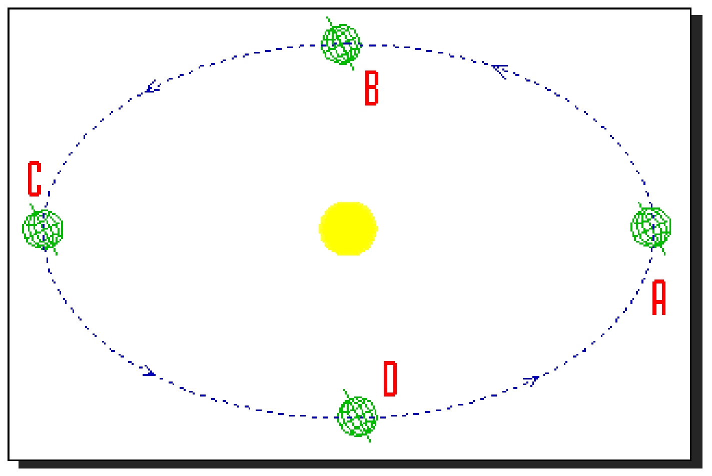
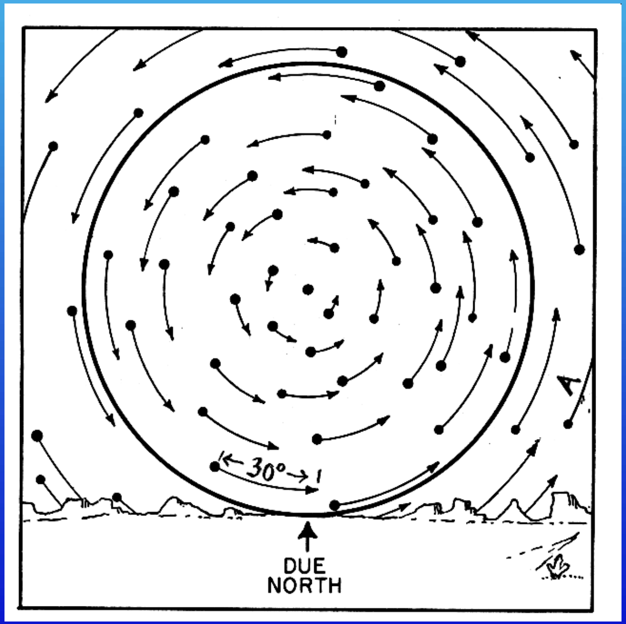
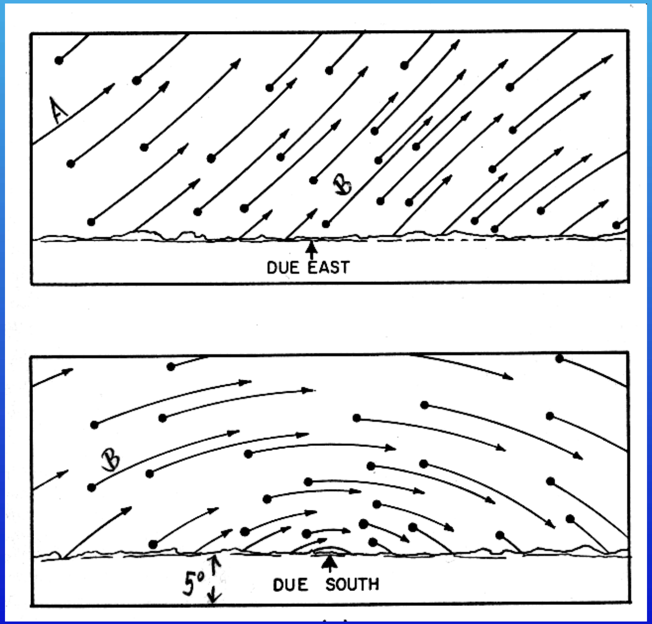
COSMOLOGY & ASTRONOMY in ANCIENT GREECE



The ancient Greeks had no telescopes, but they did some have access to very old Egyptian astronomical records. They knew about the seasons, the tilt of the earth's axis with respect to the ecliptic, and the main thing they wished to understand was the apparently regular motions of the heavenly bodies in the sky. The heavenly bodies were for them the visible stars, the sun & moon, the 5 visible planets (seen as stars which moved with respect to the others), shooting stars (ie., meteorites) and the occasional comet. All of this was very impressive to them (as it was to all the ancient civilisations, and even before). They had no accurate timepieces but could measure distances (and hence angles) fairly accurately.

The most obvious regularity was the turning of the celestial sphere every 24 hours, about an axis which projected on the sky close to the 'Pole Star'. All other heavenly bodies moved slowly with respect to the 'fixed stars' (usually assumed fixed on a 'celestial sphere).

