Announcements

- Please turn in your planetarium assignments
- **Quiz 2 due tonight**, problem sets 2A and 2B for practice
- Reading assignment: Finish Chapter 1
- We will (probably) start Chapter 2 on Friday

Stargazing This Week

For **extra credit** (+1% on final grade), attend one of the sessions listed below, write a short summary of what you did and observed, and turn it in before the last day of classes

- **Where:** UWM Physics Observatory Deck
- **When:** Weather permitting, observing/stargazing will be offered on the following dates:
  - **Feb 3, 4, 5, 6 at 8:00-9:00 pm**
  - **Wed, Feb 12 at 8:00-9:00 pm**
  - **Wed, March 12 at 8:00-9:00 pm**
  - *Note the later time for the following sessions!*
  - **Wed April 9 at 9:00-10:00 pm**
  - **April 21, 22, 23, 24 at 9:00-10:00 pm**
  - **May 14 at 9:00-10:00 pm**
- **More info on D2L**

This week,
Monday – Thursday!

Where? 4th floor of Physics building, then take stairs to roof

Weather permitting – check for updates:

https://twitter.com/uwmplanetarium

http://www4.uwm.edu/planetarium/shows/stargazing.cfm

Astronomy 103

From the Greeks to Newton: Part 2

Which of the following objects has an apparent motion with retrograde loops?

A Sun

B Moon

C Both of these

D Neither of these

Which of the following objects has an apparent motion with retrograde loops?

- A — Sun
- B — Moon
- C — Both of these
- D — Neither of these

Which of the following objects has an apparent motion with retrograde loops?

A Venus

B Mars

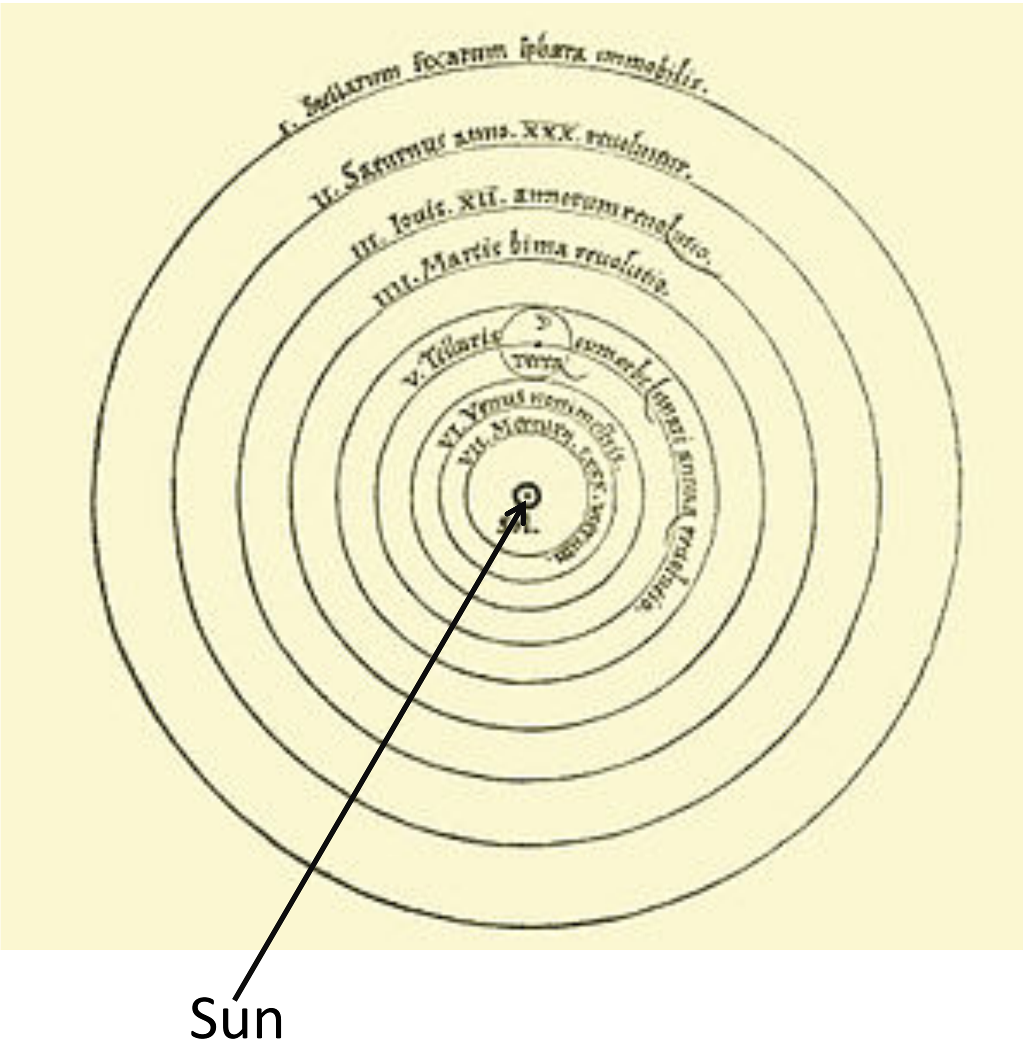
C Both of these

D Neither of these

Which of the following objects has an apparent motion with retrograde loops?

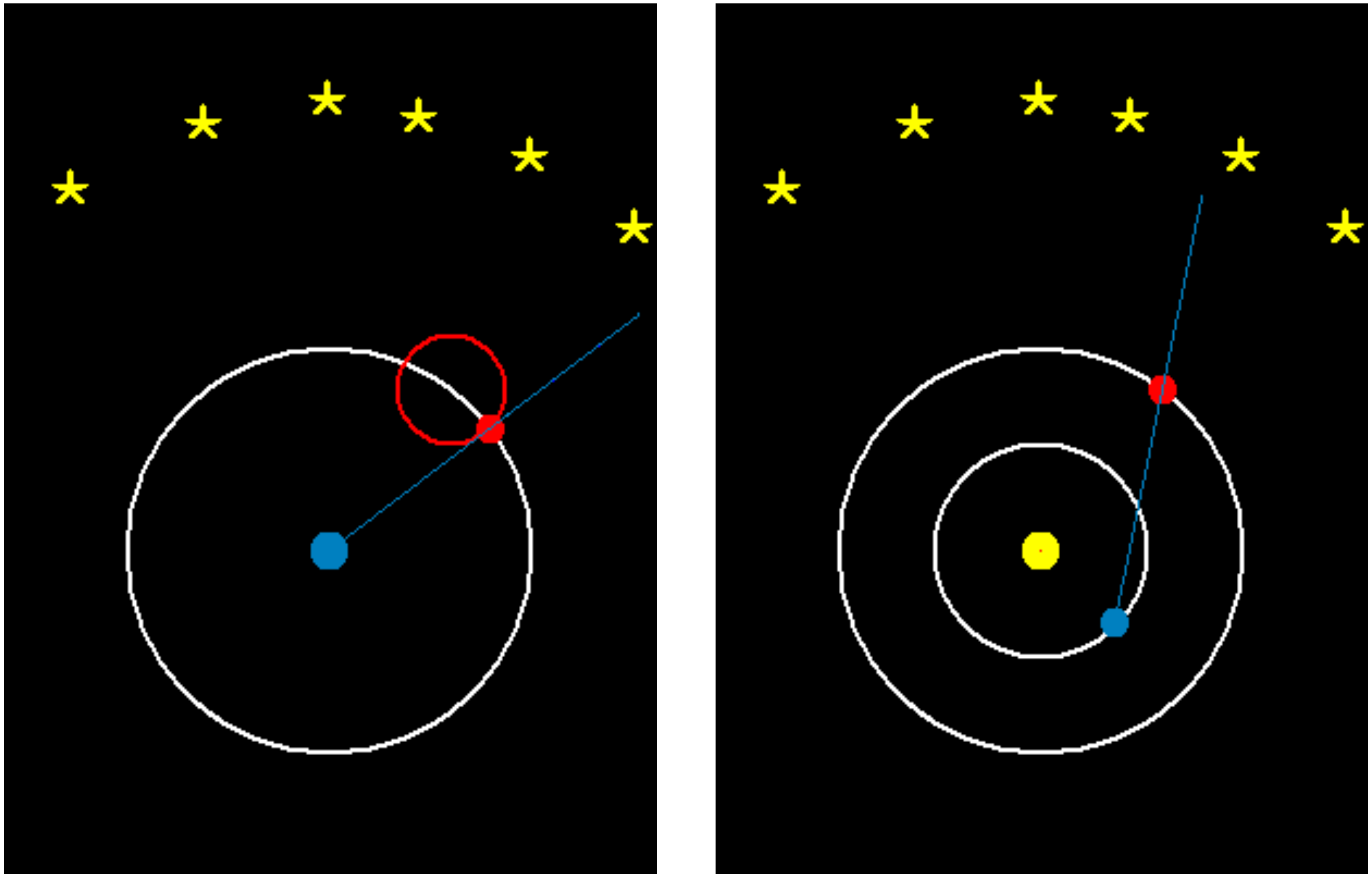
- A Venus
- B Mars
- C Both of these
- D Neither of these

Successes of the Copernican model



- Explains the retrograde motion of planets without the need for major epicycles,
- Explains the maximum angle of the inner planets
- Explains the Jupiter-Saturn coincidences
- Copernicus correctly predicted the relative distances from the Sun of each of the six known planets

What Copernicus did *not* do was to improve on the accuracy of the Ptolemaic system. He had to rely on copies of observations that were thousands of years old, and a prerequisite for further development was a more accurate knowledge of planetary motion.



Because the planets do not move in exact circles, Copernicus followed Ptolemy in introducing small epicycles to describe deviations from circular orbits. The result was that Copernicus' full system was as complicated as Ptolemy's and no more accurate.

