"My profession is to be forever journeying, to travel about the Universe so that I may know all its conditions."

- Abu Ali ibn Sina (Avvicena), 980-1037 AD, physician, philosopher, mathematician and astronomer
Chinese Astronomy

Chinese astronomy has a long history.

Oracle bones from the Yin Dynasty (2nd millennium BC) record eclipses and novae.

The crab nebula is the remnant of a “guest star” recorded by the Chinese in 1054
Chinese Astronomers

Gan De (4th century BC) recorded the world’s first star catalog. He also wrote two books, the Treatise on Jupiter and the 8-volume Treatise on Astronomical Astrology, which are now lost.

Shi Shen (4th century BC) recorded the positions of 121 stars, and was the first to make records of sun spots.

Zhang Heng (78-139 AD) was a Chinese astronomer, geographer, and mathematician. He constructed a celestial globe, believing that the world was round.

"The sky is like a hen's egg, and is as round as a crossbow pellet; the Earth is like the yolk of the egg, lying alone at the centre. The sky is large and the Earth small."
Sumerian Astronomers

Sumerian Tablets

Record of Lunar Eclipse
Describes how Venus will appear in Sky
The month of March-April Description
Describes Length of a Year
Weather Report
Describes Constellations
History of Night Sky

http://www.mathisradical.com
Aristotle (Ἀριστοτέλης) (384 BC – March 7, 322 BC)

Aristotle was one of the most influential of Greek philosophers. He was a student of Plato, and tutored Alexander the Great.

The term Philosophy means “love of wisdom” which during Aristotle’s time encompassed all intellectual reasoning. Natural philosophy was the study of the natural world, which we today call physics.

Aristotle’s teachings are mainly qualitative and not quantitative. He also made some obvious mistakes, which because of his reputation alone, were accepted as truth for almost 2000 years.
He was a cavalry commander at the age of 18.
He succeeded his father Philip II to the throne of Macedon when he was 20.
He conquered the Persian Empire and explored India by the age of 30.
Alexander the Great  356 – 323 B.C.

Alexander founded the city of Alexandria, Egypt in 331 B.C. and spread Greek culture throughout the western world.
Alexander wept when he heard from Anaxarchus that there was an infinite number of worlds; and his friends asking him if any accident had befallen him, he returns this answer:

“Do you not think it a matter worthy of lamentation that when there is such a vast multitude of them, we have not yet conquered one?”

- Plutarch
Alexander the Great in Coinage
Alexandria, Egypt

Alexandria was one of the famous cities of the ancient world. It was the capital of Egypt for 1000 years.

Its lighthouse Pharos was one of the seven wonders of the world. It stood over 120 meters high (> 360 feet), and was the tallest building in the world.

At night fire lit the lighthouse. During the day a mirror reflected sunlight. It could be seen 50 km away!
Breakup of Alexander’s Empire

On the 10th or 11th June 323 BC, at the age of 32, Alexander died in the palace of Nebuchadnezzar II, in Babylon.

His empire was broken up
Library of Alexandria

The library was initially set up by Demetrius of Phaleron, a student of Aristotle under Ptolemy I Soter. It was built in the style of Aristotle's Lyceum and set adjacent to and in service of the Musaeum, which is a Greek Temple (House of Muses).

The library contained a Peripatos walk, a gardens, a dining room, lecture and meeting halls, an acquisition department, and a cataloguing department, in addition to its stacks of over 500 thousand papyrus scrolls (bibliothekai).

Carved into the wall above the shelves, a famous inscription read:

The place of the cure of the soul.

The library was given a royal mandate to aggressively collect all books.
Library of Alexandria

The library became famous throughout the world, and the head librarians were famous researchers.

Galen the Roman historian wrote that Books were collected from all visitors To Alexandra and copied regardless of language. They were placed in the section “Books of the Ships”

The library was eventually destroyed.

Plutarch wrote that Julius Caesar accidently burned down the library when in a battle he set fire to his own ships to set the harbor aflame. The fire spread to the great library.

The library was restored, but it was obliterated during the Roman Emperor Aurelian’s attack on the city between 270-275 A.D.
15 March 44 BC: Julius Caesar is murdered by 60 men in the Senate
August 30 BC: Octavius entered Egypt. Marc Antony and Cleopatra commit suicide
Aristarchus (310 BC – 230 BC)

Aristarchus was born in Samos (Greece). He was a Head Librarian at Alexandria.

He was the first to propose that the Earth revolved around the Sun. This idea was not popular among the Greeks and never caught on.

