Welcome to

Starry Monday at Otterbein

Astronomy Lecture Series

-every first Monday of the month-

April 2, 2007

Dr. Uwe Trittmann

Today's Topics

- Galileo and the Birth of Modern Astronomy
- The Night Sky in April

On the Web

- To learn more about astronomy and physics at Otterbein, please visit
  - http://www.otterbein.edu/dept/PHYS/weitkamp.asp (Observatory)
  - http://www.otterbein.edu/dept/PHYS/ (Physics Dept.)

Galileo and the Birth of Modern Astronomy

- Resources:
  - Discoveries and Opinions of Galileo, transl. and introduced by Stillman Drake, Anchor Books 1957
  - The Galileo Project at Rice University, TX http://galileo.rice.edu/

Galileo and his Contemporaries

- Elizabeth I. (1533-1603) – Queen of England
- Tycho Brahe (1546-1601) – Danish Astronomer
- Francis Bacon (1561-1626) – English Philosopher
- Shakespeare (1564- 1616) – Poet & Playwright
- Galileo Galilei (1564-1642) – Italian PAM
- Johannes Kepler (1571-1630) – German PAM
- Rene Descartes (1596 - 1650) – French PPM
- Christiaan Huygens (1629-1695) – Dutch PAM

Epochs

- Renaissance: 1450-1600
  - "Rebirth", back to the roots
- Baroque: 1600-1715
  - Epoch of the religious wars
  - Later: Louis XIV and Newton
- Rococo: 1715-1775

The Baroque Setting

- In the 1600s church through counter-reformation much stricter
- G. BRUNO (Italian; 1548) proposes that the Sun is just one star out of an infinite number ➔ burned at the stake for heresy 1600
- 30 Years War (1618-1648) between religions
- New inventions: telescope, air pump, etc.

Tycho Brahe – The Data Taker

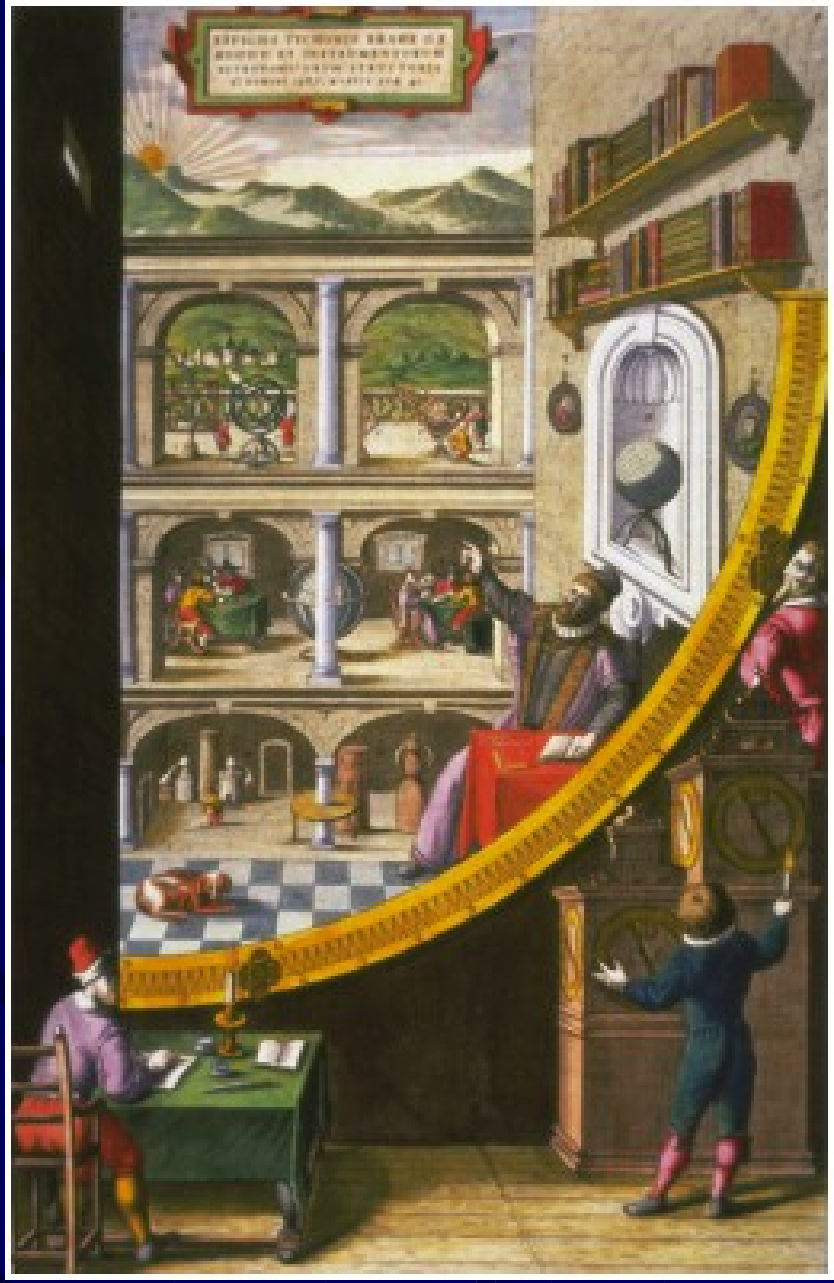
- Key question:
  Where are things?

- Catalogued positions of planets in Uraniborg and Prague
- Working without telescope
- Data ten times as accurate as before
- Died at banquet binge drinking

Tycho Brahe (1546–1601)

Tycho Brahe

- collects detailed and accurate (1-2' accuracy) observations of stellar and planetary positions over a period of 20 years
- His research costed 5-10% of Danish GNP
- shows that comets and novas are extralunar contrary to Aristotle
- Shows that stars can change (Supernova of 1572)



Tycho Brahe observing

Johannes Kepler–The Phenomenologist

- Key question:

How are things happening?

Major Works:

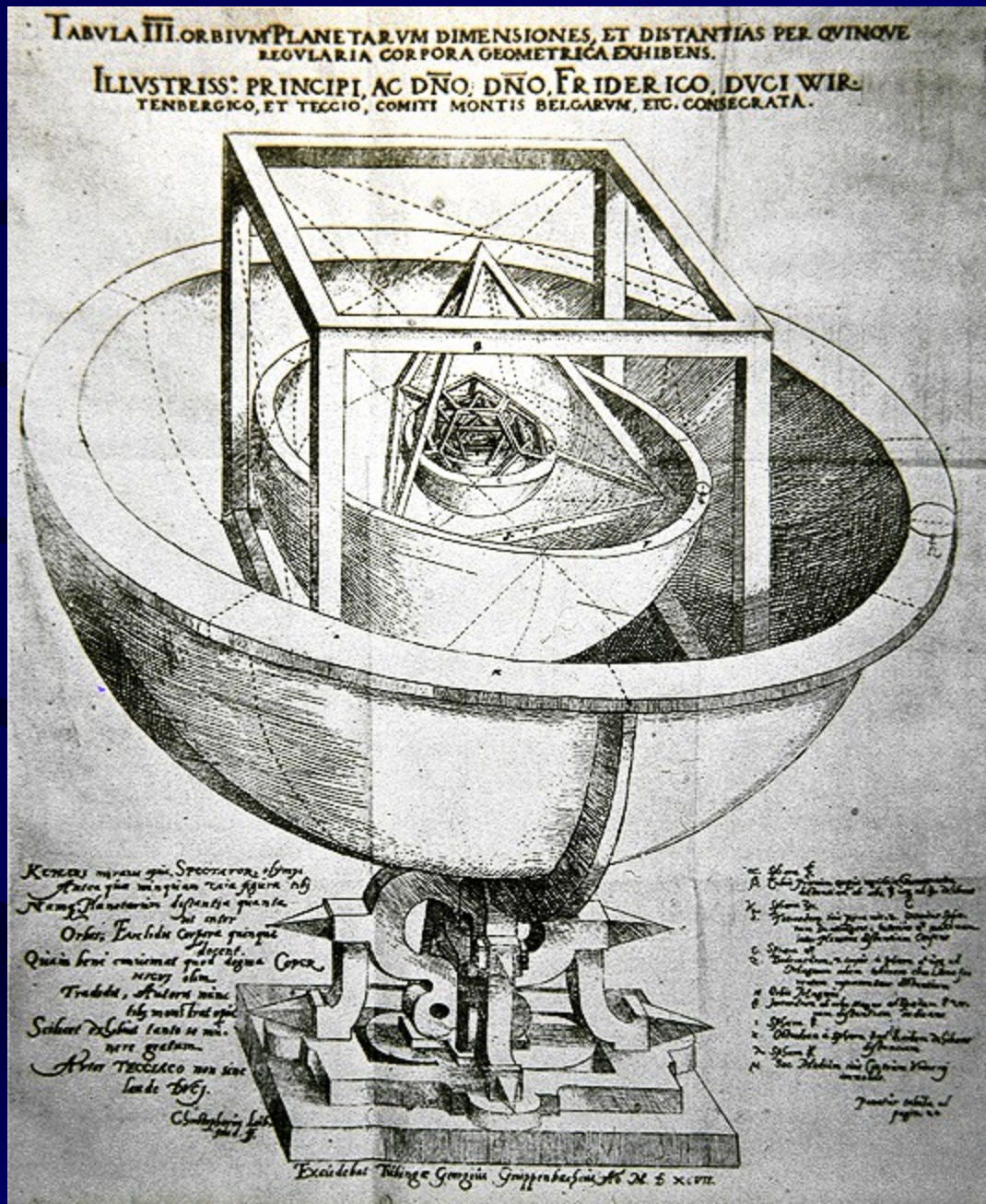
- Harmonices Mundi (1619)
- Rudolphian Tables (1612)
- Astronomia Nova
- Dioptrice

