Armillary Spheres

Roger Bailey

NASS Montreal 2001

Armillary Spheres in Portugal

- Armillary spheres are everywhere!
- Traffic circle/ fountain
- Flag, money, coat of arms
- Churches, monasteries, convents, schools, monuments, flagpoles
- What is an armillary sphere and why is it the symbol of Portugal?

What is an Armillary Sphere?

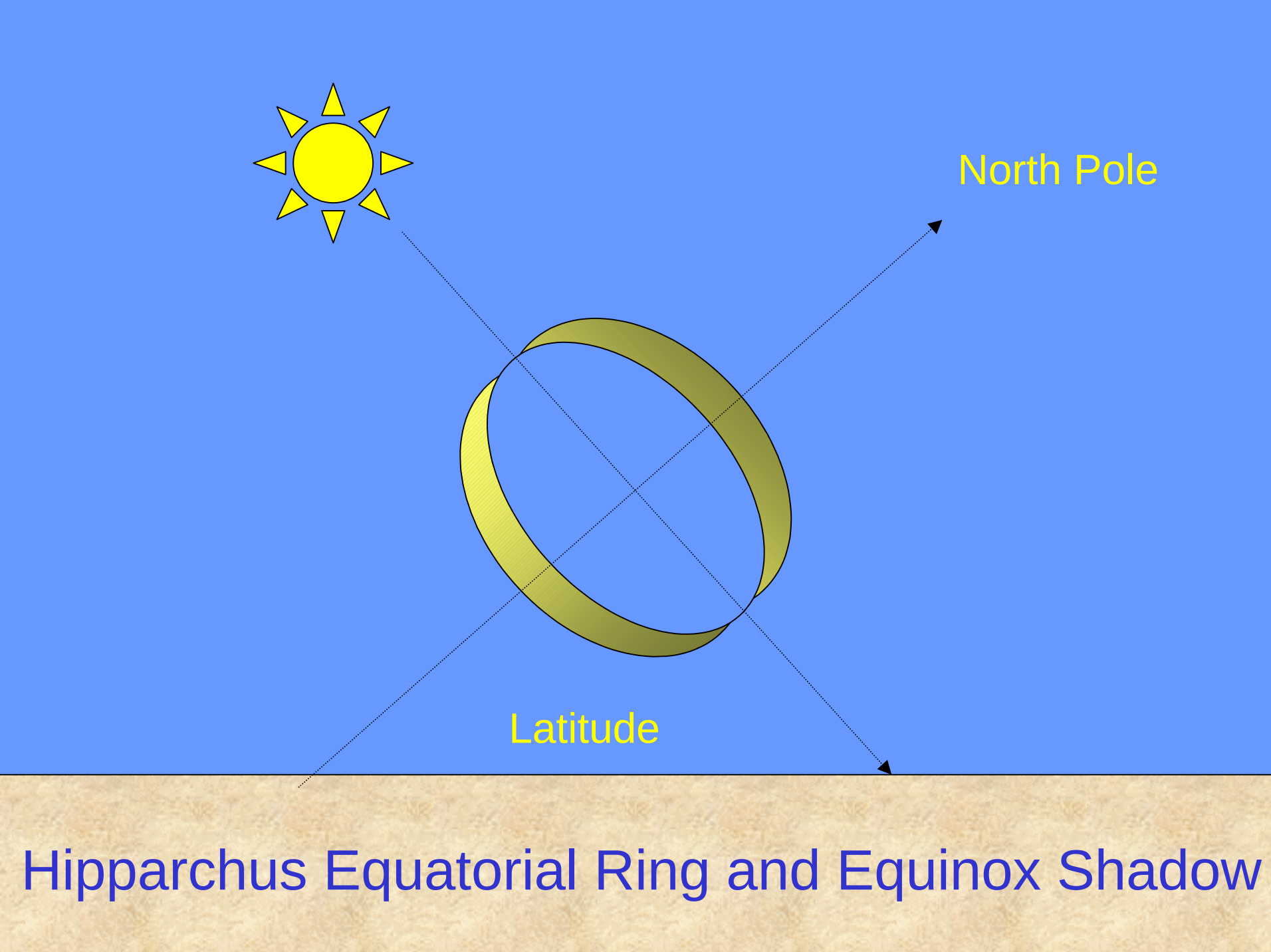
- Sundial ?
- Astronomical instrument?
- Analogue computer?
- Navigation tool?
- Horoscope calculator?
- Model of the Universe?
- Symbol of science, technology and the universe?

Quadrant and Ring

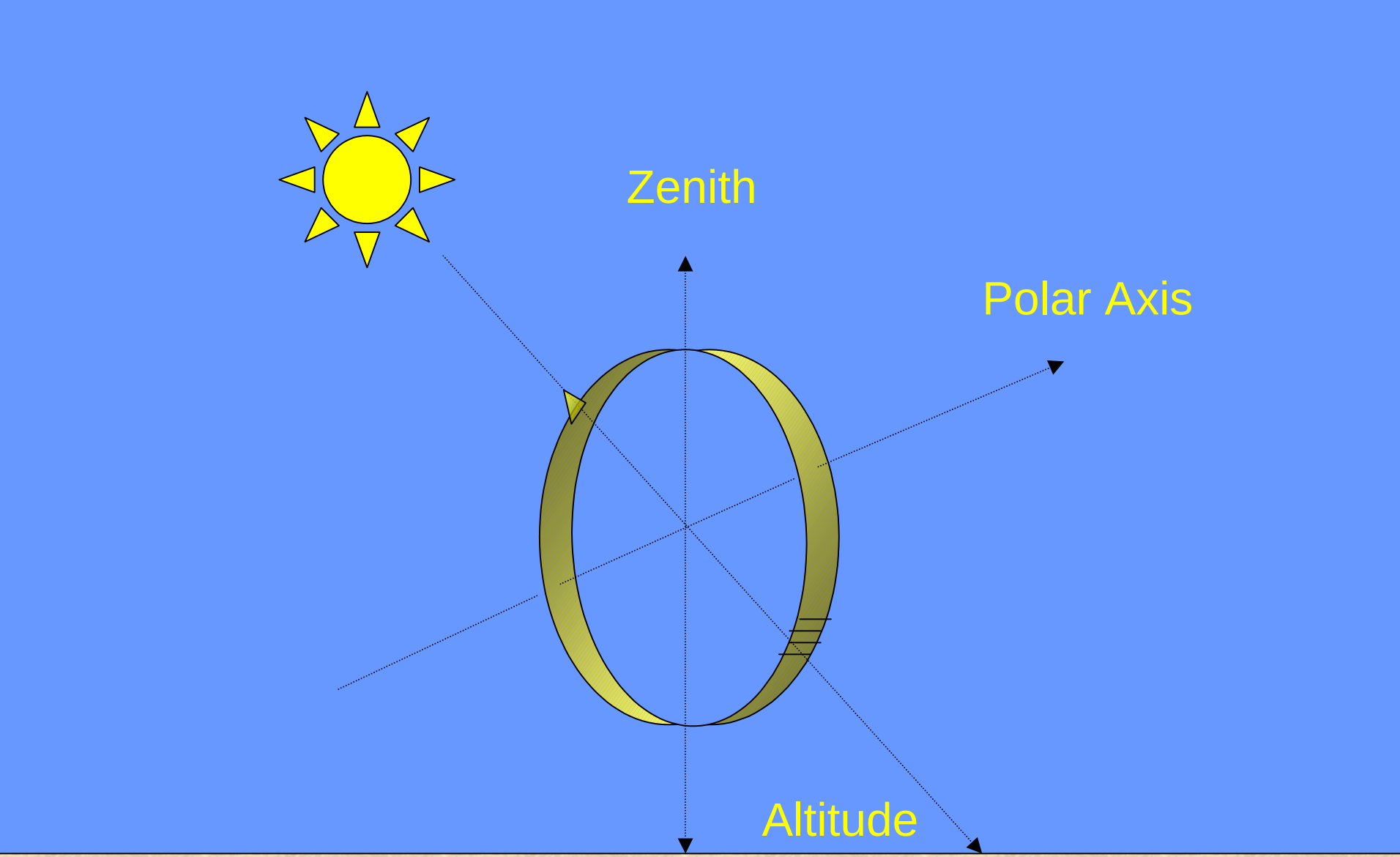
- Equatorial Ring identifies time of equinox when the shadow from the upper ring is totally cast on the lower portion of the ring
- Quadrant measures noonday altitude of sun
- Hipparchus used the bronze equatorial ring in the Square Hall in Alexandria to determine the equinox and precession about 130 BC
- St John’s College, Annapolis