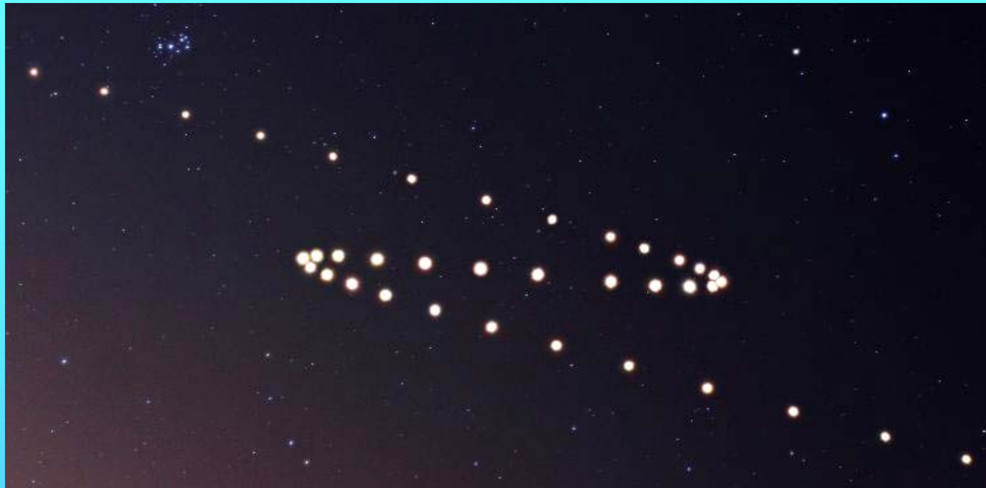


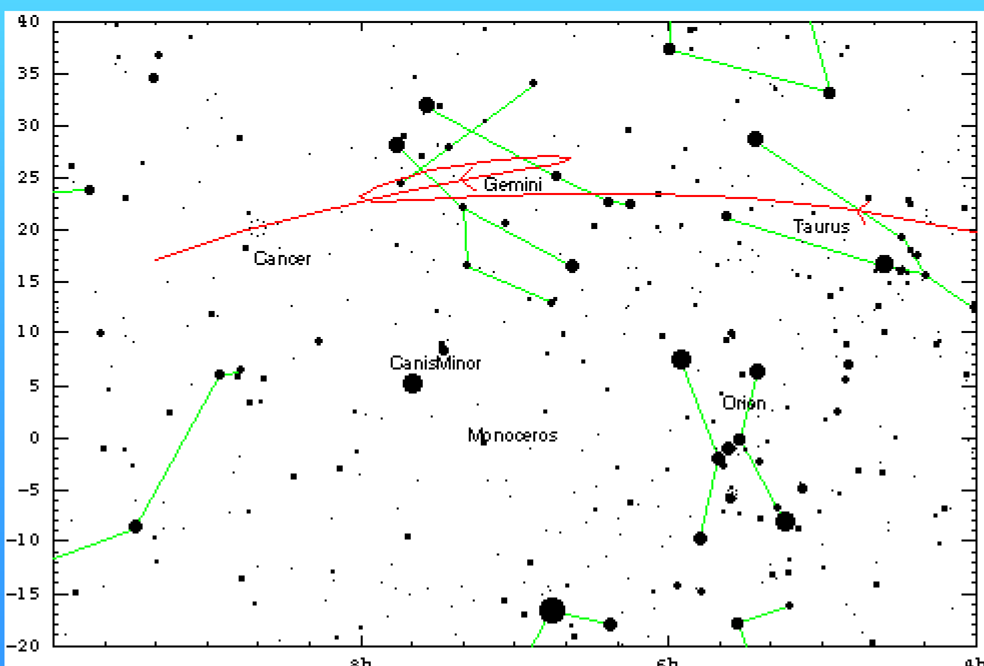


MOTION of the PLANETS

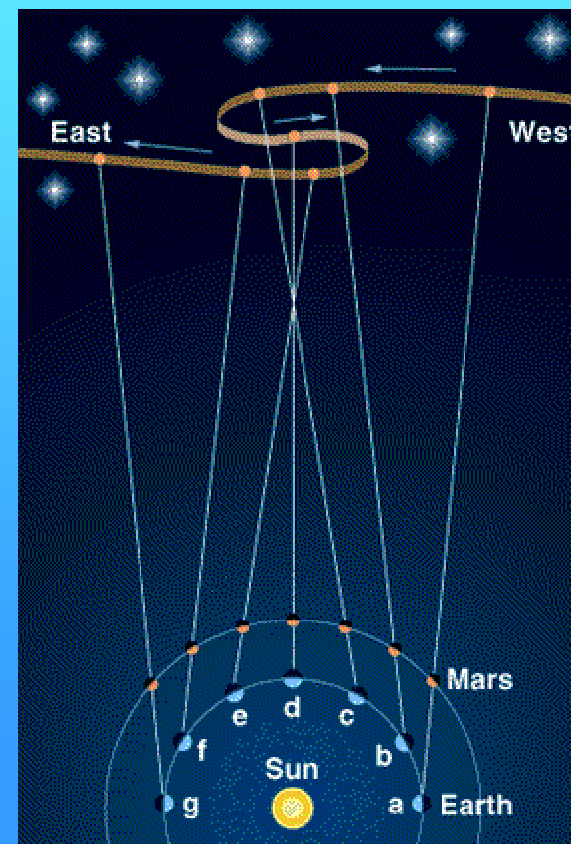
The planets all show 'retrograde' motion In the sky – the inner planets (Mercury, Venus) oscillate back and forth past the sun as it moves around the ecliptic, and the outer planets (Mars, Jupiter, Saturn) do it almost every year in their long paths around the ecliptic (and they appear brighter during the retrograde phase).

BELOW: Motion of Mars in the sky



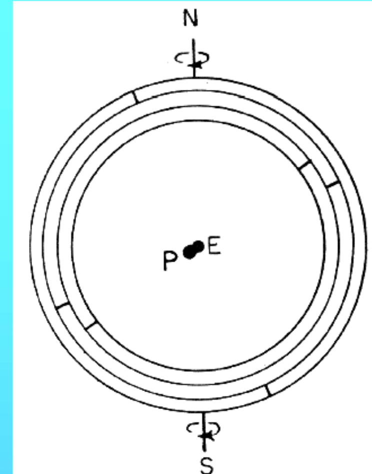