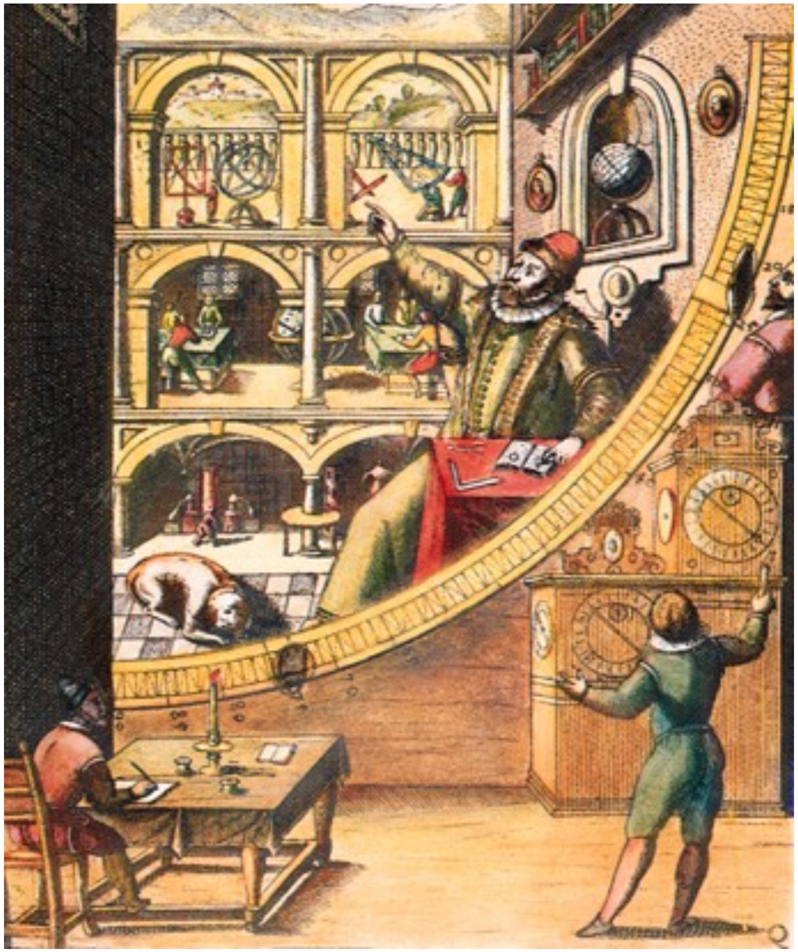
The **scientific method** does not distinguish between the Copernican model and the Ptolemic model. Both can successfully predict the observed motions of the planets. However, the Copernican model is slightly simpler, which is appealing.

The Copernican does make certain predictions which are different than the Ptolemic model, which we will see next. It is a combination of these predictions, which were successfully tested, Kepler's laws of motion, and Newton's unification of the laws of nature which made the Copernican model the accepted theory of the solar system.

Tycho Brahe (1546-1601)

- Born in 1546, three years after Copernicus died
- In 1572, when he was 26, he noticed a new star
  - This was actually the death of an old star, a supernova, and this one was named after Tycho
- The King of Denmark, Wilhelm IV, was enthusiastic about astronomy, met Tycho, and offered him funds equal in value to about a ton of gold to set up an observatory on an island overlooking Elsinore
- At today's prices, this is about $60 million!

Tycho Brahe (1546-1601)



There were as yet no telescopes, and Tycho's instruments were designed to measure precise positions of stars and planets.

Tycho Brahe's years of careful observations of the planet's positions against the background stars made him the greatest observational astronomer in 1000 years.

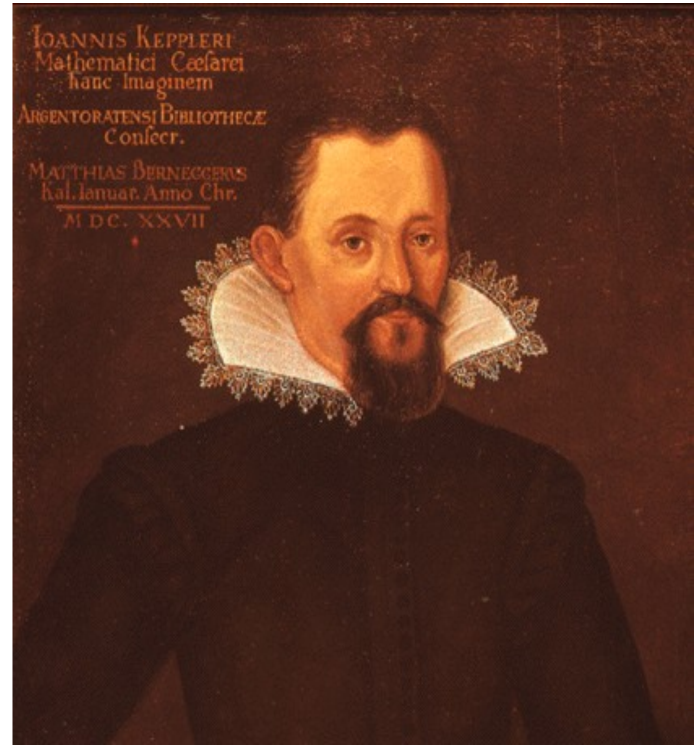
Kepler (1571-1630)

German mathematician, astronomer, and astrologer

Kepler Fun Facts

Kepler's mother collected herbs and concocted potions in whose power she believed. She was accused of being a "malevolent witch", and only his intervention saved her.

Kepler himself was born prematurely with myopia and multiple vision; his stomach and gall bladder gave him constant trouble.

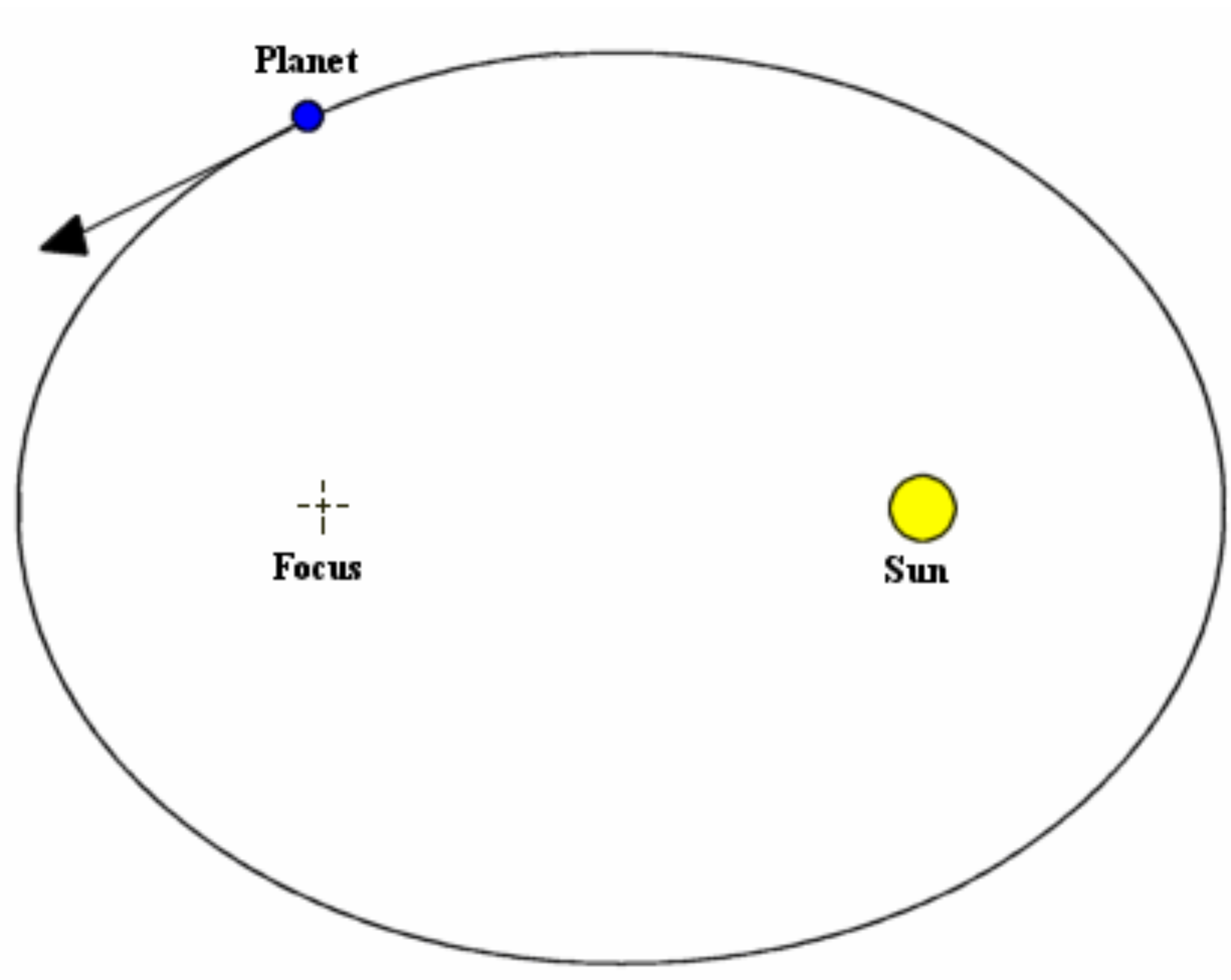


Kepler was recognized as a brilliant mathematician by Tycho Brahe, who invited Kepler to help analyze his extraordinary data.

Kepler found that the observed paths of the planets – all of Tycho's data – followed from three simple laws!! This took over fifteen years from the time Kepler met Brahe.

Kepler's First Law:

