Copernicus, Kepler, Galileo, Newton

How did we Discover the Earth is Round?

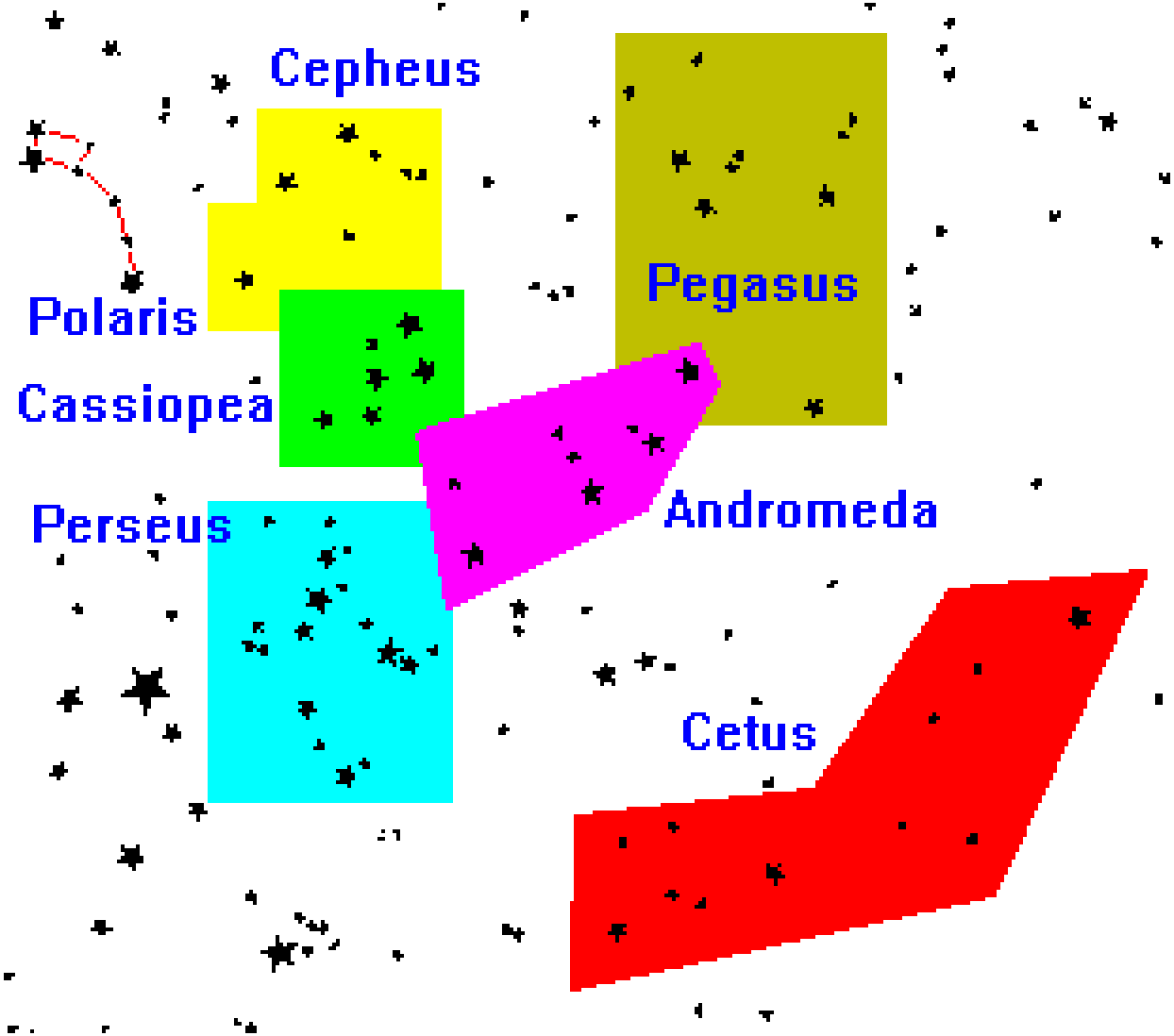
- Traditional: as a ship sails away, the hull diasppears below the horizon before the sails
- Problem: ancient ships were so tiny they would be mere specks on the horizon.
- More likely: someone on a *ship* saw the *land* come into view

How did we Discover the Earth is Round?

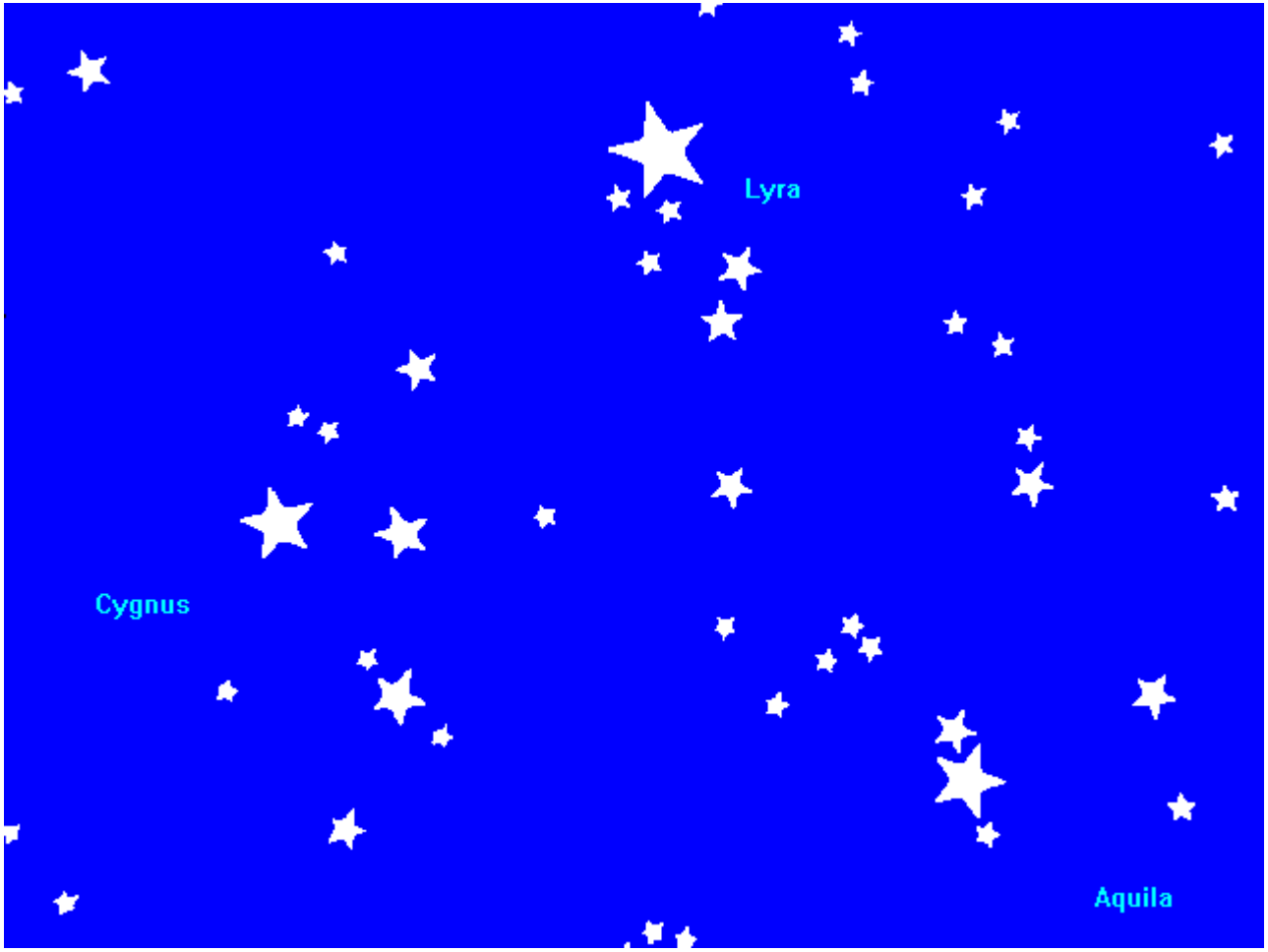
- Other possibilities: storm clouds with bases below the horizon
- Why is there a horizon at all? Why can't we just see forever?
- Contrary to myth, the knowledge of a round earth was *never, NEVER* forgotten during the Middle Ages