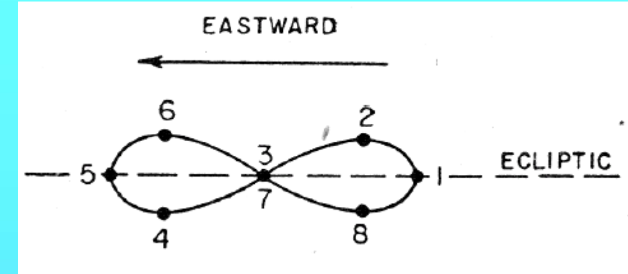
The explanations given by the ancients were sometimes quite complicated. To understand them you may find it easiest to look at the modern picture, depicted at right.



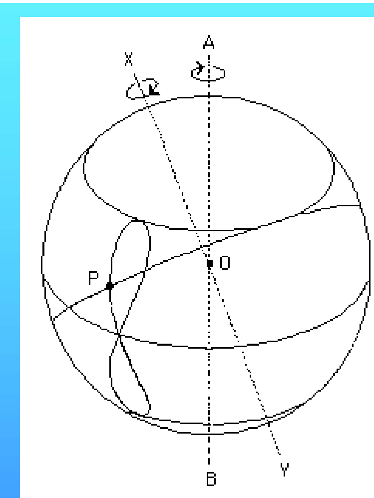
CELESTIAL SPHERES

An explanation of the motion of heavenly bodies in terms of celestial spheres came first from Eudoxus (408-355 BC). His planets moved between a pair of spheres, being carried along by each. These spheres were NOT co-axial, and rotated in opposite directions.