Greek Armillary Spheres

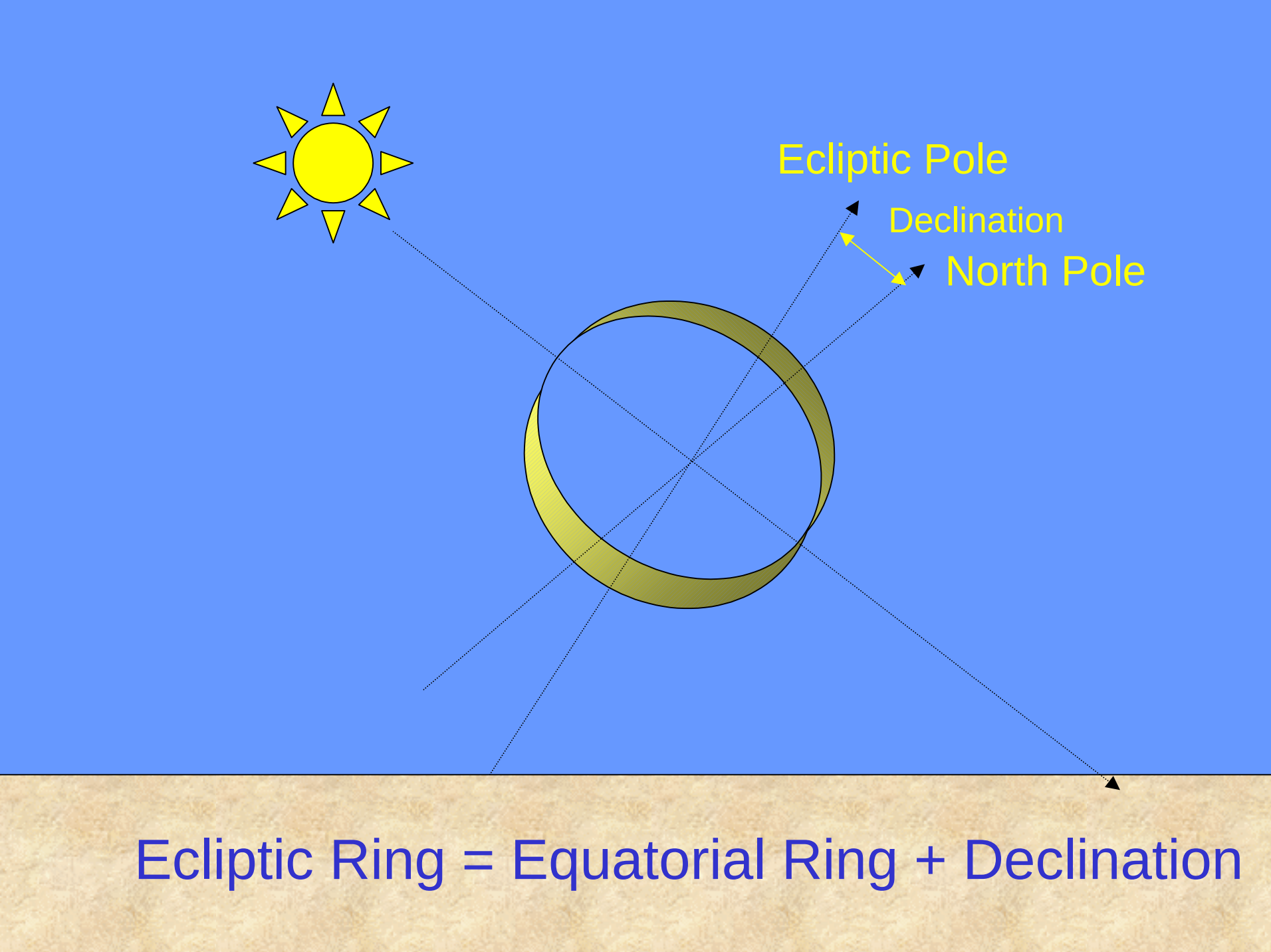
- Greek astronomers devised armillary spheres as observational instruments, models of the universe and the basis for navigation and geography
- In his “Almagest”, Ptolemy described the meridian ring (1-12), equatorial ring (3-1), ecliptic observation rings (5-1) and solid celestial sphere (7-4)



Hipparchus Equatorial Ring and Equinox Shadow

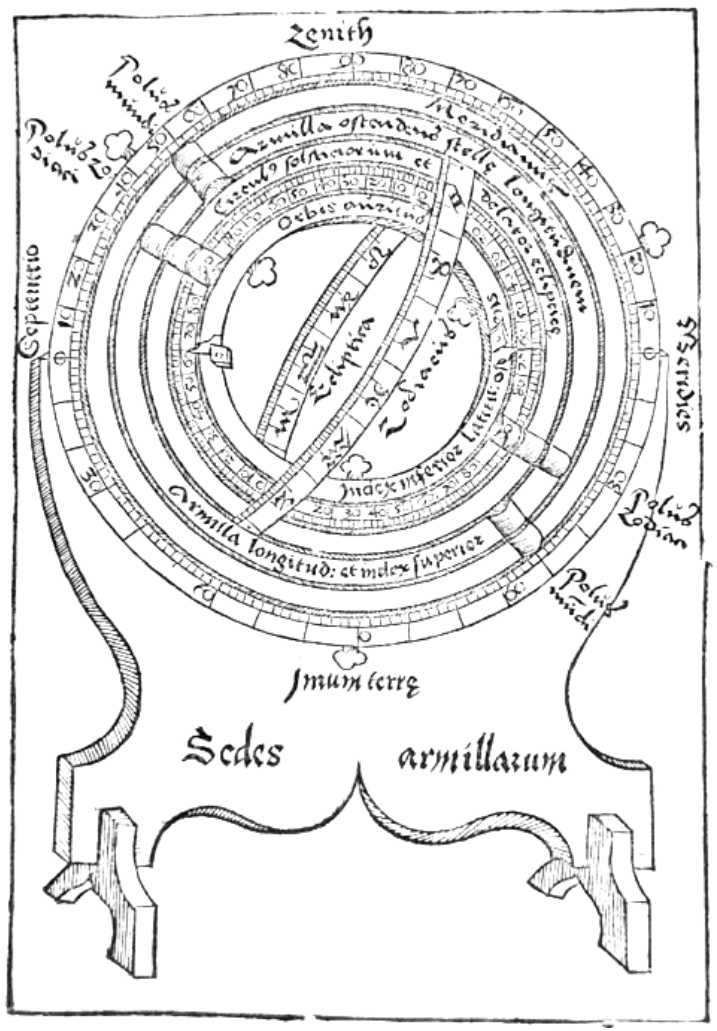


Ptolemy Meridian Ring and Noon Shadow



Ecliptic Ring = Equatorial Ring + Declination

Ptolemy's Ecliptic Armillary



- Ptolemy's Almagest 5 –1
- "On the Construction of the Astrolabe"
- Determine ecliptic coordinates of celestial objects
- Set meridian and latitude rings to equatorial pole
- Sight on Inner Ring
- Read ecliptic latitude and longitude rings
- Sketch from Regiomontanus

Rings of the Magi ?

- Armillary used by the ancient astronomers to track the path of the planets, sun and moon and cast horoscopes
- Did the Magi, Zoroastrian astrologers, use armillary spheres to track the Star of Bethlehem?
- Heliacal rising of conjunction?
- Precession to age of Pisces?