Planets moves in *ellipses* with the Sun at one focus



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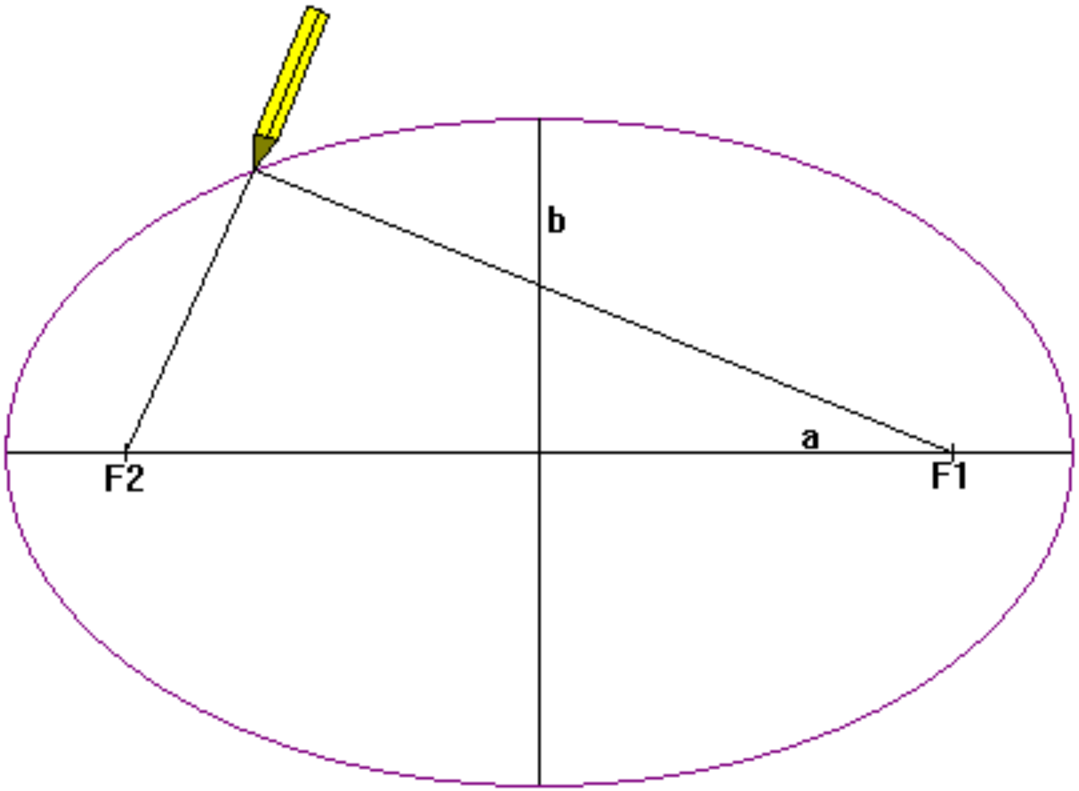
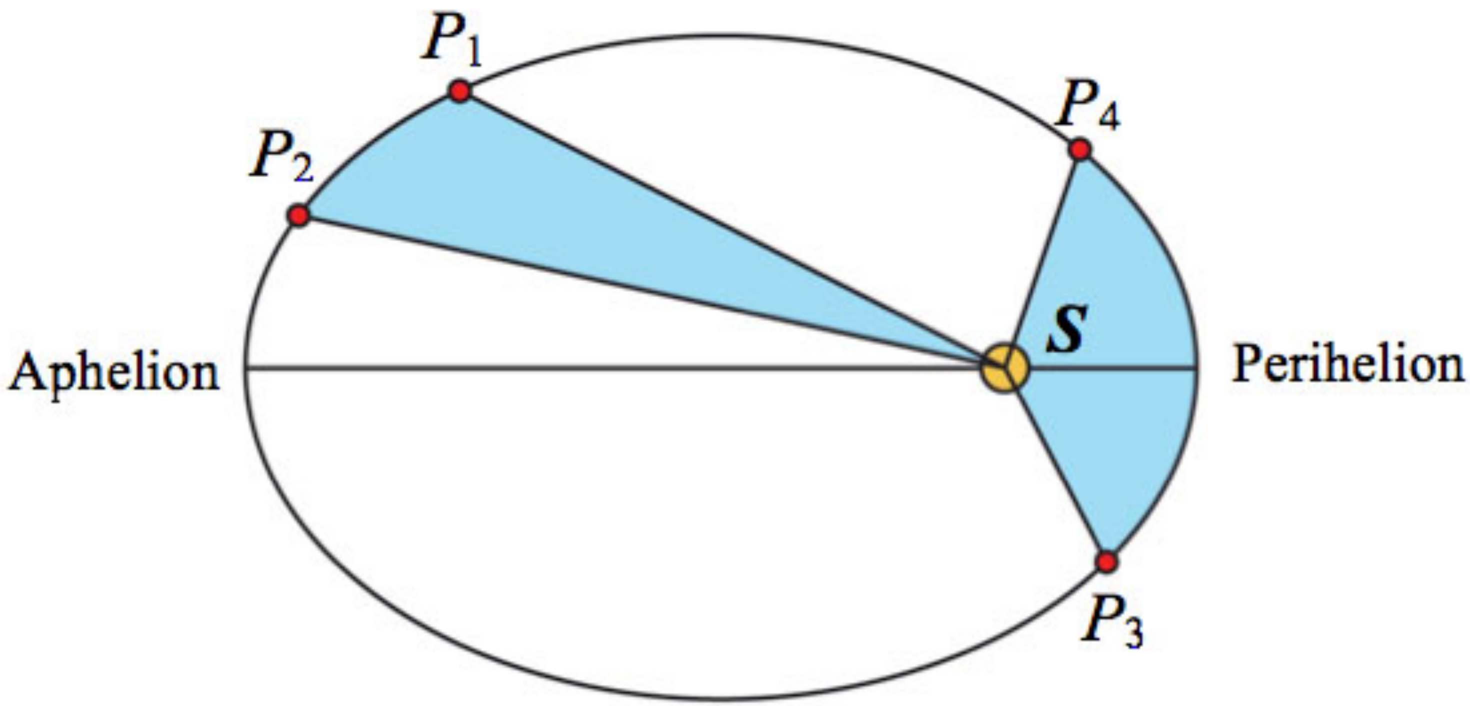


Kepler's Second Law:

The line from the Sun to a planet sweeps out equal areas in equal intervals of time.



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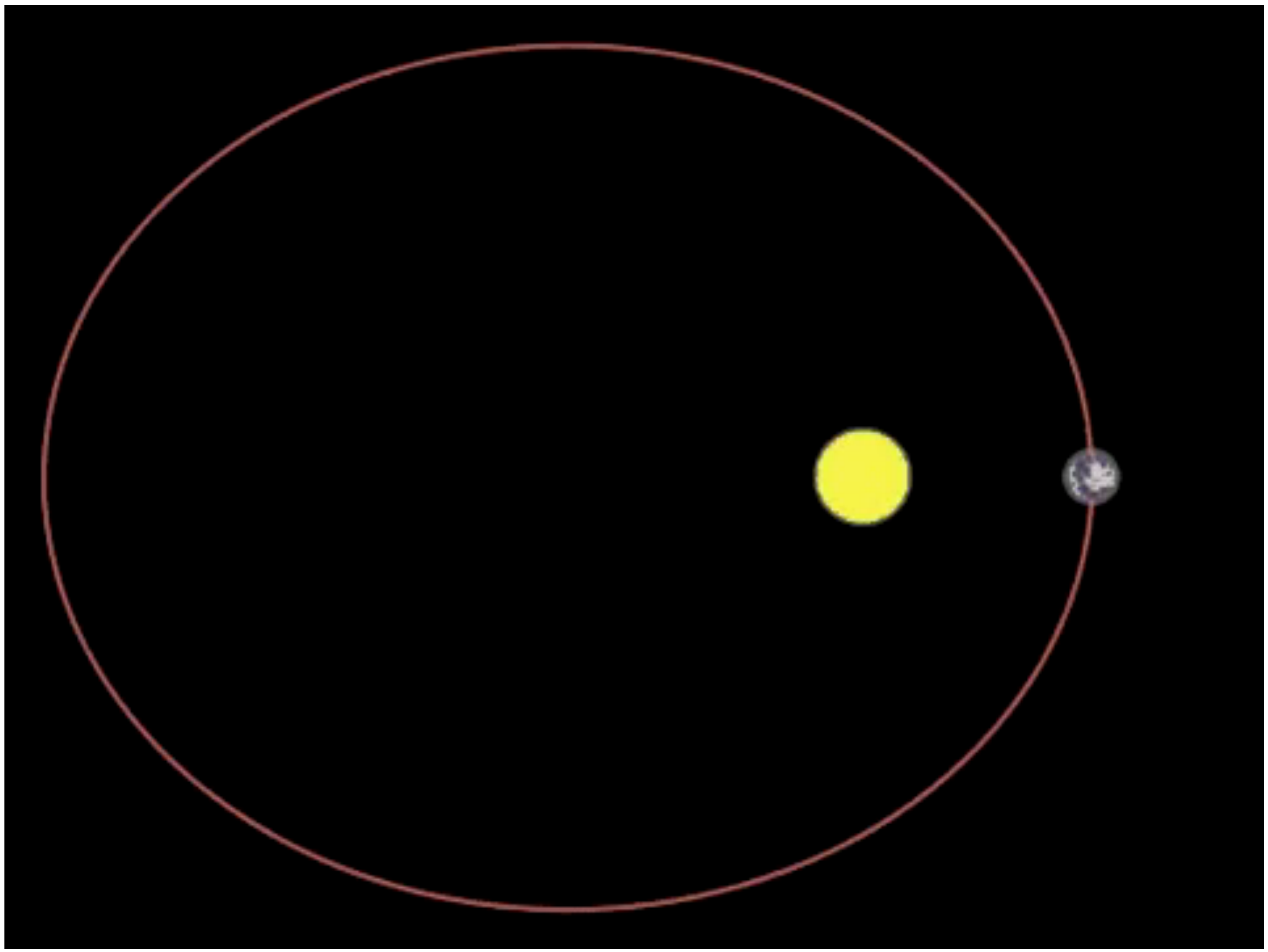
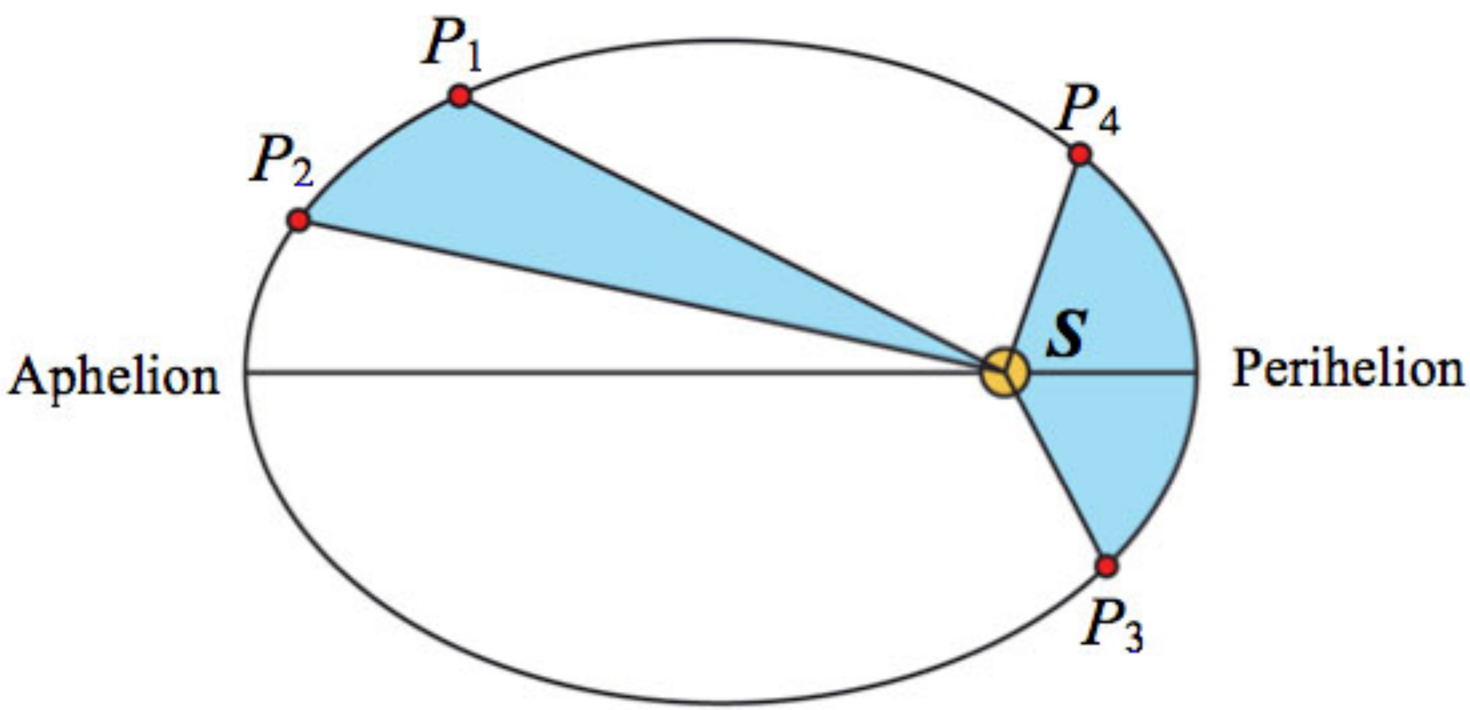


Kepler's Second Law:

The line from the Sun to a planet sweeps out equal areas in equal intervals of time. This means the planet moves **fastest when it's closest** to the Sun (*perihelion*) and **slowest when it's farthest** from the Sun (*aphelion*).



