Observational Astronomy - Lecture 5
The Motion of the Earth and Moon
Time, Precession, Eclipses, Tides

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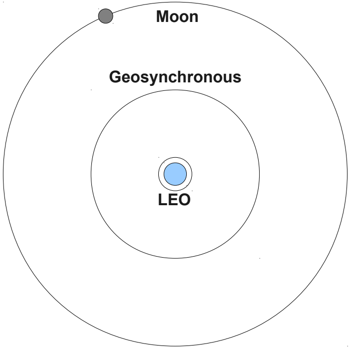
Geosynchronous Orbits

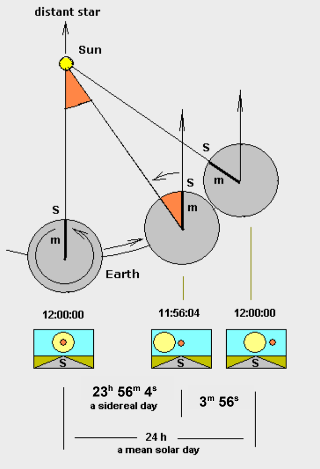


Not to scale.

- Objects in Low Earth Orbit (LEO) circle the Earth in about 90 minutes.
- The moon circles the Earth in 27.3 days (about 655 hours).
- At the right distance (about R = 42000 km), a satellite will circle the Earth in one sidereal day (23h 56m).
- These satellites stay fixed in the sky.

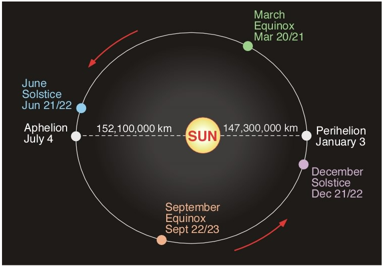
Planet	a(km)	T(Hr)	a^3/T^2 (1E11 km^3/hr^2)
LEO	6700	1.53	1.29
Moon	381000	655.20	1.29
GEO	42000	23.93	1.29

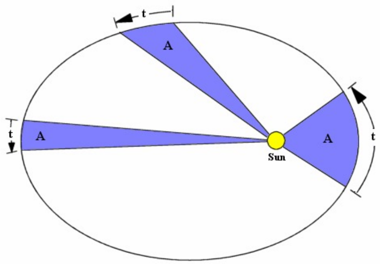
Solar Time vs Sidereal Time



- The time from one noon to the next is called a *solar day*
- The time from one star transit to the next is called a *sidereal day*
- A sidereal day is 4 minutes less (actually 3 minutes 56 seconds) less than a solar day.

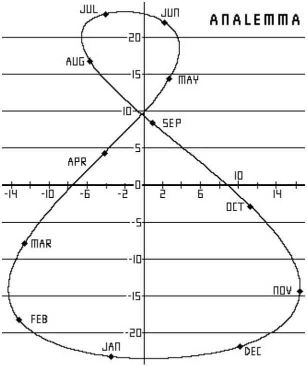
Origin of Solar Day

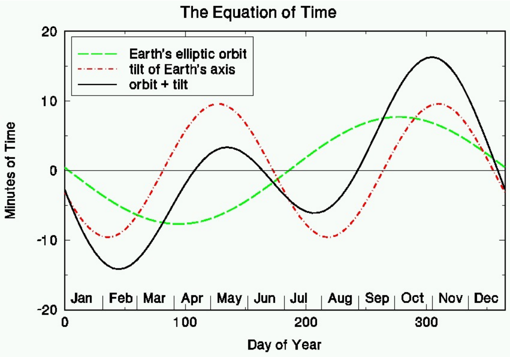




- One solar day $= 23^{\mathrm{h}}56^{\mathrm{m}}4^{\mathrm{s}} + 3^{\mathrm{m}}56^{\mathrm{s}}$.
- The $23^{\mathrm{h}}56^{\mathrm{m}}4^{\mathrm{s}}$ is the time it takes the Earth to rotate on its axis.
- This time is very accurately constant - within microseconds per day.
- The $3^{\mathrm{m}}56^{\mathrm{s}}$ varies through the year, because the Earth's speed in its orbit varies due to Kepler's second law.
- We define the *Mean Solar Day* as the average of this quantity through the year.

