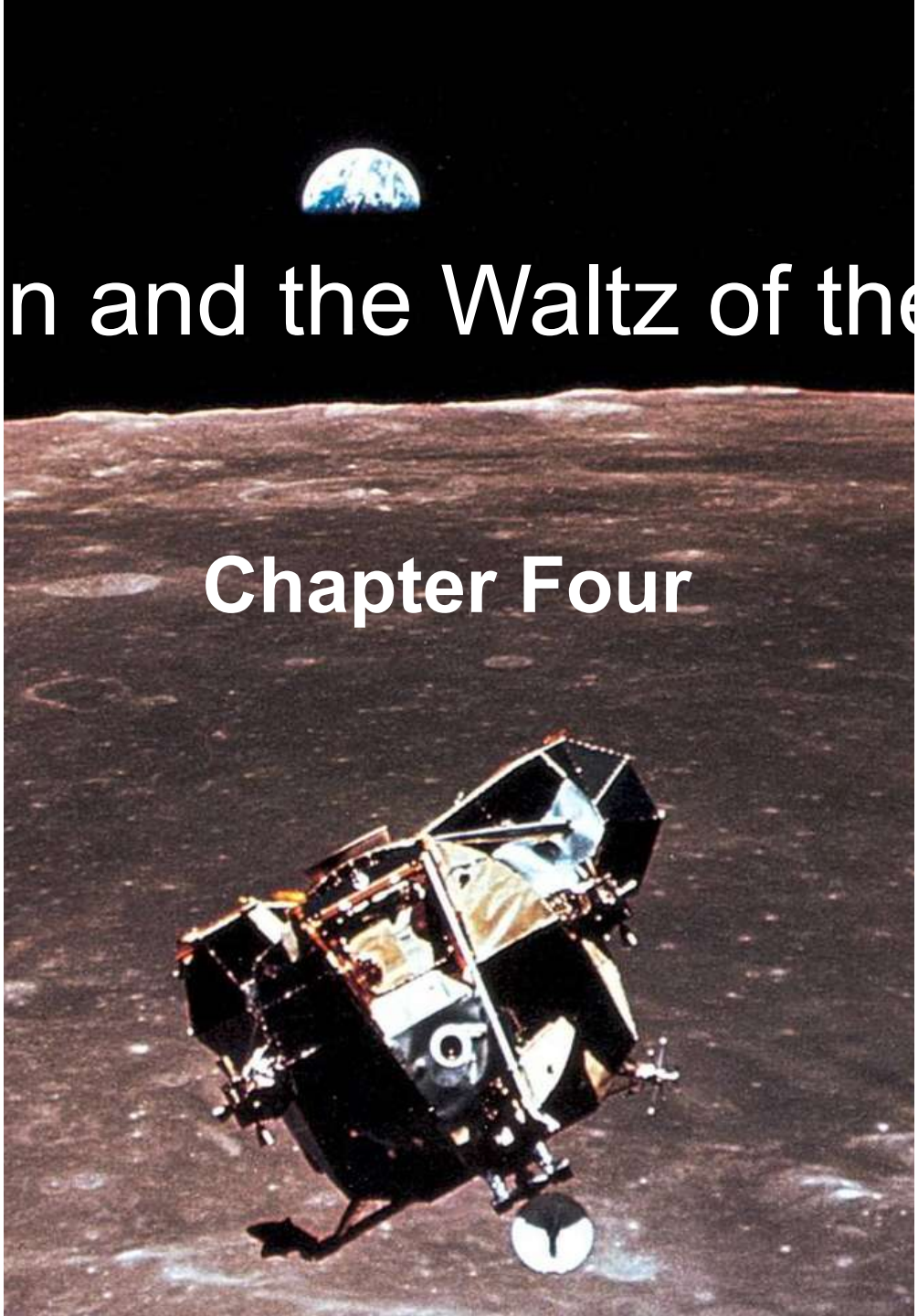
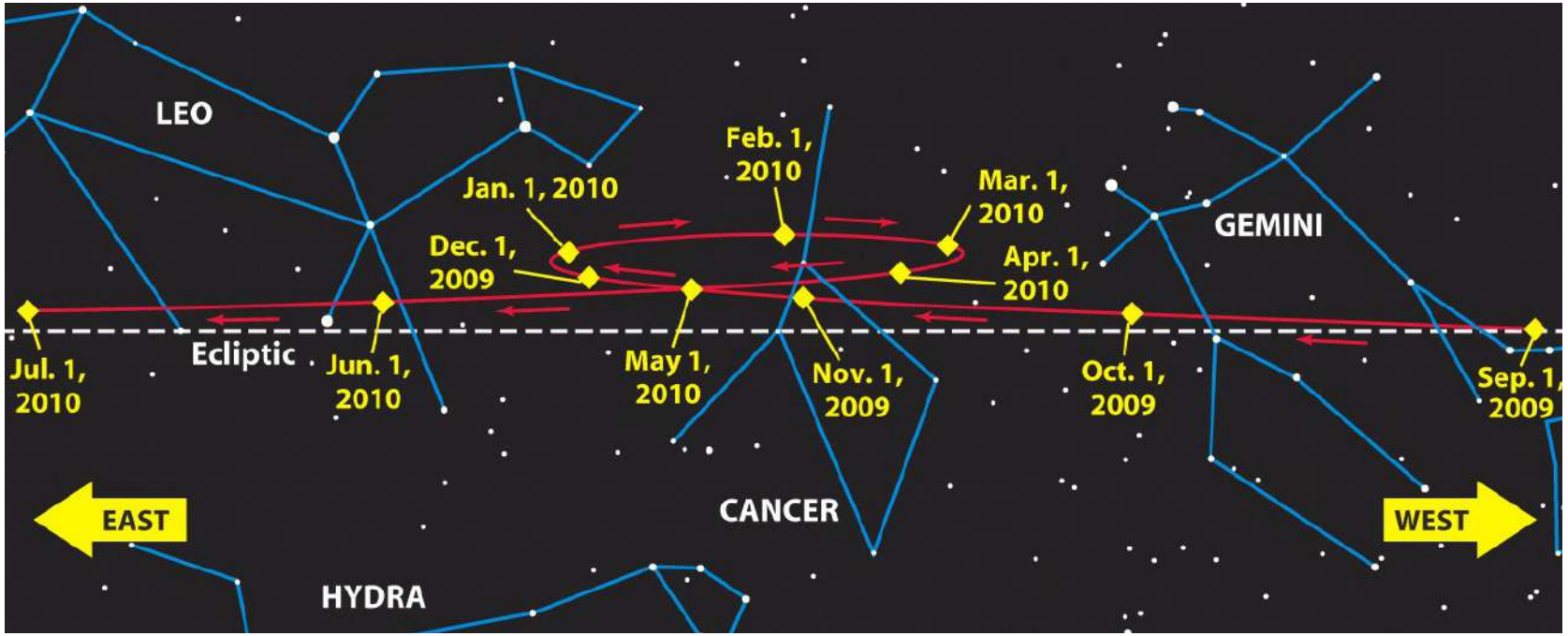
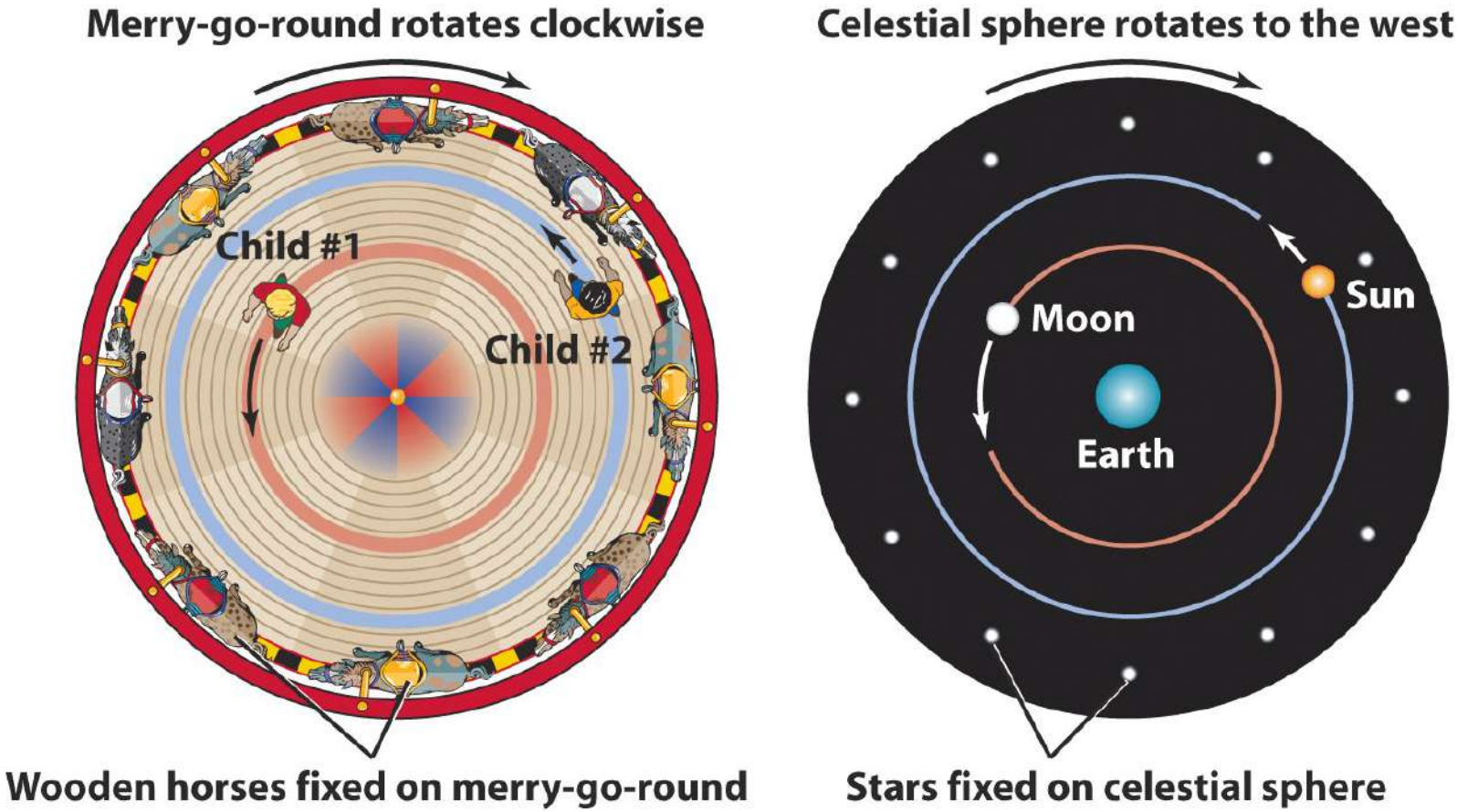