Constellations and Culture

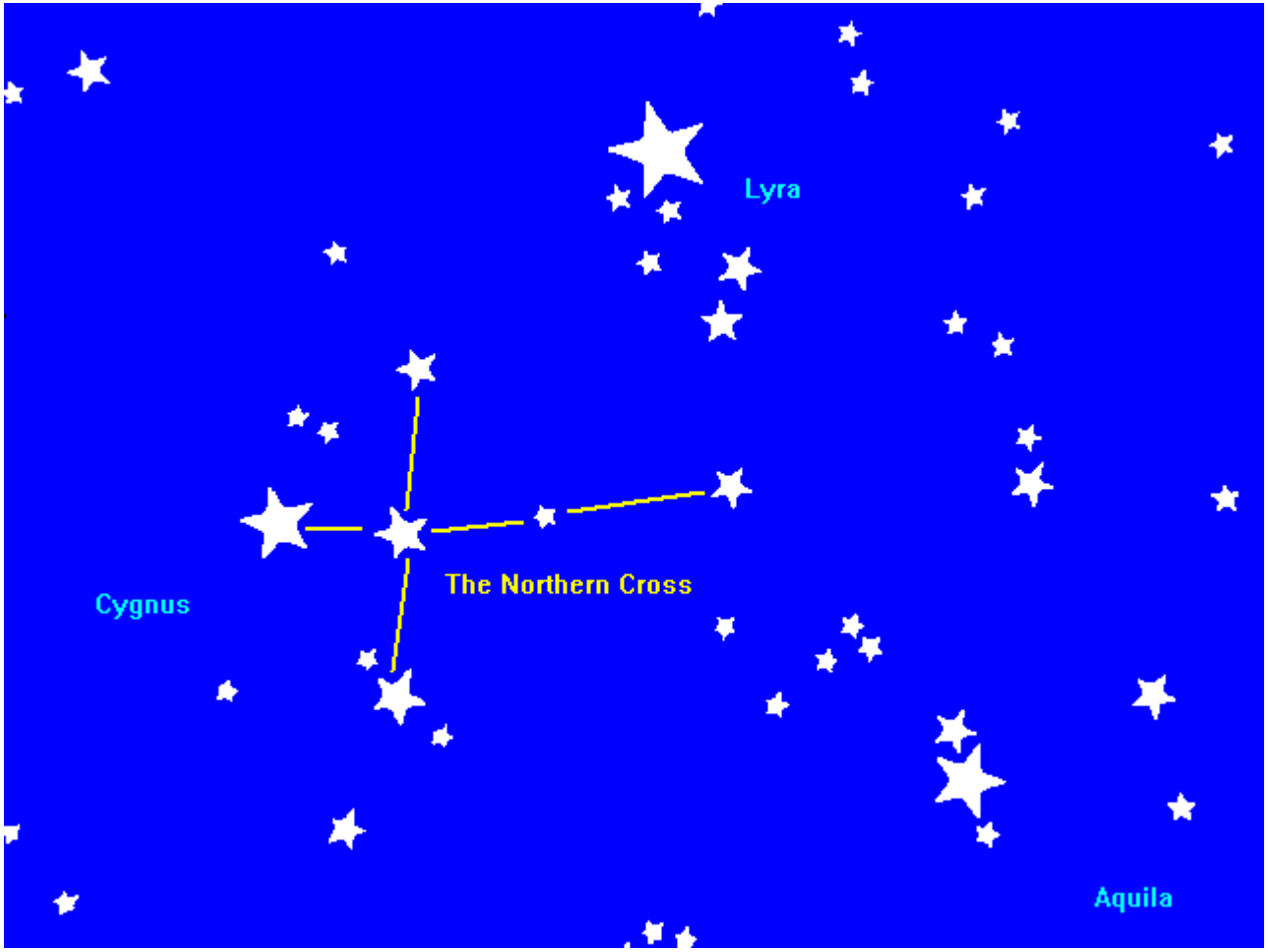
A Myth in the Autumn Sky



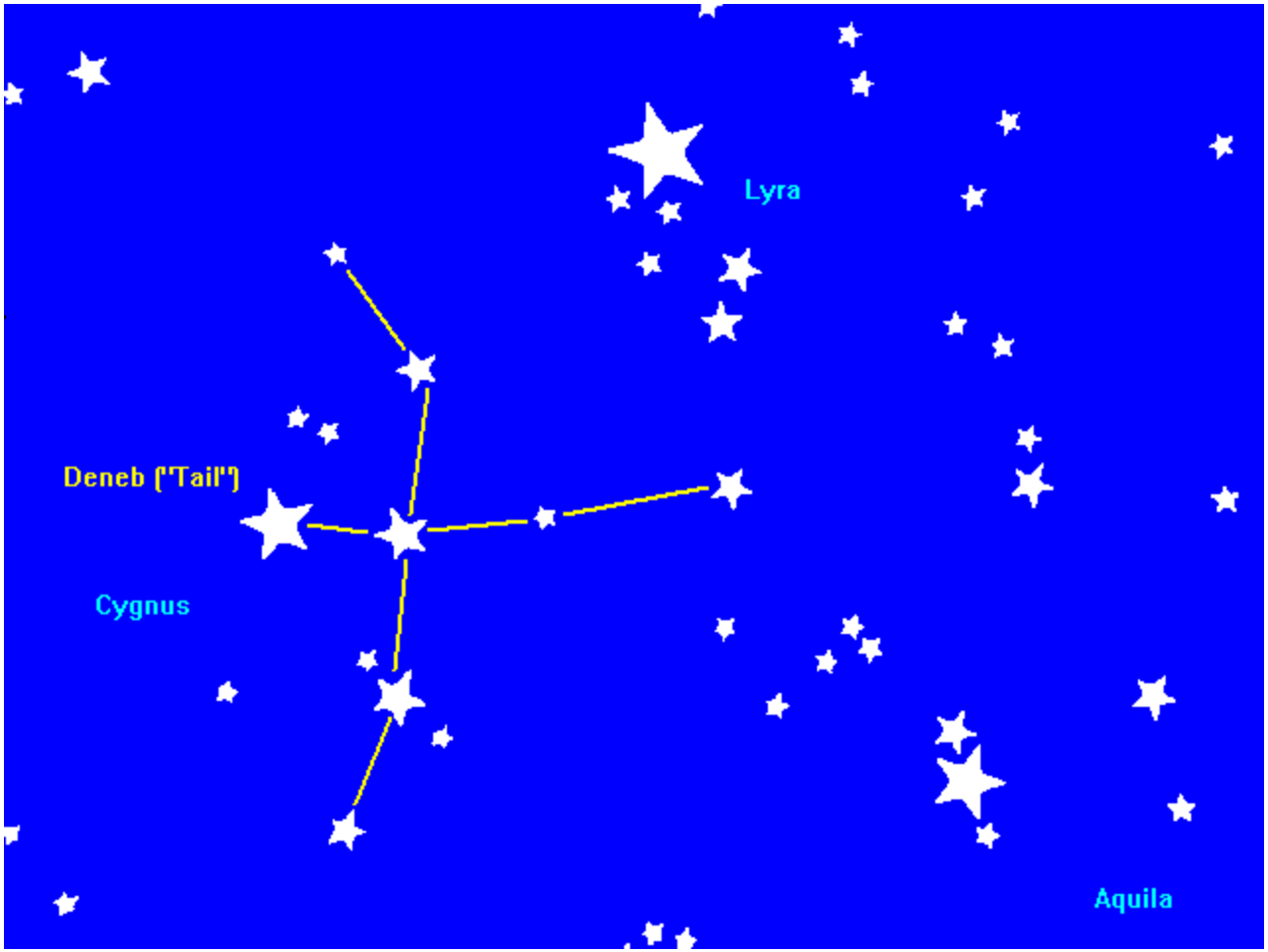
A Portion of the Northern Sky