Aristarchus also used eclipses to estimate that the Sun was 20 times further away than the Moon (it is more like 400).
Eratosthenes (276 BC - 194 BC)

Eratosthenes was born in Cyrene which is now in Libya in North Africa. He was appointed Head Librarian at the great Library of Alexandria.

It was written on a scroll that he read that in the city of Syene to the south of Alexandria on the Summer Solstice, no shadows are cast.

This obscure fact, led him to conclude that the Earth is a sphere. He computed the circumference to within 2%.

Using data from an eclipse, he computed the distance to the sun (too far by a factor of 1000), and to the moon (too far by a factor of 300).
The World According to Eratosthenes

Size of the Earth as measured by Eratosthenes (270–195 B.C.): 252,000 stadia.

Parallels and Meridians of Eratosthenes:
- Parallel of Thule
- Parallel of Rhodes
- Parallel of Alexandria
- Tropic
- Parallel of Meroe
- Southern limit of habitable world
- Meridian of Alexandria

Map of the world according to Eratosthenes, showing the locations of Alexandria and Syene.
Hipparchus (190 BC – 120 BC)

Hipparchus was born in Nicaea in Bithynia, which is now Iznik Turkey.

He calculated the length of the year to within 6.5 minutes.

He also discovered the precession of the equinoxes and found it to be 46" per year (compared with the modern value of 50.26"

Hipparchus's compiled a star catalogue which contained about 850 stars.
Antikythera mechanism (circa 150 BC)

Discovered in a shipwreck in 1901. Its purpose was not understood until very recently.

It is the oldest known scientific calculator consisting of over 32 gears (made about 1500 years before it is thought gears were invented)
The device is remarkable for the level of miniaturization and for the complexity of its parts, which is comparable to that of 17th century clocks. It has over 30 gears, although Michael Wright has suggested as many as 72 gears, with teeth formed through equilateral triangles. When a date was entered via a crank (now lost), the mechanism calculated the position of the Sun, Moon, or other astronomical information such as the location of other planets. Since the purpose was to position astronomical bodies with respect to the celestial sphere, with reference to the observer's position on the surface of the Earth, the device was based on the geocentric model.
Ptolemy (85 AD – 165 AD)

Ptolemy was one of the most influential of classical thinkers.

He lived in Alexandria, Egypt and was a Roman citizen of Greek descent. In his classical work the *Almagest*, he compiled the astronomical works of the ancient Greeks and Babylonians.

He carried on the ideas of Aristotle, and proposed a geocentric view of the universe, where everything was centered about the Earth.
Star Trails
Epicycles

As we saw, from the perspective on Earth, the planets sometimes move backwards. This is called retrograde motion. To describe this they invented Epicycles. The planets were thought to go around the Earth not only on a circular orbit but on circles upon circles.
Retrograde Motion Understood

However, leaving the Earth, we were able to see with Celestia, that the retrograde motion is an illusion caused by the planets passing each other in orbit.
Heliocentric Theory

Copernicus would later suggest that the Planets (including the Earth) orbit the Sun (Helios).
Brat Pack: Cleopatra, Octavian, Mark Antony, Herod

15 March 44 BC: Julius Caesar is murdered by 60 men in the Senate
August 30 BC: Octavius entered Egypt. Marc Antony and Cleopatra commit suicide
Roman Empire to Holy Roman Empire

Hundreds of years passed in the west, as the Roman Empire was transformed into the Holy Roman Empire.

These were the Dark Ages.

The science of the Greeks was neglected. The engineering of the Romans forgotten.

Rome itself fell into ruin along with the rest of Europe. The population of Rome at one point fell to a mere 60,000! Until the Black Death arrives in Italy in 1348...
Arab Astronomers

The Abbasid Caliphate was the second of the two great Sunni Dynasties.

They set their capitol in Baghdad in 762 AD and heavily supported the study of astronomy.

The results of the studies at the centers in Baghdad and Damascus were published in a volume titled “The Verified Table in the 9th Century”. By the end of the 900s, they had compiled tables of planetary positions with unprecedented accuracy. Baghdad astronomers arrived at the figure of 33° 20' for the latitude of Baghdad - an error of only 10"
Arab Astronomers and Star Names

The Arab astronomers left their mark by naming many of the stars.

To this day many of the brightest stars have Arab names that astronomers still use.

Aldebaran = Al Debaran
Alnitak = Al Nitak
Alnilam = Al Nilam
Algorithm

Abu Ja'far Muhammad ibn Musa Al-Khwarizmi (~ 790 ~ 840 AD)

Al'Khwarizmi was an Islamic mathematician who wrote in Hindu-Arabic numerals and was the first to use zero as a place holder in positional base notation.