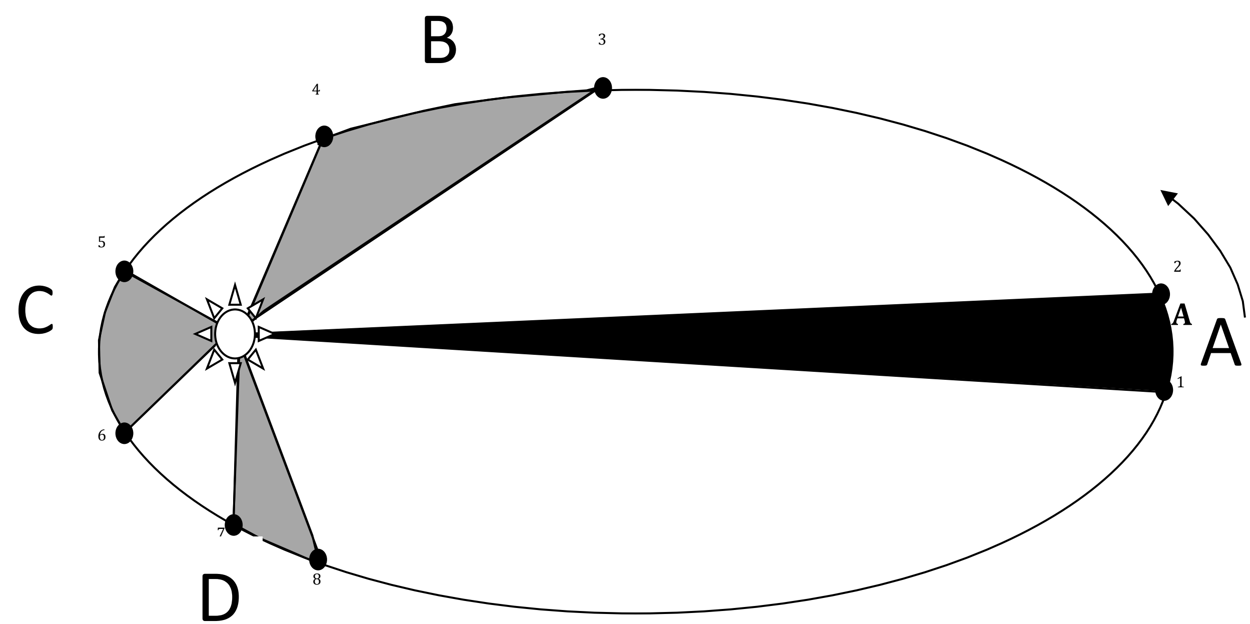
During which part of the planet's orbit (A, B, C, or D) would the planet move with the greatest speed?

A A

B B

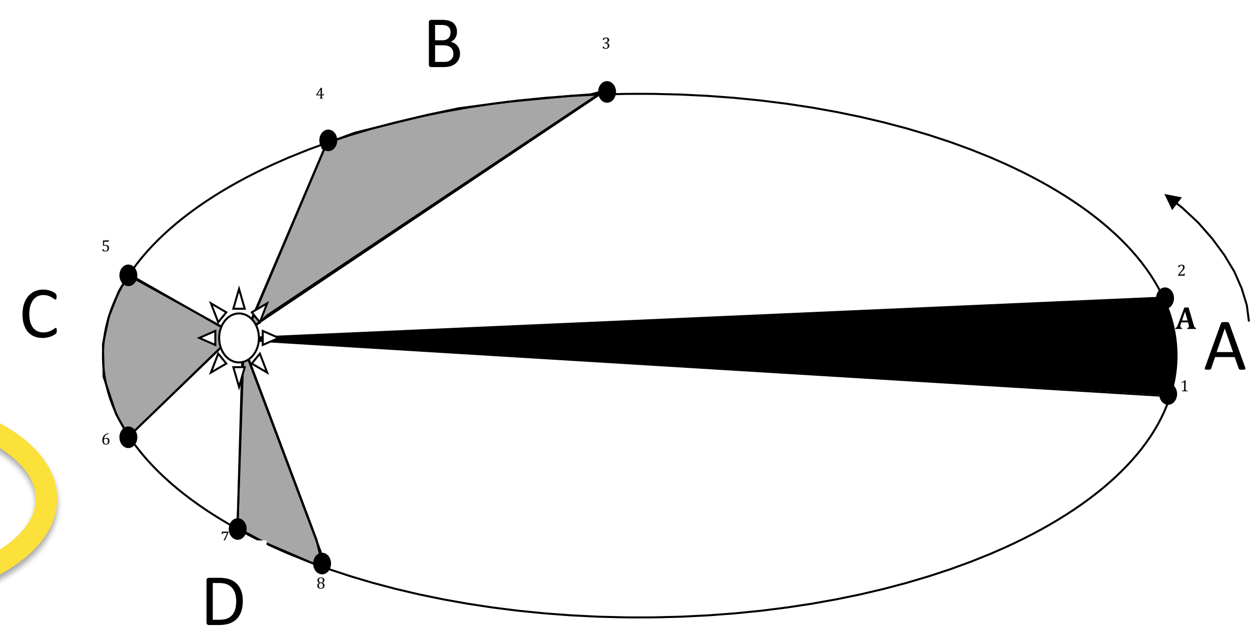
C C

D D



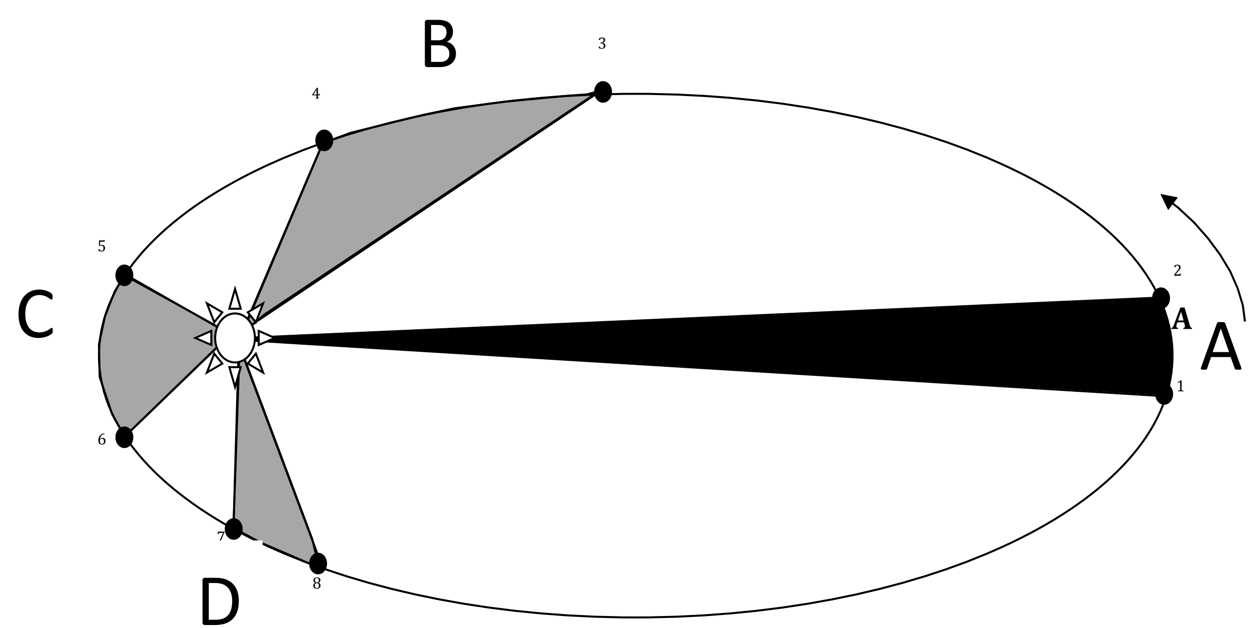
During which part of the planet's orbit (A, B, C, or D) would the planet move with the greatest speed?