The Northern Cross

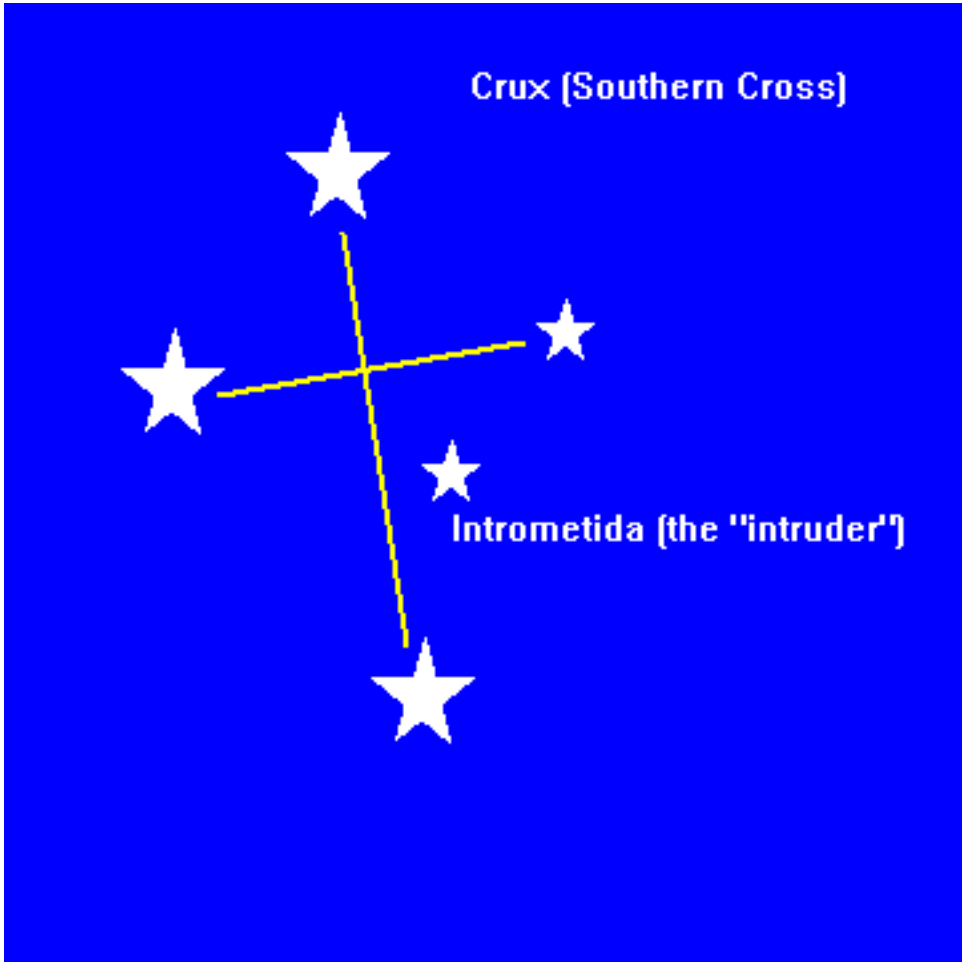


The Traditional Constellation

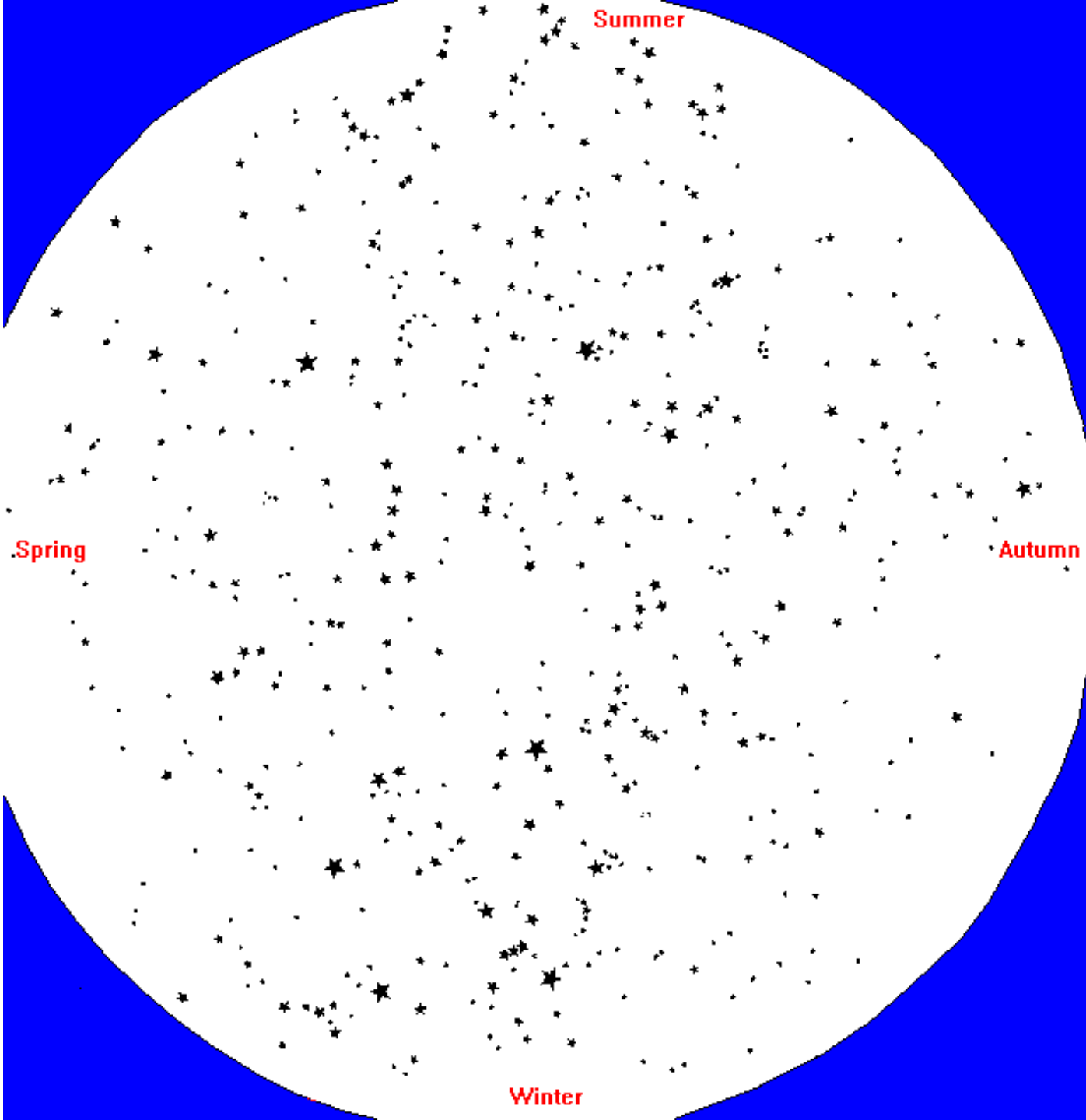


Why Didn't the Ancients Picture this as a Cross?