Johannes Kepler (1571–1630)

Kepler's Beginnings

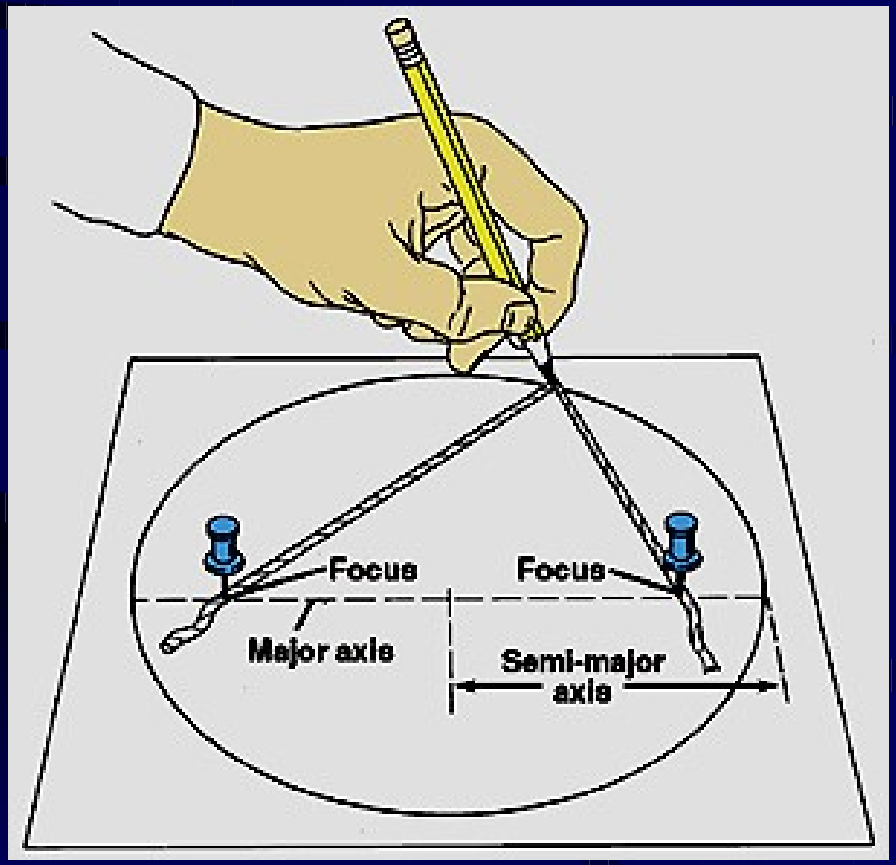
- Astrologer and Mystic
- Tried to find "music in the skies"
- Tried to explain distances of the 5 known planets by spheres resting on the 5 mathematical bodies

➔ **pre-scientific**

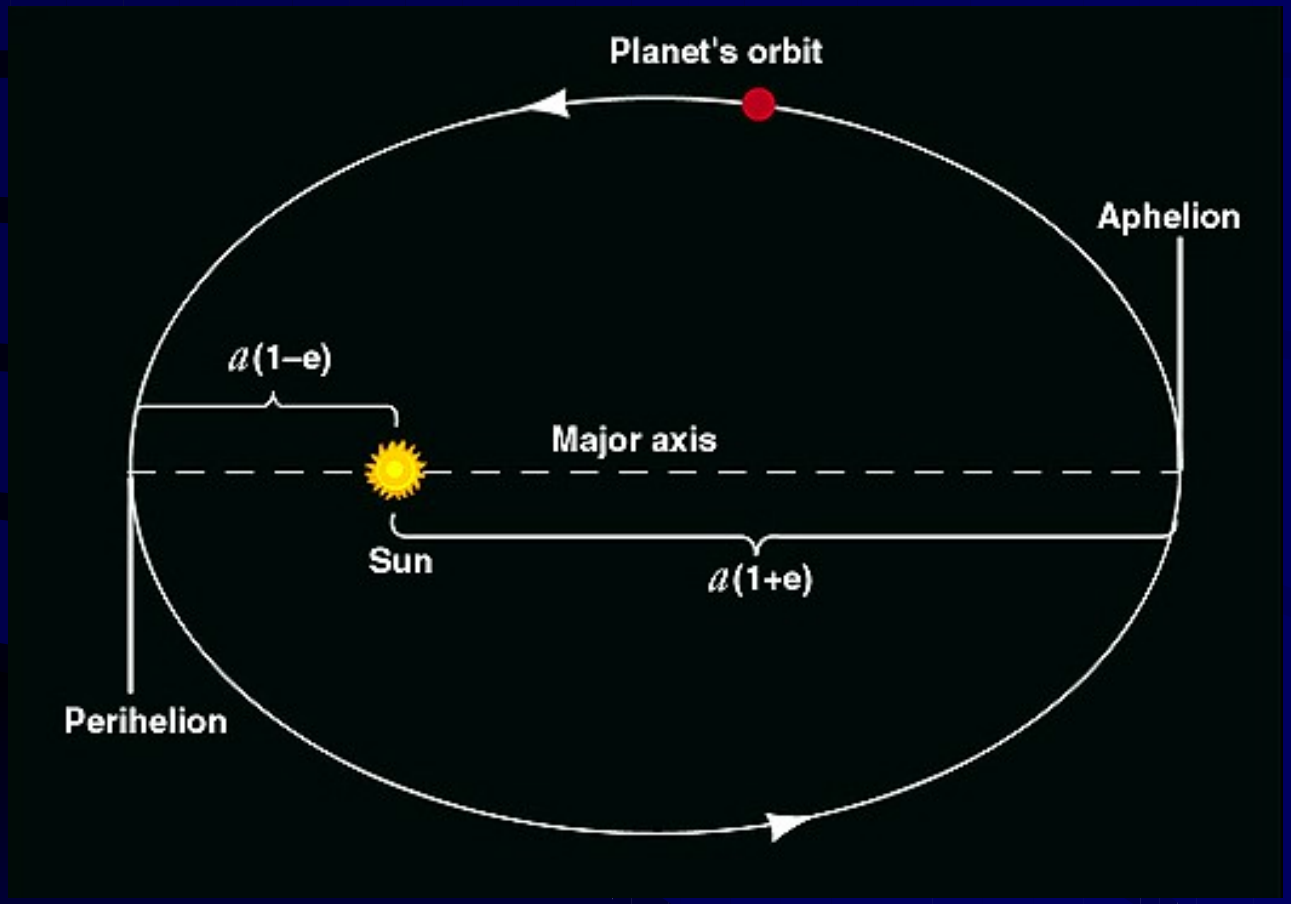


Kepler's First Law

The orbits of the planets are ellipses, with the Sun at one focus

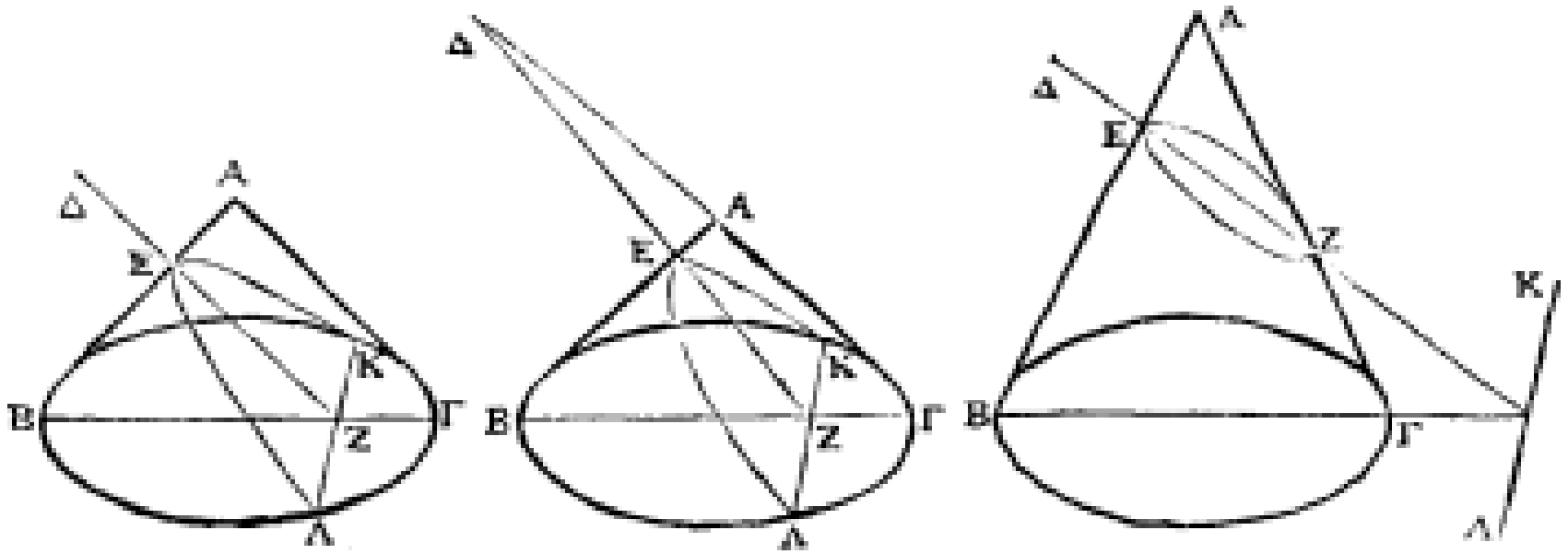


Ellipses



a = “semimajor axis”; e = “eccentricity”