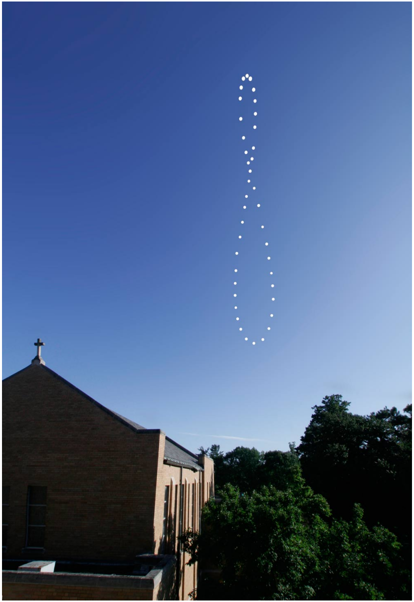
Equation of time



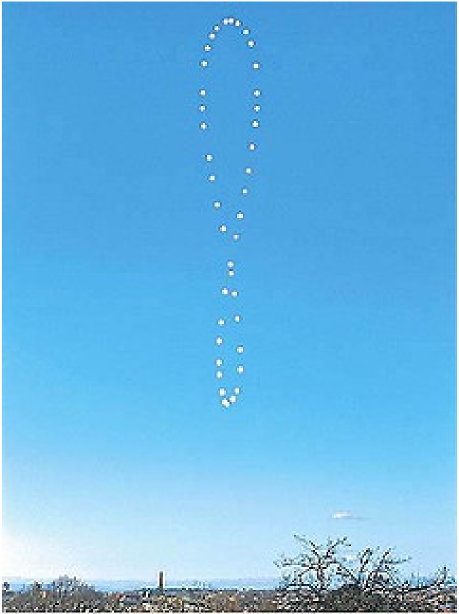


- There are two effects - variation in speed due to elliptical orbit.
- Variation in speed due to inclination of Earth's axis.

Analemma image - taken at same time each day



Another analemma - What is different?



The analemma in a sundial

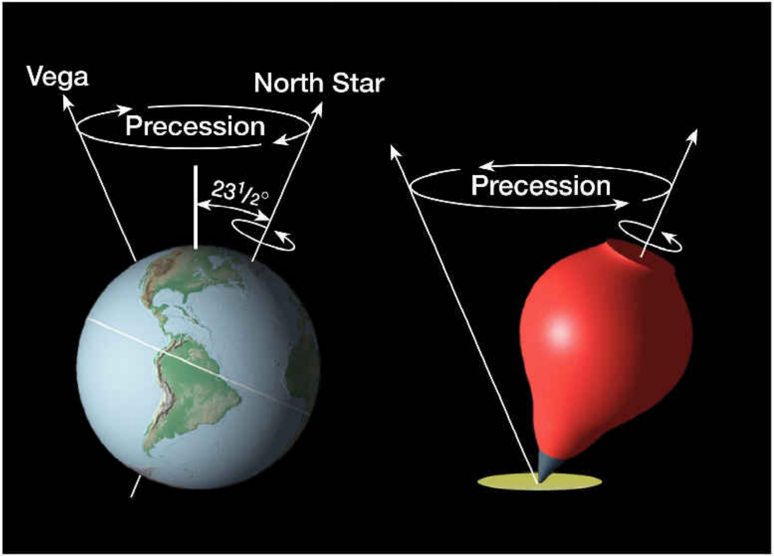
Why our calendar works as it does.