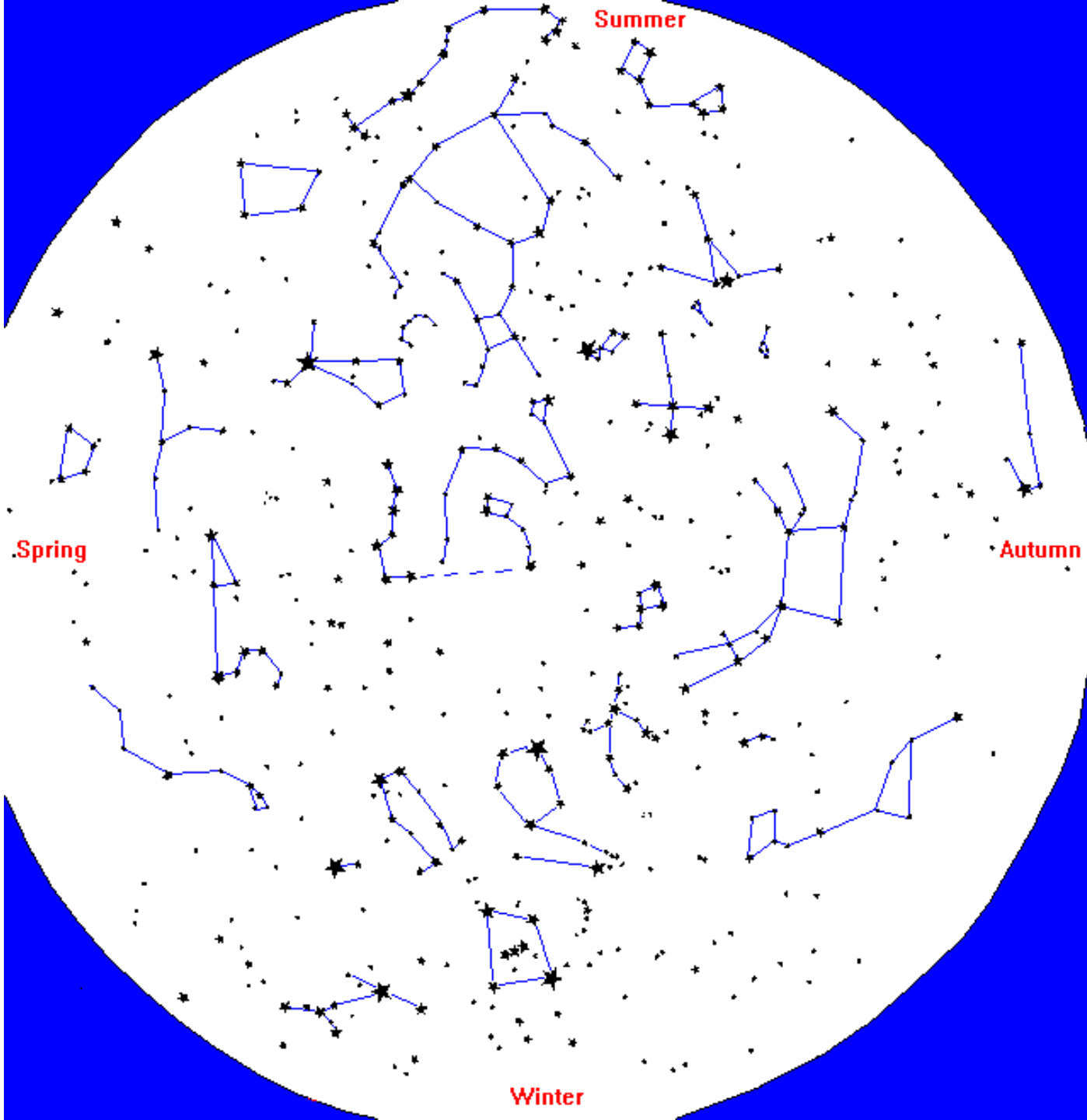
The Southern Cross



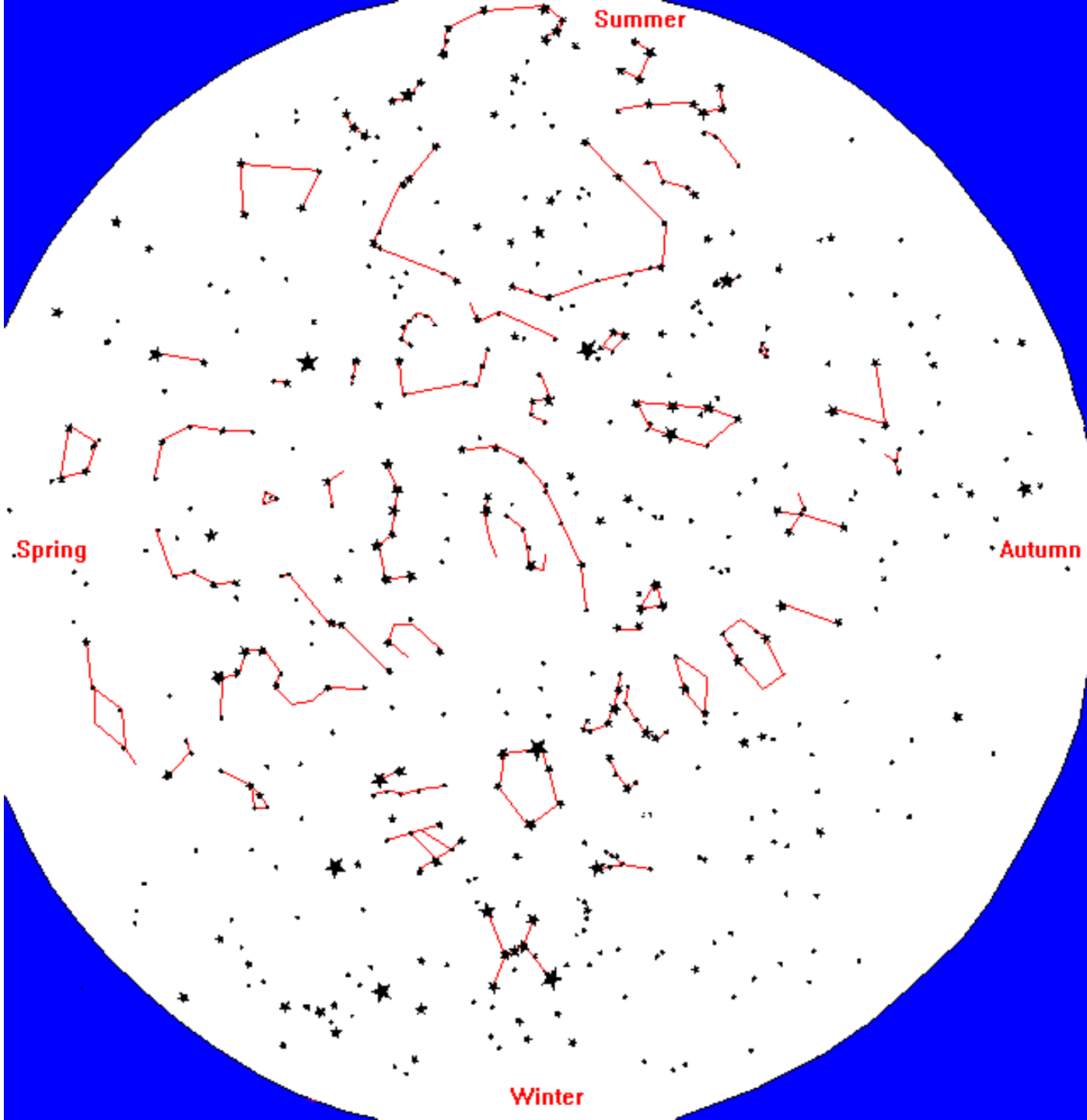
A Star Map



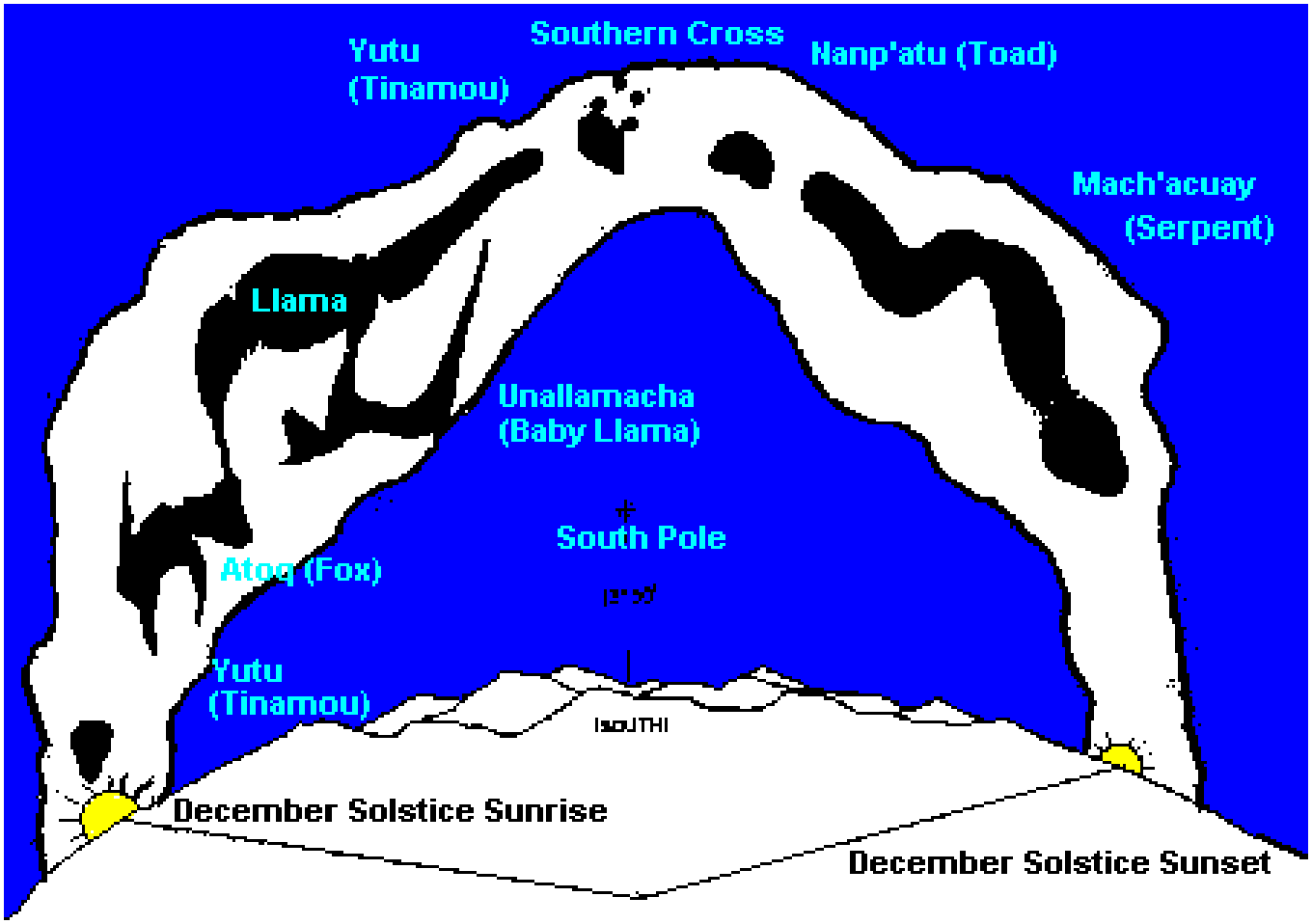
Western Constellations



Chinese Constellations



The Inca “Dark Constellations”