Conic Sections

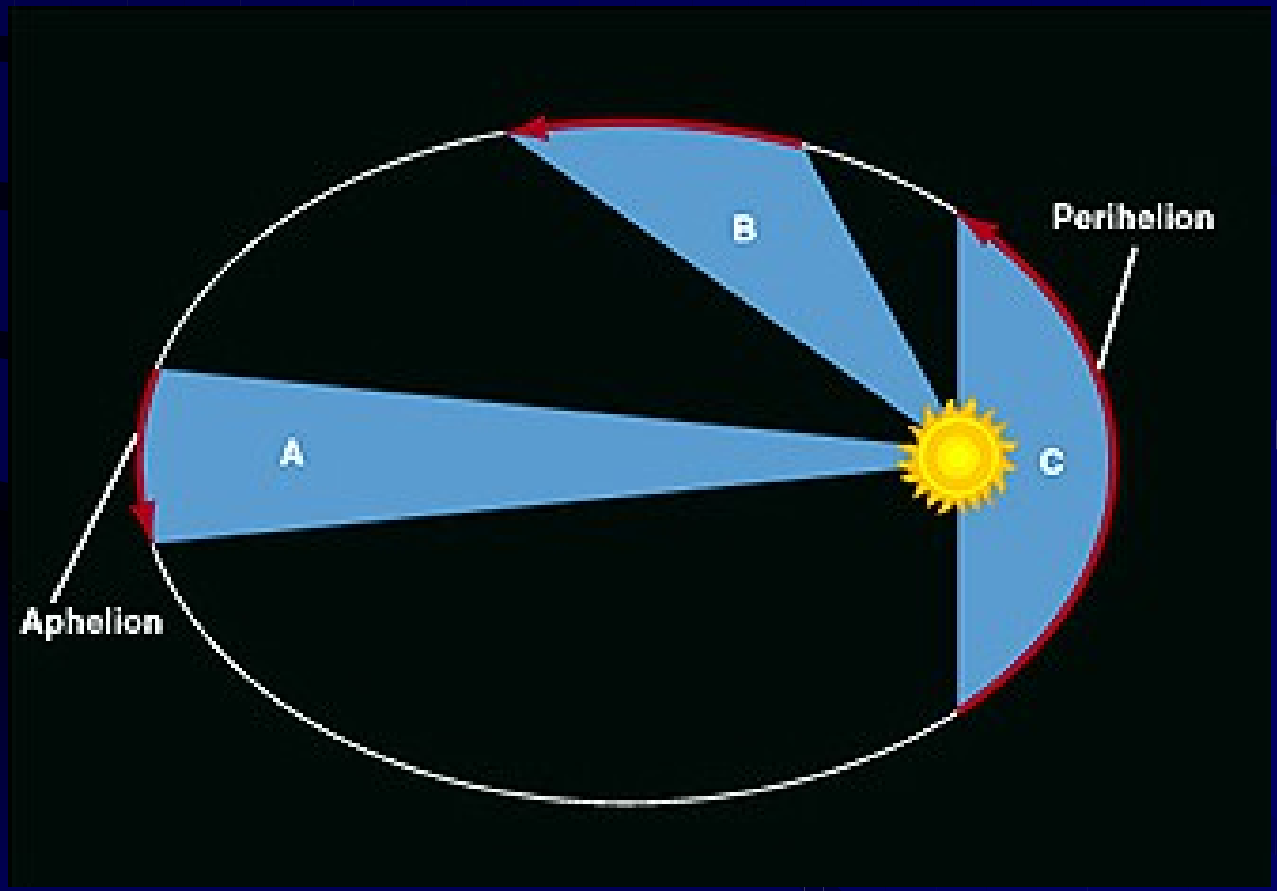


Aus der Konika-Ausgabe von E. Halley, Oxford, 1710.

From Halley's book (1710)

Kepler's Second Law

An imaginary line connecting the Sun to any planet sweeps out equal areas of the ellipse in equal times



Kepler's Third Law

The square of a planet's orbital period is proportional to the cube of its orbital semi-major axis:

$$P^2 \propto a^3$$

	a	P		
Planet	**Orbital Semi-Major Axis**	**Orbital Period**	**Eccentricity**	**P^2/a^3**
Mercury	0.387	0.241	0.206	1.002
Venus	0.723	0.615	0.007	1.001
Earth	1.000	1.000	0.017	1.000
Mars	1.524	1.881	0.093	1.000
Jupiter	5.203	11.86	0.048	0.999
Saturn	9.539	29.46	0.056	1.000
Uranus	19.19	84.01	0.046	0.999
Neptune	30.06	164.8	0.010	1.000
Pluto	39.53	248.6	0.248	1.001
	(A.U.)	**(Earth years)**		

Galileo Galilei – The Experimentalist

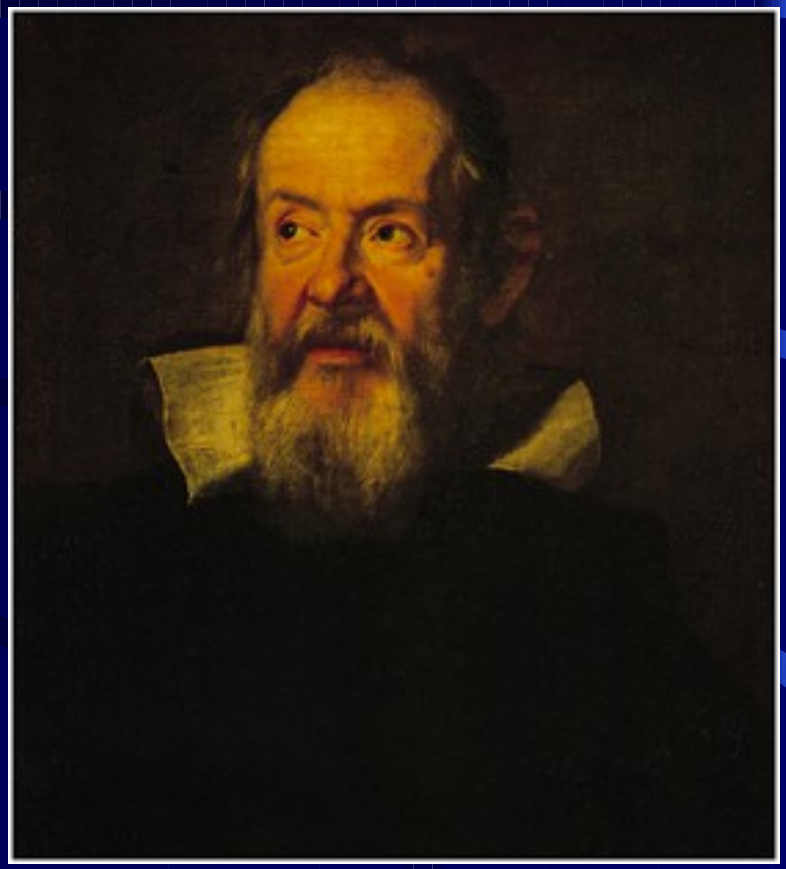
Did experiments (falling bodies) rather than studying Aristotle

Major Works

- Siderius Nuntius (1610)
- Dialogue concerning the Two Chief World Systems (1632)

The latter discusses Copernicus vs Ptolemy ➔ban by Church (1633)

– revoked by pope 1992



(1564–1642)

SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se recens beneficio sunt obseruata in FACIE LVNÆ AVTE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumvolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author deprę-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

DIALOGO
DI
GALILEO GALILEI LINCEO
MATEMATICO SOPRAORDINARIO
DELLO STVDIO DI PISA.
E Filosofo, e Matematico primario del
SERENISSIMO
GR. DVCA DI TOSCANA.
Doue ne i congressi di quattro giornate si discorre
sopra i due
MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;
Proponendo indeterminatamente le ragioni Filosofiche, e Naturali
tanto per l'vna, quanto per l'altra parte.

CON PRI  VILEGI.

IN FIORENZA, Per Gio: Batista Landini MDCXXXII.
CON LICENZA DE' SVPERIORI.

Siderius Nuntius (1610)

Dialogo (1632)

Galileo's Places

- Born at Pisa, Tuscany
- Childhood in Florence, Tuscany
- Studies at University of Pisa
- Begins teaching at Pisa
- Gets a position at Padua, Province of Venice
- Stays for 18 years

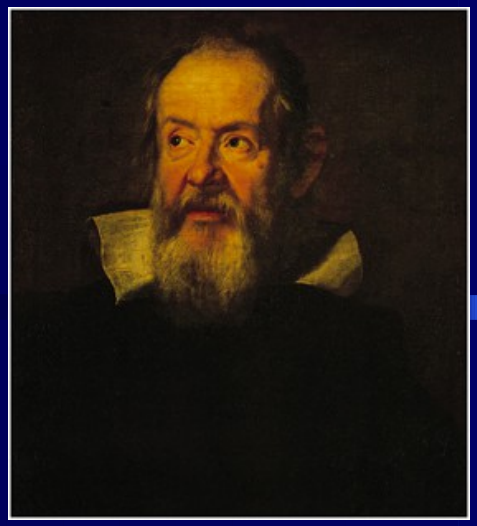
Galileo's Places (cont'd)

- Returns to Florence, Tuscany in 1610 under Grand duke Cosimo II.
- 1633: Trial in Rome
- From 1633: house arrest in Acetri, near Florence
- 1637: loses eyesight
- 1992: ban on Galileo lifted by Pope John Paul II.