A | A
B | B
C | C
D | D



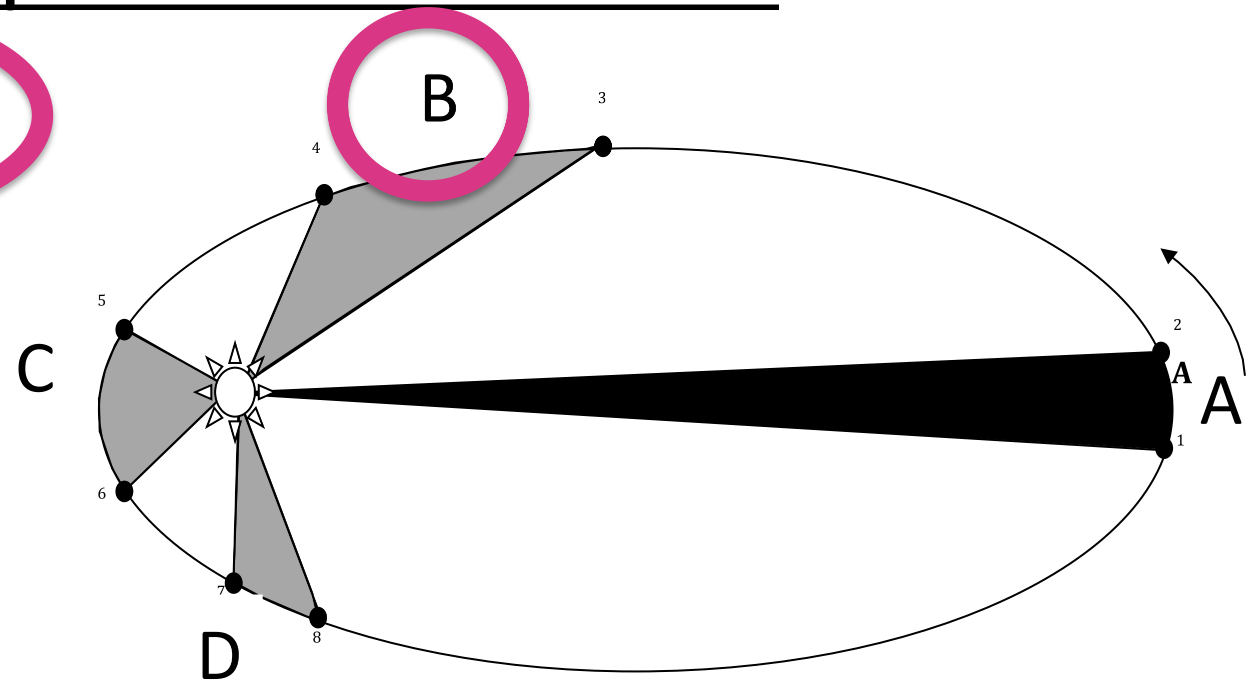
During how many of the portions shown of the planet's orbit (A, B, C and D) would the planet be <u>speeding up the entire time?</u>

A	1
B	2
C	3
D	4



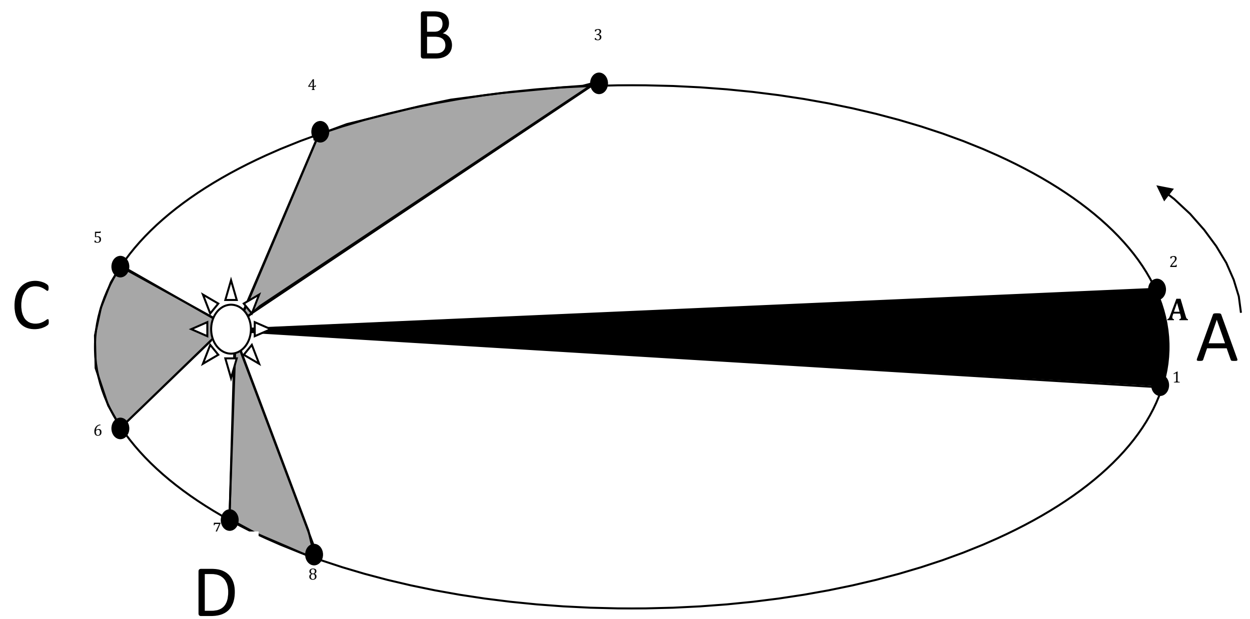
During how many of the portions shown of the planet's orbit (A, B, C and D) would the planet be <u>speeding up the entire time?</u>

- A 1
- B 2
- C 3
- D 4



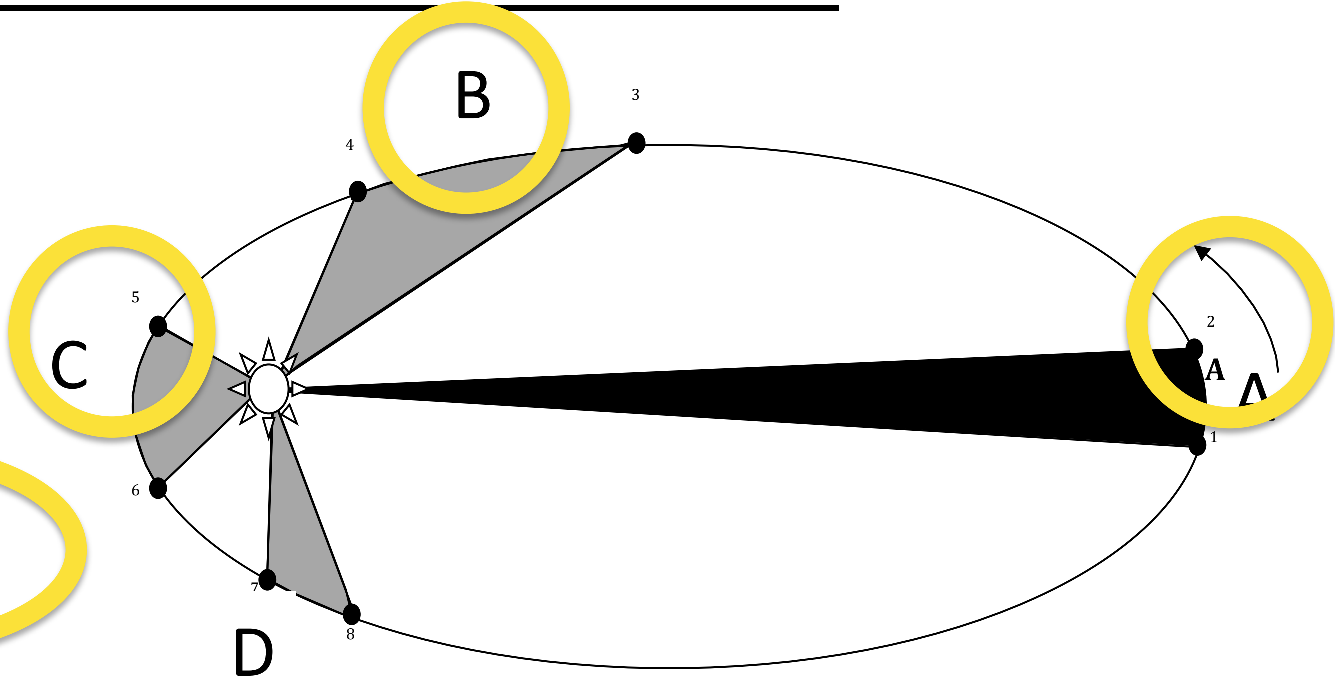
For how many of the portions of the planet's orbit shown would the planet experience an <u>increase in speed for at least one moment?</u>

A	1
B	2
C	3
D	4



For how many of the portions of the planet's orbit shown would the planet experience an increase in speed for at least one moment?

- A — 1
- B — 2
- C — 3
- D — 4



Kepler's Third Law:

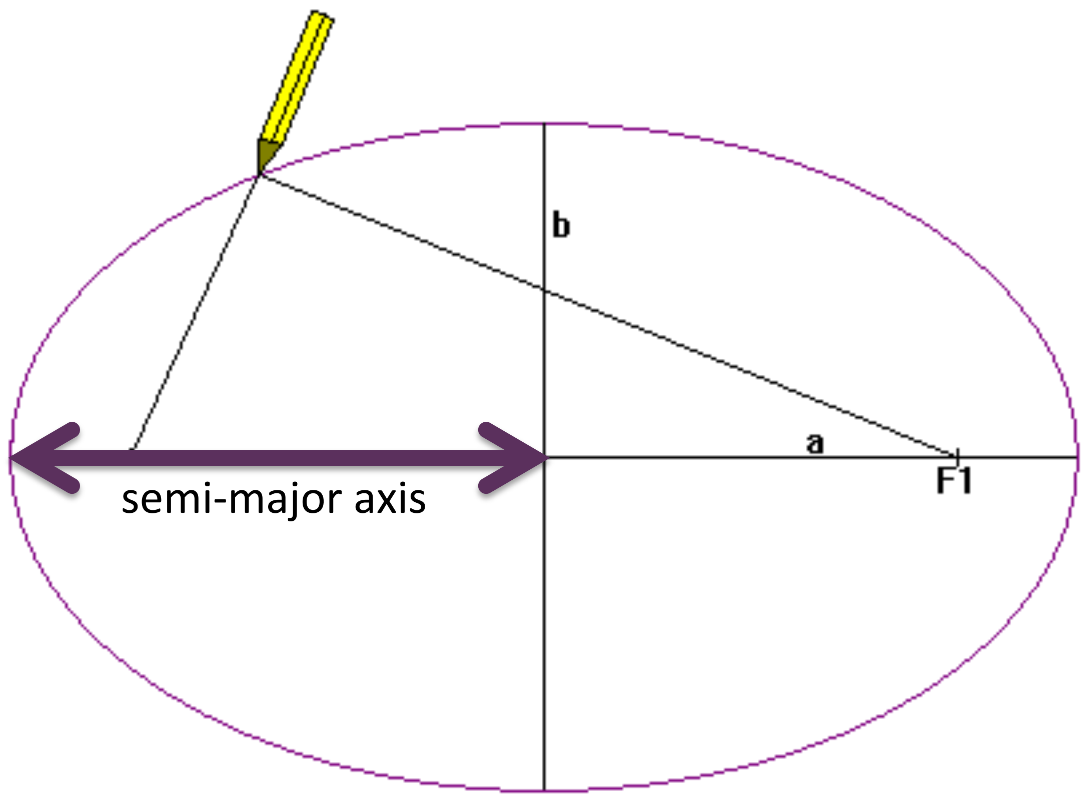
The period of each planet is related to its average distance from the Sun by the formula

$$a^3 = P^2$$

a = planet's average distance from Sun (semimajor axis of ellipse) in AU

P = planet's period in years

Reminder: semi-major axis



Using Kepler's Third Law: Examples

$$a^3 = P^2$$

Earth has a period of 1 year and a semi-major axis of 1 AU:
$1^3 = 1^2 = 1$.