Copernicus: Precursory events

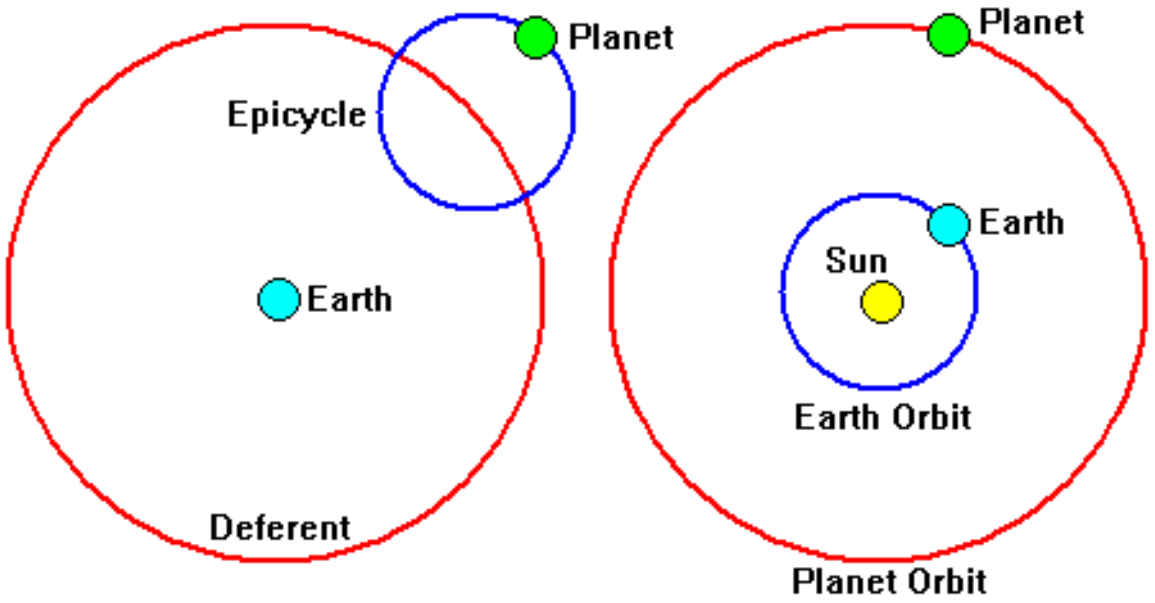
- Thomas Aquinas reconciles Aristotelian Philosophy with Christianity.
- King Alfonso the Wise of Castile publishes Alfonsine tables, based on Ptolemaic System, late 1200's.
- Concept of "Law of Nature" arises from medieval theology and philosophy.
- Ideal motion thought to be perfectly circular in heavens, rectilinear on earth.

Immediate Setting

- Printing invented 1457.
- Michelangelo, 1475-1564.
- Luther, 1483-1546.
- Protestant Reformation begins ca. 1520.
- Shakespeare 1564-1616.
- Age of Exploration, Colonization.
- Supernovae, 1572, 1604 shook idea of heavens as unchanging.

Ptolemaic System

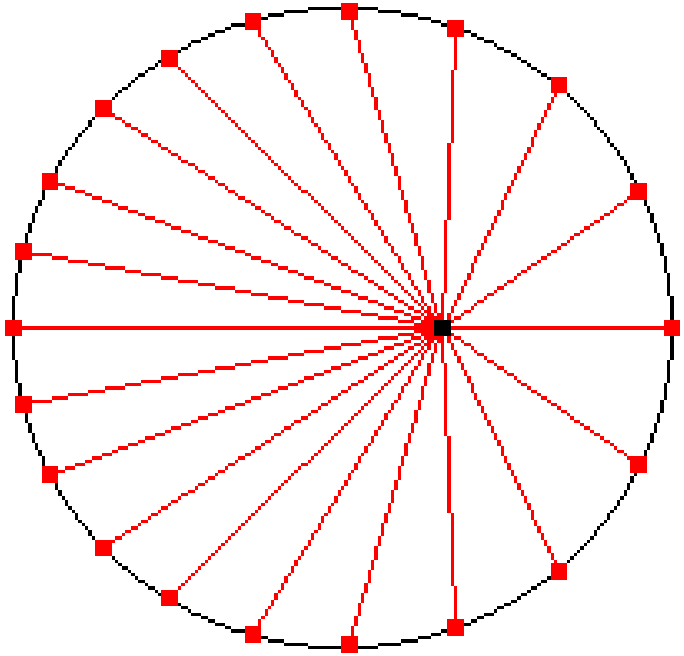
- Planets appear to reverse motions at times.
- Ptolemy explained motions in terms of orbits (epicycles) carried on a larger orbit (deferent).



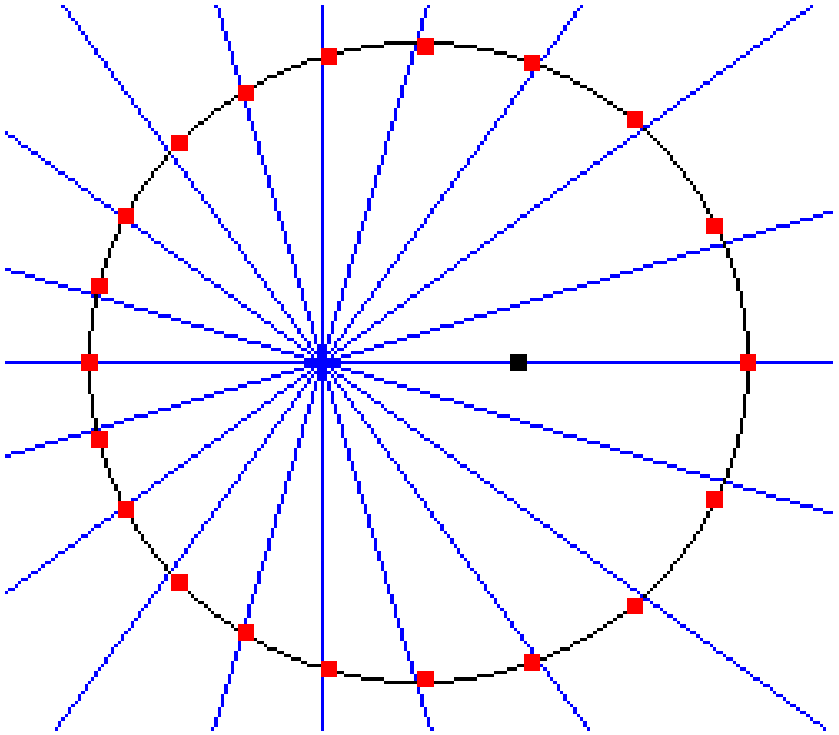
Ptolemaic System

- Epicycle deferent ratios were very close to modern values of planet/earth orbit ratios. System worked very well.
- Contrary to popular myths, Ptolemy's system was not overly cumbersome, and it accounted for subtleties like the uneven motion of the Sun
- It is not Ptolemy's fault he did such a good job that it took 1500 years to improve on him!

How Ptolemy Dealt With Unequal Speeds



Kepler's Second Law



Ptolemy's Equant Method

Why this was a hot topic

- Alfonso the Wise of Castile published tables based on Ptolemy, 1200's
- Tables were out of date by 1500
- System began to seem cumbersome and inelegant
- Need for calendar reform
- Gregorian Calendar, 1582
- System was beginning to seem clumsy

Nicolaus Copernicus 1473-1543

- First known modern person to propose the Earth circles the Sun
- Not known how he arrived at the idea
- Died just as theory was published
- Not much story to tell
- Luther; “this *fool* wants to overturn the whole science of astronomy”