Chinese Armillary Spheres

- Armillary sphere of Guo Shoujing (1231-1314) at the Purple Mountain Observatory at Nanjing.
- These instruments predate by 350 years similar instruments at the Beijing Ancient Observatory provided by Jesuits (Schall-1666, Verbiest-1673)

The Dark Ages

- Vandals sack Rome, Alexandria etc
- Greek/Roman civilization collapses
- Warlords dominate feudal life
- Science moves east with Moslems and Hindus
- Technology stalled in Europe for over 1000 years

Henry the Navigator

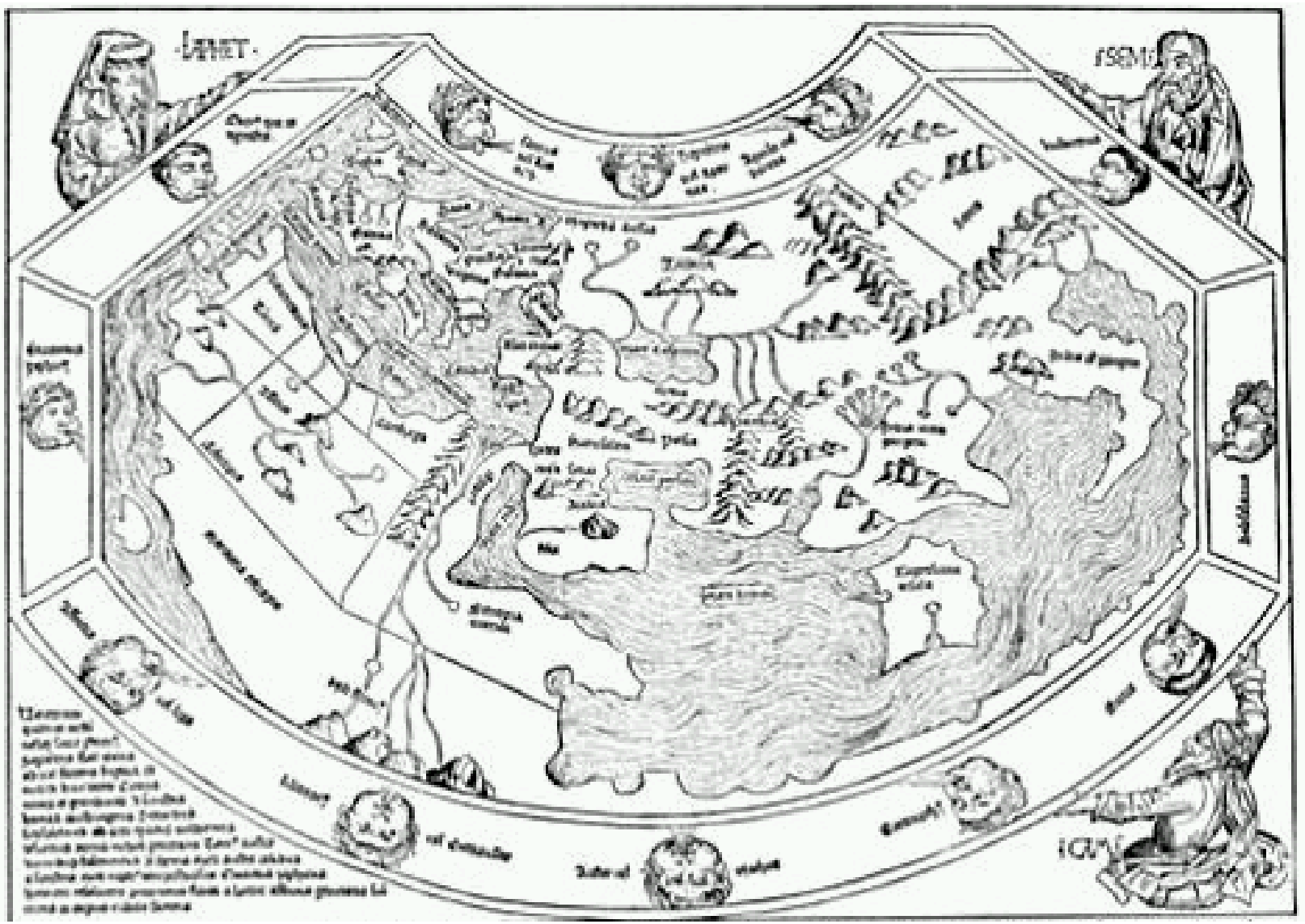
- Renaissance man 1394-1460
- Third son of João & Phillippa
- School of Navigation at Sagres, Cape Vincent, Portugal
- Applied Ptolemy's navigation technology: armillary sphere maps and marine astrolabe
- Sponsored "Voyages of Discovery" to Africa, Azores, India, Spice Islands and Brazil

Henry and the Discoverers, Belem

Ptolemy's Geography

- Celestial sphere defined terrestrial positions on globe
- Eratosthenes, inventor of the armillary sphere, calculated the diameter of the earth from shadow angles
- Ptolemy's “Geography” gave latitude and longitude for known world from Thule to Ceylon

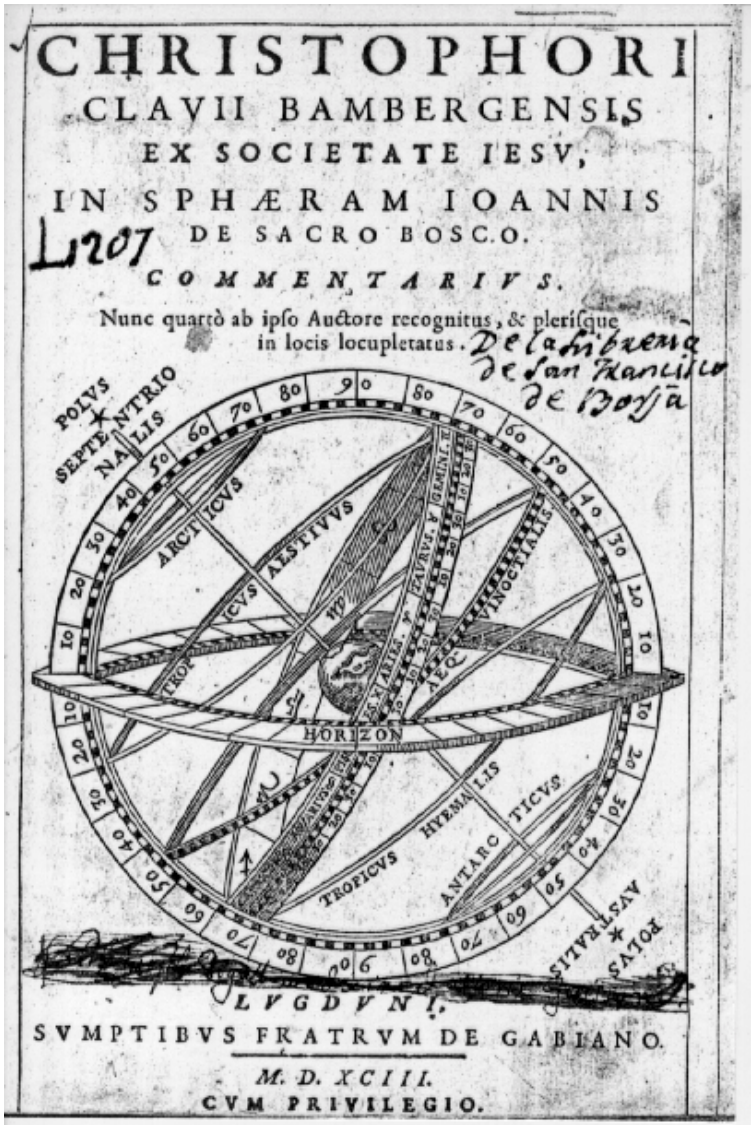
Ptolemy's Geography



Mariners' Astrolabe

- Mariners' astrolabe as used by Portuguese navigators to determine the altitude of the sun
- Reproduction by Tony Moss