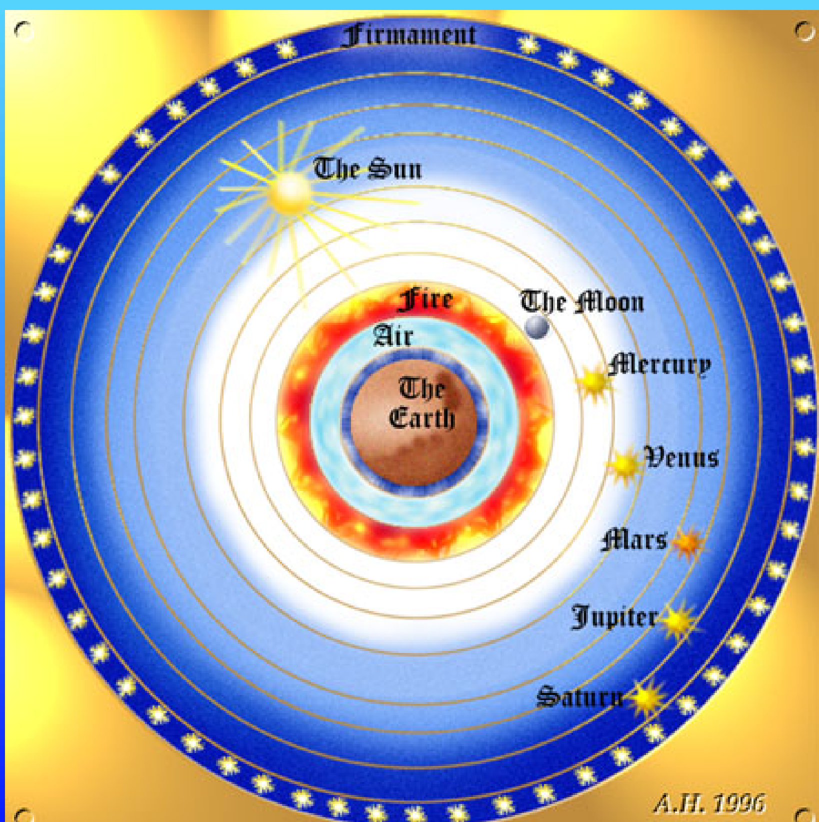




These 2 spheres were in turn carried by other adjacent ones.



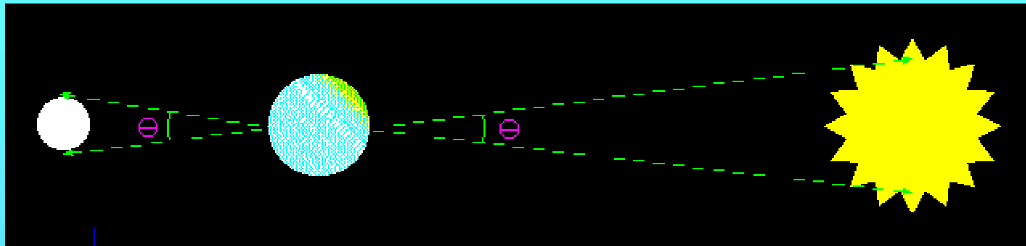
The net result was a complex motion, in which a planet traced out a 'figure of 8' motion (the 'hippopede') at the same time as it was carried around the sky.



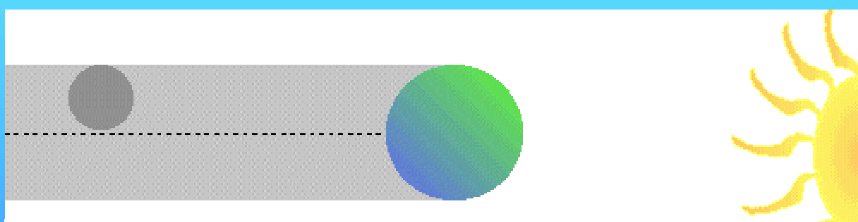
Aristotle's cosmos was also based on spheres (55 of them), divided between the sublunary spheres, filled by a mixture of the 4 imperfect elements (earth, water, air, & fire) & the super-lunary spheres, also filled by a plenum of 'aether' made from the 5th element ('quintessence') which allowed perfect, everlasting & regular motion through it. Aristotle did not attempt any sophisticated treatment of the heavenly motions.

MEASURING the COSMOS: ARISTARCHUS

Lost in the grand designs like those of Aristotle, was any quantitative understanding of the size of the cosmos.

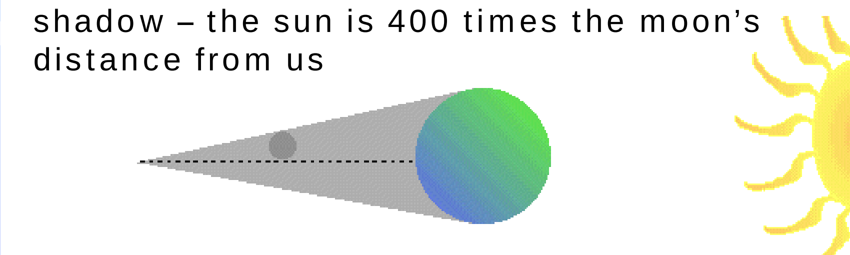


ABOVE: angular diameters of moon & sun seen from earth

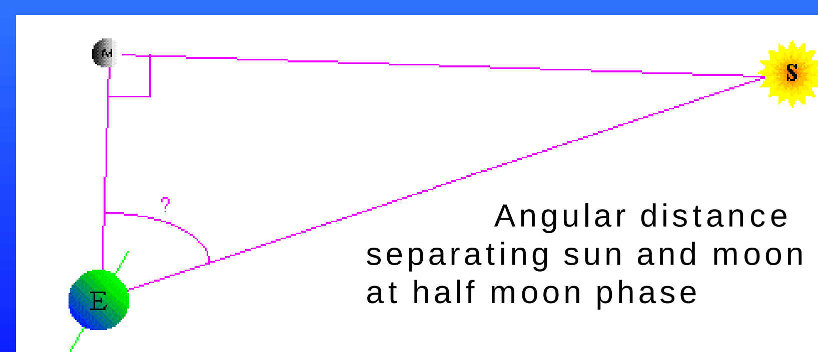


ABOVE: size of earth's shadow cast at the moon, if the sun is infinitely distant

BELOW: The actual form of the earth's shadow – the sun is 400 times the moon's distance from us