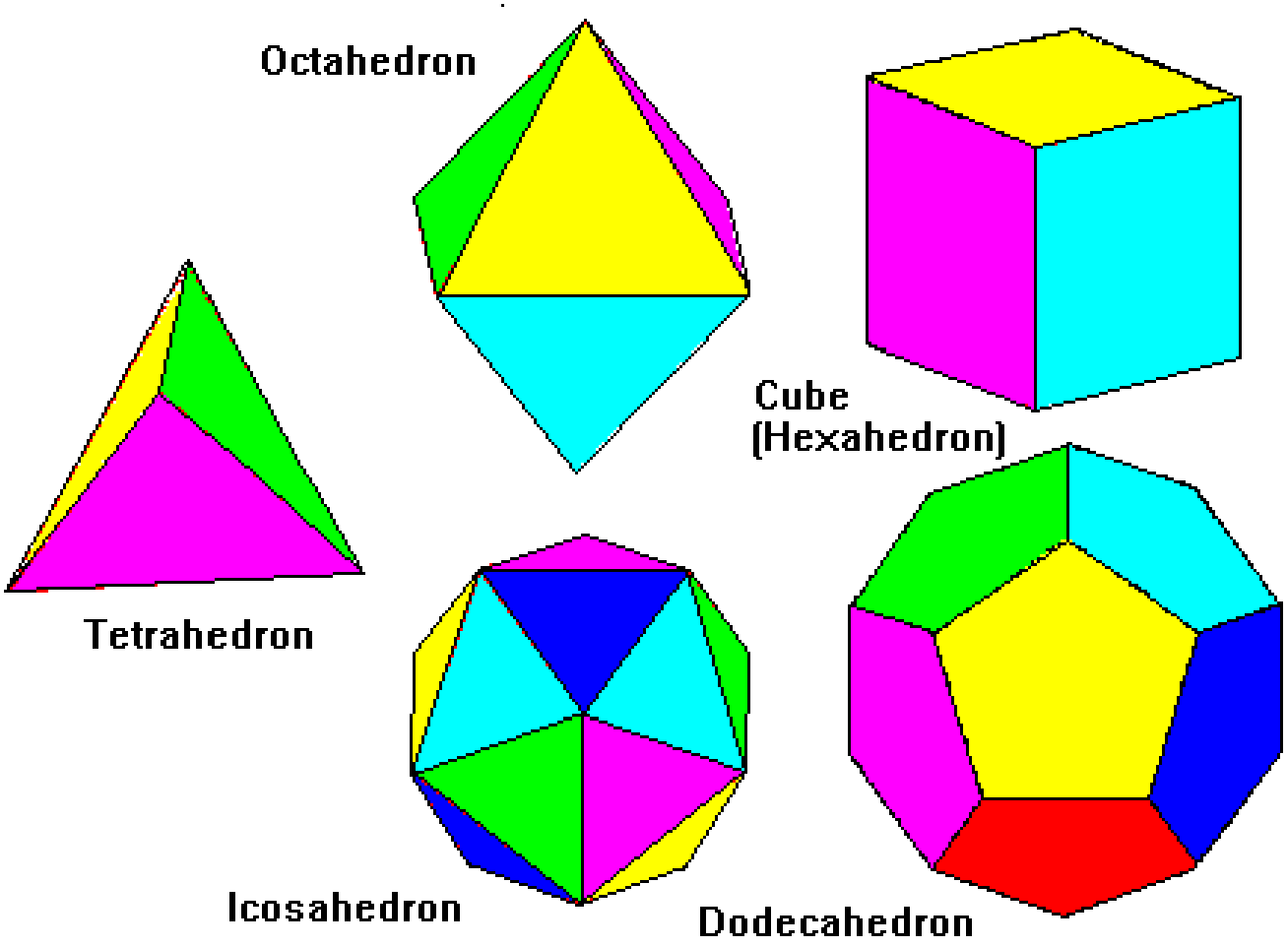
Possible clues to Copernican idea

- Epicycle motions for Venus and Mercury opposite other planets.
- Epicycle for Sun's motion appeared in schemes for all other planets.
- References to now-lost ideas of Aristarchus of Samos

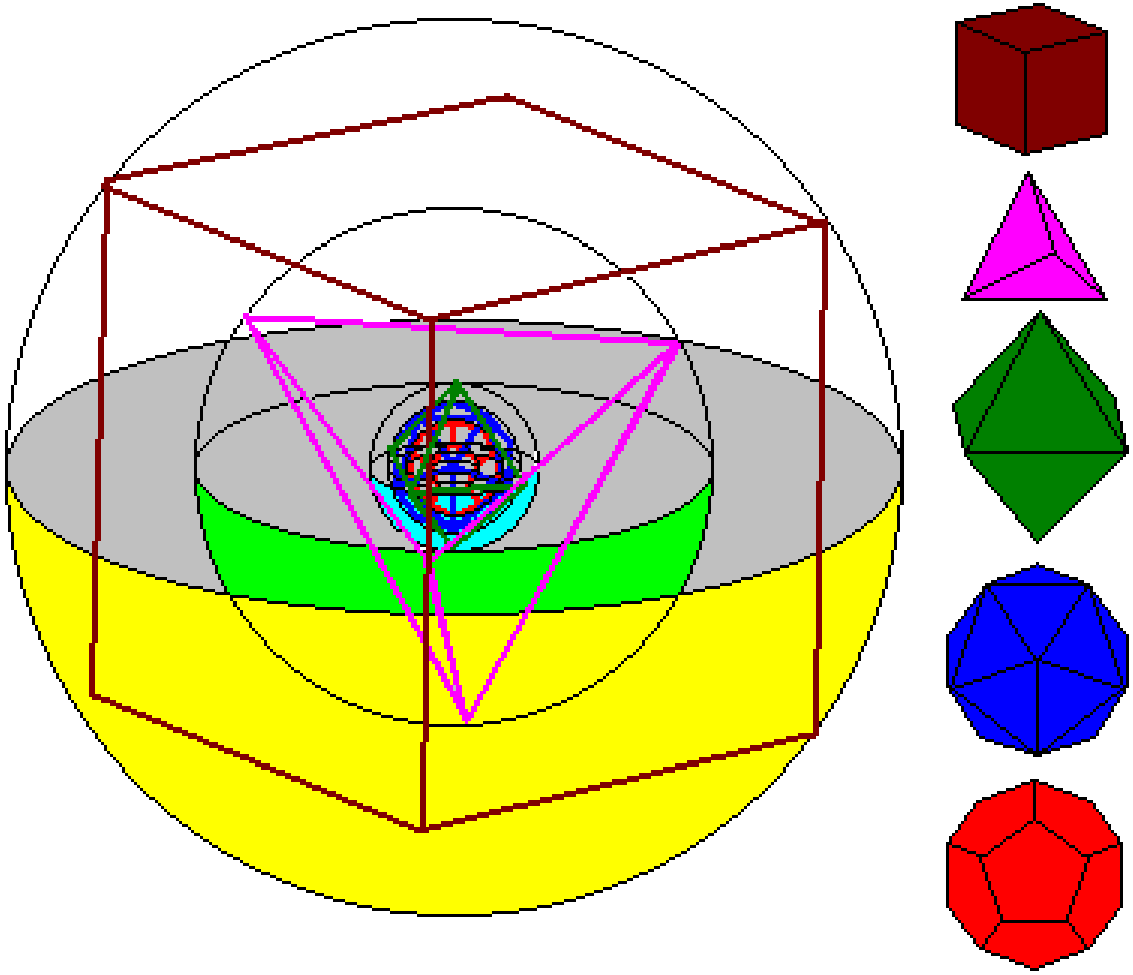
Johannes Kepler 1571-1630

- A thoroughgoing medieval mystic
- Left detailed accounts of his reasoning
- Generally a much more interesting story than Copernicus