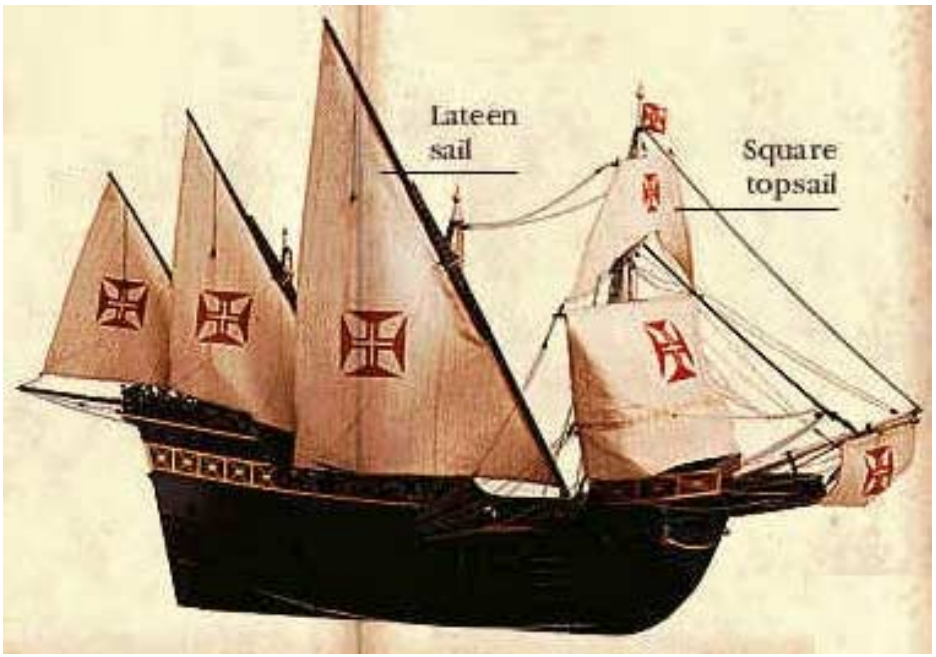
Sacro Bosco's de Sphaera Mundi


CHRISTOPHORI
CLAVII BAMBERGENSIS
EX SOCIETATE IESV,
IN SPHÆRAM IOANNIS
DE SACRO BOSCO.
COMMENTARIVS.
Nunc quartò ab ipso Auctore recognitus, & plerisque in locis locupletatus.
HORIZON
LVGDVNI,
SVMPTIBVS FRATRVM DE GABIANO.
M. D. XCIII.
CVM PRIVILEGIO.

- John Holywood of Yorkshire, (Joannis de Sacro Bosco) wrote "de Sphaera Mundi" about 1220
- This text updated Ptolemy and explained the use of armillary spheres in astronomy and navigation
- "Commentary" by Christoph Clavius 1570

Sagres Compass Rose and Sundial

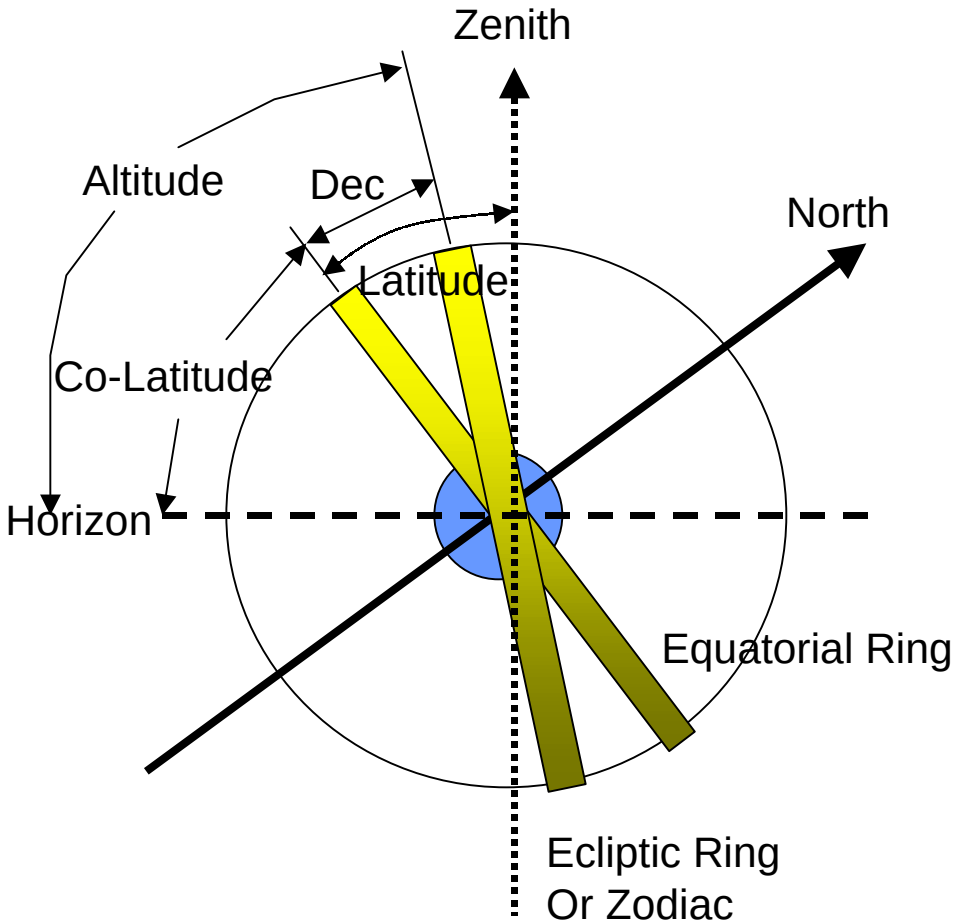
Christopher Colombus



Portuguese Caravel

- Christopher Columbus rescued from shipwreck at Sagres in 1479
- Later he sailed to Madeira, married the daughter of the governor and set up a shipping company
- Spanish (Ferdinand and Isabella) provided venture capital for his exploration to the new world in 1492 and gained the benefits
- Did he learn navigation from the Portuguese at Sagres?

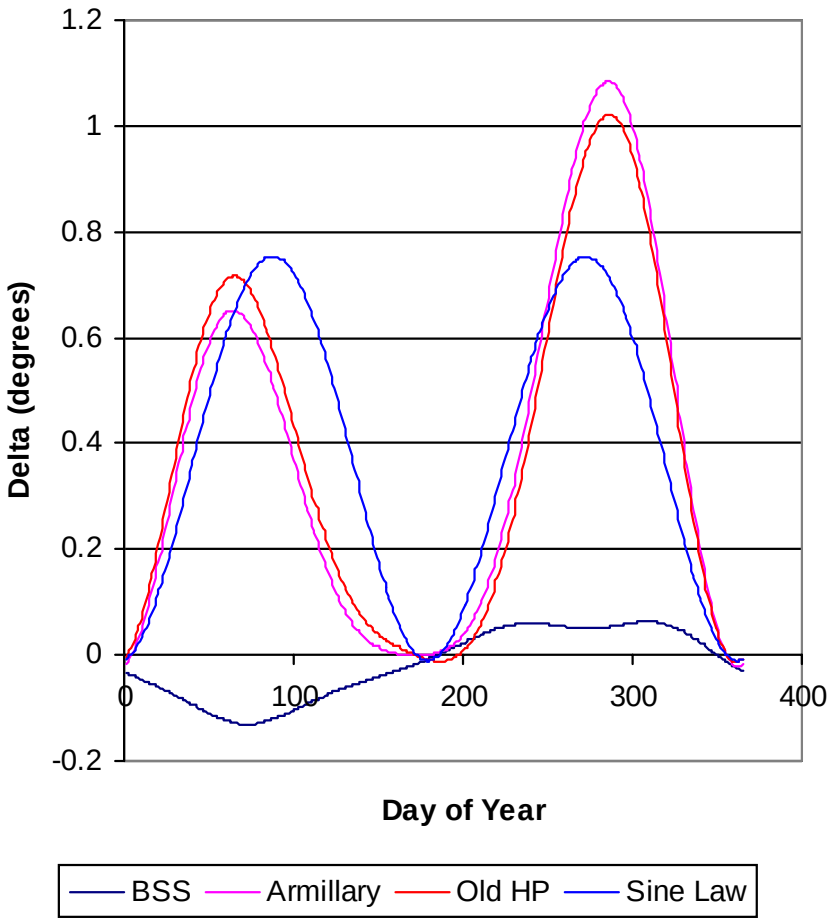
Armillary Spheres and Navigation



Lat = 90-Alt+ Dec

- Armillary Sphere is a model of the Universe
- The earth is round. You cannot sail off the edge
- The position of the sun and stars can tell you where on earth you are, and how to get back to where you started
- The ecliptic ring tells you the declination of the sun
- The noon altitude sight and declination determine the latitude