Galileo's Telescopes

- Galileo's first telescope was 3x magnifying
- his last one 32 x

Galileo Galilei (1564–1642)

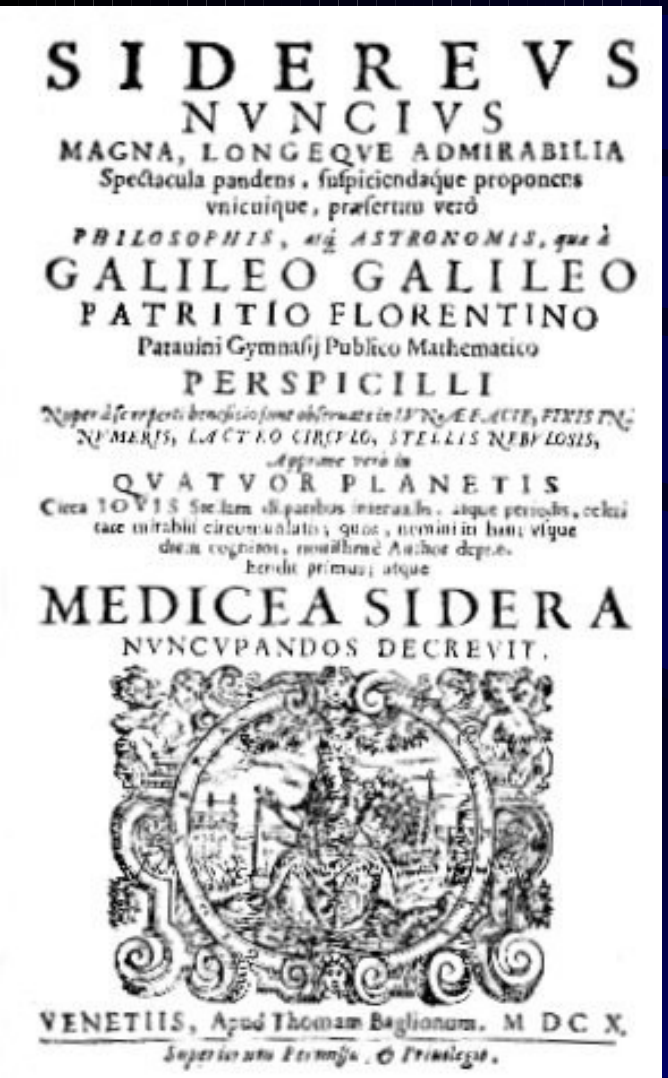


- Astronomical observations that contradict Aristotle:
  - Observed mountains on the Moon, suggesting that the Earth is not unique
  - Sunspots; suggests that celestial bodies are not perfect and can change
  - Observed four moons of Jupiter; showed that not all bodies orbit Earth
  - Observed phases of Venus (and correlation of apparent size and phase); evidence that Venus orbits the Sun
- Also observed
  - the rings of Saturn
  - that the Milky Way is made of stars

Federico Cesi (1585-1630) and the Accademia dei Lincei

- The "Academy of the lynx-eyed" was very important for Galileo in getting his works published and supported against increasingly hostile opponents (church et al)

The Starry Messenger



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Nuper à se reperti beneficio sunt obseruata in FACIE, FINIS PVN-
CTIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprimè verò in
QVATVOR PLANETIS
Circa IOVIS Stellam diuersis interuallis, atque periodis, celeri-
tate mirabili circumvolantibus; quos, nemini in hunc vsque
diem cognitos, nouissimè Author deprę-
hendit primus, atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Privilegio.

- Revealing great, unusual, and remarkable spectacles, opening these to the consideration of every man, and especially of philosophers and astronomers;

As observed by Galileo Galilei, gentleman of Florence, Professor of Mathematics in the University of Padua

With the aid of a Spyglass recently invented by him

In the surface of the moon, in innumerable fixed stars, in nebulae, and above all:

In four planets, swiftly revolving about Jupiter at differing distances and periods, and known to no none before the Author recently perceived them and decided that they should be named

THE MEDICEAN STARS

Venice, 1610


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
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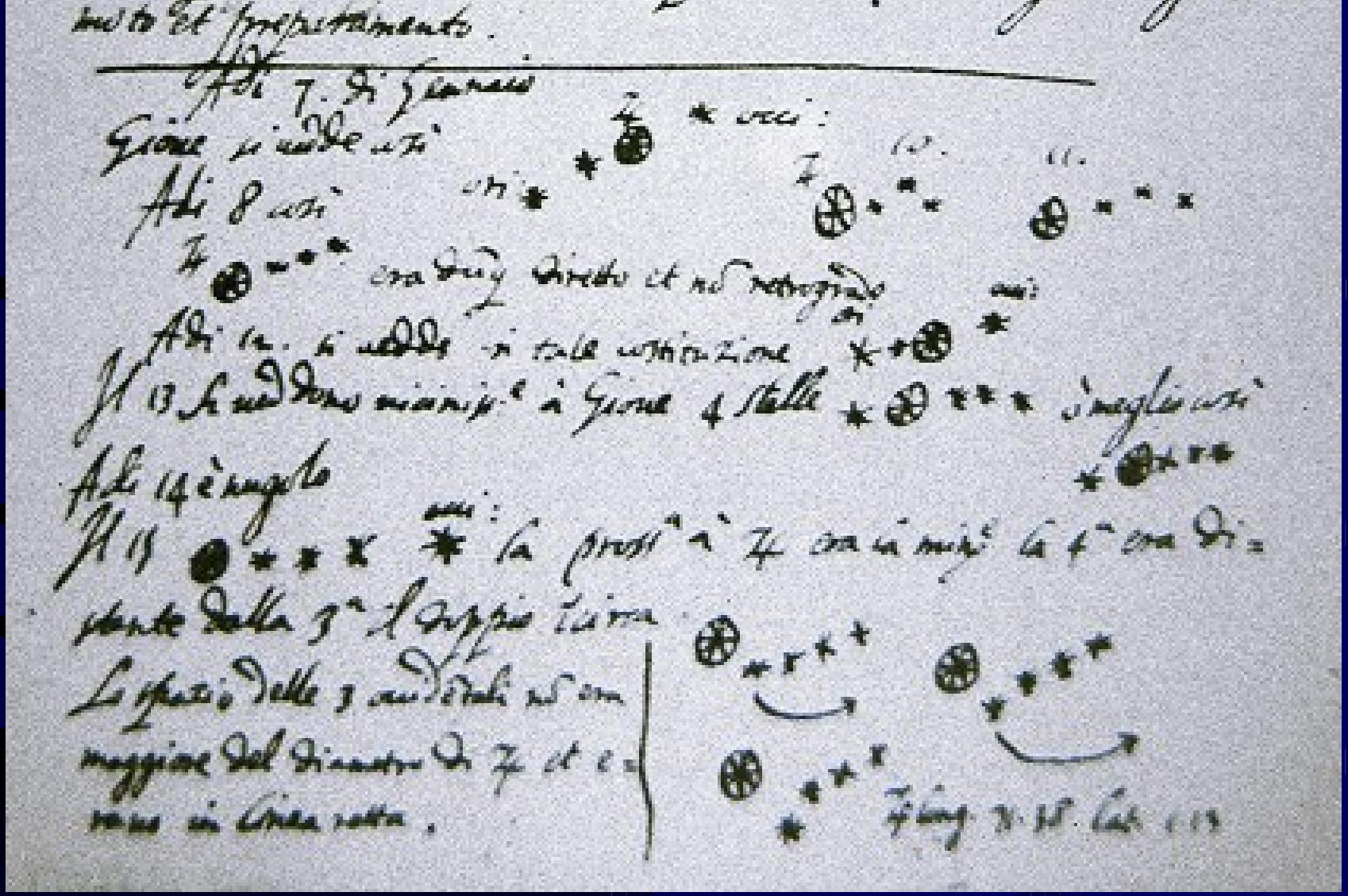
The Medicean Stars

- Now called the Galilean Moons of Jupiter
- The four largest moons of Jupiter: Io, Europa, Ganymede, Callisto