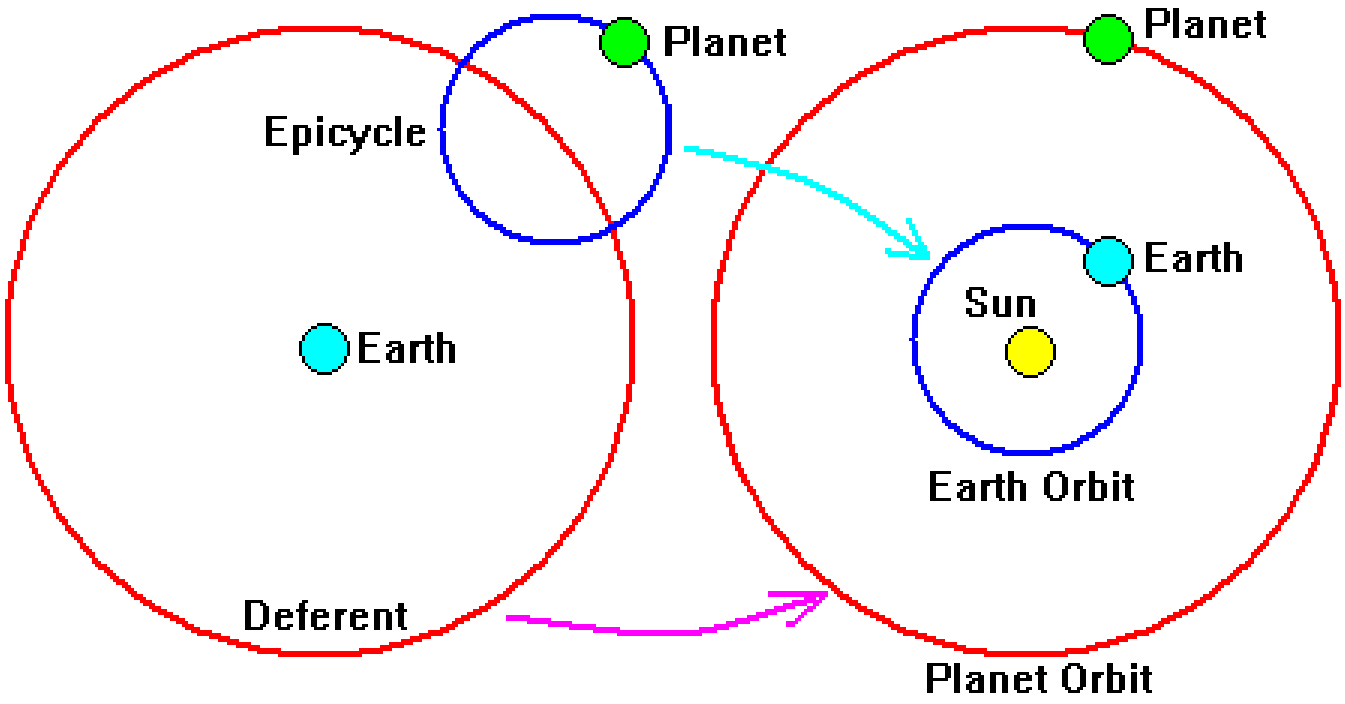
The Platonic Solids



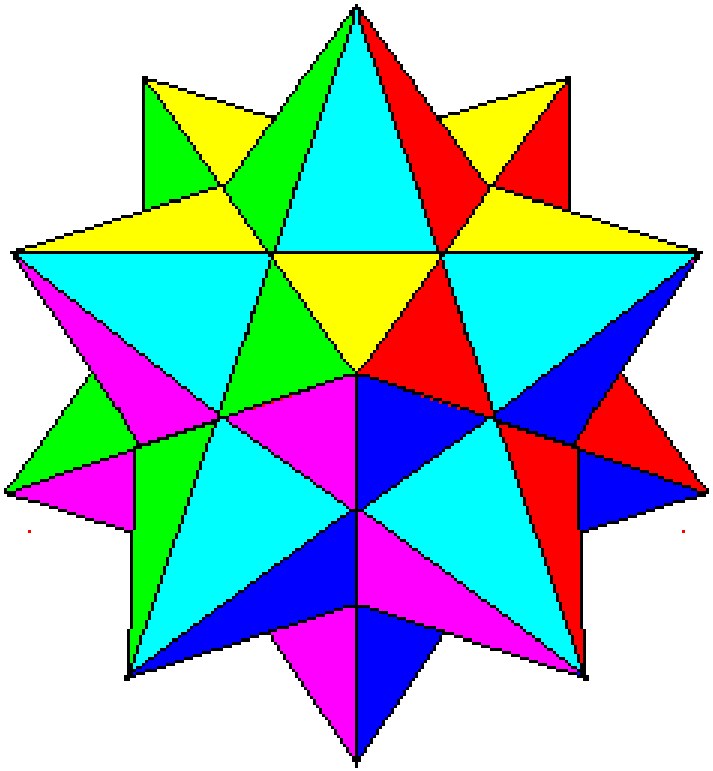
Kepler's Nested Spheres



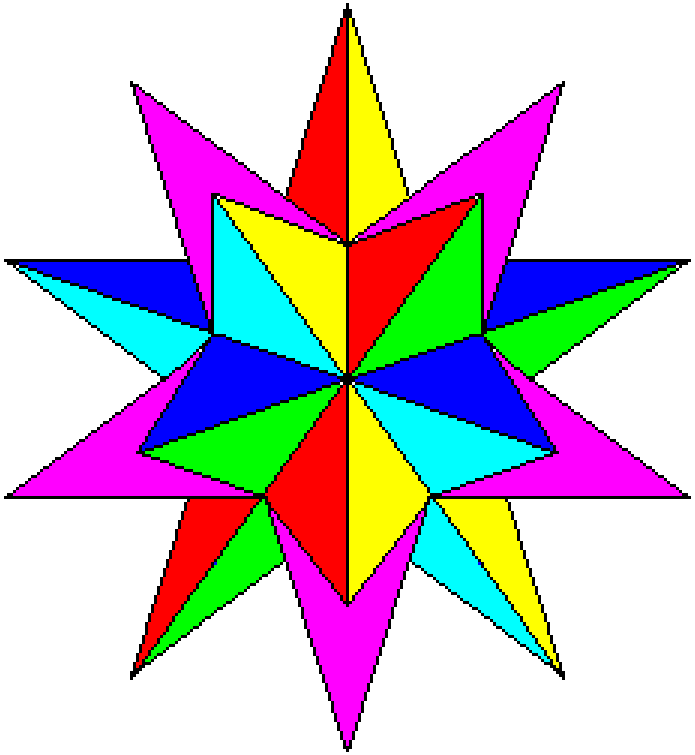
How Did Kepler Know the Spacing?



The Kepler Solids

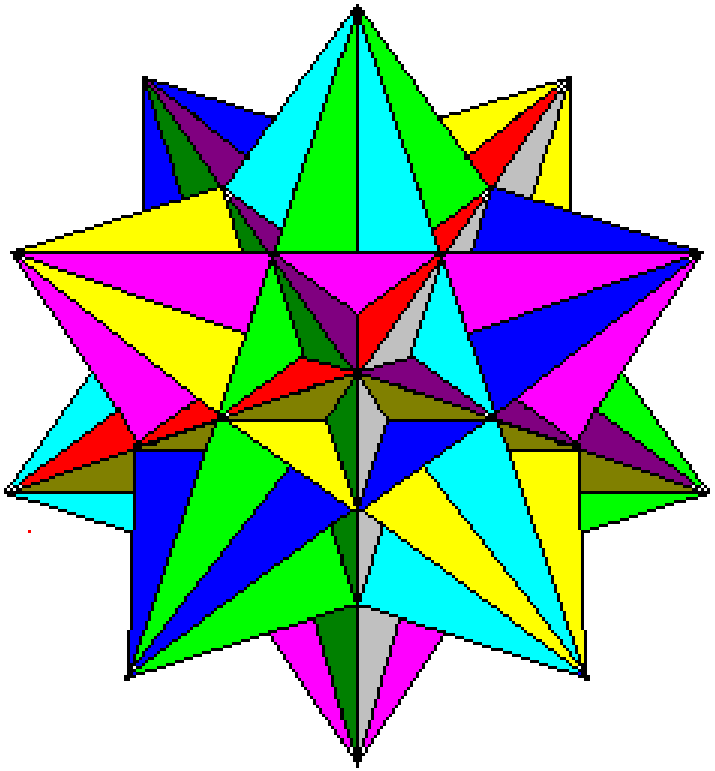


Small Stellated Dodecahedron

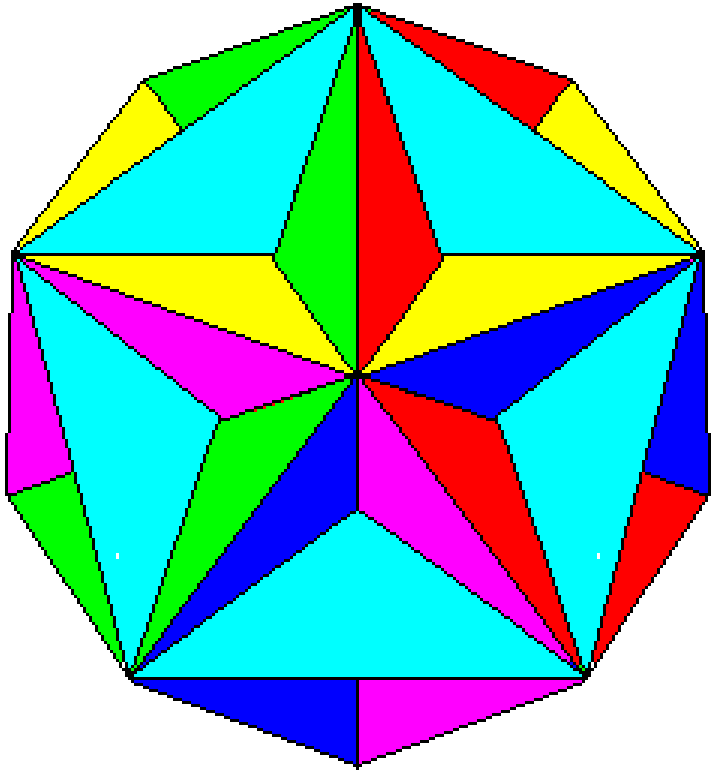


Great Stellated Dodecahedron

The Poinsot Solids



Great Icosahedron



Great Dodecahedron

Strange Start - Good Finish

- Kepler started off with mystical ideas, and ended up correctly describing the motions of the planets. How can this be?

Science often proceeds by a process of successive approximation

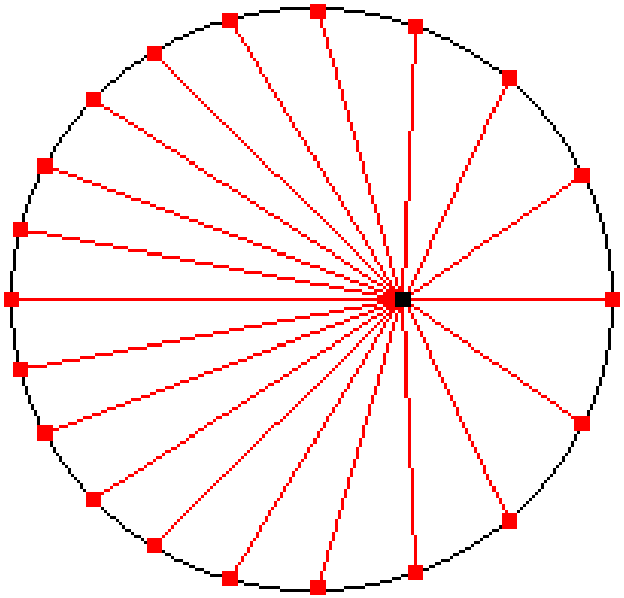
- Make an assumption
- See how it fits reality,
- Modify it (junk it if necessary) and try again.
- After a few iterations of successive approximation you can be very far from your starting point,
- Even fairly strange initial assumptions can lead to correct results.