Declination Error Analysis

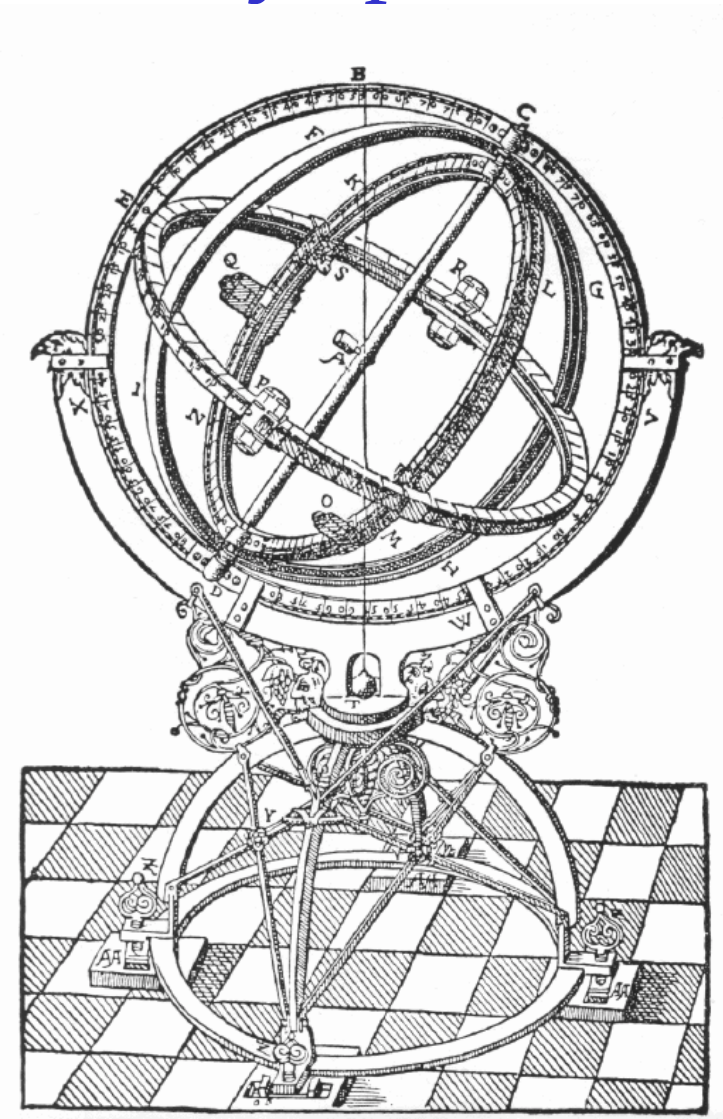


- Armillary assumes circular orbits vs elliptical. Error?
- Estimate is reasonable compared to commonly used equations
- Greatest error (0.7°) at equinox when rate of change is greatest (0.4°/day)
- Date of equinox is critical

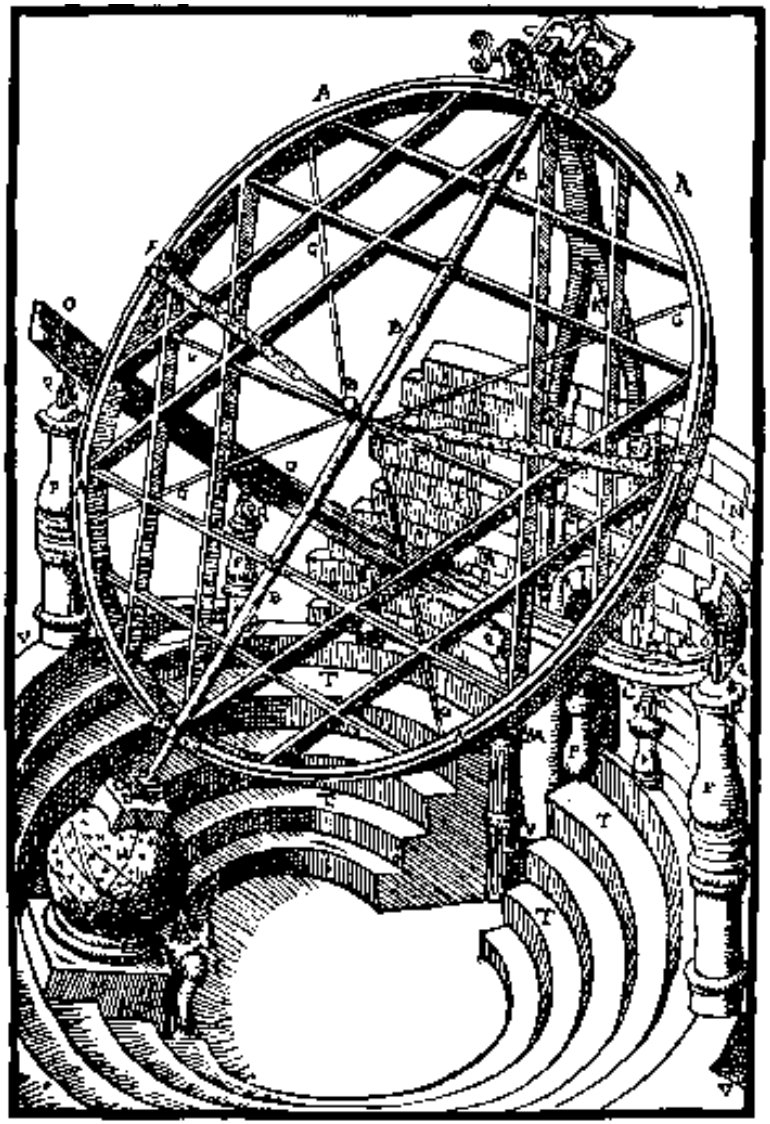
Wenger Uniglobe

- Modern armillary sphere for teaching celestial navigation
- Adds angle measuring spanner to meridian, great circle and equatorial (time) rings
- Adds solution of the navigation triangle to traditional uses

Armillary Sphere As Astronomical Instrument



- Ptolemy's brass rings
- Tycho Brahe’s instruments of 1581
- Beijing Ancient Observatory of 1670
- Location at zenith
- Sighting points on meridian ring
- Determines celestial coordinates: right ascension and declination



Equatorial Armillary

- Tycho's great equatorial armillary of 1531
- Abandoned as too complex and inaccurate
- Replaced with giant quadrant

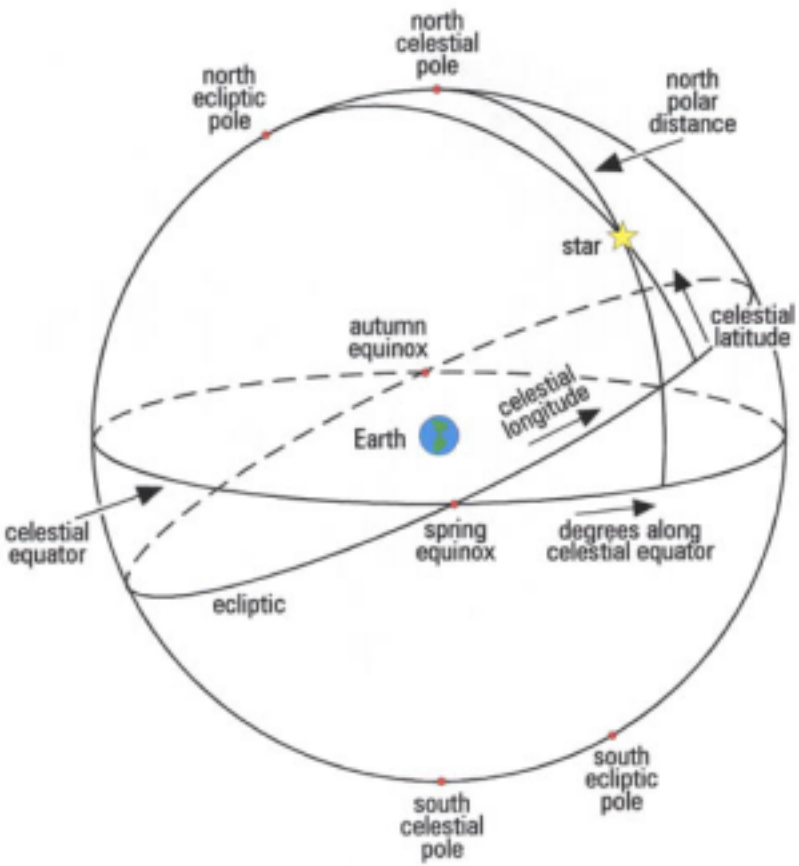
Armillary Sphere as a Model of the Universe

- Ptolemy's geocentric model
  - Earth is a sphere at the center of the universe
  - Stars on celestial sphere rotating around the earth
- Copernicus: Earth and planets rotate around sun
  - Sun moon and planets rotate on the ecliptic path
  - Anomalies as epicycles
- Kepler: Elliptical orbits
- Armillaries had removable centers!