n and the Waltz of the
Chapter Four

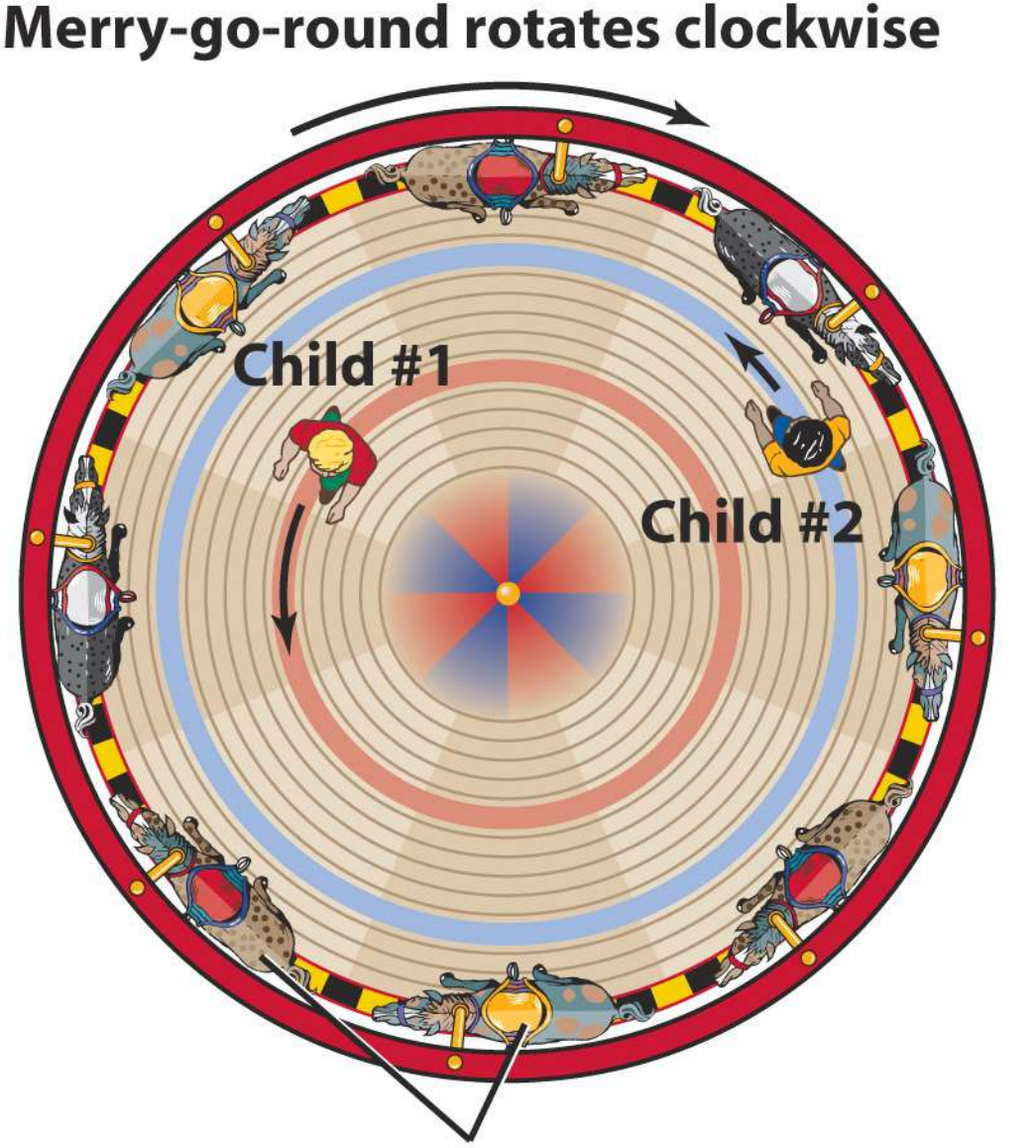

Total Lunar eclipse 16-05-2003
Philippus Lansbergen
Middelburg
Nederland
Rijk-Jan Koppejan


LEO
Feb. 1, 2010
Jan. 1, 2010
Mar. 1, 2010
GEMINI
Dec. 1, 2009
Apr. 1, 2010
Jul. 1, 2010
Ecliptic
Jun. 1, 2010
May 1, 2010
Nov. 1, 2009
Oct. 1, 2009
Sep. 1, 2009
EAST
CANCER
WEST
HYDRA

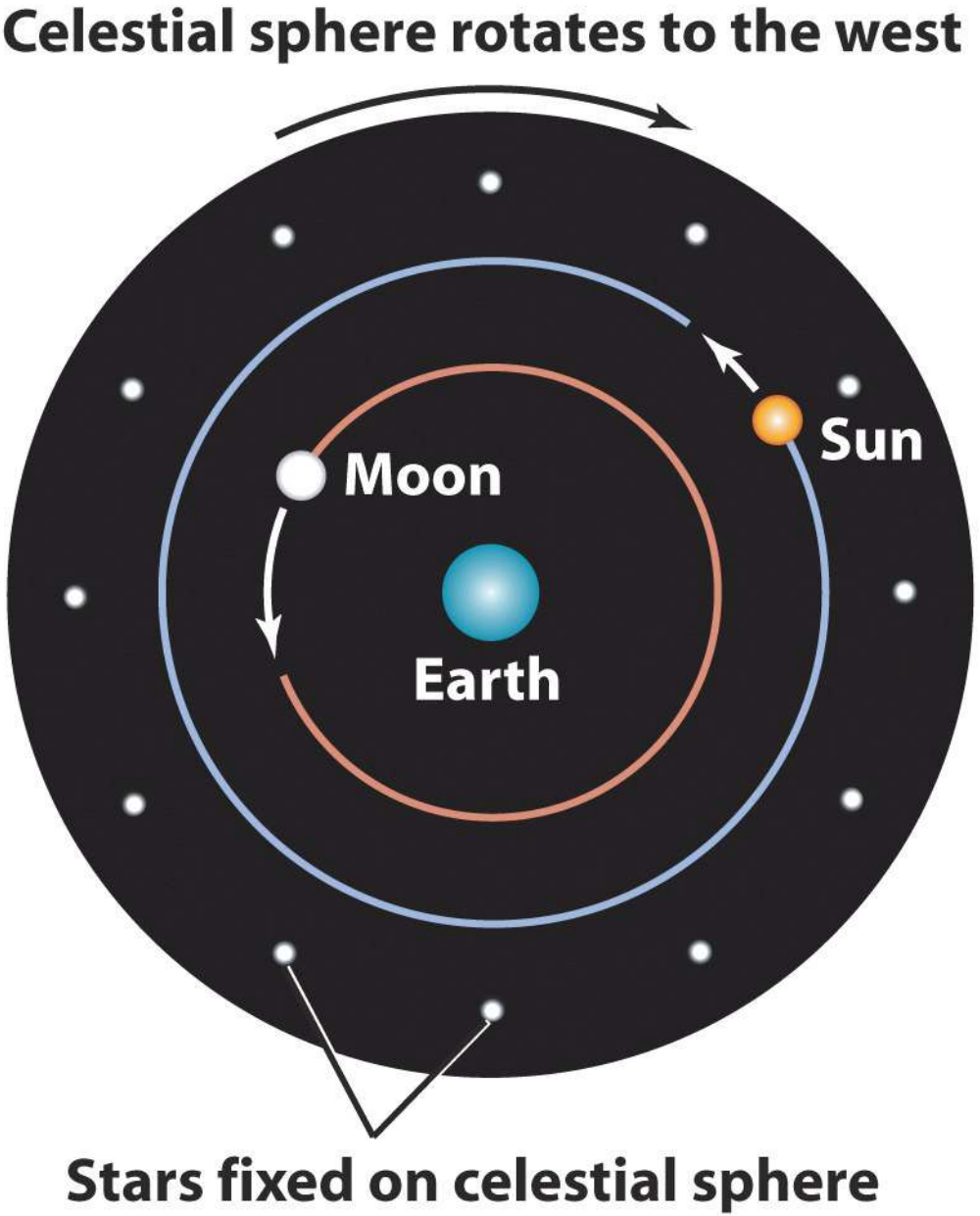
- Ancient astronomers believed the Earth to be at the center of the universe
- They invented a complex system of epicycles and deferents to explain the direct and retrograde motions of the planets on the celestial sphere