- Measurements tell us there are 365.2425 mean solar days in a year.
- Early calendars had 365 days in a year.
- The Julian calendar (45 BC), added an extra day every 4 years.
  - This calendar has 365.25 days per year.
  - It loses one day every 133 years (1 / .0075).
- By the middle ages, the Julian calendar had drifted $\approx$ 10 days relative to the sun.
- Pope Gregory, in 1582, proposed the adoption of the Gregorian calendar, which we use today.
- This calendar works as follows:
  - 365 days in a normal year = 365.0000
  - Add a day every 4 years = 365.2500
  - Skip the leap year if the year is divisible by 100 = 365.2400
  - Add it back in if it is divisible by 400 = 365.2425

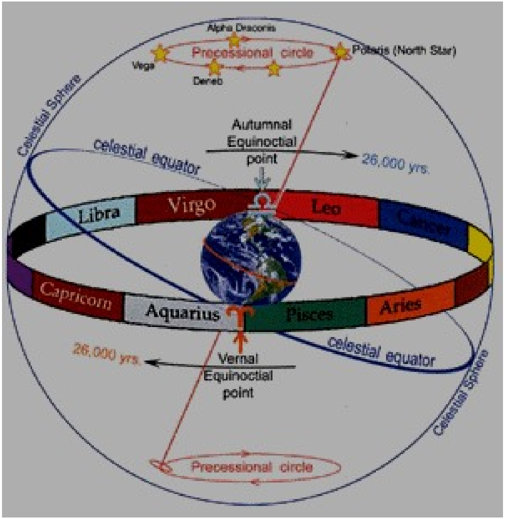
The Julian day

- Our calendar is complicated - calculating the difference between two dates is hard.
- Astronomers (and computer programmers!) use the concept of Julian Day.
- This is a sequential counting of days starting on January 1, 4713 BC.
- Today (March 3, 2014) is Julian Day 2,456,719.

The precession of the Earth



Precession

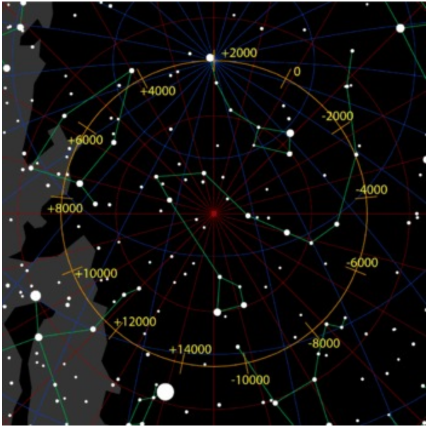


Precession causes the equatorial coordinate system to move.
One complete circle takes 26,000 years.

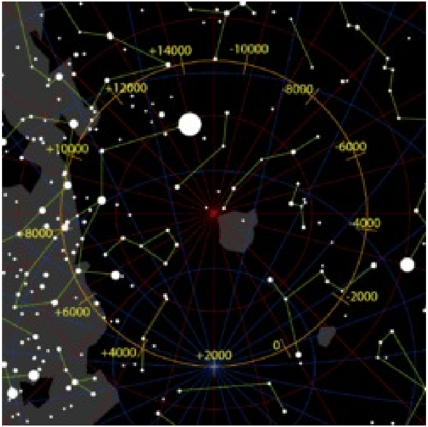
How much do the coordinates change?

- Example - Aldebaran - α Tauri.
- B1950 : Dec $= +43$ 30' RA $=$ 16h25m
- J2000 : Dec $= +43$ 59' RA $=$ 16h31m