1. A planet is at 2 A.U. What is its period?

Solve Kepler's 3rd law for P: $P = \sqrt{a^3} = a^{3/2}$

The period of the planet is $P = \sqrt{2^3} = 2.8$ years

Using Kepler's Third Law: Examples

$$a^3 = P^2$$

Earth has a period of 1 year and a semi-major axis of 1 AU:
$1^3 = 1^2 = 1$.

2. A planet is at 3 A.U. What is its period?

Solve Kepler's 3rd law for P: $P = \sqrt{a^3} = a^{3/2}$

The period of the planet is $P = \sqrt{3^3} = 5.2$ years

Using Kepler's Third Law: Examples

$$a^3 = P^2$$

Earth has a period of 1 year and a semi-major axis of 1 AU:
$1^3 = 1^2 = 1$.

3. A planet is at 0.1 A.U. What is its period?

Solve Kepler's 3rd law for P: $P = \sqrt{a^3} = a^{3/2}$

The period of the planet is $P = \sqrt{0.1^3} = 0.03$ years

Notice that planets with *a*>1 AU have periods greater than 1 year, and planets at *a*<1 AU have periods less than 1 year.

Using Kepler's Third Law: Examples

$$a^3 = P^2$$

Earth has a period of 1 year and a semi-major axis of 1 AU:
$1^3 = 1^2 = 1$.

4. A comet has a period of 1000 years. What is its distance from the Sun?

Solve Kepler's 3rd law for a: $a = \sqrt[3]{P^2} = P^{2/3}$

The distance of the comet from the Sun is $a = \sqrt[3]{1000^2} = 100$ AU

Using Kepler's Third Law: Examples

$$a^3 = P^2$$

Earth has a period of 1 year and a semi-major axis of 1 AU:
$1^3 = 1^2 = 1$.

5. A planet has a period of 0.5 years. What is its distance from the Sun?

Solve Kepler's 3rd law for a: $a = \sqrt[3]{P^2} = P^{2/3}$

The distance of the planet from the Sun is $a = \sqrt[3]{0.5^2} = 0.63$ AU

Objects with P>1 year are more than 1 AU from the Sun.

Using Kepler's Third Law: Examples

$$a^3 = P^2$$

Earth has a period of 1 year and a semi-major axis of 1 AU:
$1^3 = 1^2 = 1$.

6. A satellite around the Sun has a period of 10 years and a semi-major axis of 3 A.U. Is this possible?

Use Kepler's 3rd law to check: $10^2 = 100$ and $3^3 = 27$.

$100 \neq 27$, so this is not possible.

A planet is 4 AU from the Sun. What is its period?

$$a^3 = P^2$$

A. 2 years

B. 4 years

C. 8 years

D. 16 years

A planet is 4 AU from the Sun. What is its period?

$$a^3 = P^2$$

$a = 4$

$4^3 = 64$

$P = \sqrt{64} = 8$

- A — 2 years
- B — 4 years
- C — 8 years
- D — 16 years

Kepler's three laws of planetary motion

1. Planets move in **ellipses** with the Sun at one focus

2. The line from the Sun to a planet sweeps out **equal areas in equal times**. This implies that each planet moves faster when it is closer to the Sun and slower when it is farther away.

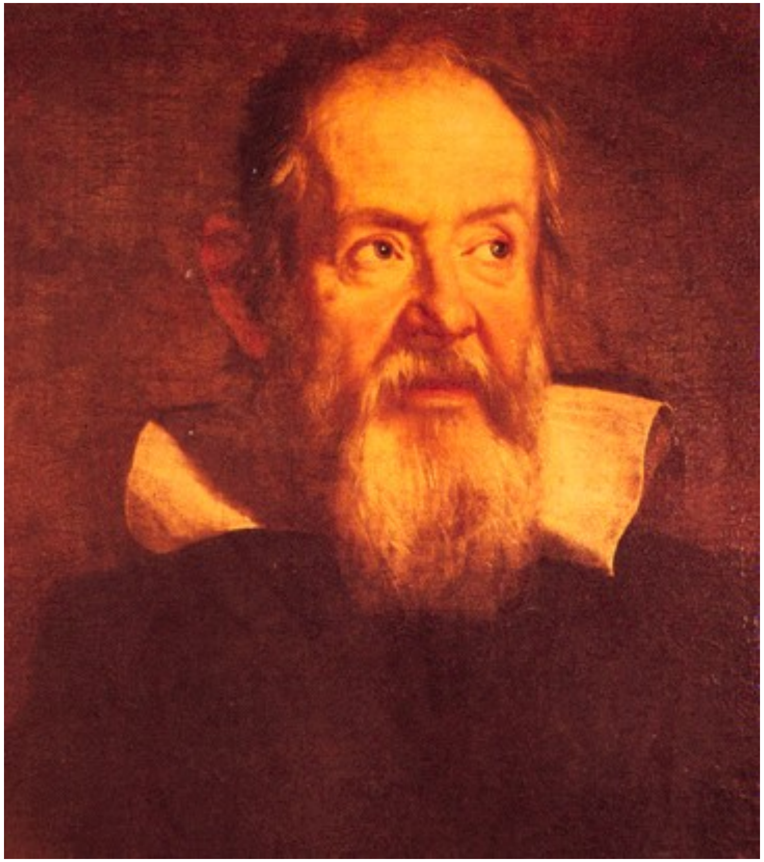
3. The period of each planet is related to its average distance from the Sun by the formula

$$\mathbf{P^2 = a^3},$$

   where *a is the average distance in AU and P is the period in years.* Technically, the "average distance" here is half of the long diameter of the ellipse (half the long diameter is called the "semi-major axis").

Galileo (1564 – 1642)

The first telescope that attracted much attention was built by the Dutch spectacle maker Hans Lippershey in 1608. Galileo, without having seen a telescope, constructed his own, more accurate version. He was the first person to make significant astronomical observations with a telescope --- and they were spectacular.



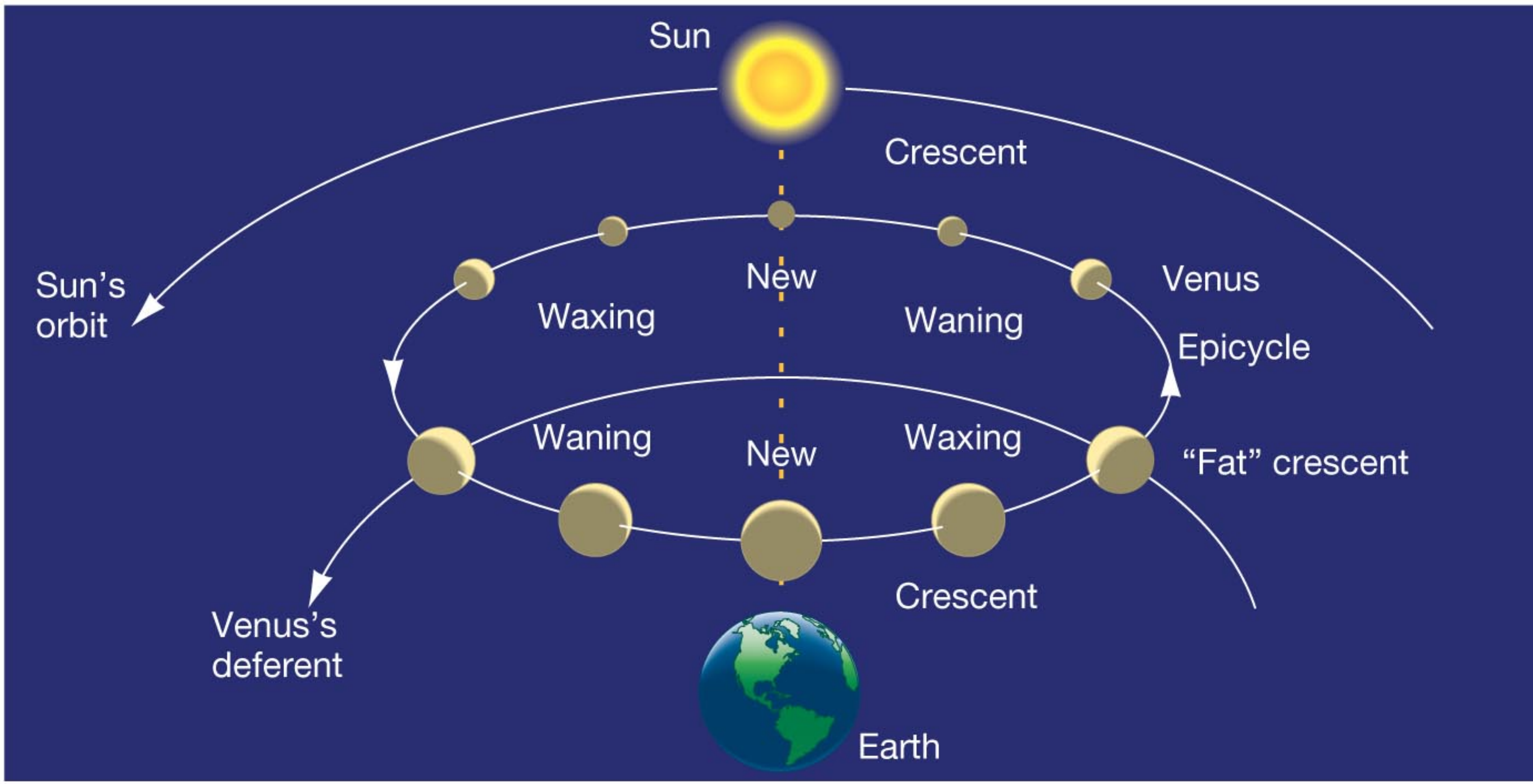
Galileo's Observations

- Four moons of Jupiter (Their orbits about Jupiter turned out to obey Kepler's laws)
- Craters on our Moon
- Spots on the Sun --- found that the Sun rotated by watching the spots move.
- Venus has phases like the moon, and they agree with the Copernican, not the Ptolemaic model.
- He also found far more stars and clusters of stars than anyone had seen before, and he resolved the Milky Way, showing that it is a myriad of stars – but it was not yet clear that we, too, are part of the Milky Way.