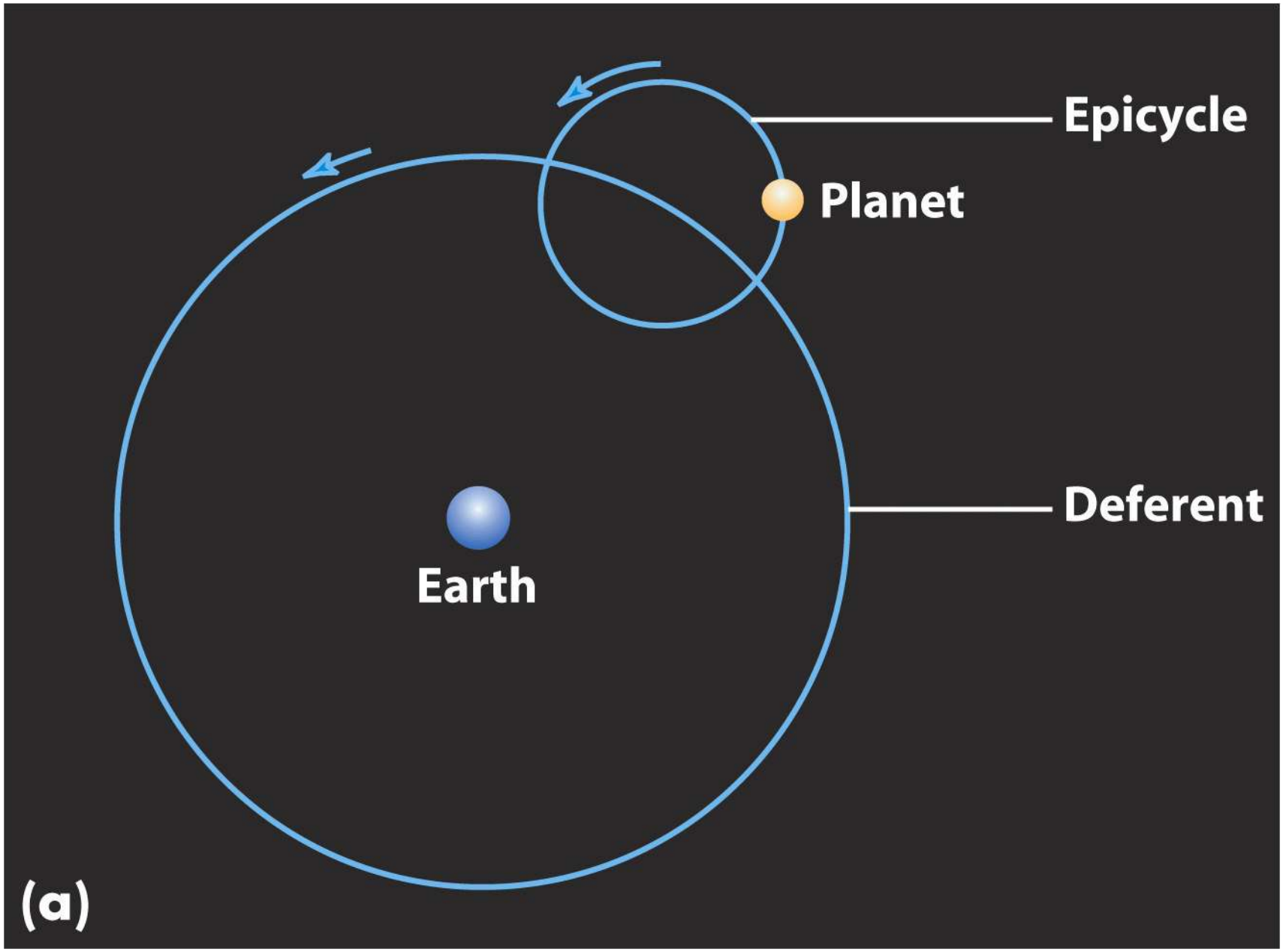


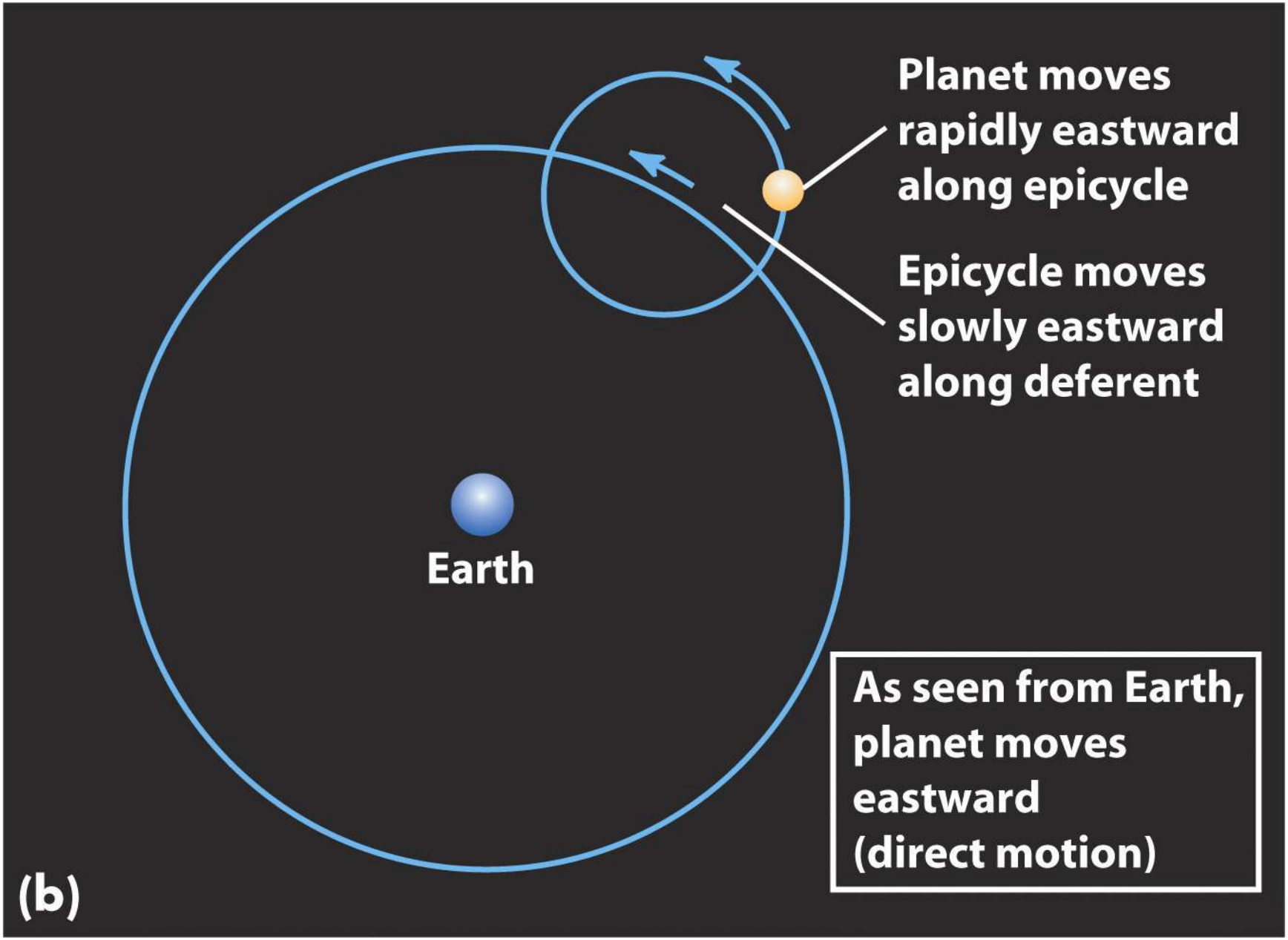
A rotating merry-go-round

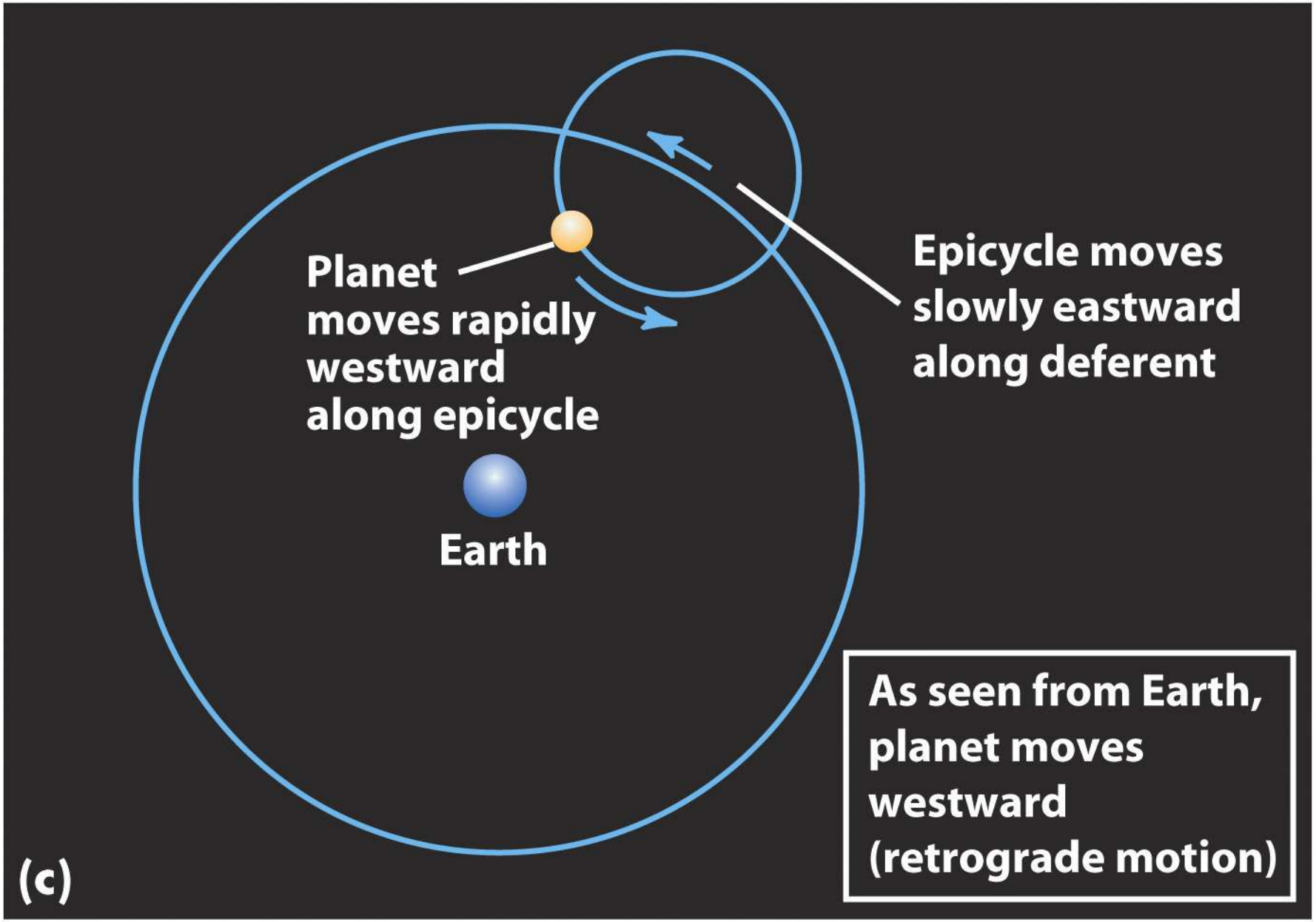


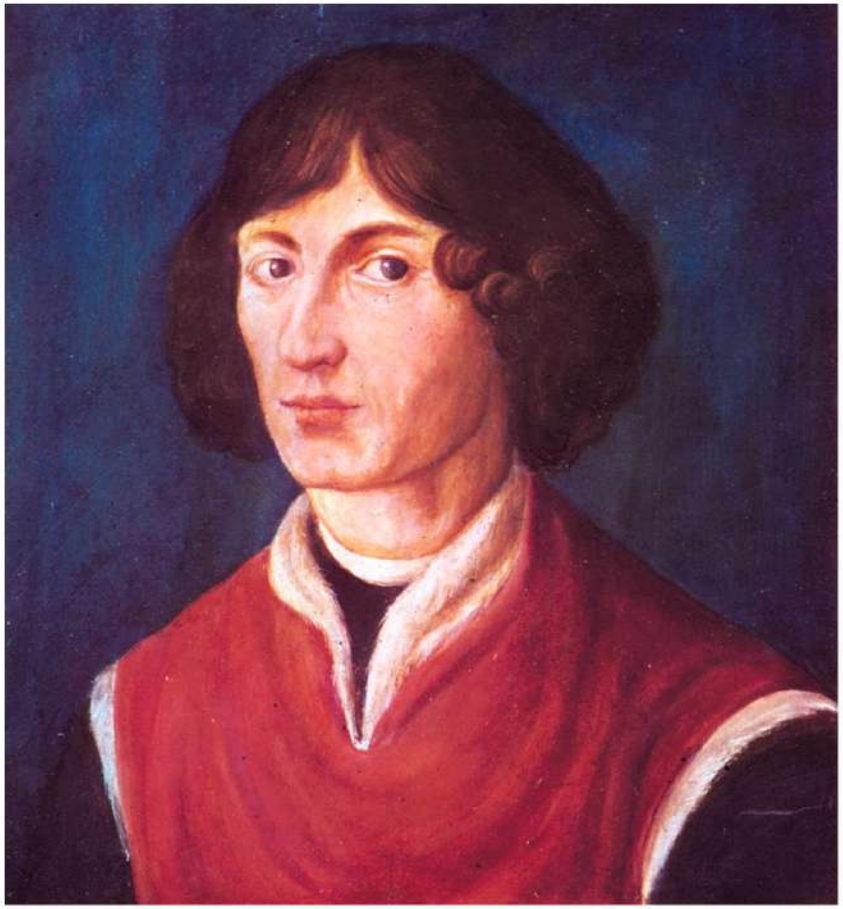
The Greek geocentric model

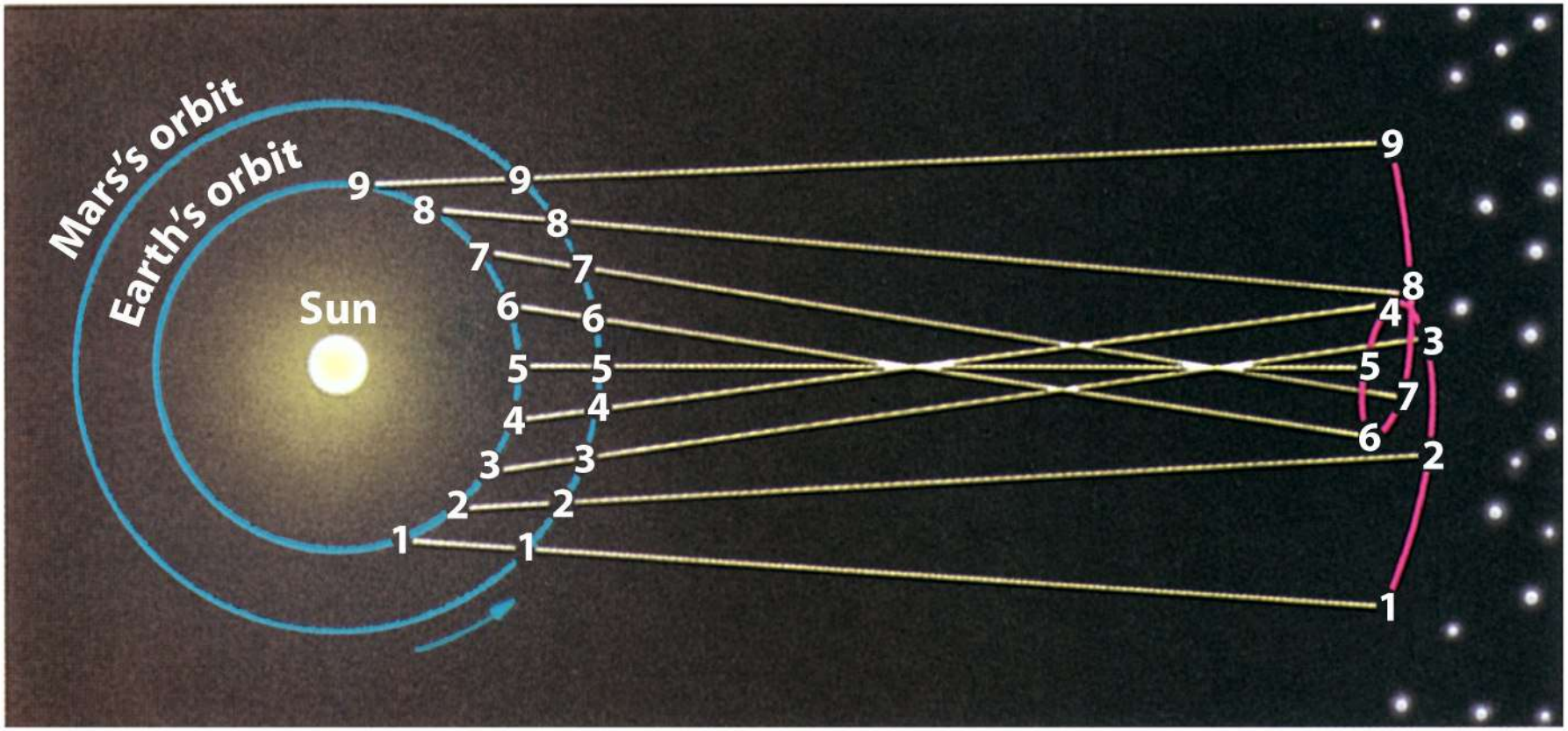



Epicycle
Planet
Deferent
Earth
(a)

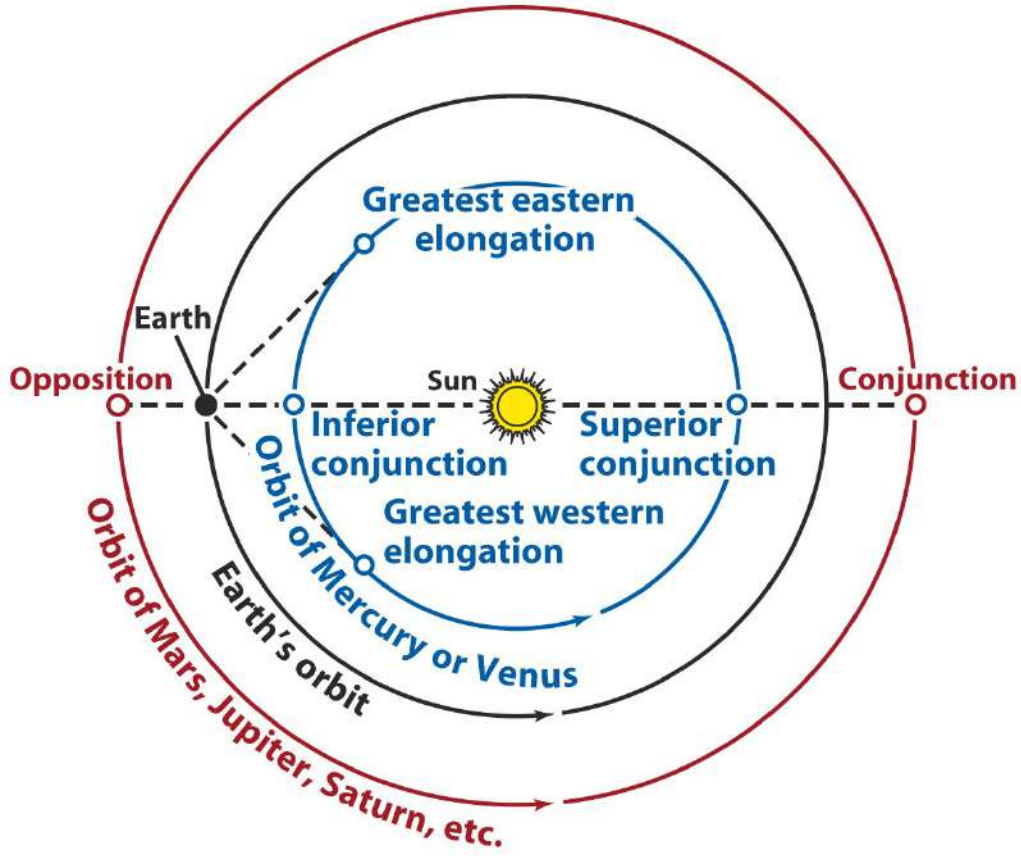

Planet moves rapidly eastward along epicycle
Epicycle moves slowly eastward along deferent
Earth
As seen from Earth, planet moves eastward (direct motion)
