica*
(Mathematical Principles of Natural Philosophy)

# Announcements

The 12:30 class today is being audiorecorded to accommodate those students participating in the demonstration on the Quad.

If you would like to join that demonstration, you may either attend the 2:00 class or listen to the recording at home, following along with the slides, and work on the *Lecture Tutorials* with a friend.

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If you ever need accommodations in this class to work around your *bona fide* participation in the political process, please let me know.

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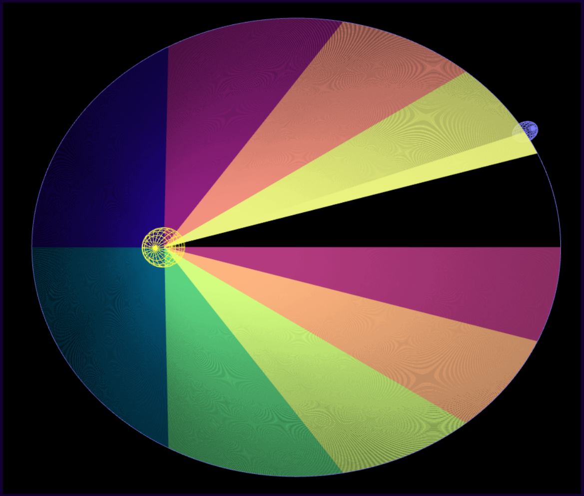
- Warmup question for Tuesday will be sent out tonight

# Kepler's laws, summarized

- 1. Planets travel in elliptical orbits, with the Sun at one focus
- 2. The line going from the Sun to the planet sweeps out equal areas in equal times
- 3. The time that a planet takes to go around the Sun increases as the 3/2 power of the long axis of the ellipse.

# Kepler's second law

The line from the Sun to the planet sweeps out equal areas in equal times.



Each colored wedge has the *same area*, and the planet takes the *same time* to go through each.

# Kepler's Third Law

Kepler's third law of orbital motion says that the square of a planet's *orbital period* is proportional to the cube of its *semimajor axis*.

Simply put: if a planet is further from the Sun, it takes longer to go around.

If the distance is doubled, the time required *more than doubles*.

Let's watch this...

Saturn's orbit is about 10 AU across, while Uranus' orbit is about 20 AU across.

Saturn takes about 30 years to orbit the Sun. About how long does Uranus take?

A: About 30 years
B: Between 30 and 60 years
C: More than 60 years
D: It depends on the masses of Uranus and Saturn

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E: I looked it up on Wikipedia...

Complete *Lecture Tutorials* pp. 21-24 (Kepler's second law) and pp. 25-28 (Kepler's third law).

We will do something else after this (15-20 min)

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*No. Think about the earth and the moon. Moon is orbiting around the earth, and Kepler's laws should also apply [to the] moon's orbiting.*

–Jiaqi

# Are Kepler's laws of orbital motion fundamental laws of Nature

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*[There is a] more fundamental thing that cause[s] them. In my opinion, we [see] the planets that orbit this way because of the gravity from star[s]. The gravity of stars attracts the planet and Kepler's laws explain the result of gravity in a mathematical way.*

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## Where are we now?

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But he thought there was more: that the planets' orbits were *caused* by the interplay of more fundamental agents.

He didn't have a good name for them: we now call them "gravity" and "inertia". We'll learn about those soon.

# Natural laws vs. their consequences

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- The elliptical motions of the planets (?)
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- The diversity of rocks on Earth
- Even the simplest living things
- ... language, culture, music, art, and all the creations of humankind...

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- Calculus – the mathematics of changes
- Gravity is such a force
- The mathematical description of gravity
- Principles of optics
- The mathematics of cooling
- ... and much more

## Newton's biggest idea

"Forces cause objects to accelerate"

$$F = ma$$

$$F/m = a$$

"The strength of a force, divided by the mass of the thing it acts on, gives that thing's acceleration"

# The law of gravity

Newton showed mathematically what Kepler suspected.

All objects attract all other objects with a force that is:

- Proportional to the product of their masses
- Inversely proportional to the distance between them squared

In symbols:

$$F = \frac{Gm_1m_2}{r^2}$$

Suppose two asteroids are floating out in space. Asteroid A is twice as massive as asteroid B.

If the force of A's gravity on B is ten tons, the force of B's gravity on A will be...

A: 5 tons

B: 10 tons

C: 20 tons

D: 40 tons

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Notice I didn't say which mass was which. It doesn't matter!

Suppose two asteroids are floating out in space, 20 miles apart. Asteroid A is twice as massive as asteroid B, and the force of A's gravity on B is ten tons.

Suppose I now move the two asteroids closer, so they're only 10 miles apart. What will the force of A's gravity on B be now?

A: 5 tons

B: 10 tons

C: 20 tons

D: 40 tons