Armillary as a Model of the Universe

- Demonstrate motions of celestial objects
- Show ecliptic path of sun, moon and planets
- Explain equinox and precession
- Explain solstice and tropics

Armillary as a Computer



- Translate coordinate systems
  - Horizon/Zenith: Alt/Az
  - Polar/equatorial: Dec & RA
  - Ecliptic: Latitude/Longitude
- Determine position of celestial objects
- Determine declination from date
- Determine latitude from declination and altitude
- Determine rise / set times and azimuth

Armillary as a Symbol

- Symbol of Science in art
- Typically a learned man with an armillary, the epitome of knowledge
- Here Descartes teaches science to Queen Christina of Sweden
- “Triumph of Faith” at Jeronimos Monastery, Lisbon shows an armillary sphere as the guide to salvation.

"Triumph of Faith"

Portuguese Royal Symbol

- Portuguese gain control of the spice trade
- Wealth and power flows to Portugal
- Dom Manuel I adopts the armillary as the Royal symbol
- Manueline architecture uses the Royal Armillary in palaces, churches, monasteries, built with taxes on spices

Azulejos tile from Sintra Palace

Portuguese Flag

Manueline Architecture

Royal symbols over convent doorway at Estremoz

Manueline Monasteries

Steeple at Jeronimos, Belem
Cloister tracery at Batalha

Batalha Cloister Noon Mark

Typical Portuguese Church

Armillary on the steeple of Nossa Senhora da Conceição, Ferragudo

Armillary on Sintra Town Hall

Portuguese Boom as a High Tech venture

- Navigation technology conquered the universe
- Voyages of Discovery gave Portugal the wealth and power of a colonial empire
- Rapid expansion led to huge venture capital requirements for ships, navies, armies, weapons etc
- Profits diverted to palaces and cathedrals
- Competitive spin offs like Columbus and Spain
- Lost technological edge with introduction of the Inquisition and expulsion of the knowledge workers
- Lure and cost of colonies bankrupted Portugal

Armillary Spheres and Sundials

- Waugh armillary at Mystic, CT
- Armillary spheres lead to sundial designs
  - Equatorial
  - Polar
  - Analemmatic
  - Horizontal / Vertical
  - Wenger Globe

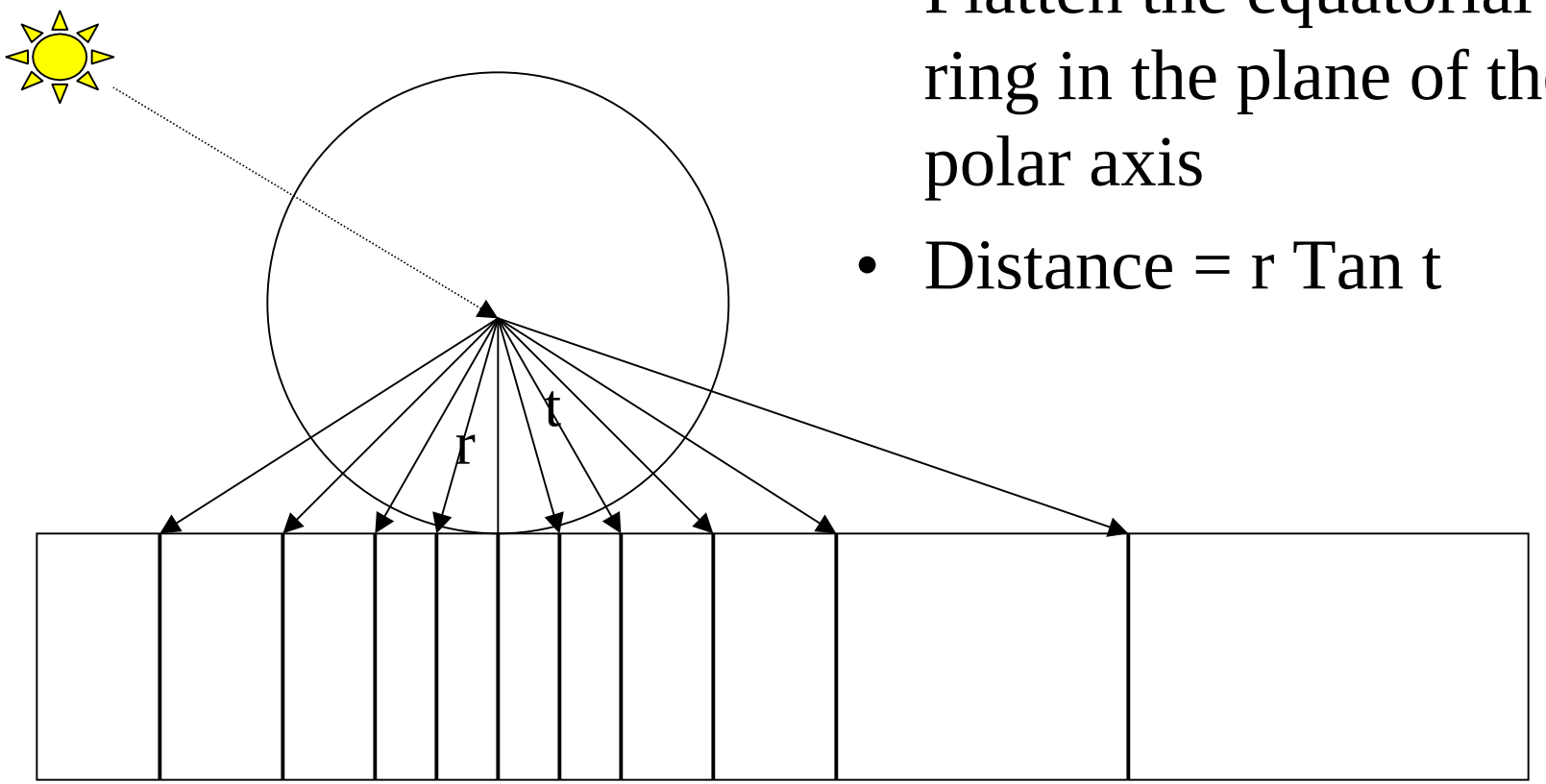
Armillary Spheres and Equatorial Sundials

- Schmoyer Dial by Tony Moss for Mike Shaw
- Gnomon is polar axis
- EQT correction in gnomon
- Hour scale on equatorial ring
- Linear scale 15°/hour
- Ring opened to avoid equinox shadows