(b)


Planet
moves rapidly
westward
along epicycle
Epicycle moves
slowly eastward
along deferent
Earth
As seen from Earth,
planet moves
westward
(retrograde motion)
(c)




Mars's orbit
Earth's orbit
Sun
9
8
7
6
5
4
3
2
1

A planet's synodic period is measured with respect to the Earth and the Sun (for example, from one opposition to the next)



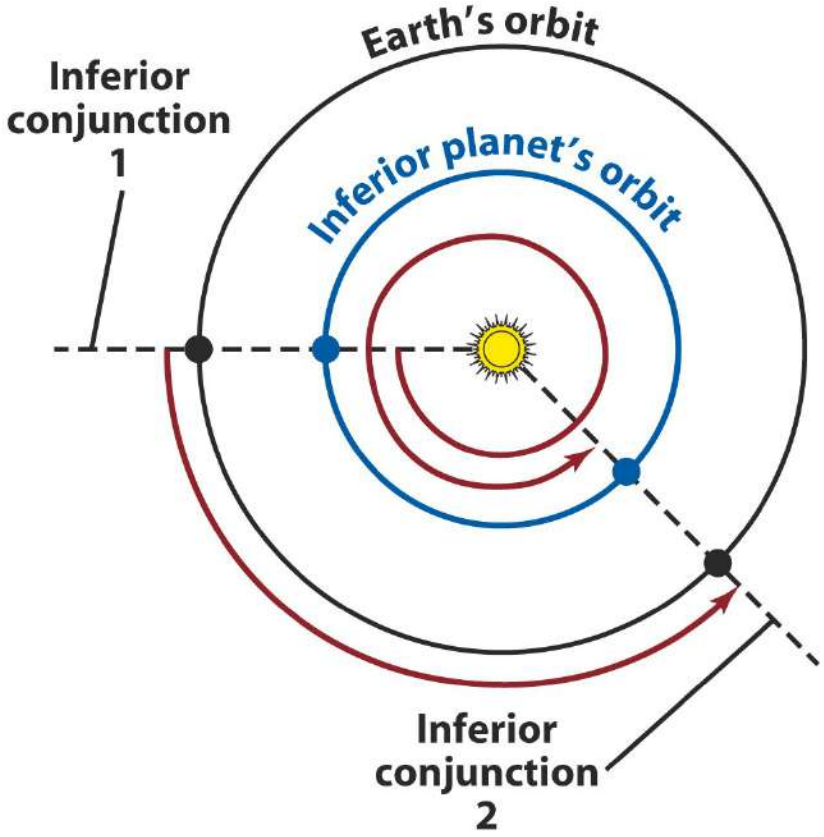


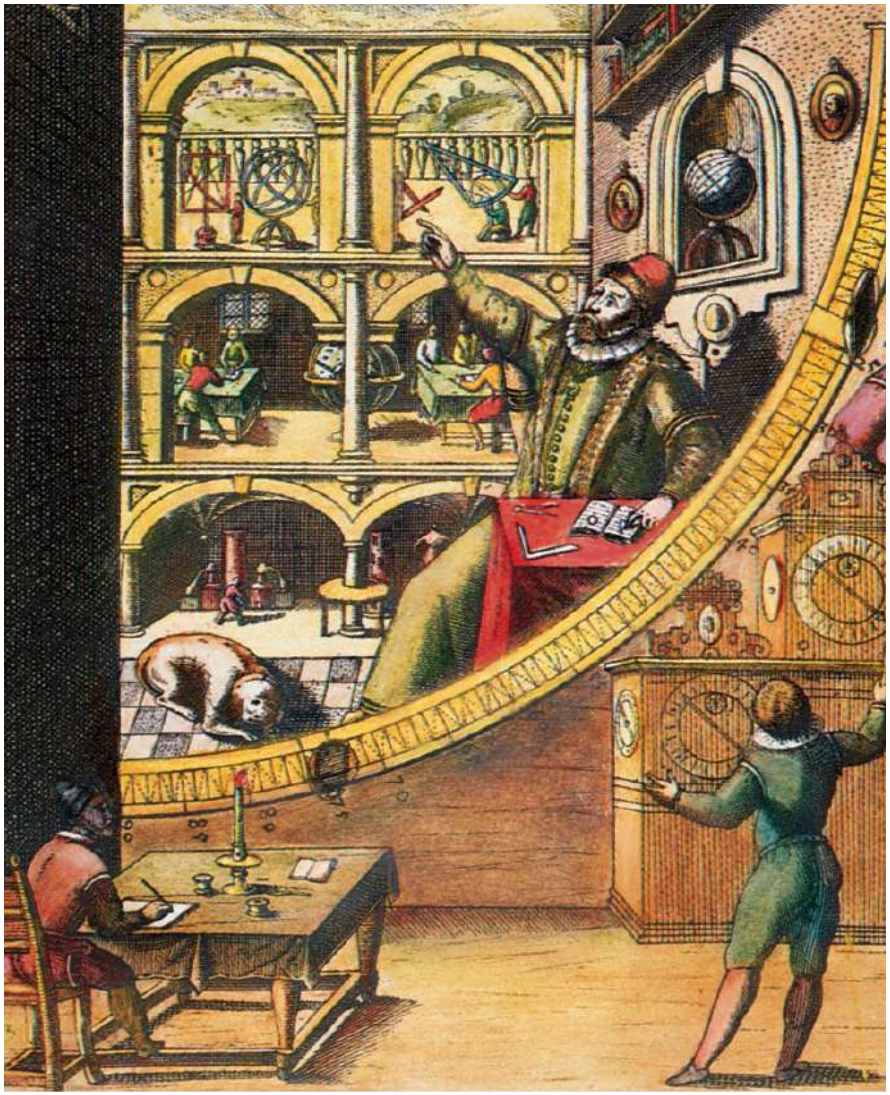
table 4-2 Average Distances of the Planets from the Sun