Galileo's Journal on the Discovery of Jupiter's Moons



Sometimes sees 2,3,4 objects, sometimes left, sometimes right of Jupiter

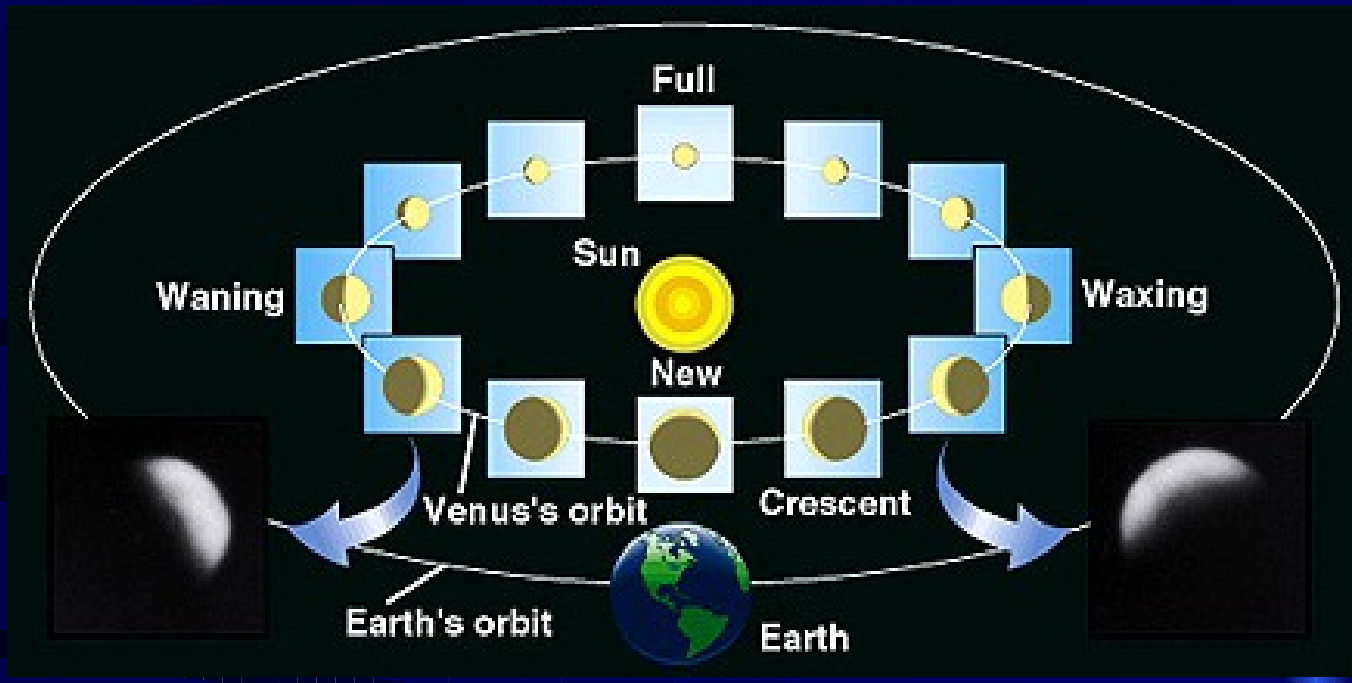
Phases of Venus

Geocentric vs Heliocentric: How do we know?

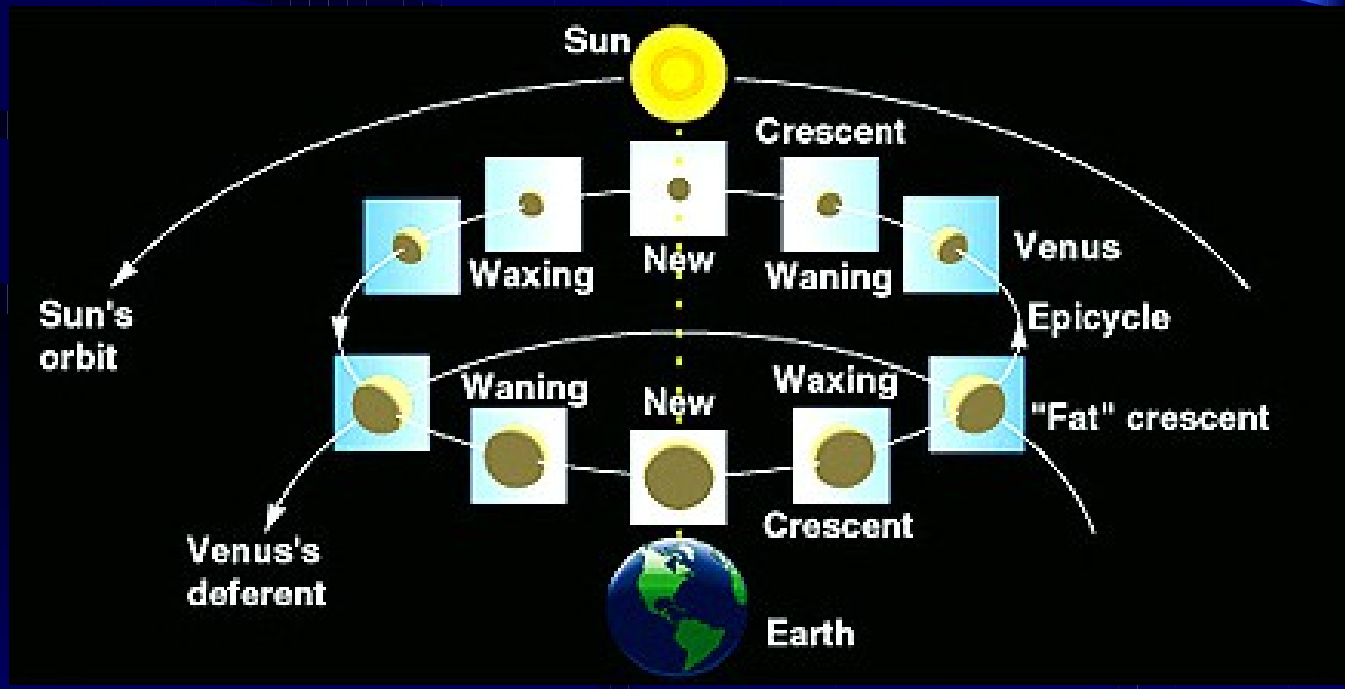
- Is the Earth or the Sun the center of the solar system?
- How do we decide between these two theories?
- Invoke the scientific methods:
  - both theories make (different) predictions
  - Compare to observations
  - Decide which theory explains data