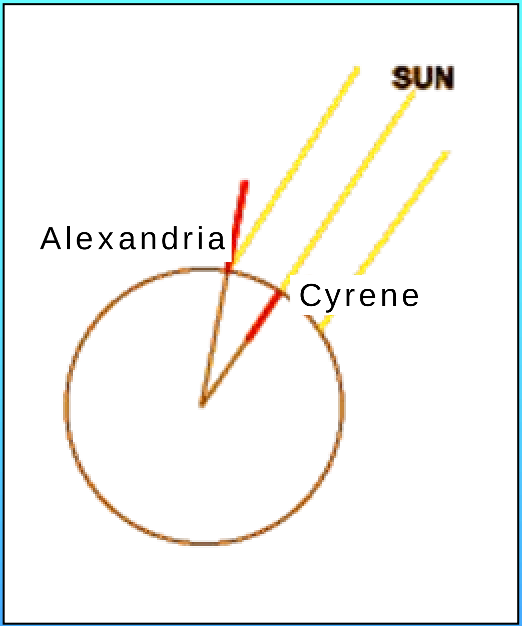


Luckily those of a more mathematical bent were trying. Aristarchus of Samos (c. 310-230 BC) realized that he could easily find the relative sizes of the earth and moon by looking at the size of the earth's shadow compared to the moon during a lunar eclipse (see left). He could also find the relative distances of the sun and moon by measuring the angle seen in the sky between their positions at full moon and half-moon Phases (see diagram below). Finally, knowing the size of the earth, and the relative angular diameter of sun and moon, he could have found the sizes and distances apart of all 3 bodies. Apparently however he did not know the size of the earth.



Actually his results were rather inaccurate – the naked eye was not a good enough instrument to resolve the small angles (see notes for details). But the ideas were perfectly correct.

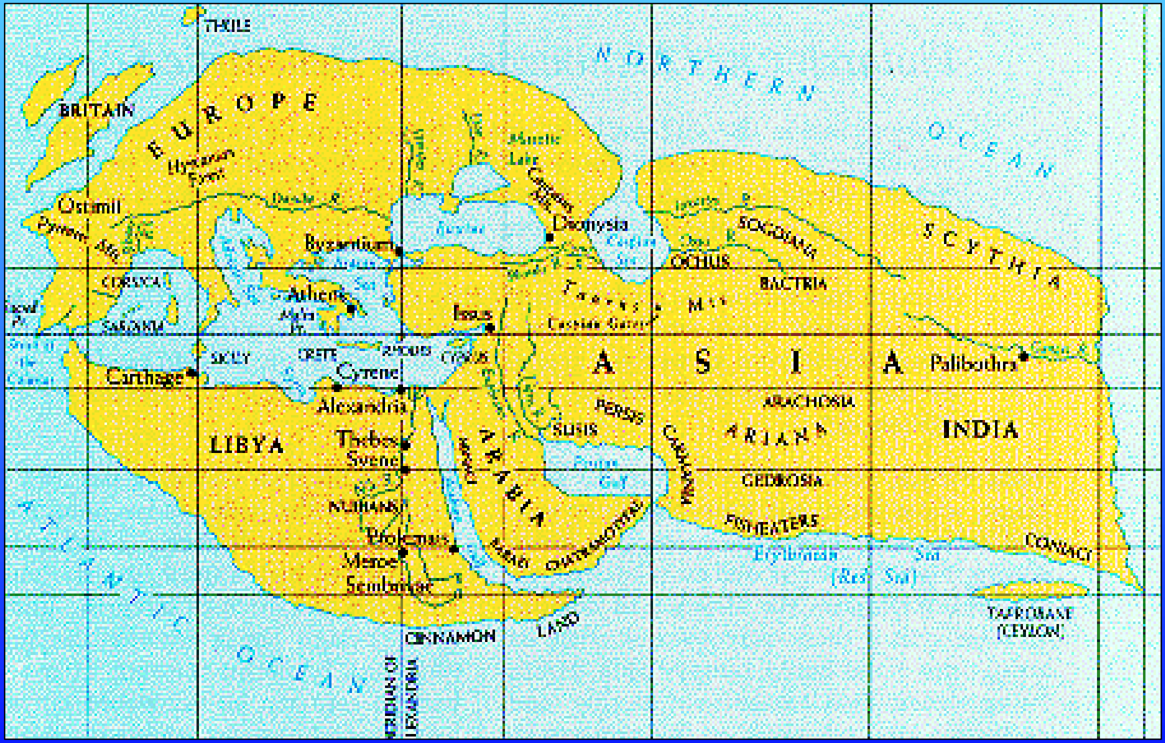
MEASURING the EARTH: ERATOSTHENES



The first that we know of to measure the size of the earth was Eratosthenes of Cyrene (276–194 BC); he also composed on of the of the early Greek maps of the earth as known to them at that time.