In addition, Galileo's experiments with rolling balls show that you do not need a force to keep an object moving, only to change its motion. This was the central fact that allowed Newton to show that Kepler's laws were really consequences of a single law – the law of gravity.

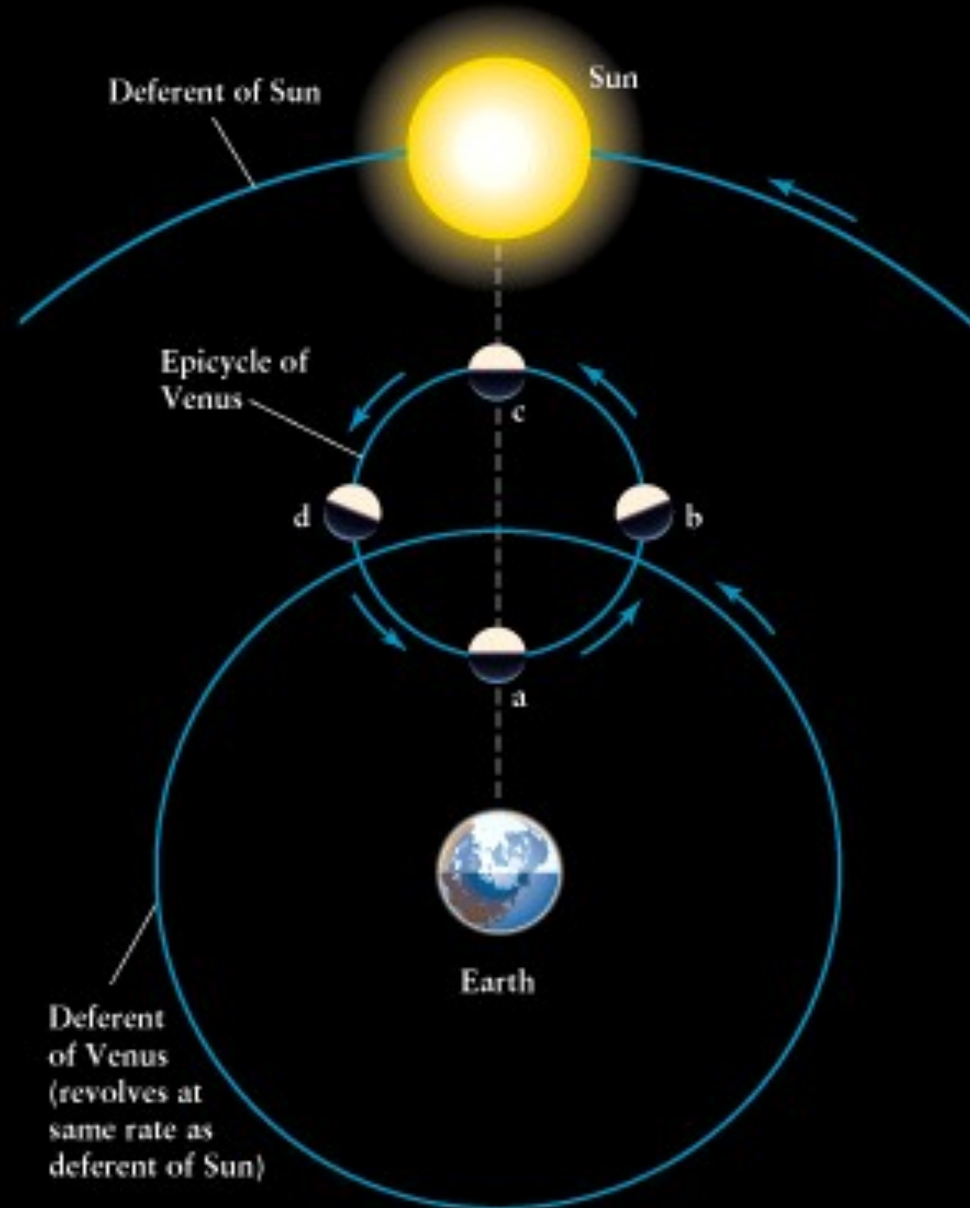
Galileo and the Phases of Venus

- Galileo's observations of Venus verified the Copernican predictions and refuted those of Ptolemy (the Earth-centered model).
- The model must explain both the **phase** (how much of it we see) and the **apparent size** of Venus.
- Here are two diagrams of Venus in different positions along its epicycle in Ptolemy's model.

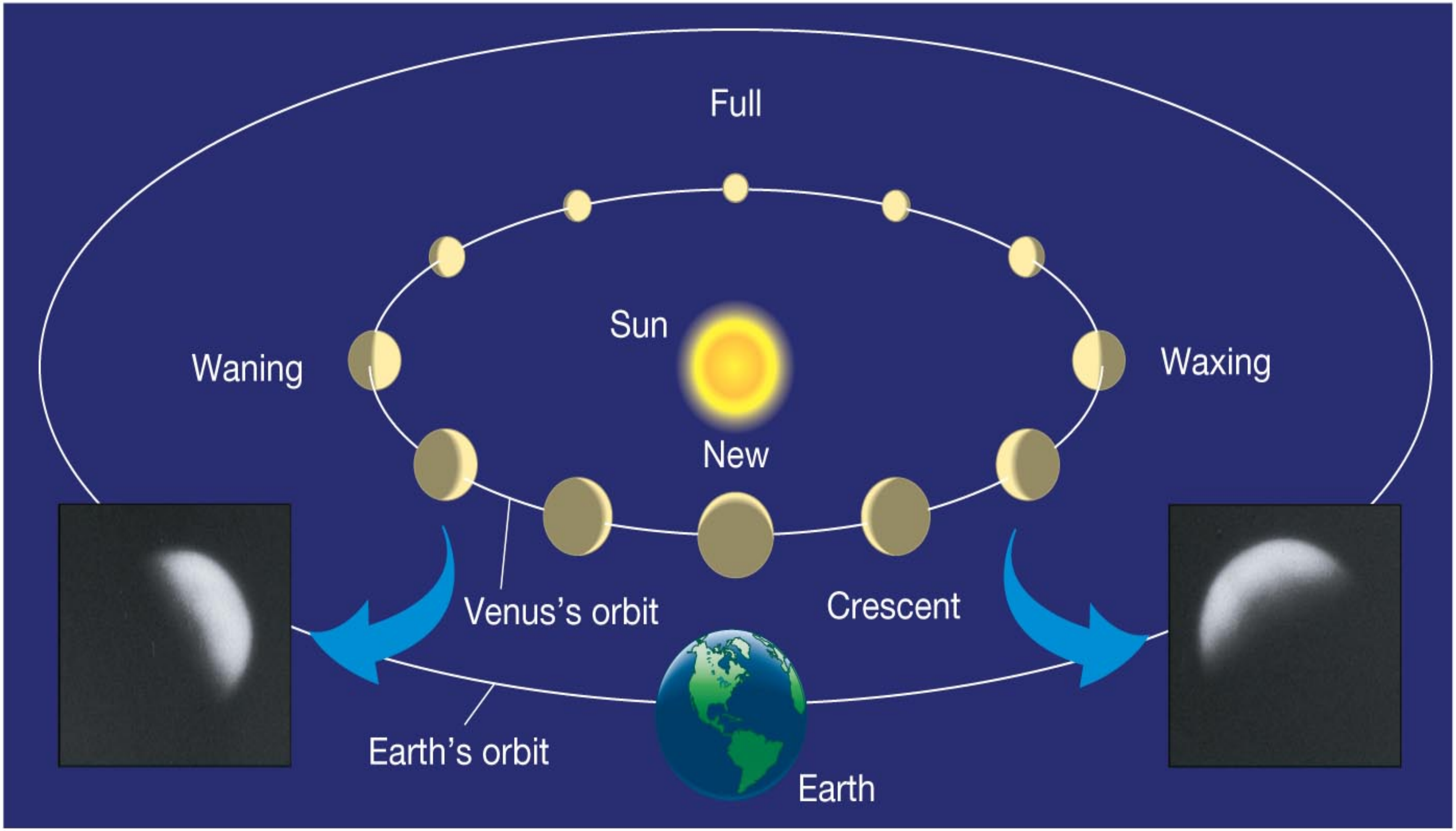


(b) Ptolemy's model

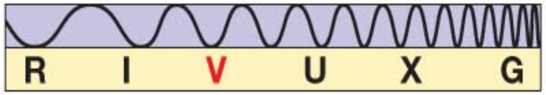
Another diagram of Ptolemy's model. Venus is crescent at all parts of its orbit, going from new to crescent to fatter crescent and back to new.