Path of the celestial poles

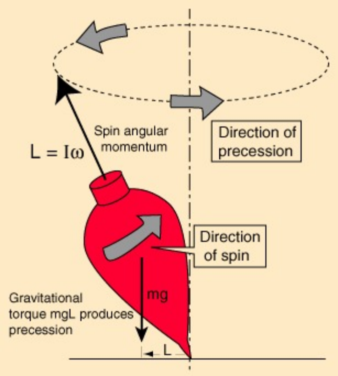


North Celestial Pole

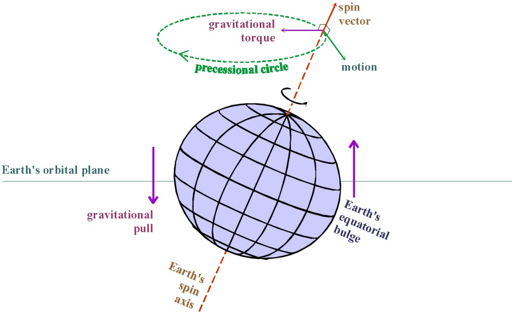


South Celestial Pole

Physics of precession

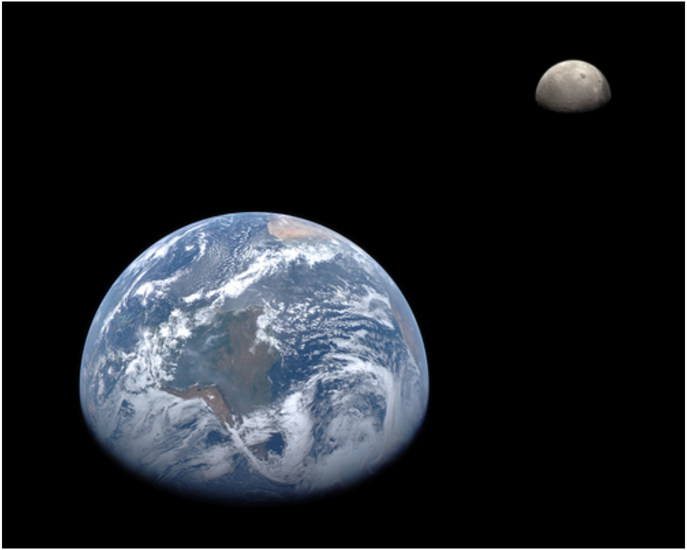


The top precesses because of gravity.



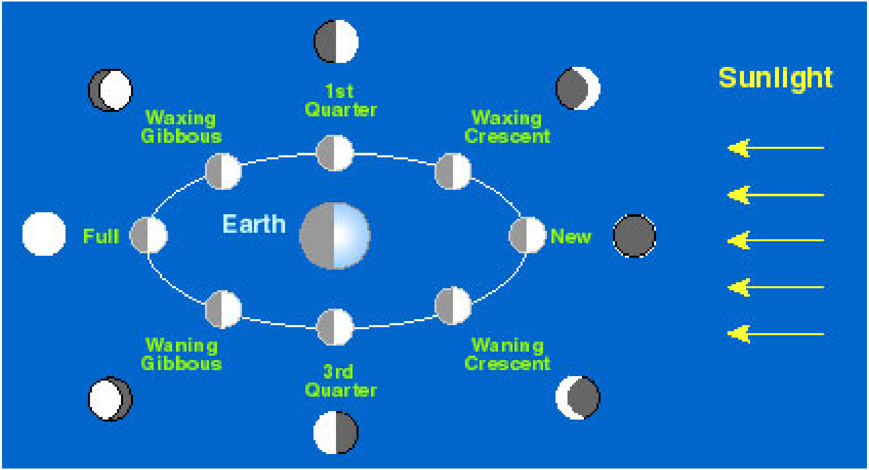
The Earth precesses because of the gravitational pull of the sun and moon on the Earth's equatorial bulge.

The Earth and Moon

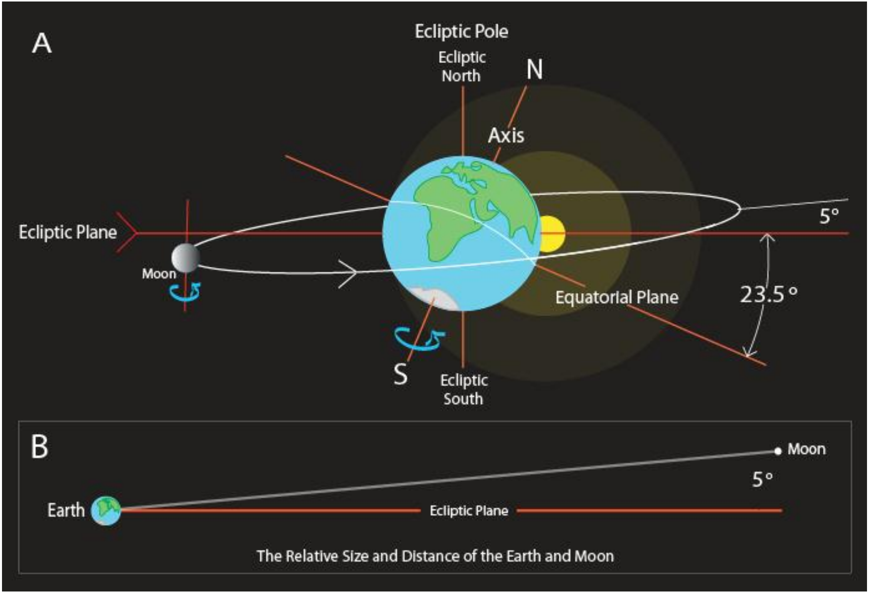


An actual photograph of the Earth and Moon.