His result was strikingly simple and accurate – it consisted in measuring the angles of shadows cast by vertical posts, when the sun was directly south. Knowing the distance between the 2 places he could determine the earth's diameter.

The result was strikingly accurate –he got it right to within 1%.

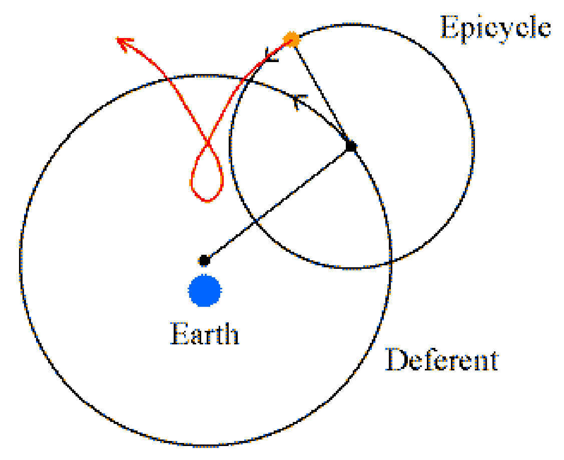


Unfortunately the Greeks largely ignored this result, and those of Aristarchus. Notably, the beilef of Aristarchus in a heliocentric system was also largely forgotten.

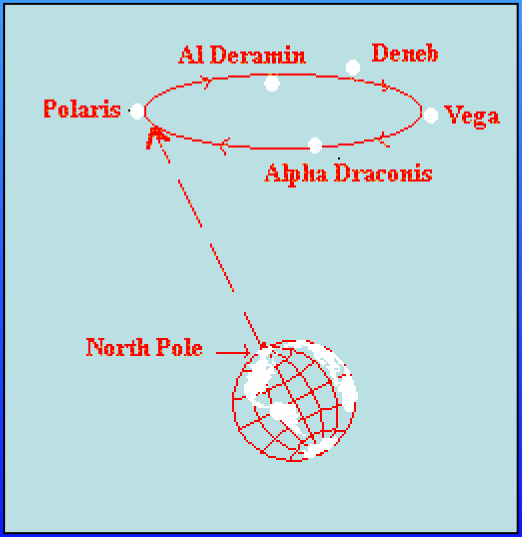
MAPPING the SKY: HIPPARCHUS

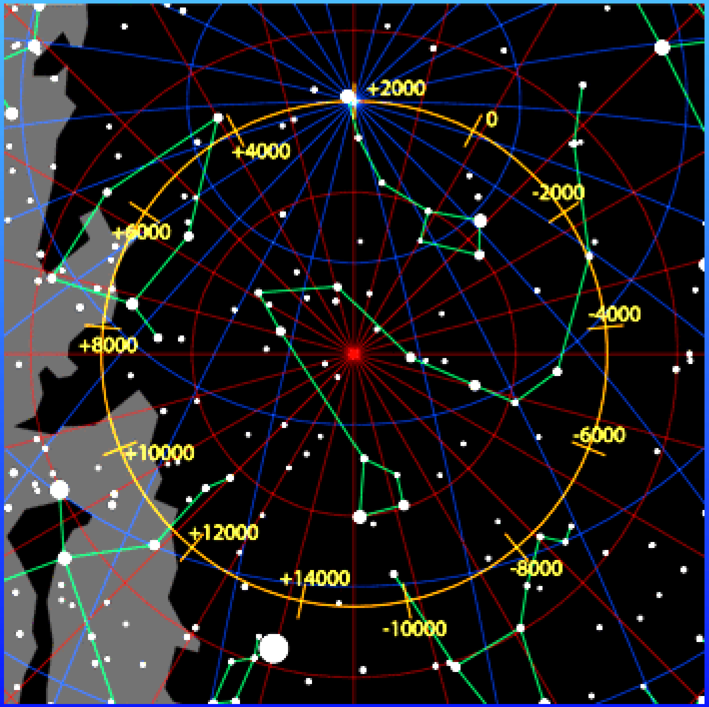
Hipparchus (c. 190-120 BC) was perhaps the greatest of the Greek astronomers – unfortunately his work is mostly known from that of Ptolemy, writing 3 centuries later.