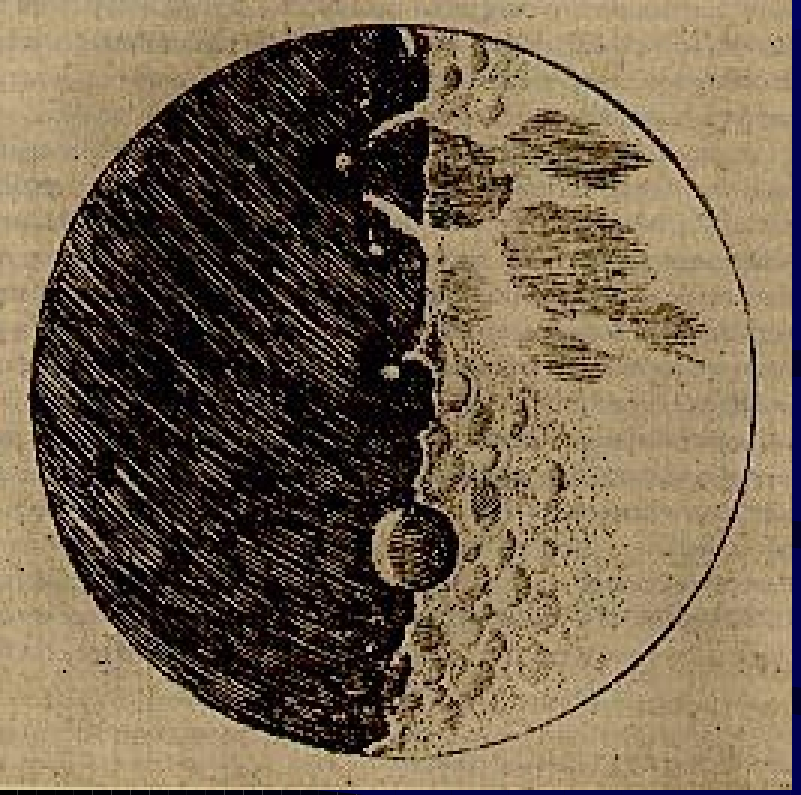
Phases of Venus

Heliocentric



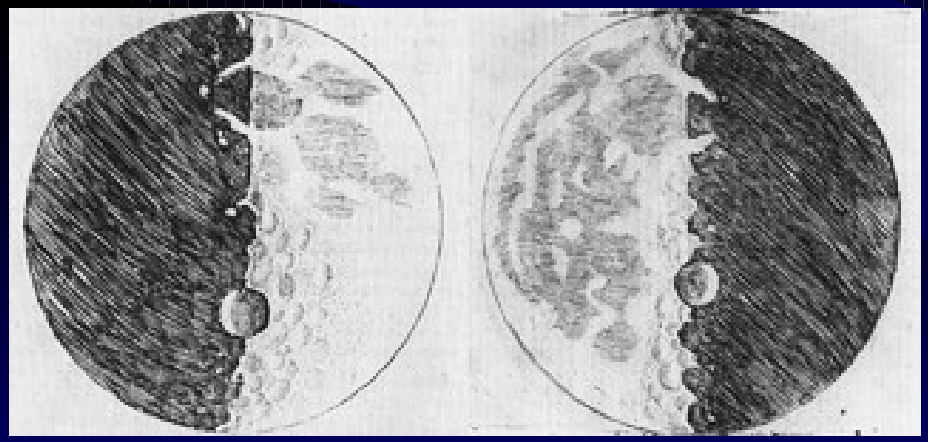
Geocentric



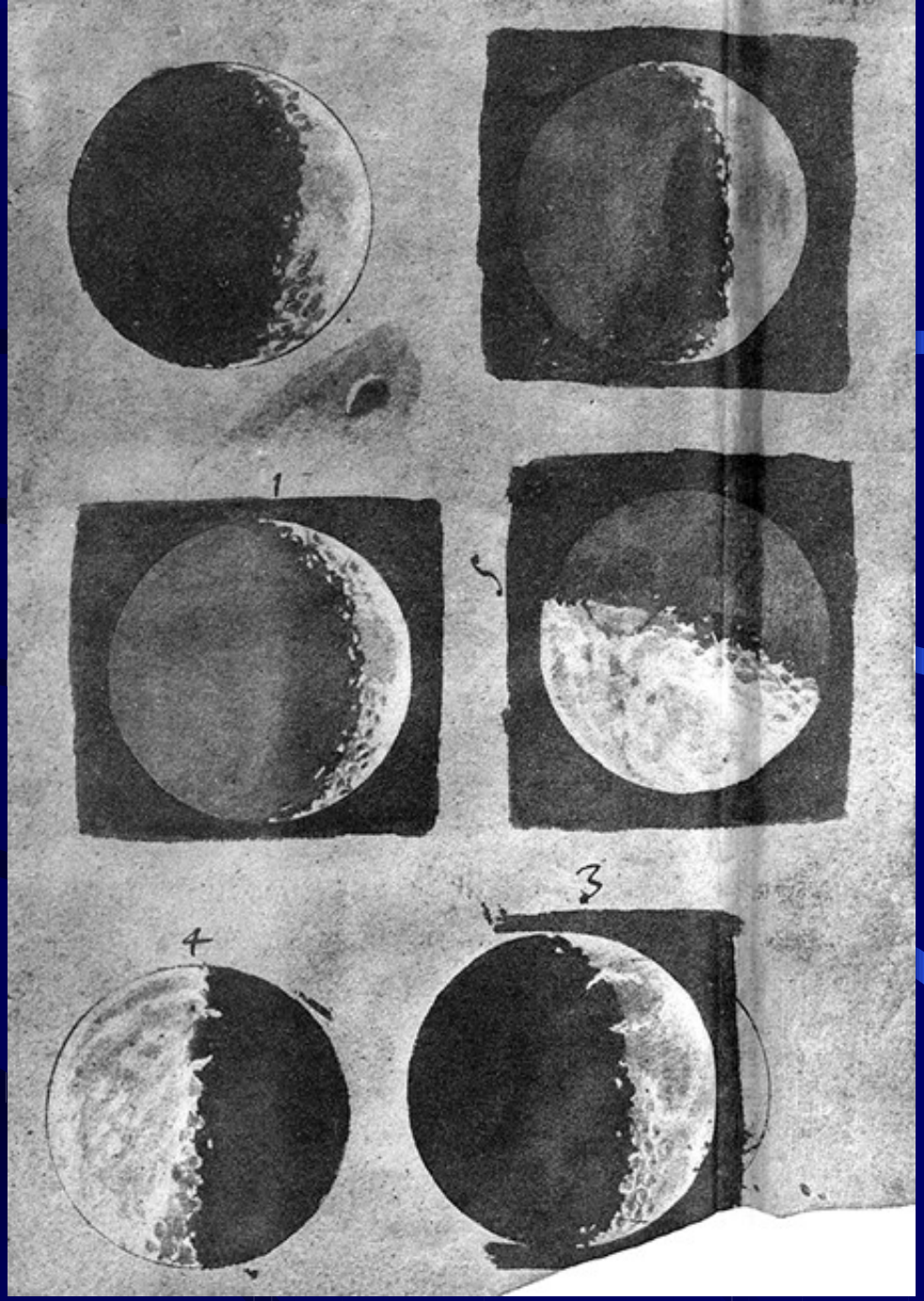


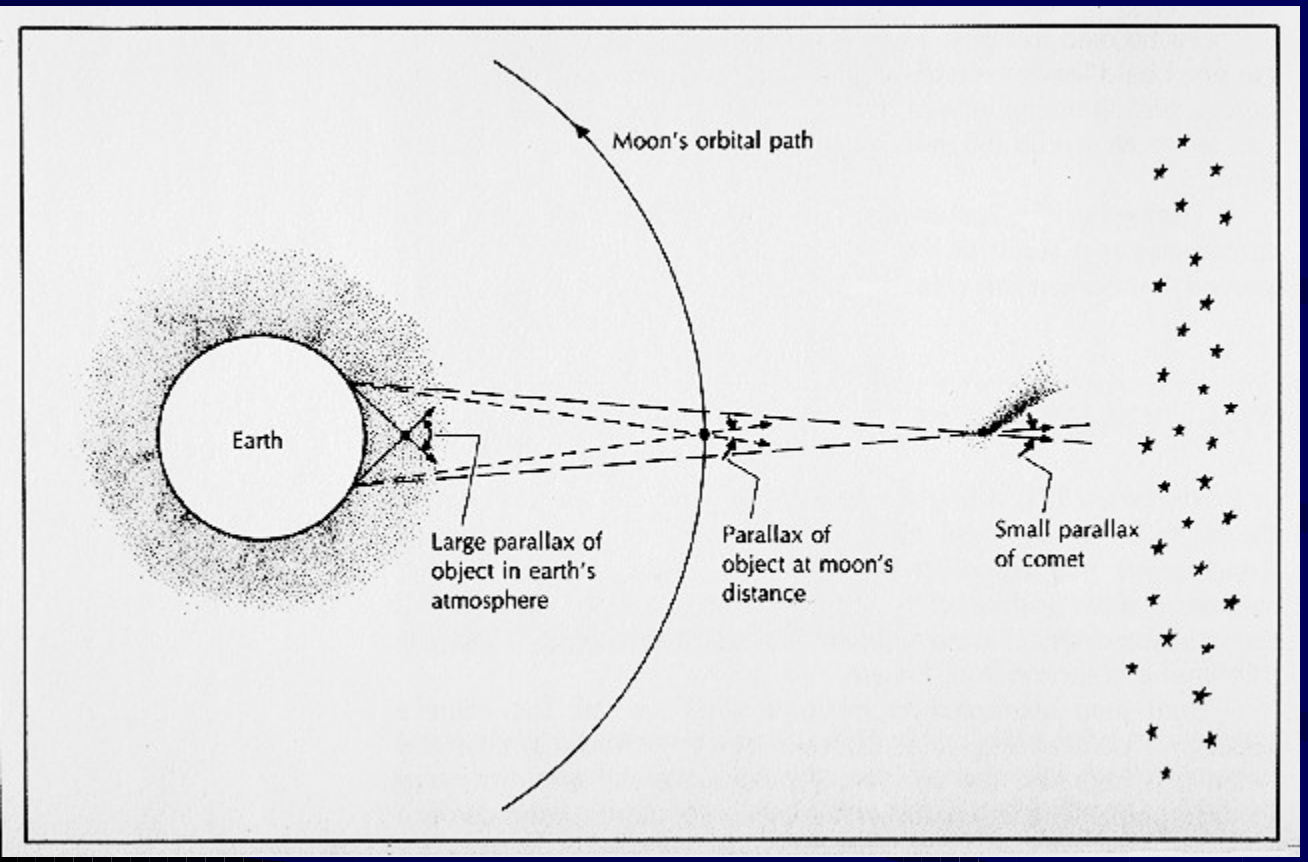
Mountains on the Moon

- Galileo observed the mountains of the Moon with his telescope
- Estimated their elevation correctly



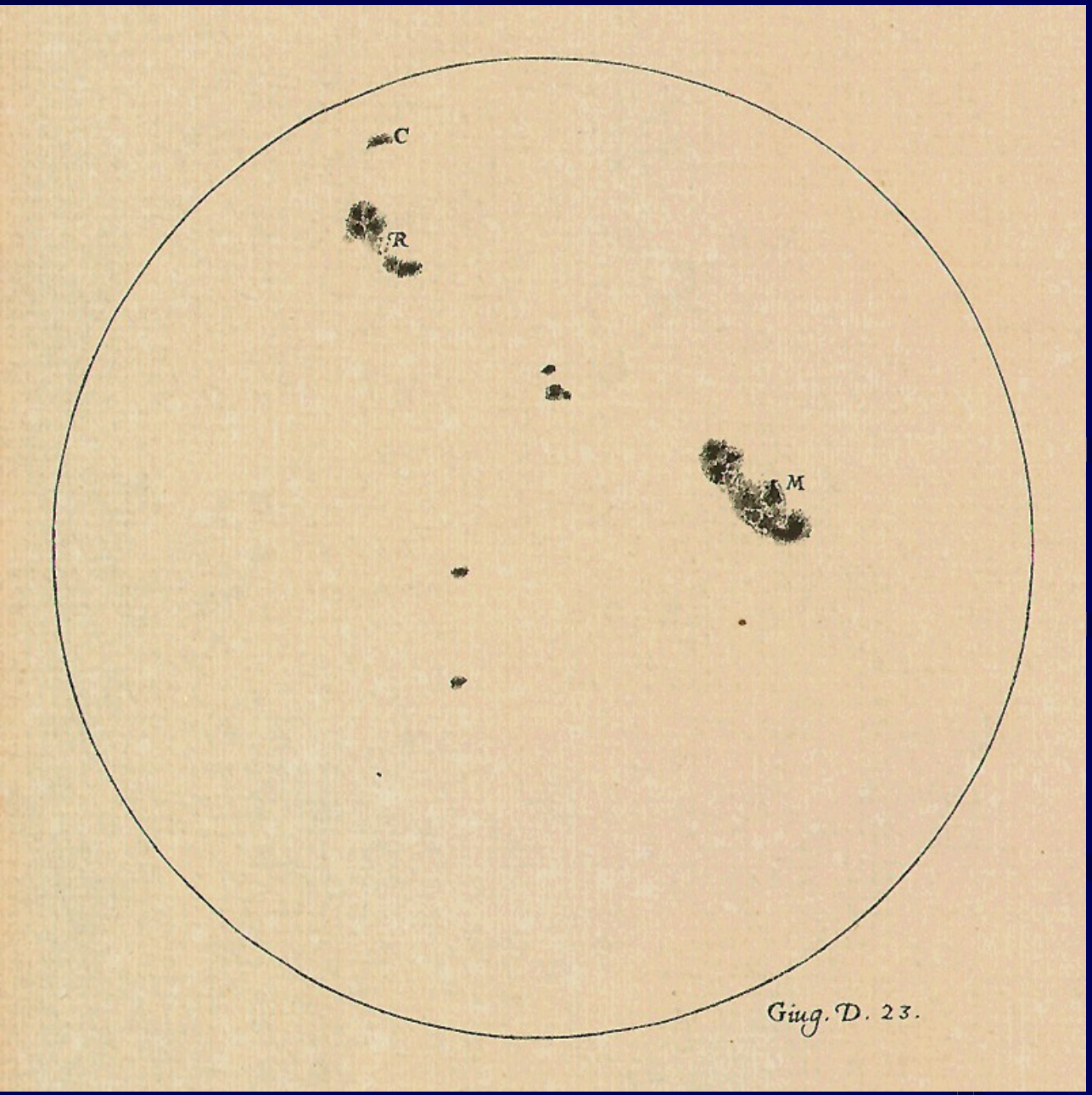
Artsy eyepiece sketches





Measuring distances with the Parallax

- The closer an object is, the more relocated it appears with respect to the fixed stars from different points on Earth