The word algorithm derives from his name.
Algebra

Hisab al-jabr w'al-muqabala

“That fondness for science, ... that affability and condescension which God shows to the learned, that promptitude with which he protects and supports them in the elucidation of obscurities and in the removal of difficulties, has encouraged me to compose a short work on calculating by al-jabr and al-muqabala, confining it to what is easiest and most useful in arithmetic.”

al-jabr means "restoring", referring to the process of moving a subtracted quantity to the other side of an equation.

al-muqabala is "comparing" and refers to subtracting equal quantities from both sides of an equation.
Finding Your Way Around
Planetary Coordinates

To describe positions on a planet, we use Latitude and Longitude.

N10° = +10°
S10° = -10°

Equator is halfway between the poles.

Prime Meridian 0° LAT
Passes through Greenwich England
By projecting the Sphere onto a Cylinder, we can make a map called a Mercator Projection.

Such maps are called Conformal Maps as angles between lines are preserved.

Latitude are equally spaced, but do no appear so on the Map.
Mercator Projection for Earth

Thus the polar regions, such as Greenland and Antarctica are extremely distorted.
Coordinates on Earth

Chicago IL is at 41.90° N 87.65° W

That is:
41° 54’ N
87° 39’ W

How far is 1° Latitude?
Latitude and Distance

There are 180° of Latitude that span half the Circumference of the Earth, so it would take 360° to go all the way around.

Circumference = 2 \( \pi \) R

\[
= 2 \times 3.14 \times 3959 \text{ mi}
\]

\[
= 24,900 \text{ mi}
\]

\[
\frac{24,900 \text{ mi}}{360^\circ \text{ Lat}} = \frac{69.2 \text{ mi}}{1^\circ \text{ Lat}}
\]

\[
D = \frac{2 \pi R}{\theta}
\]
Longitude and Distance

For Longitude, it depends on your latitude

At the poles, all the longitudes are the same.

At the equator, they are maximally spread out at 69.2 miles per degree.

\[ D = \frac{2 \pi R \cos \theta}{\phi} \]

where \( \theta \) is the latitude and \( \phi \) is the longitude.
Mercator Projection for Mars

The same coordinate systems are used for the other planets. Similar maps are made as well.
Latitude and Longitude on Mars

Opportunity’s Landing Ellipse
Zenith and Nadir

Zenith is the direction straight up.

Nadir is the direction straight down.
The Meridian is the circle that goes through the zenith and is oriented in a North-South direction.
The North Star Polaris

Polaris almost lies in the direction of the Earth’s rotational axis.

It is almost Celestial North

Zenith

Meridian

Nadir

Polaris

S

W

N

E
The Big Dipper

Zenith

Meridian

Nadir

Polaris
Azimuth is an angle that describes the direction of an object in the sky as seen from the surface.

- North is 0°
- East is 90°
- South is 180°
- West is 270°
Altitude is an angle that describes the direction of an object in the sky from the horizon. Horizon is 0°, Zenith is 90°.
You can imagine that the Earth is surrounded by a Sphere of Stars.

This gives us a coordinate system, much like the Latitude and Longitude on the Surface.
Equator

The plane of the Earth’s equator gives us one reference point.

[Diagram showing celestial north and south, zenith, nadir, and equator.]
The planets orbit very nearly in a single plane. This plane is called the Ecliptic, and it gives us another reference point.
Equinoxes

The directions from the Sun to the point in the Earth’s orbit where the Equinoxes occur are given by the intersection points between the Equatorial Plane and the Ecliptic.
Equinoxes

The position of the Sun during the Equinoxes is given by the intersection points between the Equatorial Plane and the Ecliptic.
Equinoxes

The position of the Sun during the Equinoxes is given by the intersection points between the Equatorial Plane and the Ecliptic.
Celestial Coordinates

We now have two circles from which we can define angles.
Declination

Declination (Dec) is the angle from the equator.

This is analogous to Latitude on the Surface.

An object along the ecliptic has declination of 0°, above the North Pole 90°, and -90° above the South Pole.
Right Ascension

Right Ascension is the angle from the Vernal Equinox.

This is analogous to Longitude on the Surface.

The exception is that Right Ascension (RA) is given in hours rather than degrees.
Measuring Angles

An Outstretched Fist subtends approximately 40 minutes of Right Ascension, which is about 10 degrees of arc.

Your thumb held up with you arm outstretched is about 1.5 degrees, or the angular size of the Moon.