Apart from compiling & using the first tables of chords (so that he became a pioneer of trigonometric methods) and compiling a comprehensive atlas of the stars (later used by Ptolemy), he also invented a number of astronomical measuring instruments. He investigated & tried to explain lunar and planetary motion using the idea of epicycles (originally due to Apollonius of Parga); in doing so he introduced the idea of displacing the earth from the centre of the orbits of heavenly bodies), to get a better quantitative fit to observations



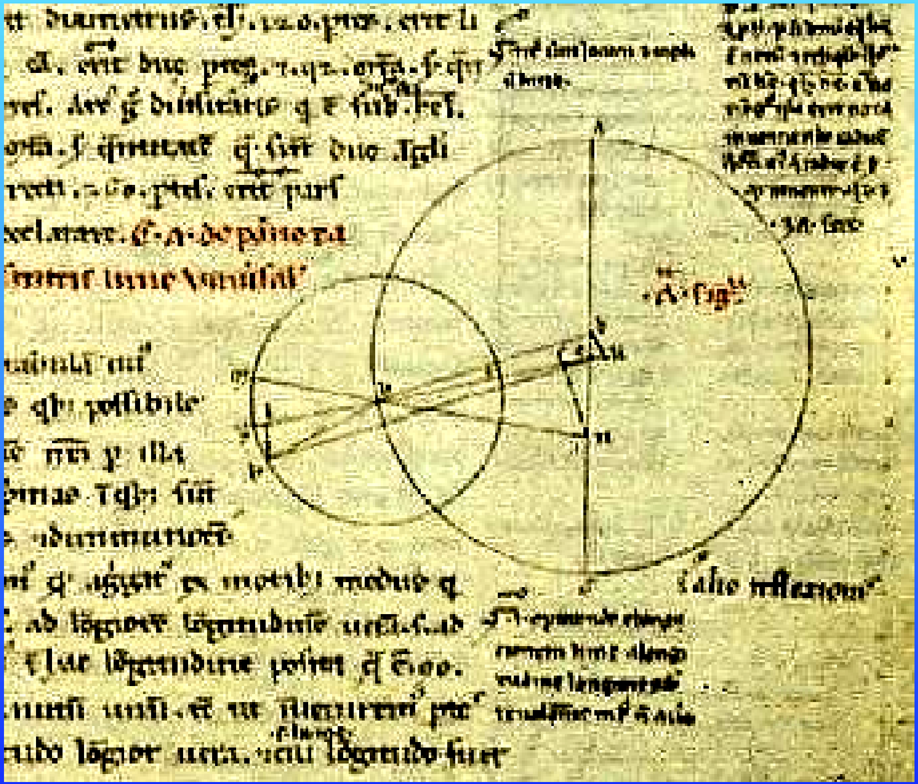
His most remarkable achievement was the discovery of the precession of the equinoxes, which can be explained by the slow precession of the direction of the earth's axis relative to the stars, shown at right (the period is 25,764 years). We now know this is caused by tidal forces from the sun and moon





PTOLEMY & the ALMAGEST

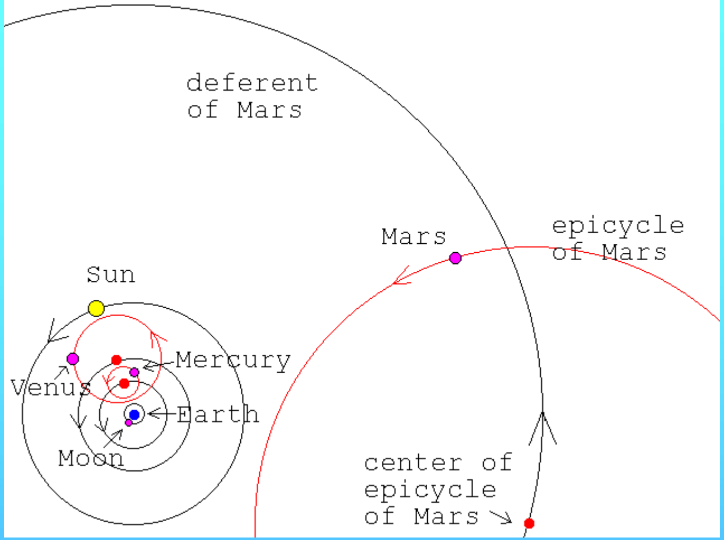
The astronomer Claudius Ptolemeaus (c. 85-165 AD), usually known simply as Ptolemy, had by far the largest influence on subsequent astronomical ideas, mainly because his work survived. His most important work was the "*Almagest*", a 13-volume treatise; he also wrote an 8-vol. work on geography & a 5-vol. work on optics. The Almagest's impact on Western thought was huge; it dominated astronomical thinking for 1300 years. The most important original contribution was his extension of epicycle theory to include the idea of 'equants' (see next page).