Sunspots

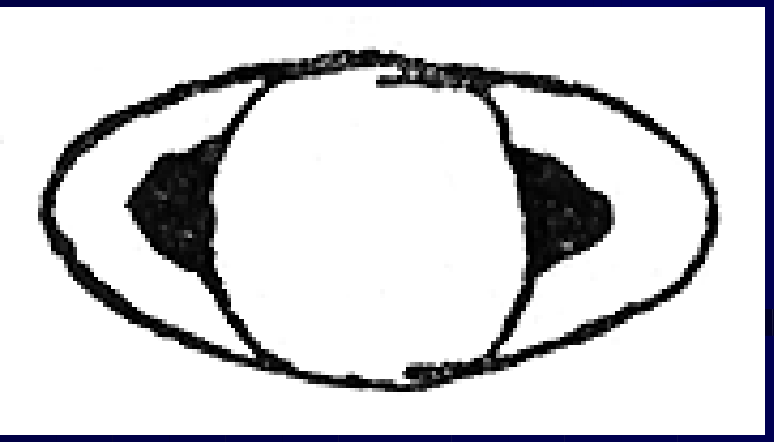
MPEG video from
(June 2 – July 8,
1613)

Galileo's Genius

- Careful observation of a phenomenon
- Deriving conclusions from "data"
- Making new predictions
- Publishing results "for everyone" [in Italian]
- Anticipates his opponents arguments, and nullifies them by using stringent logic

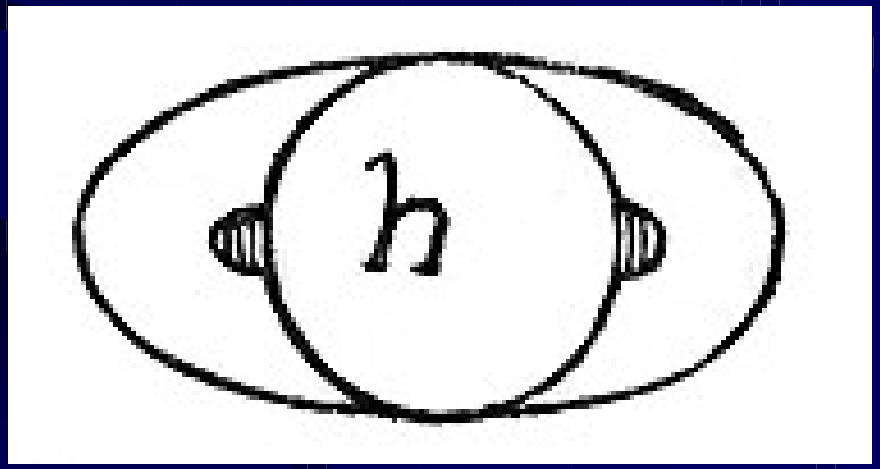
Galileo's Genius – Applied to Sunspots

- Careful observation of a phenomenon
  - Observes sunspots (as did others before him)
  - Follows them over several weeks
- Deriving conclusions from "data"
  - Concludes that these are things very close to the Sun's surface
- Making new predictions
  - Deduces that the sun rotates around itself in 26 days
  - Makes a prediction as to the Sun's rotational axis
- Publishing results "for everyone" [in Italian]
  - "Letters on Sunspots" (1612)
- Anticipates his opponents arguments, and nullifies them by using stringent logic
  - Shows that sunspots can't be inner planets



Saturn

- Sketch of 1616
- Engraving in “The Assayer” (1623)



Applications

- From the distance r between two bodies and the gravitational acceleration a of one of the bodies, we can compute the mass M of the other

$$F = ma = G\,Mm/r^2 \quad (m \text{ cancels out})$$

  - From the weight of objects (i.e., the force of gravity) near the surface of the Earth, and known radius of Earth $R_E = 6.4\times10^3$ km, we find $M_E = 6\times10^{24}$ kg
  - Your weight on another planet is $F = m \times GM/r^2$
    - E.g., on the Moon your weight would be 1/6 of what it is on Earth

Applications (cont'd)

- The mass of the Sun can be deduced from the orbital velocity of the planets: $M_S = r_{Orbit} v_{Orbit}^2 / G = 2 \times 10^{30}$ kg
  - actually, Sun and planets orbit their common center of mass

- *Orbital mechanics*. A body in an elliptical orbit cannot escape the mass it's orbiting unless something increases its velocity to a certain value called the escape velocity
  - Escape velocity from Earth's surface is about 25,000 mph (7 mi/sec)

Objections to the Heliocentric Model Answered

- If the Earth is moving, why do dropped objects appear to fall straight down?
  - Dropped objects start with the velocity of Earth (Galileo)
- If the Earth rotates, why don't we get thrown off?
  - Earth's rotation isn't fast enough!
- If the Earth revolves around the Sun, why don't we observe stellar parallax?
  - It's there, but very small, because the stars are so far away (Aristarchus)
- Why don't we feel the wind of our motion?
  - The air moves along with the Earth

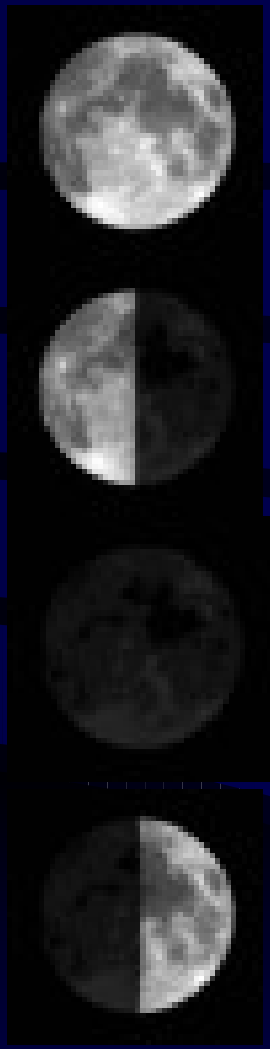
Problems of Both Models

- Lack of a fundamental explanation?
  - Provided by Newton (but what explains Newton?!)
- Lack of direct evidence?
  - Proof that the Earth rotates:
    - Coriolis force (hurricanes are counterclockwise in the Northern Hemisphere)
    - Foucault pendulum
  - Proof that earth and other planets revolve around the sun:
    - Aberration of starlight observed 1729
    - Stellar parallax observed 1838
    - Phases of Venus (Galileo)

The Night Sky in April

- Nights still long, but EDT => later observing!
- Spring constellations are up: Cancer, Leo, Big Dipper
- Saturn dominates the evening, Jupiter early morning.