Your Pinky’s width, is about a degree.
Orion

Here again, we have Orion

http://joemorris.mystarband.net/images/Orion%20Constellation.jpg
Orion

Here again, we have Orion

http://joemorris.mystarband.net/images/Orion%20Constellation.jpg
Orion

And here it is in a Star Atlas

Betelgeuse (α Ori)
RA: 05 55 10.3   DEC: +07 24 25.4

Rigel (β Ori)
RA: 05 14 32.2   DEC: -08 12 05.9

Bellatrix (γ Ori)
RA: 05 25 07.8   DEC: +06 20 58.9

Mintaka (δ Ori)
RA: 05 32 00.4   DEC: -00 17 56.7

Alnilam (ε Ori)
RA: 05 36 12.8   DEC: -01 12 06.9

http://www.asahi-net.or.jp/~zs3t-tk/atlas/atlas.htm
Orion

And here it is in a Star Atlas

Betelgeuse (α Ori)
RA: 05 55 10.3  DEC: +07 24 25.4

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RA: 05 36 12.8  DEC: -01 12 06.9

http://www.asahi-net.or.jp/~zs3t-tk/atlas/atlas.htm
The Pyramids of Giza

Let's check them out on Google Earth
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
The Pyramids of Giza
Tilt of the Earth’s Axis

The Earth’s rotational axis is titled with respect to the plane on which the Earth revolves around the Sun by an angle of about 23.45°.

This is why the ecliptic is tilted with respect to the equatorial plane.
The Earth’s axis is titled by $23.45^\circ$ from being perpendicular to the plane of the ecliptic. The direction of the axis of the Earth’s rotation stays roughly constant throughout the year.
Precession of the Equinox

The Earth’s axis precesses like a top. This precession has a period of about 25800 years.

This means that the position of the Sun in the sky during the Spring Equinox changes slowly.

This is why the constellations no longer line up in time with the astrological signs of the Zodiac.

http://en.wikipedia.org/wiki/Age_of_Aquarius
Currently, when the Spring Equinox occurs, the Sun is in the constellation Pisces. This time period (one 12\textsuperscript{th} of 25800 years) is called an Age. This is the Age of Pisces.

In the 27\textsuperscript{th} century, we will enter the Age of Aquarius as the Sun moves into Aquarius at the Spring Equinox. Remember, this is not a motion of the Sun, but a periodic precession of the Earth’s axis.
Days

A Solar Day is the time for the Earth to make one full rotation on its axis with respect to the Sun.
A Solar Day is 24 h

A Siderial Day is the time for the Earth to make one full rotation on its axis with respect to the stars.
A siderial day is 23h 56m 04.0905s
References

Indexes of Biographies
http://www-history.mcs.st-andrews.ac.uk/BiogIndex.html

Michael Fowler, Galileo and Einstein Lecture Notes
http://galileoandeinstein.physics.virginia.edu/lectures/aristot2.html

Zenith http://www.nmm.ac.uk/upload/img/altaz.jpg
Analemma http://www.csulb.edu/~rodrigue/geog140/analemma.gif
http://antwrp.gsfc.nasa.gov/apod/ap061230.html Dennis Mammana (Skyscapes)
Additional Slides
Aristotle’s Scientific Method

1. Define the subject matter
2. Consider the difficulties involved by reviewing the generally accepted views on the subject, and suggestions of earlier writers
3. Present his own arguments and solutions.

This is the pattern modern research papers follow. Aristotle laid down the standard professional approach to scientific research.

While research papers are written this way, this is no longer exactly how we perform research. We have Galileo to thank for that.

Reference: M. Fowler http://galileoandeinstein.physics.virginia.edu/lectures/aristot2.html
Aristotle’s Method

Aristotle used two kinds of arguments:
Dialectical: Based on logical deduction
Empirical: Based on practical considerations

Opposing arguments were often refuted by showing that it led to an absurd conclusion. This is called *reductio ad absurdum* (reducing something to absurdity).

Another relied on showing that an argument led to a *dilemma*, which means an apparent contradiction. However, dilemmas could sometimes be resolved by realizing that there was some ambiguity in a definition, say, so *precision of definitions* and usage of terms is *essential* to productive discussion in any discipline.

Reference: M. Fowler http://galileoandeinstein.physics.virginia.edu/lectures/aristot2.html
In December, the Sun is low in the New York sky.
In June, the Sun is high in the New York sky.
Compare the direction of the Sun to the Horizon.
Note that the Sun and Earth are not to scale.
Analemma

The Path that the Sun takes throughout the year when imaged at the same time every day is called an Analemma.

![Diagram of sun's path with labels for Tropic of Cancer, Equator, Tropic of Capricorn, June, September, March, December]
Analemma on Mars