Roger's Equatorial

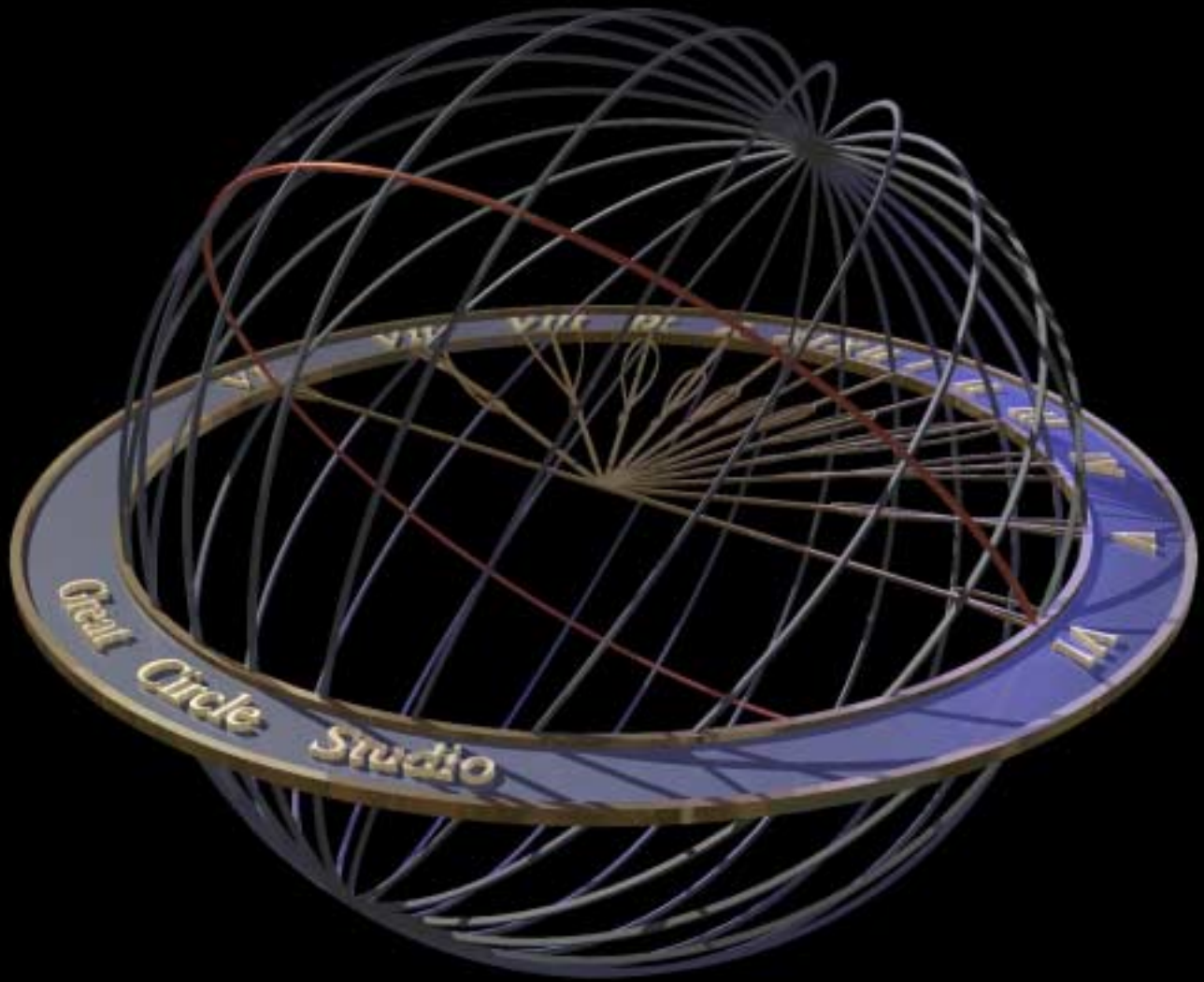
- Stainless steel (316L) 12" pipe sections
- Hand crafted with hack saw and files
- Port Elgin, Ont
  - Lat N 45:28:00
  - Long W 81:24:30

Armillary Sphere and Polar Sundials



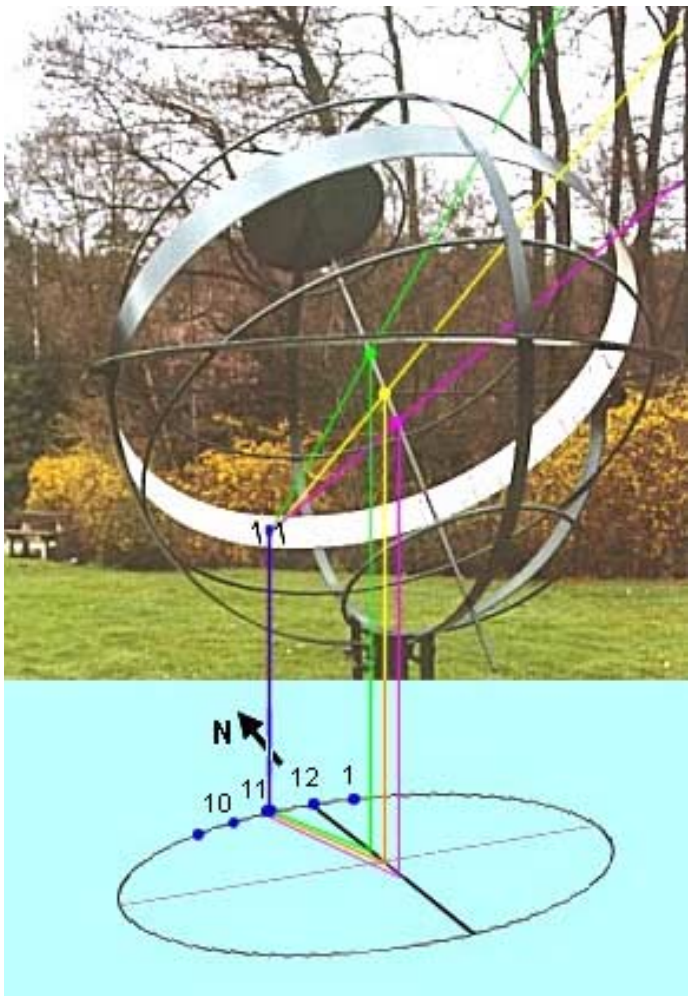
- Flatten the equatorial ring in the plane of the polar axis
- Distance = r Tan t

Armillary Spheres and Planar Sundials



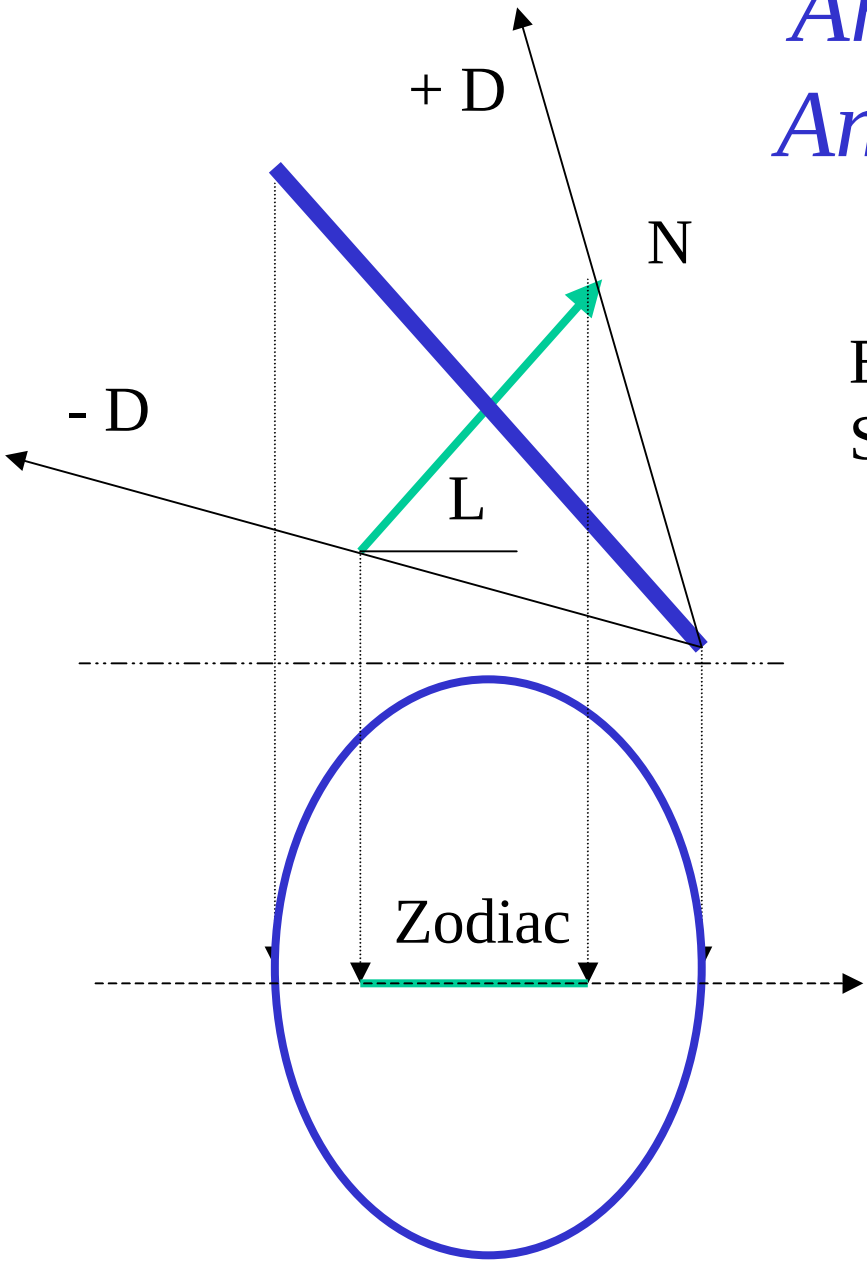
Luke Coletti gcstudio.com

Armillary and Analemmatic Sundial



- Project equatorial ring on plane for ellipse
- Project gnomon on plane for zodiac
- Declination on gnomon determines zodiac positions
- Image by Frans Maes
  www.biol.rug.nl/maes/sundials/