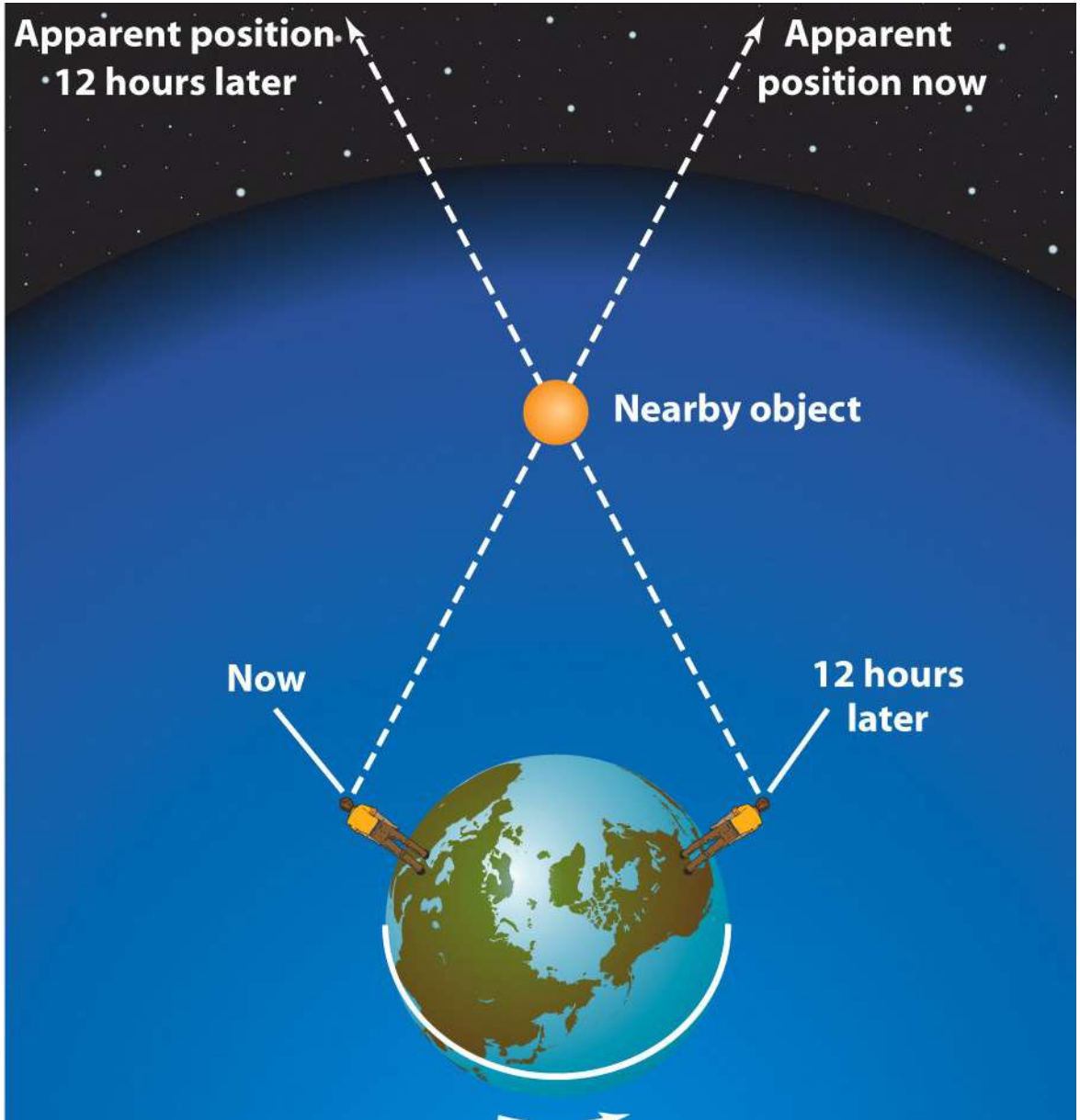
Planet	Copernican value (AU*)	Modern value (AU)
Mercury	0.38	0.39
Venus	0.72	0.72
Earth	1.00	1.00
Mars	1.52	1.52
Jupiter	5.22	5.20
Saturn	9.07	9.55
Uranus	—	19.19
Neptune	—	30.07
Pluto	—	39.54

**1 AU = 1 astronomical unit = average distance from the Earth to the Sun.*

table 4-1 Synodic and Sidereal Periods of the Planets

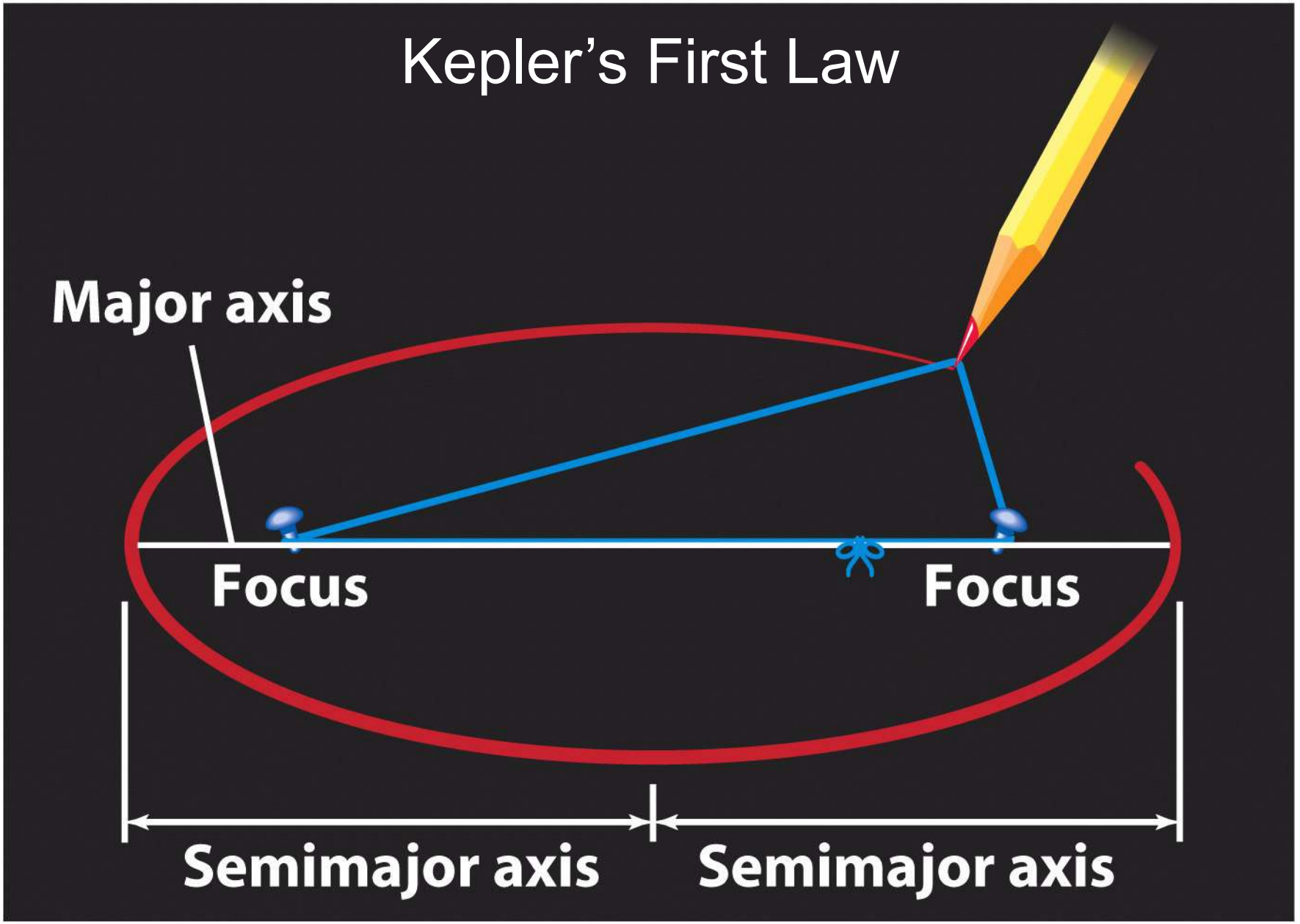
Planet	Synodic period	Sidereal period
Mercury	116 days	88 days
Venus	584 days	225 days
Earth	—	1.0 year
Mars	780 days	1.9 years
Jupiter	399 days	11.9 years
Saturn	378 days	29.5 years
Uranus	370 days	84.1 years
Neptune	368 days	164.9 years
Pluto	367 days	248.6 years

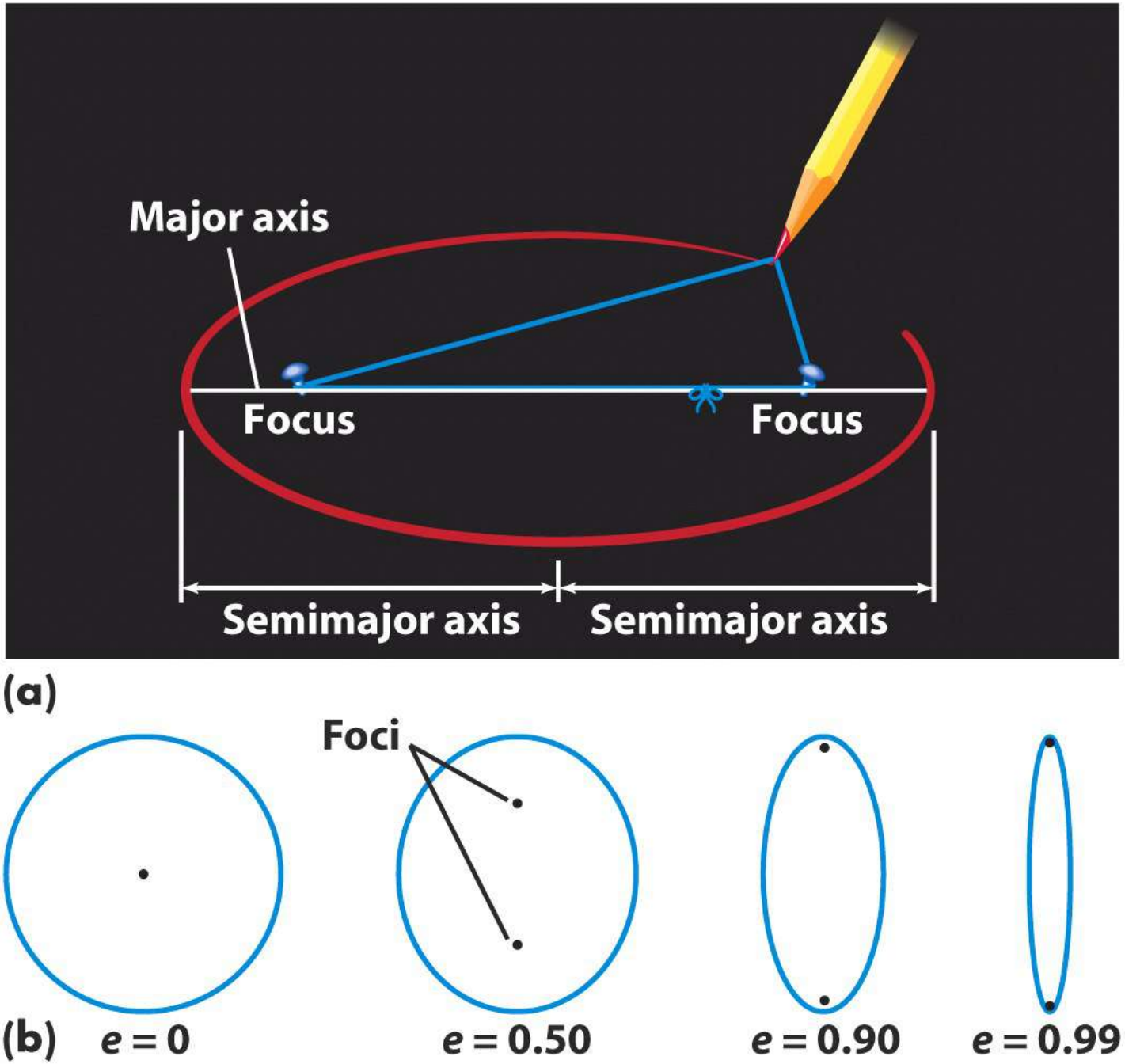



Apparent position 12 hours later
Apparent position now
Nearby object
Now
12 hours later