Successive Approximation differs profoundly from circular reasoning,

- In circular reasoning, you start off with an assumption,
- Accept, reject, or modify observations to fit the assumption,
- Then use the results as proof of the assumption.
- People who engage in circular reasoning almost never scrap or modify their initial hypothesis
- The whole point of circular reasoning is to justify the initial hypothesis at all costs.

Kepler's Laws

- Planets travel around the Sun in elliptical orbits with the Sun at one focus.
- A line from the planet to the Sun sweeps out equal areas in equal times.
- The square of a planet's period in years and its distance cubed are proportional.

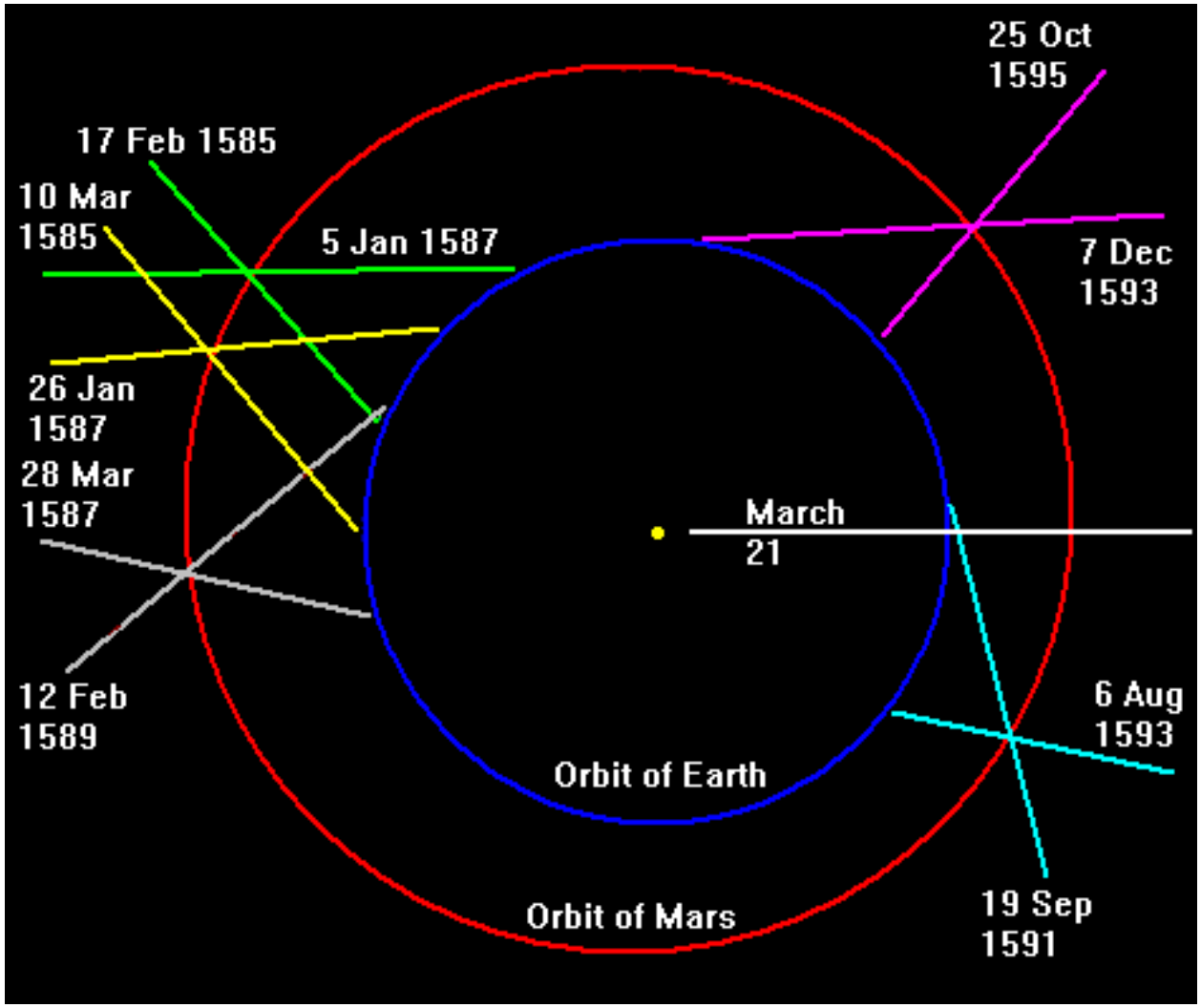


Kepler's Second Law

How Did Kepler Do It?

- One Mars year (687 days) = 2 Earth years (730 days) minus 43 days
- After 687 days, Mars is in the same place in its orbit, but Earth is not
- Mars appears to be in a different location in the sky

How Did Kepler Do It?



Tycho Brahe 1546-1601

- Tycho really did live the outrageous lifestyle shown in the video
- Really did have a gold nosepiece.
- He died the way he lived. He was hitting up some noble personage for patronage and support and, fearing that somebody else might upstage him, refused to leave to go to the bathroom. He developed a bladder infection and died.

A Neat Coincidence that's *Too Neat*

Rosenkranz and Guldenstern are Dead

Who were they?

Hamlet

- Hamlet's Uncle has:
  - Murdered his father
  - Married his mother
  - Usurped Hamlet's Crown
- Hamlet is Depressed
- How Much does Hamlet Know?

Enter Rosenkranz and Guldenstern

- Hamlet is supposed to take place in late Viking times (ca. 1000 A.D.)
- Rosenkranz and Guldenstern are student friends of Hamlet's from the University at Wittenberg
  - Which doesn't exist yet
- Recruited by Hamlet's uncle to console (spy on) him.

Exit Rosenkranz and Guldenstern

- The king sends the trio to England with a sealed letter instructing the king of England (a relative) to kill Hamlet
- Hamlet switches letters on his ex-friends
- Hamlet has it out with the king
- Bodies all over the stage, curtain falls
- See you at the cast party

What does this have to do with the planets?

- Tycho had published a widely-sold book
- Modest chap that he was, he included a portrait and 16 crests showing his lineage over four generations
- Tycho was Danish
- His estate was right across the strait from Elsinore Castle

Tycho and Shakespeare

- Guess what two of the names on the crests are
- Tycho and Shakespeare had a mutual acquaintance
- Clearly this was an inside joke for audiences in the know

Rosenkranz

Guldenstern

So Who's Galileo (1564-1642)?

- Galileo did not invent the telescope (known since at least 1590).
- One of the first to use a telescope on the heavens. Found observational evidence that challenged traditional views.
  - Craters on moon
  - Phases of Venus
  - Satellites of Jupiter

Galileo

- Others independently used telescopes on celestial objects at nearly the same time. Galileo had the best publicity.
- Main impact: An aggressive popularizer of Copernican viewpoint and satirist of Aristotelian physics.
- Very much like a 17th century Carl Sagan

Kepler and Galileo

- Galileo and Kepler corresponded.
- Galileo defended Copernican astronomy but never wrote about Kepler's model.
- Galileo may have been repelled by Kepler's mysticism.
- Moral: even the best and most innovative workers can sometimes fail to recognize a major advance.

Why was the Copernican Revolution so pivotal?

- Chance (science had to start somehow)
- Intellectually respectable pursuit, suitable for elite
- Don't get hands dirty
- Problem literally of cosmic significance
- Big problems tend to attract the best minds

Why was the Copernican Revolution so pivotal?

- Opportunity to observe laws of nature in "pure" form
- Gravity and momentum are the only laws at work
- Uncomplicated by friction, air resistance, etc.
- In a sense, the ancients were right; the heavens *are* more harmonious than Earth.

The Scientific Establishment

- Earliest means of communication, privately published books, pamphlets, letters.
- Often vigorous counter-responses published by others.
- Martin Mersenne (1588-1648), French mathematician, copied and distributed letters, acted as clearing-house. Nicknamed "Post-Box of Europe." Good analogy to informal Internet discussion networks today.

Scientific Societies and Journals

- First in mid-1600's
- Journals first published late 1600's (about 100 by 1800, nearly 50,000 now).
- By ca. 1700 books had become so specialized that publishers often refused to print them.
- About 6,000,000 scientific articles published annually now, worldwide.

Scientific Societies and Journals

- Information content has doubled about every 15 years since 1700.
- Most of history's scientists are alive now, most knowledge gained in living memory
- Same has been true since about 1700.
- Approaching saturation of resources?

Scientific Support

- Many early scientists were amateurs. *Every* science was founded by somebody not formally trained in it.
- Few opportunities for scientific employment until 19th century
  - physicians
  - engineers

Scientific Support

- Many early scientists supported by occupations that allowed leisure.
  - clergy
  - government sinecures (jobs with no responsibilities)
  - independent wealth
  - royal patronage
- Present forms of support very recent in origin
  - corporate research
  - government grant

Priority conflicts

- Newton had disputes with Robert Hooke about discovery of gravity, and Liebniz over the invention of Calculus
- Have occurred since earliest days of science even when workers were few.
- Major problems attract many workers, most attention: challenge, prestige
- Solutions often emerge simultaneously from many sources.