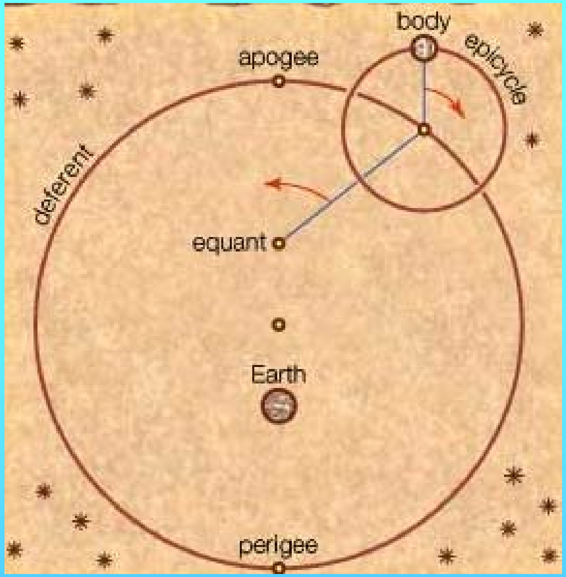
Translation of the Almagest made from Arabic to Latin in 1175 AD, by Gerard of Cremona.

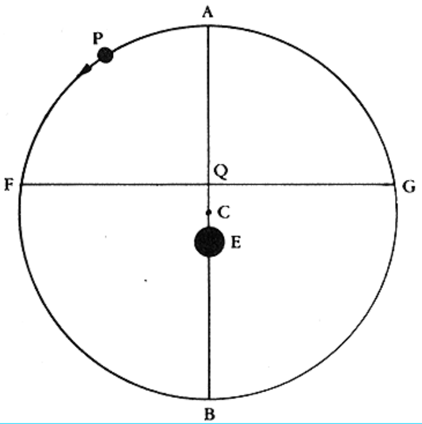
A mediaeval depiction of Ptolemy's system

The PTOLEMAIC SYSTEM



Concentric deferents and epicycles

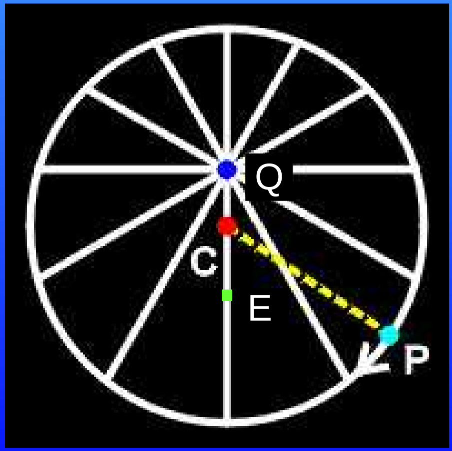




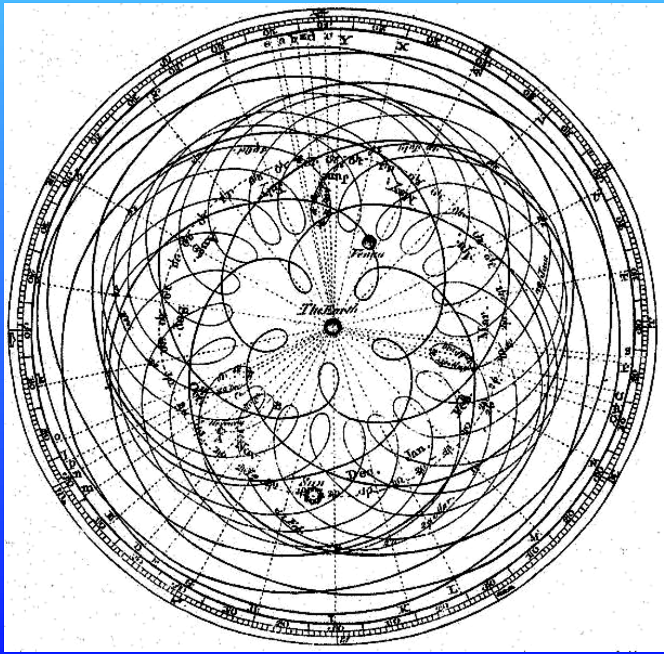
ABOVE: the equant
LEFT: adding the epicycle

The basic Ptolemaic system starts with the older idea (from Appollonius of Perga) of the deferents & epicycles shown at top left – planets move around epicycles, which themselves move around the deferents, which are centred on the earth.

We then (top right) displace the centre of the deferent from the earth. The point Q, on the other side of the deferent centre C from the earth E is called the equant. The epicycle centre now circulates around the new deferent, but Ptolemy had it moving at a constant angular velocity around the equant, as shown at right.



The predicted motion, as viewed from the assumed static earth, agreed well with observations (see left).



Apparent motion of planet around Earth