IOANNIS KEPPLERI
Mathematici Cæſarei
hanc Imaginem
ARGENTORATENSI BIBLIOTHECÆ
Conſecr.
MATTHIAS BERNEGGERUS
Kal. Ianuar. Anno Chr.
M DC. XXVII

Kepler's First Law




Major axis
Focus
Focus
Semimajor axis
Semimajor axis
(a)
Foci
(b)
e = 0
e = 0.50
e = 0.90
e = 0.99

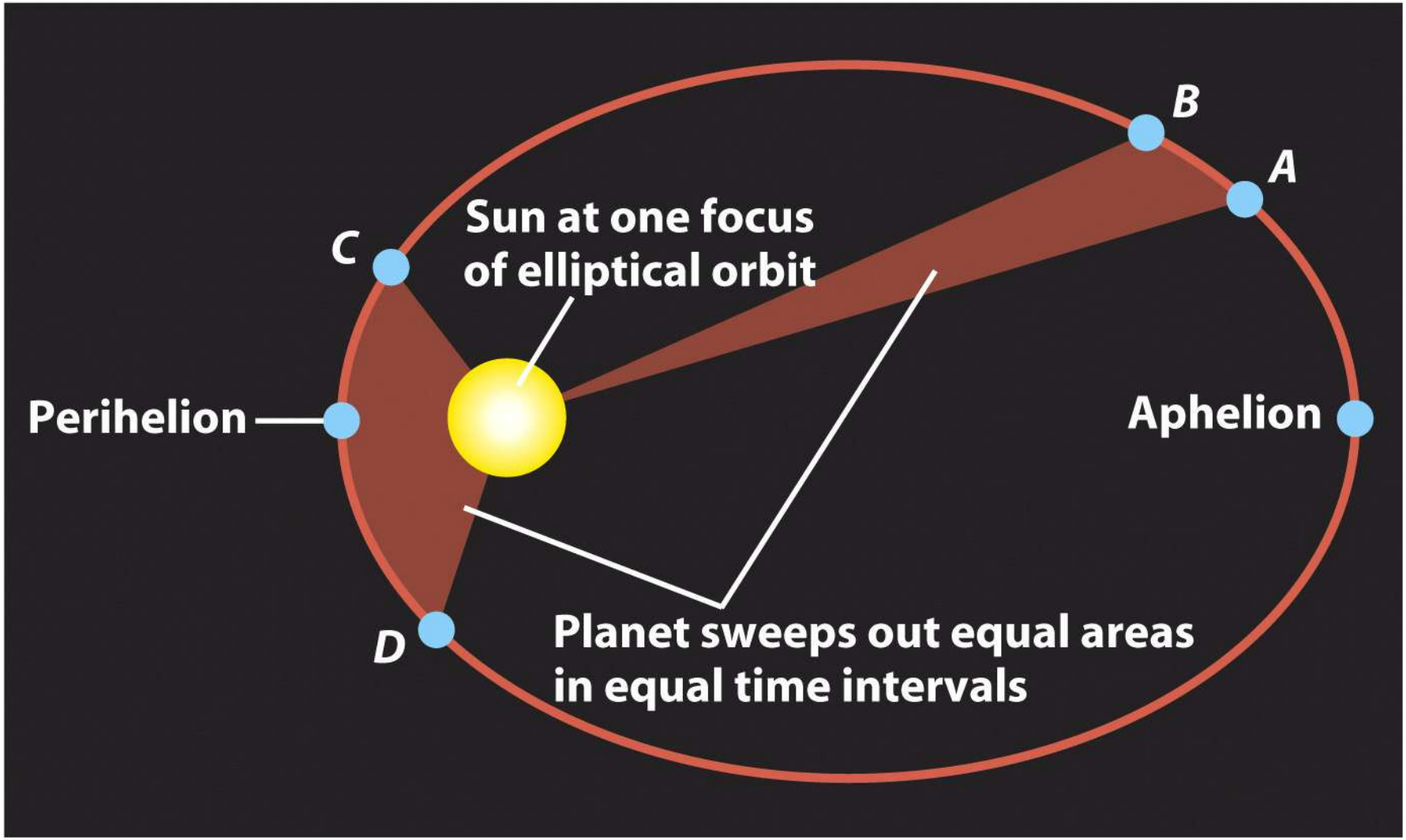
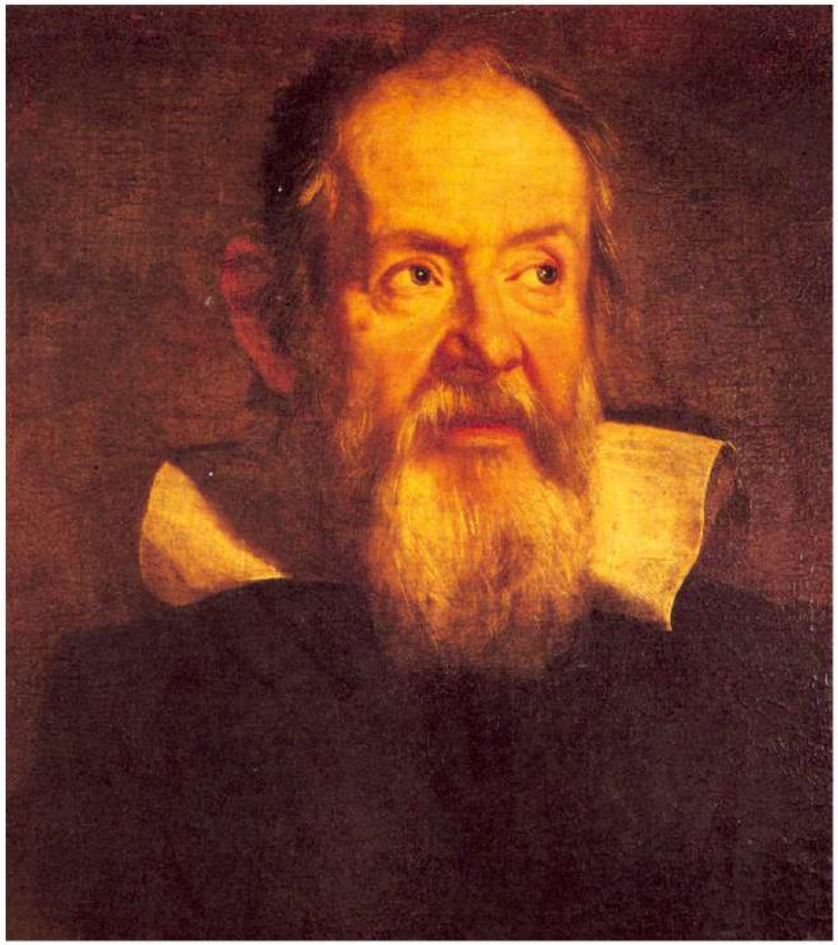
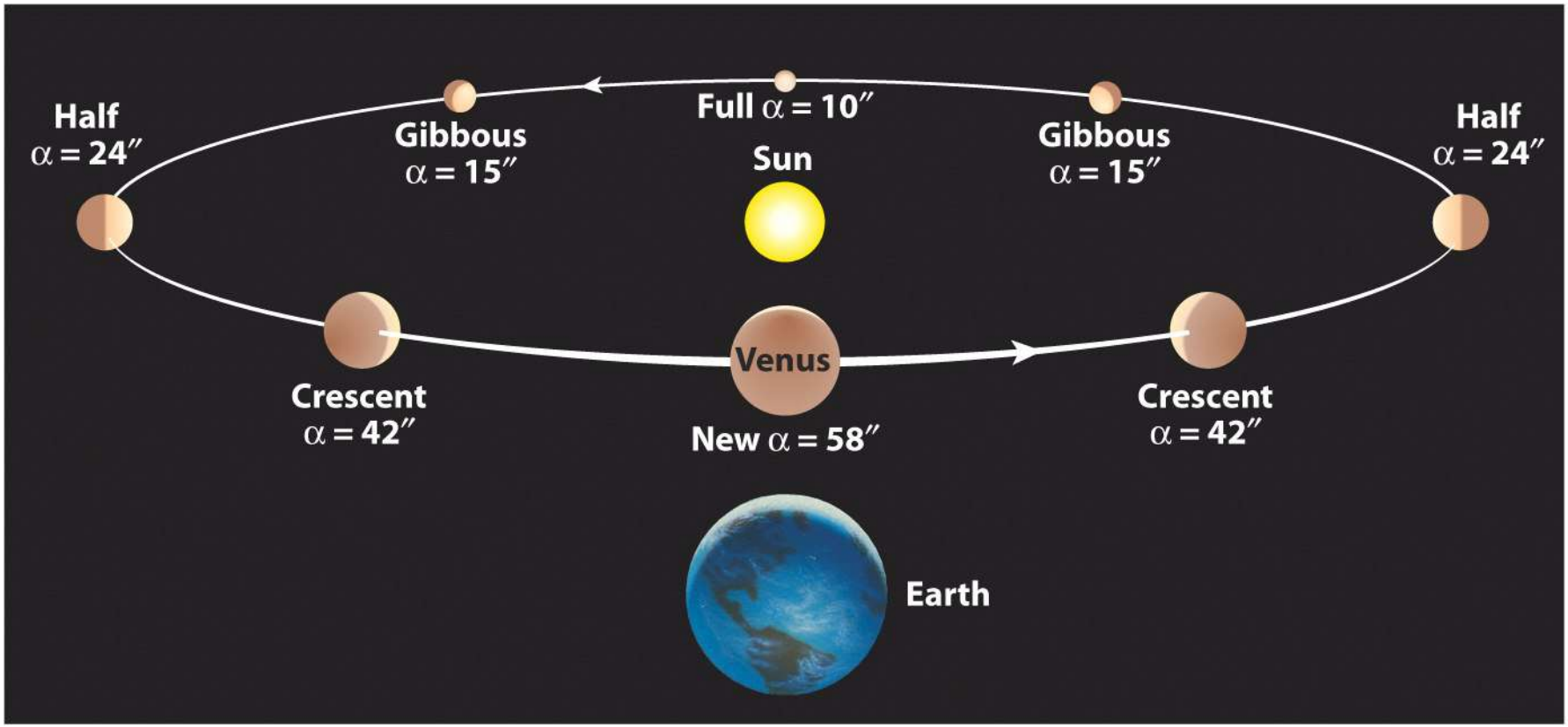

B
A
C
Sun at one focus
of elliptical orbit
Perihelion
Aphelion
D
Planet sweeps out equal areas
in equal time intervals

table 4-3 A Demonstration of Kepler's Third Law ($P^2 = a^3$)

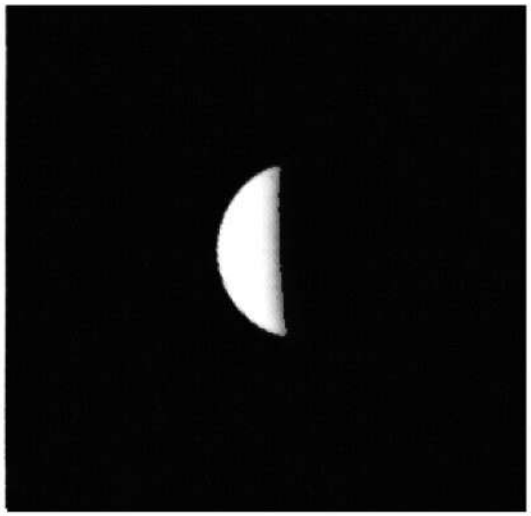
Planet	Sidereal period P (years)	Semimajor axis a (AU)	P^2	a^3
Mercury	0.24	0.39	0.06	0.06
Venus	0.61	0.72	0.37	0.37
Earth	1.00	1.00	1.00	1.00
Mars	1.88	1.52	3.53	3.51
Jupiter	11.86	5.20	140.7	140.6
Saturn	29.46	9.55	867.9	871.0
Uranus	84.10	19.19	7,072	7,067
Neptune	164.86	30.07	27,180	27,190
Pluto	248.60	39.54	61,800	61,820