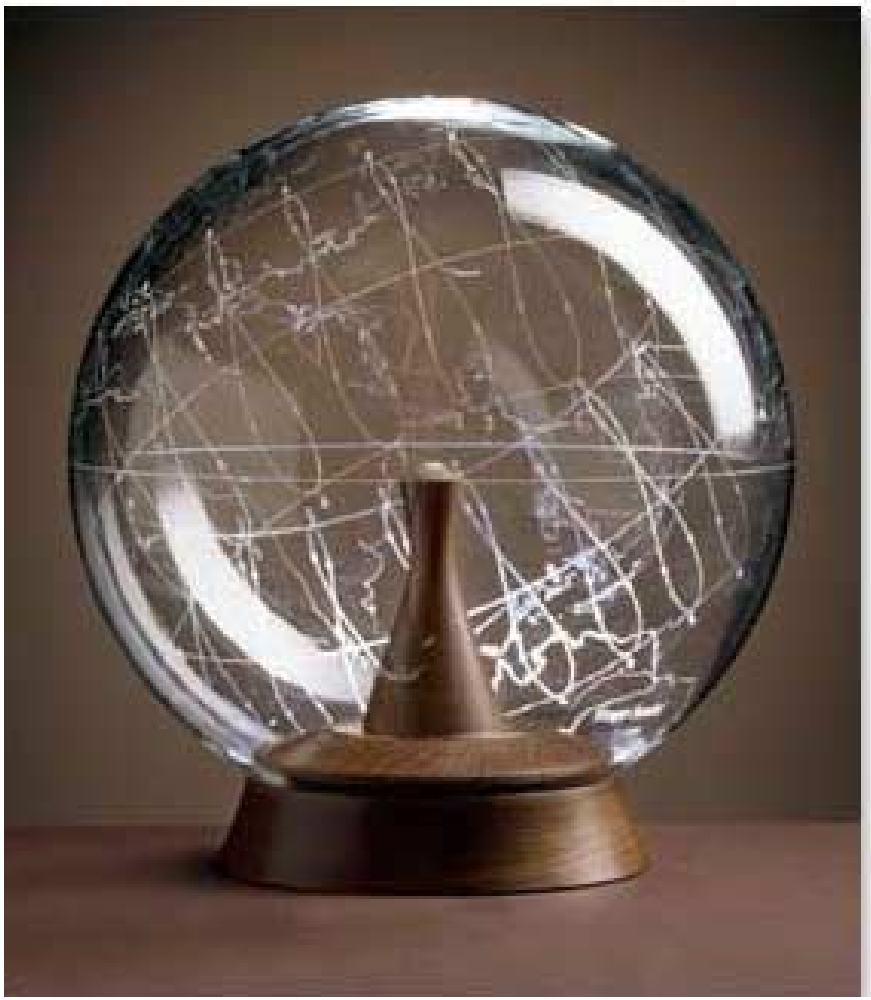
Armillary Sphere and Analemmatic Sundials



Equatorial ring projects as an ellipse
Shape depends on latitude

Gnomon projects as Zodiac on north south axis for various solar declinations

Wenger Sundial

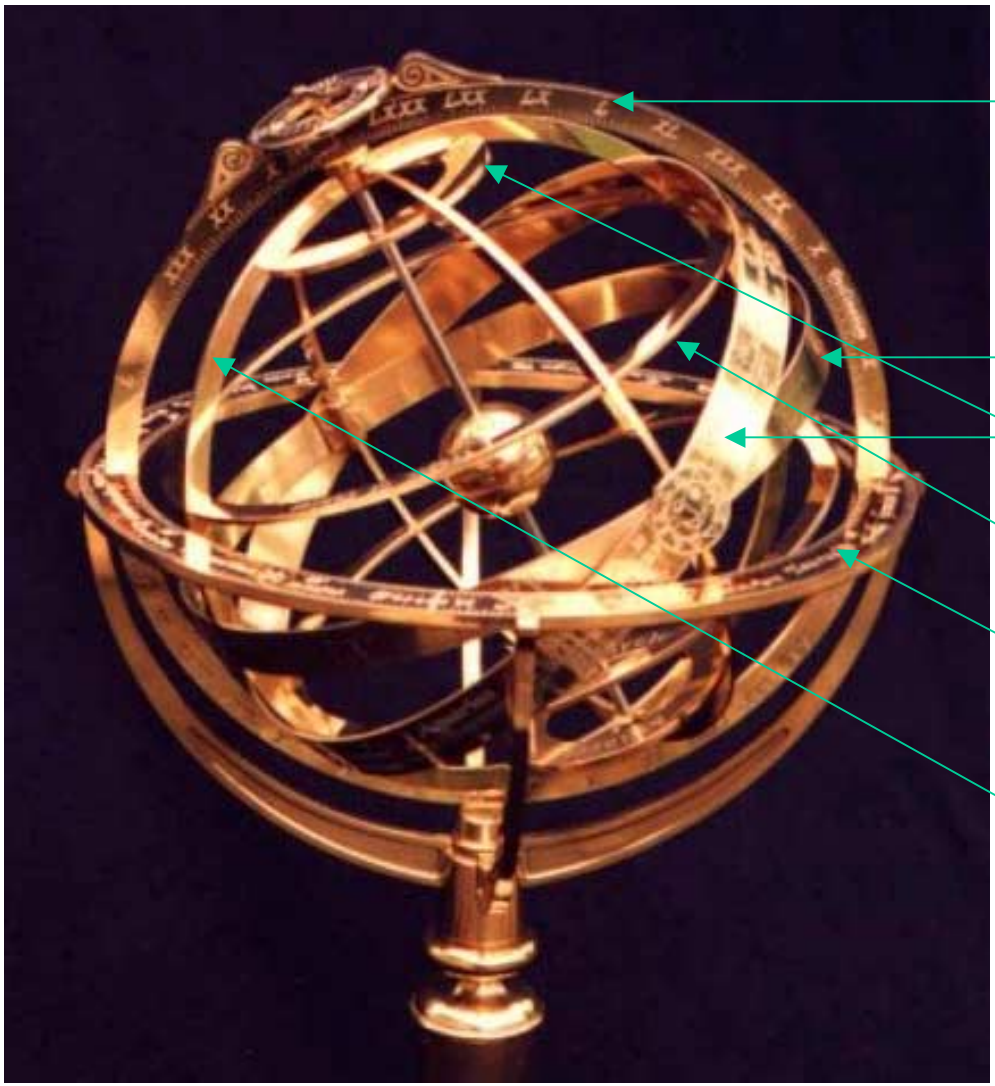


- Glass sphere inscribed with armillary rings
  - Hour meridians
  - Horizon
  - Tropics and analemmas
- Location at Zenith
- Shadow on center point gives time
- Design by Daniel Wenger
  www.wengersundial.com

Modern Armillary Spheres

- Prime market is for symbolic ornaments like garden variety sundials
- Lots of junk is offered for sale
- Rings should represent the universe
  - Equatorial, ecliptic, meridian, horizon etc
- Ecliptic ring should rotate
- Must be set for latitude
- Should have scales for hours, degrees and date

Classic Armillary Sphere



Meridian ring engraved for declination and latitude

Equatorial ring

Rotating ecliptic ring with engraved zodiac

Tropic and polar circles

Horizon ring engraved for degrees and date

Colure rings through pole

Source: Classical Science