Lunar Phases



The inclination of the moon's orbit



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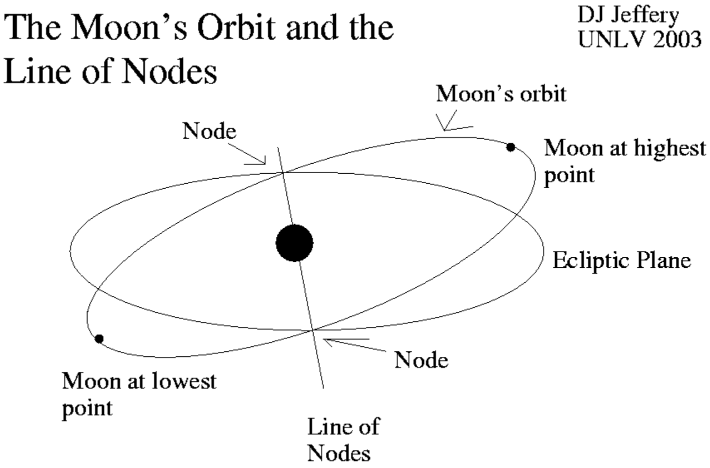
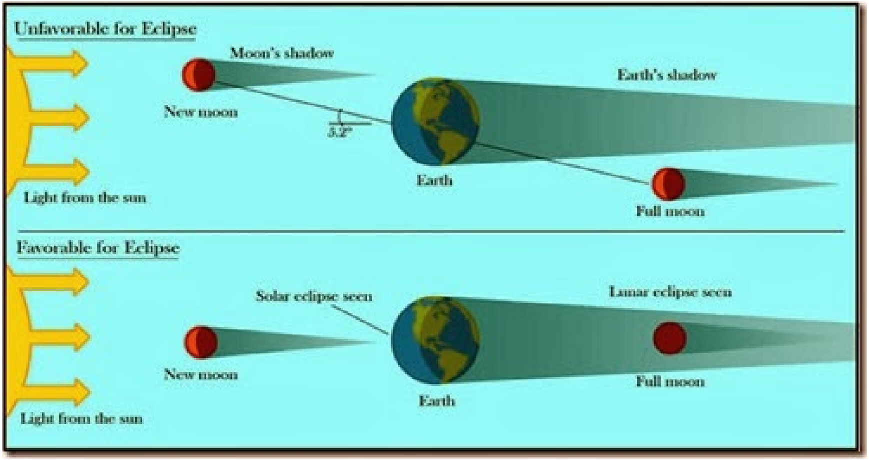
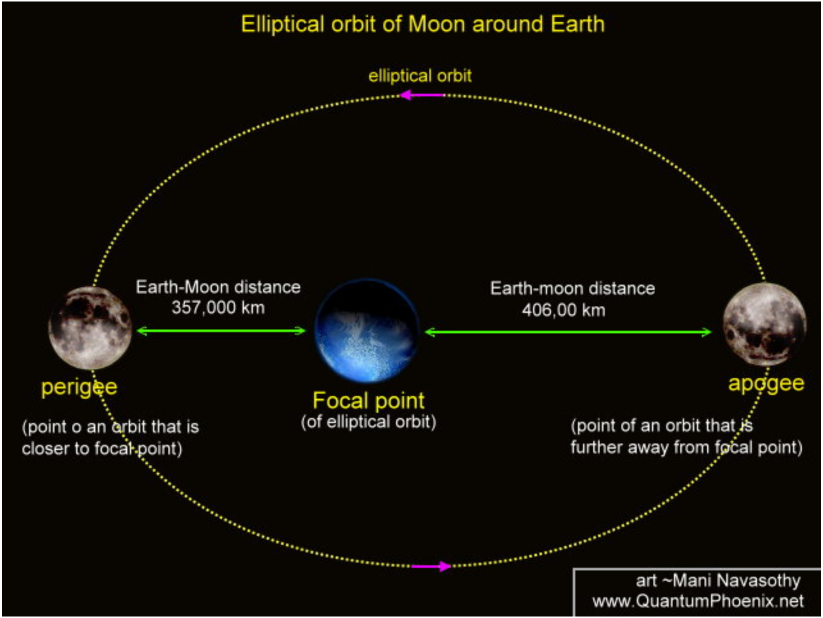