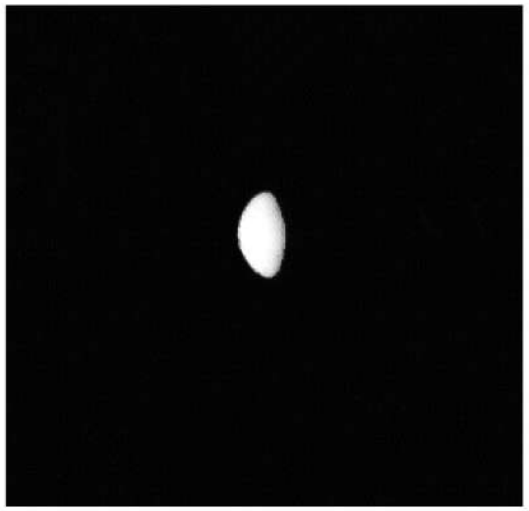

Half
α = 24″
Gibbous
α = 15″
Full α = 10″
Sun
Gibbous
α = 15″
Half
α = 24″
Crescent
α = 42″
Venus
New α = 58″
Crescent
α = 42″
Earth

$\alpha = 58^\circ$

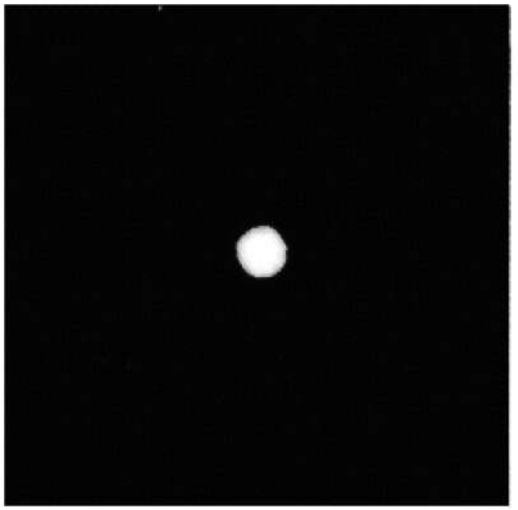
$\alpha = 42^\circ$



$\alpha = 24^\circ$

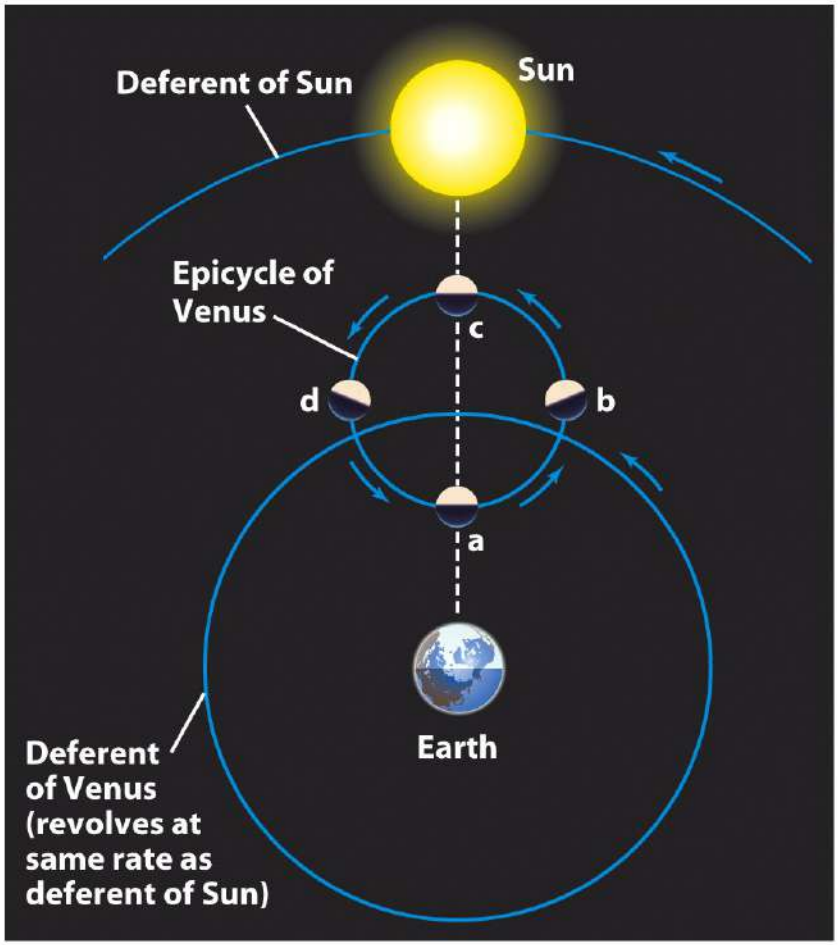


$\alpha = 15^\circ$



$\alpha = 10^\circ$

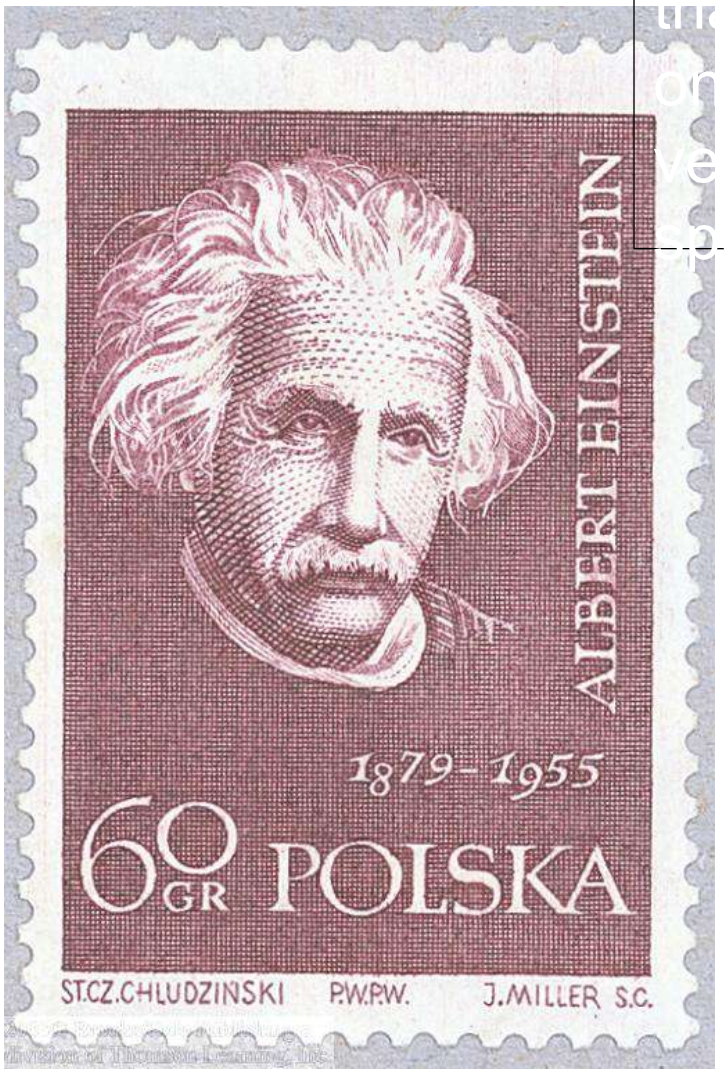
There is a correlation between the phases of Venus and the planet's angular distance from the Sun


Deferent of Sun
Sun
Epicycle of Venus
c
d
b
a
Earth
Deferent of Venus (revolves at same rate as deferent of Sun)

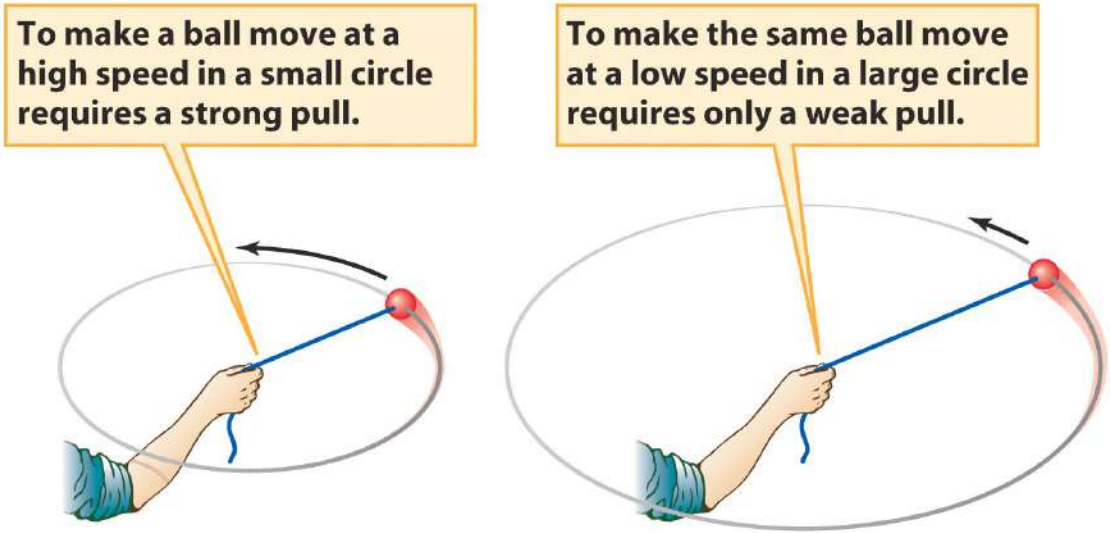
Observationes Jesuitarum
1643

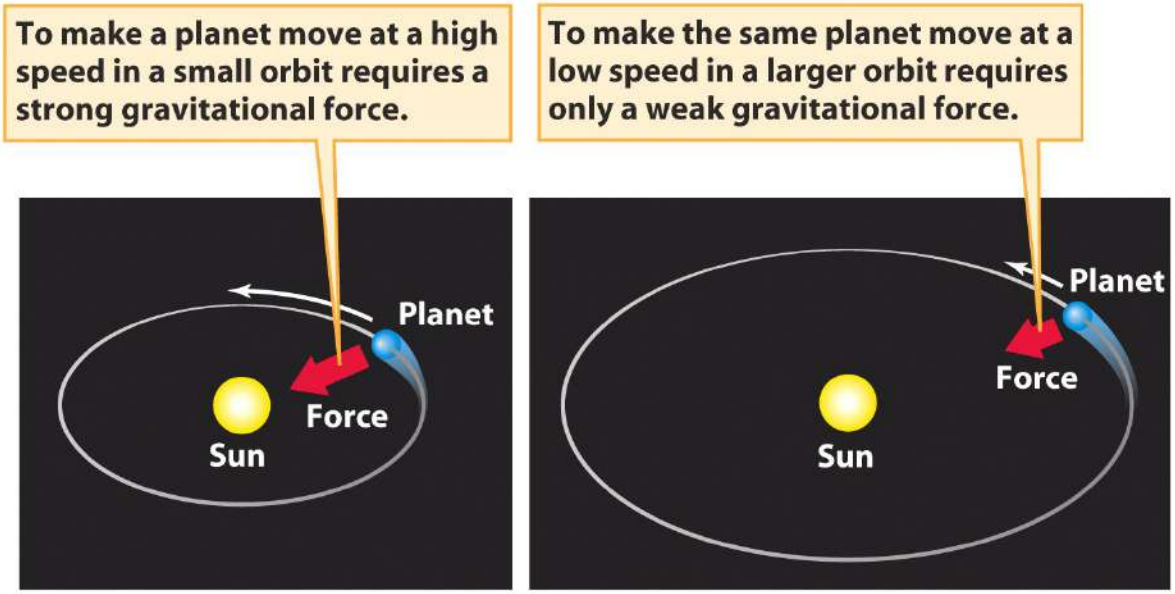
28. Jan. mane H. 12	○	*	*	
30. mane	*	*	○	*
2. Febr.	○	*	*	*
3. mane	○	*	*	
3. Ho. 5.	*	○	*	
4. mane	*	○	*	*
6. mane	*	*	○	*
8. mane H. 13.	*	*	*	○
10. mane	*	*	*	○ *
11.	*	*	○	*
12. H. 4 vesp.	*	○	*	
13. mane	*	*	○	*
14 Mane	*	*	*	○ *