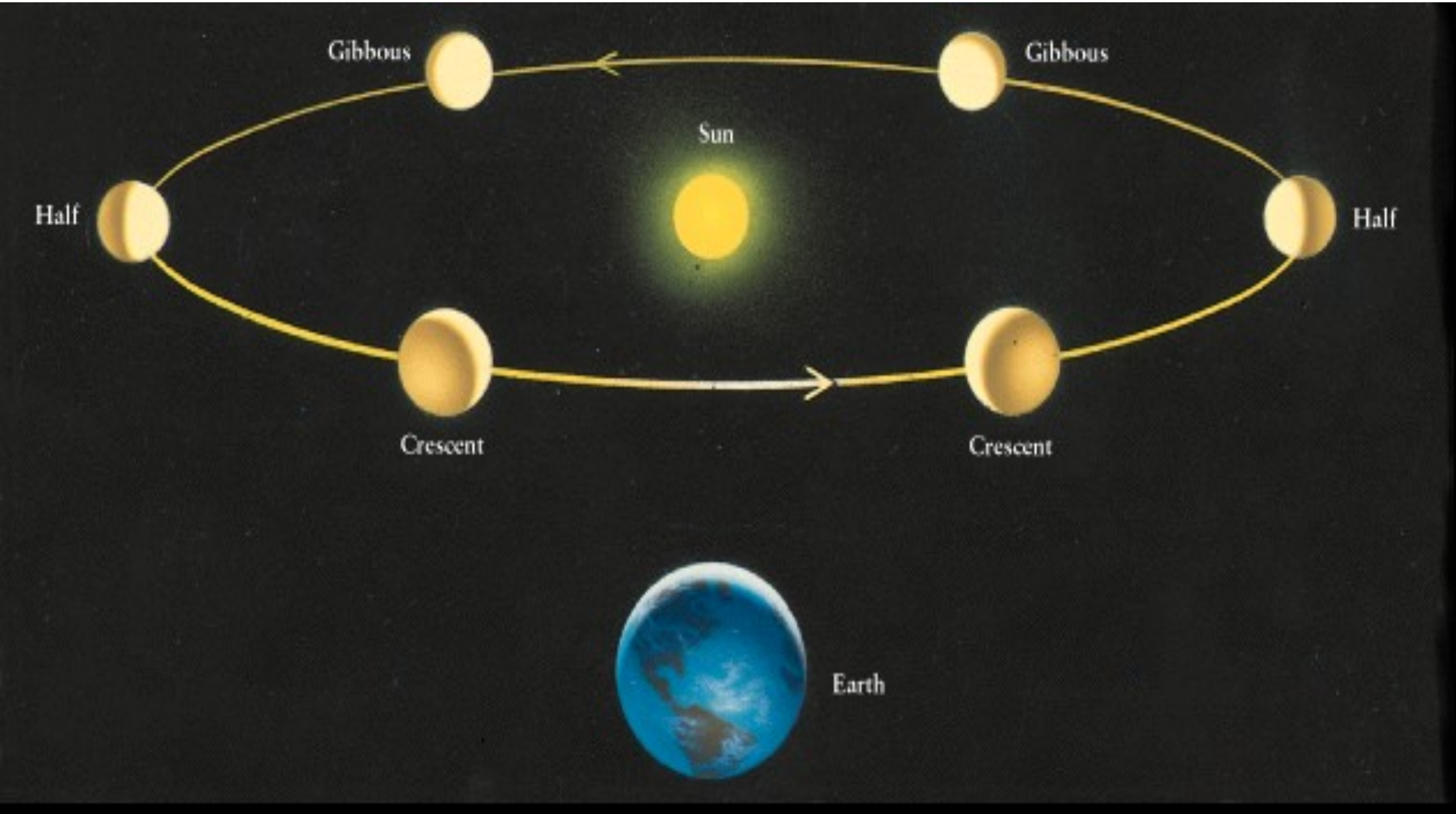
Next, two diagrams of the Copernican (Sun-centered) model:



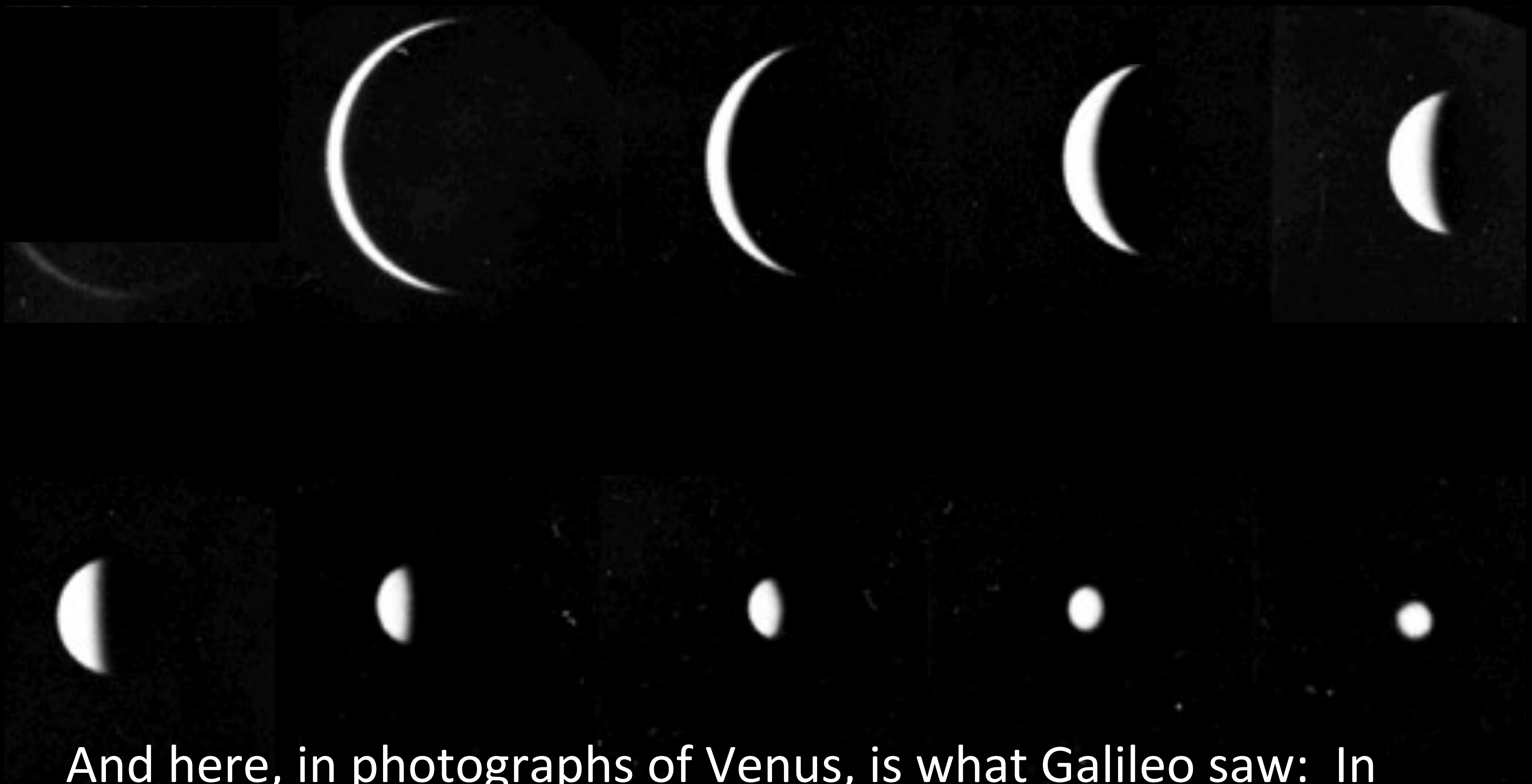
(a) Sun-centered model



The Copernican model predicts a crescent Venus when it is closest to Earth, and a gibbous Venus when it is furthest from the Earth (Venus can’t be seen when it’s full because it’s behind the Sun).



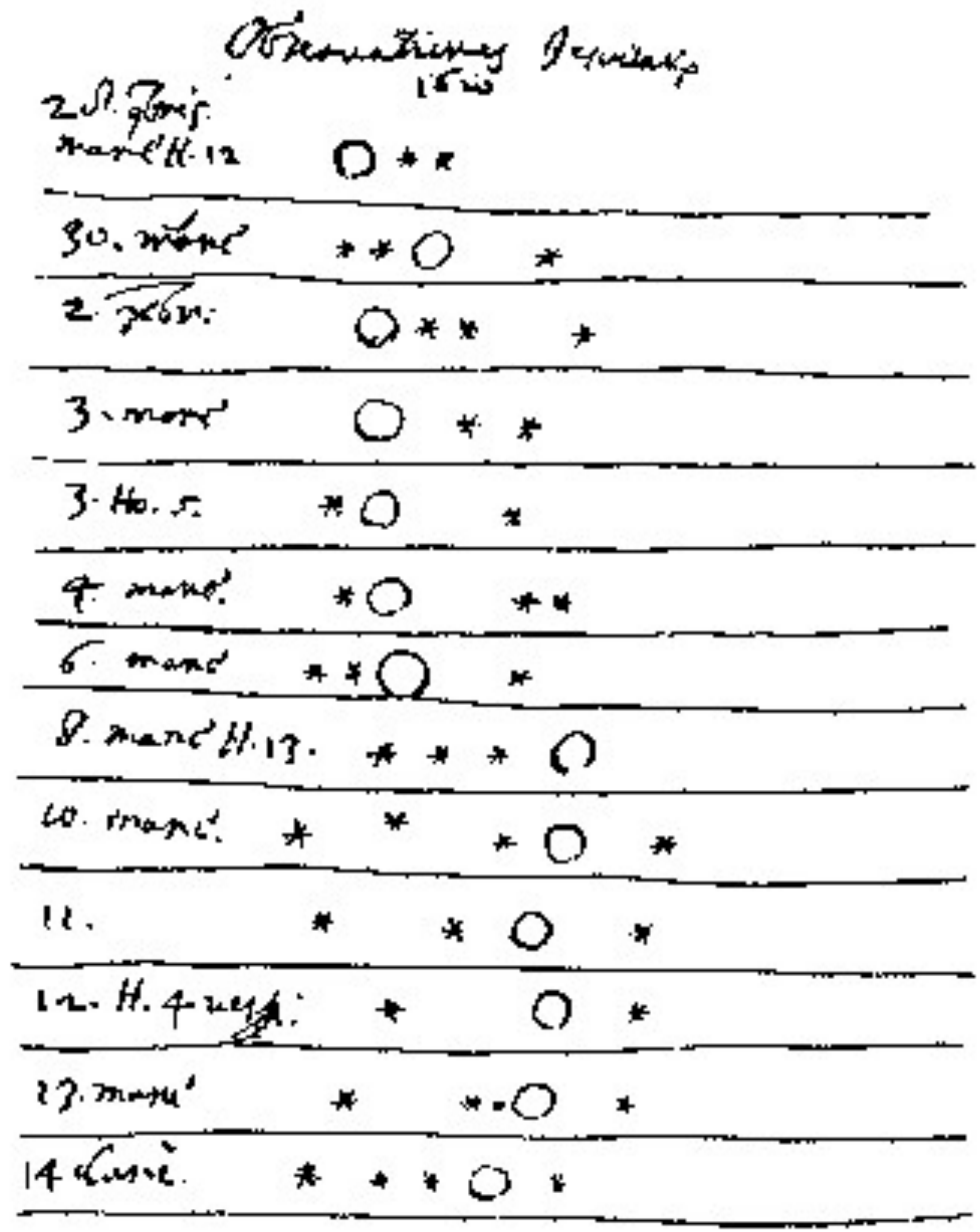
Venus over a several month period



And here, in photographs of Venus, is what Galileo saw: In exact agreement with the Copernican (Sun-centered) model, Venus shows all phases, is crescent when closest (largest) and gibbous when furthest away (smallest)

Galileo also discovered 4 Moons of Jupiter

and checked that they obeyed Kepler's 3rd law



Galileo’s sketches of the Moon

Galileo's important ***astronomical*** observations:

- Phases of Venus, agreeing with Copernican model

- Craters on the Moon

- 4 moons of Jupiter

- The Milky Way seen as a vast collection of stars

- Sunspots, whose motion showed that the Sun rotates slowly

- Rings of Saturn
(he couldn't see them well enough to know they were rings)

But Galileo also made essential contributions to physics, the nature of motion, and gravity (close to the earth) in particular