The line of nodes rotates westward 19.4 degrees per year due the gravitational perturbation of the Sun on the Earth-Moon system.

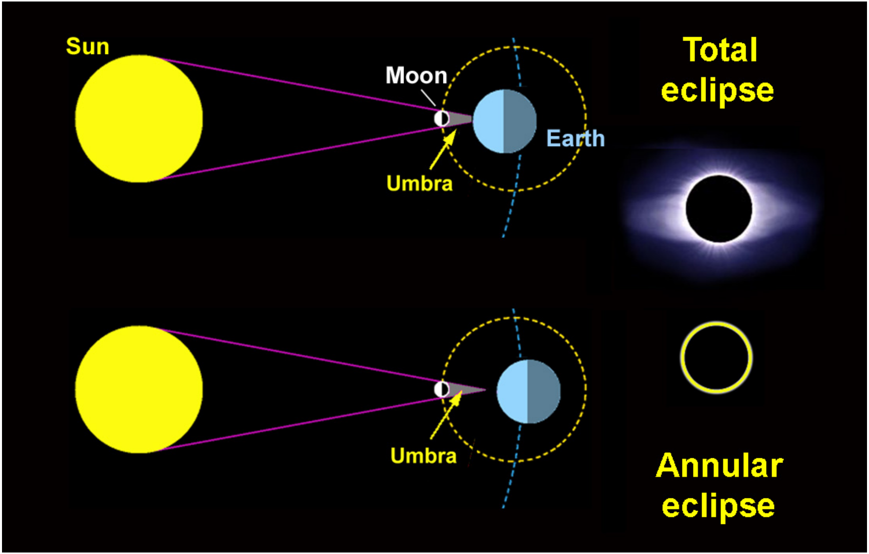
The impact of the inclination on eclipses