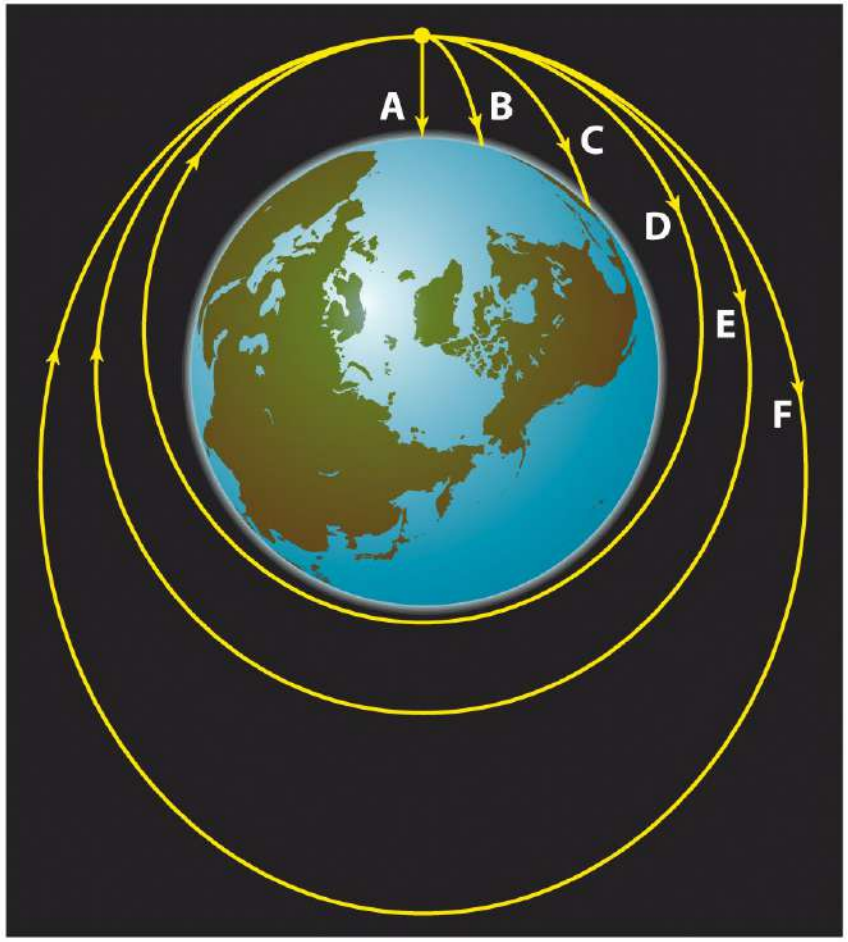
$$F = G\left(\frac{m_1 m_2}{r^2}\right)$$


ALBERT EINSTEIN
1879 - 1955
60 GR POLSKA
ST.CZ.CHLUDZINSKI P.W.P.W. J.MILLER S.C.

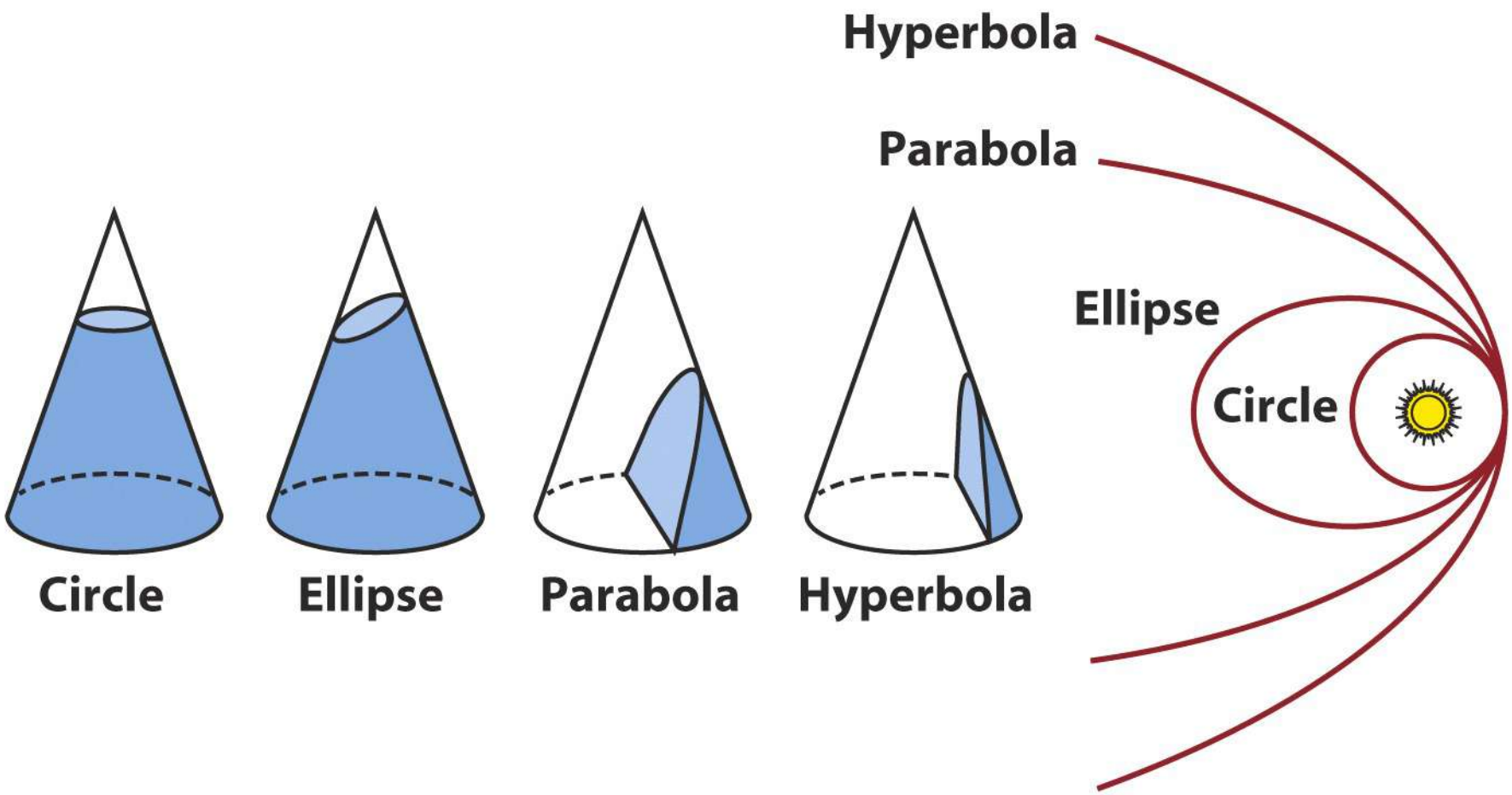
Newton's description of gravity accounts for Kepler's laws and explains the motions of the planets and other orbiting bodies

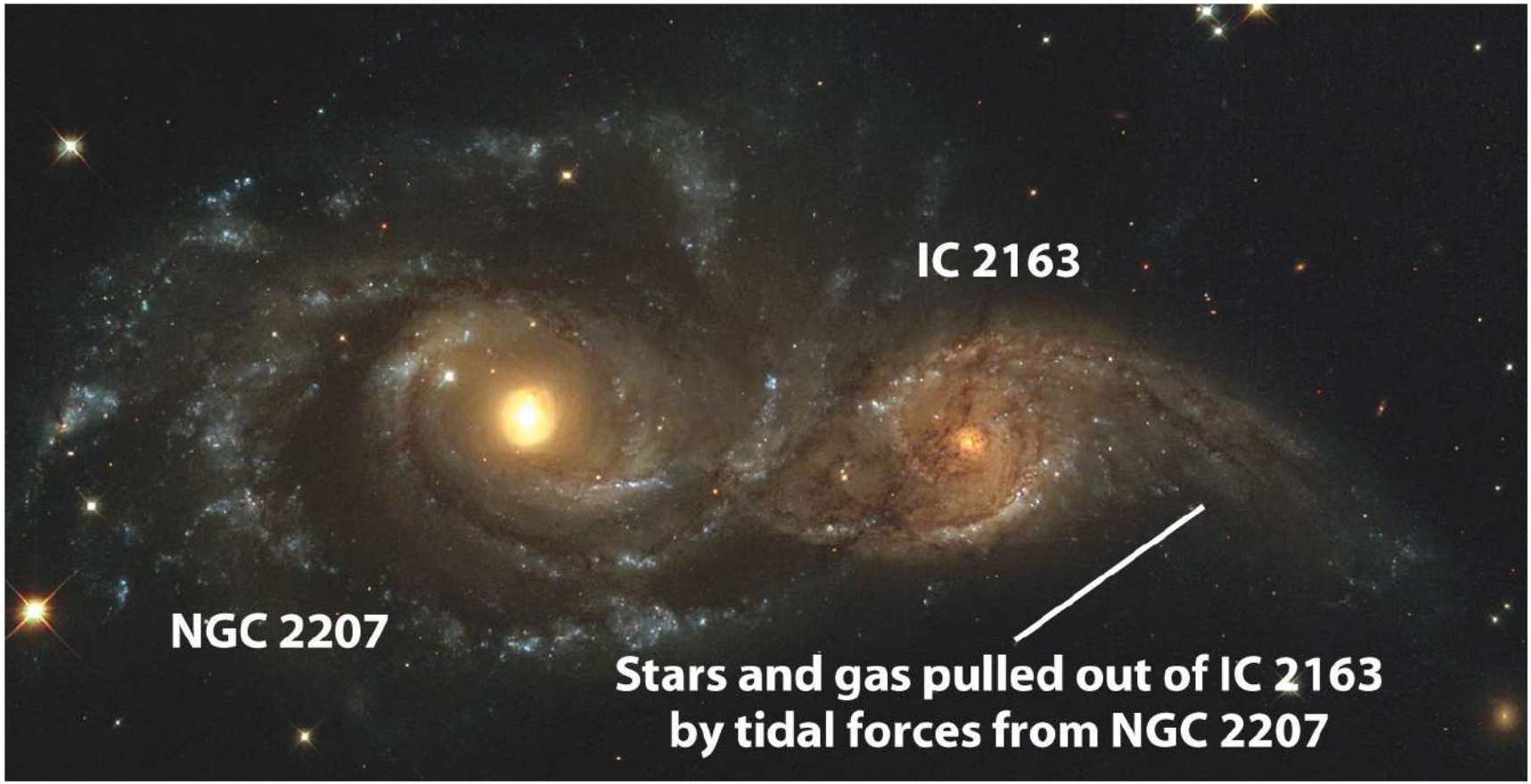





A
B
C
D
E
F

Orbits may be any of a family of curves called conic sections




IC 2163
NGC 2207
Stars and gas pulled out of IC 2163
by tidal forces from NGC 2207