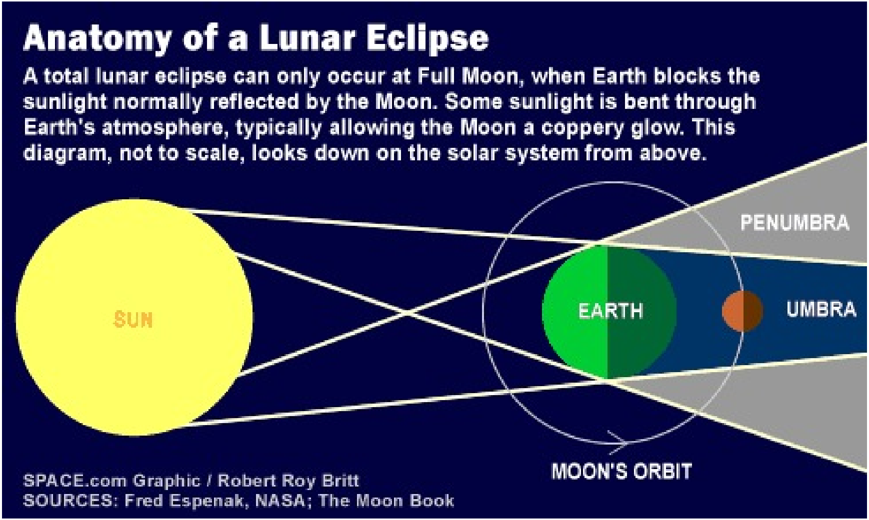
The moon's orbit is also elliptical



Solar eclipses



Lunar eclipses

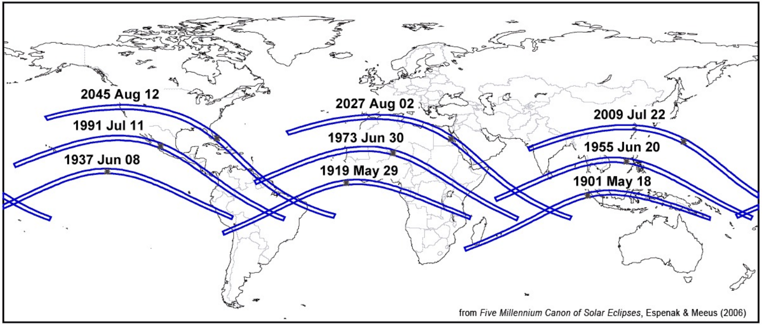


Lunar eclipse photos

Eclipse cycles - the Saros

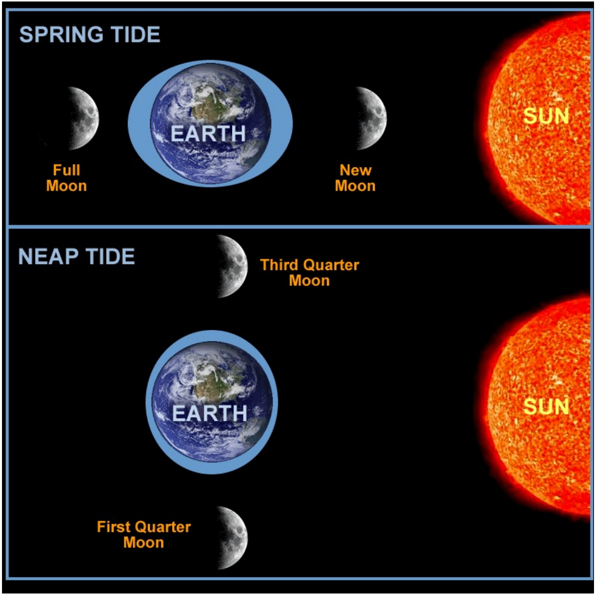
Month		Length	Number	Time
Sidereal	Stellar position	27.321661		
Anomalistic	Perigee-Perigee	27.554551	717	19756.613067
Draconic	Node-Node	27.212220	726	19756.071720
Synodic	Phase-Phase	29.530587	669	19755.962703
Year		365.2425		54.09 54 years 32.9 days

Figure 1 — Eclipses from Saros 136: 1901 to 2045



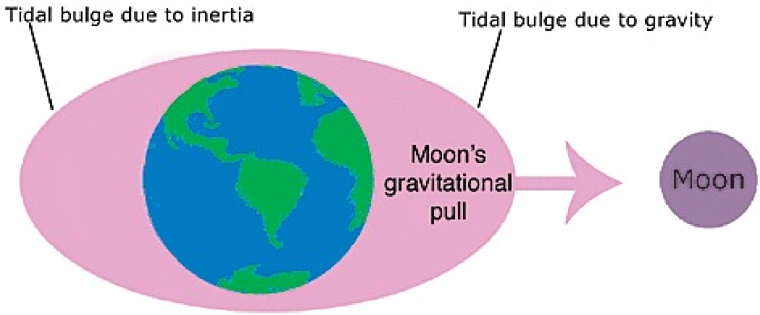
Tides

Tides



SPRING TIDE
Full Moon
EARTH
New Moon
SUN
NEAP TIDE
Third Quarter Moon
EARTH
SUN
First Quarter Moon

Why two tides?



Tidal locking and resonances

- Tides dissipate energy, and lead to "tidal locking" of orbiting bodies.
- Best known example - the moon, whose rotation rate is tidally locked to its orbital period.
- Tides are slowing down the Earth's rotation:
  - Eventually (billions of years in the future) the Earth and moon will "co-rotate", each showing the same face to the other.
- There are many examples of tidal locking known, in our solar system and in other systems:
  - Mercury is locked in a 3:2 resonance - 3 sidereal days equals 2 years, or 1 solar day equals 2 years.
  - Jupiter's three largest moons are locked in a 1:2:4 resonance.
  - There are many more examples.