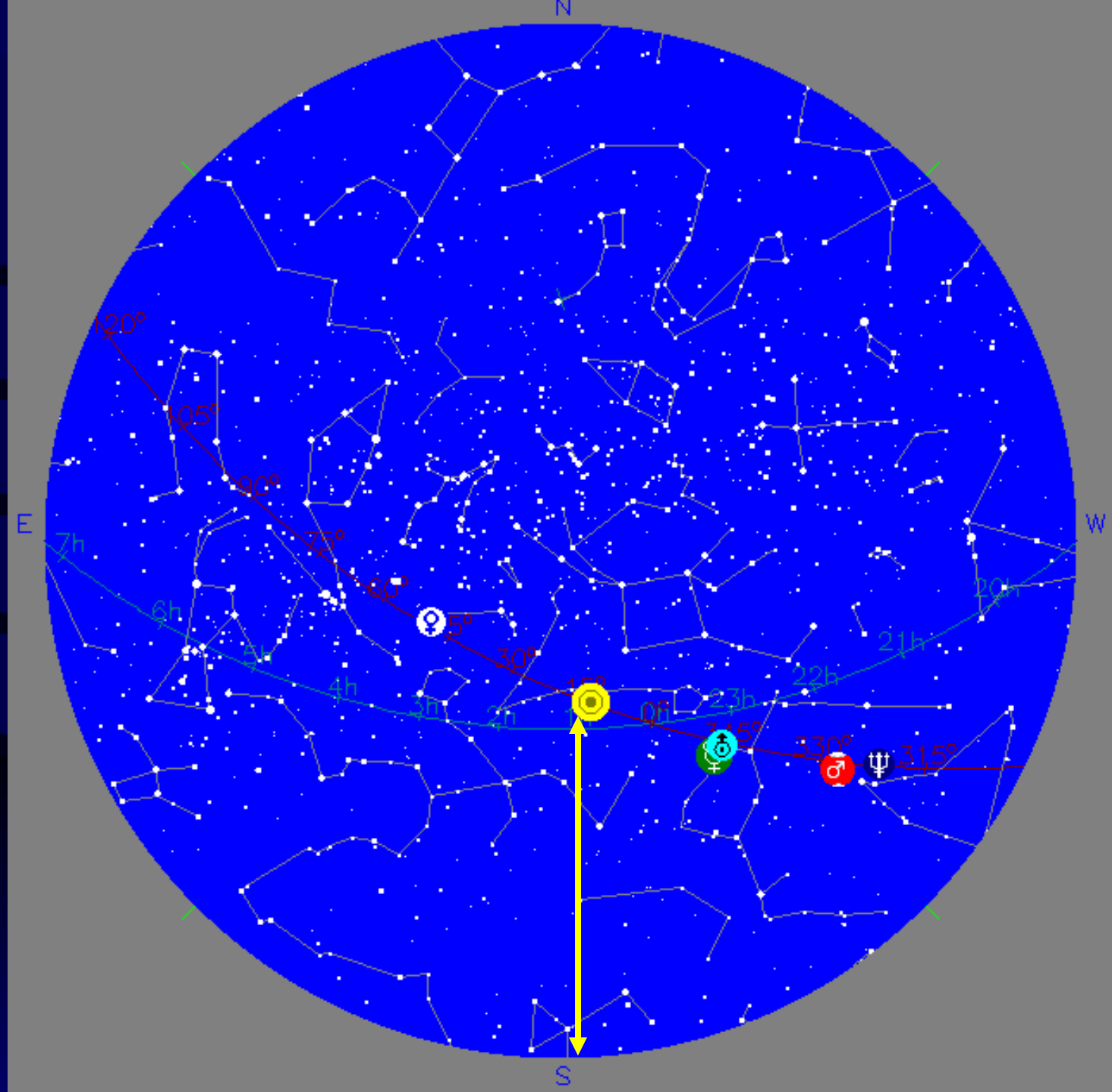
Moon Phases



- **Today: Full Moon**
- 4 / 10 (Last quarter Moon)
- 4 / 17 (New Moon)
- 4 / 24 (First Quarter Moon)

Today at Noon

Sun at meridian, i.e. exactly south

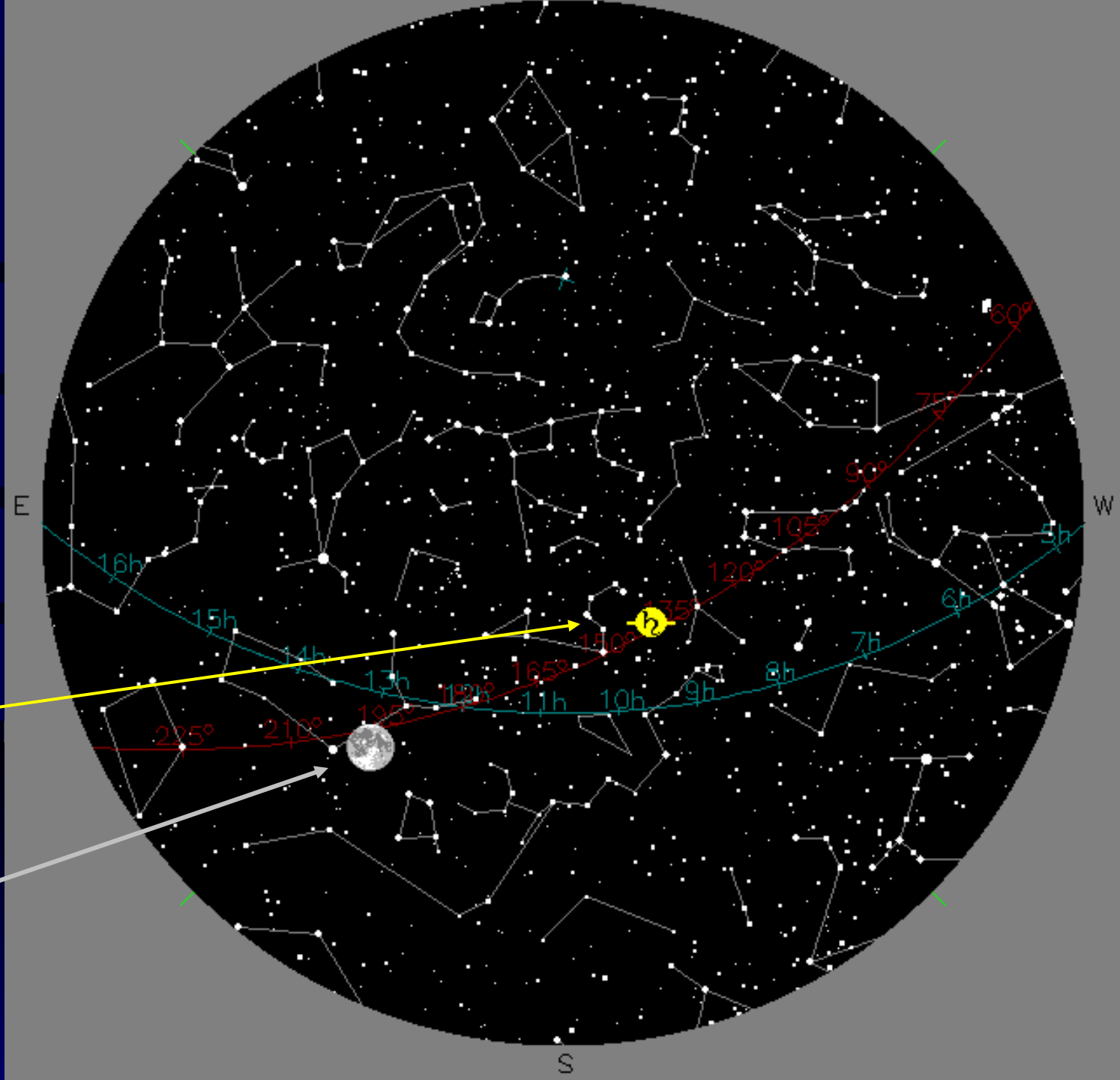


10 PM

Typical observing hour, early April

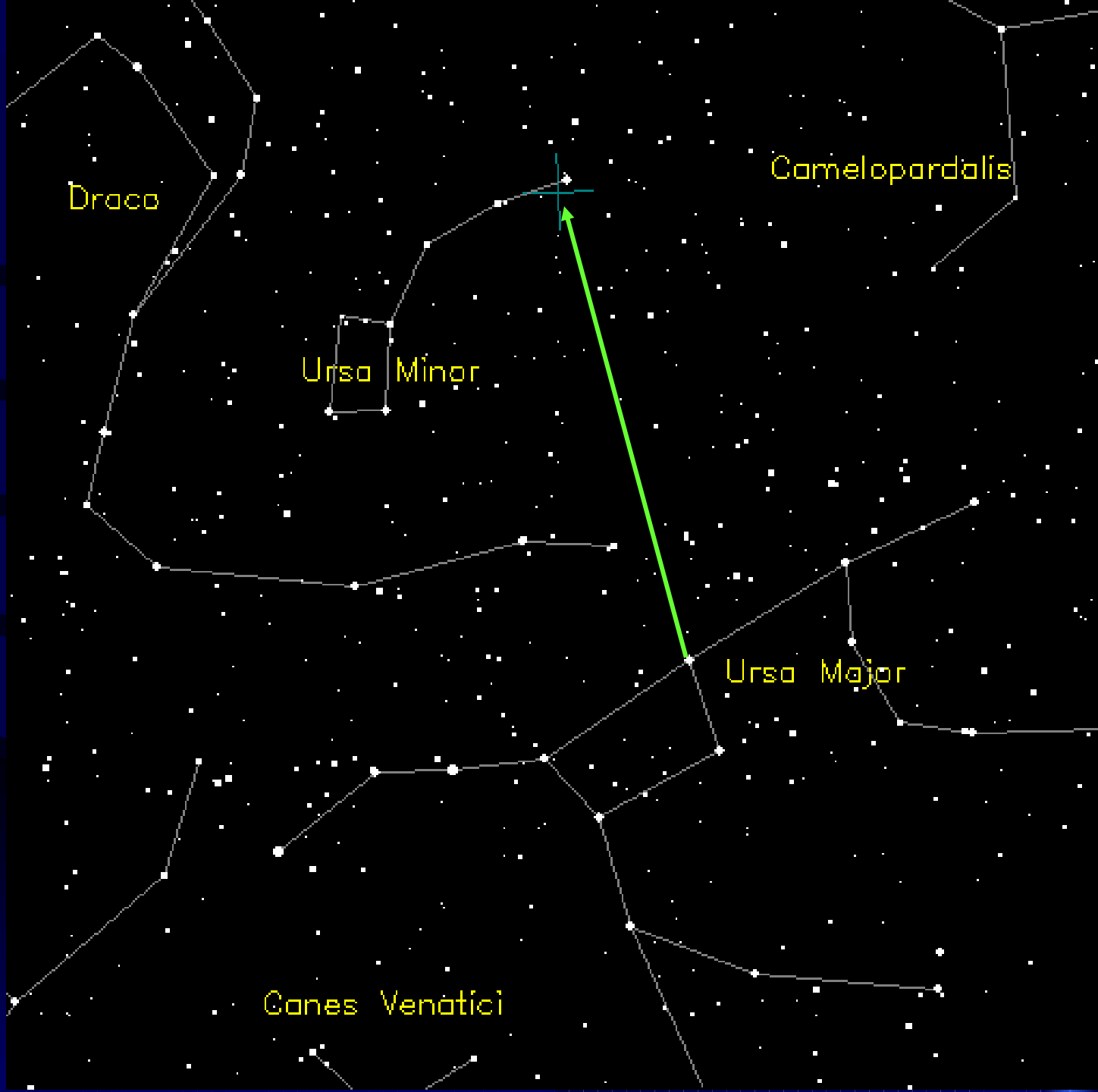
Saturn

Moon



Zenith

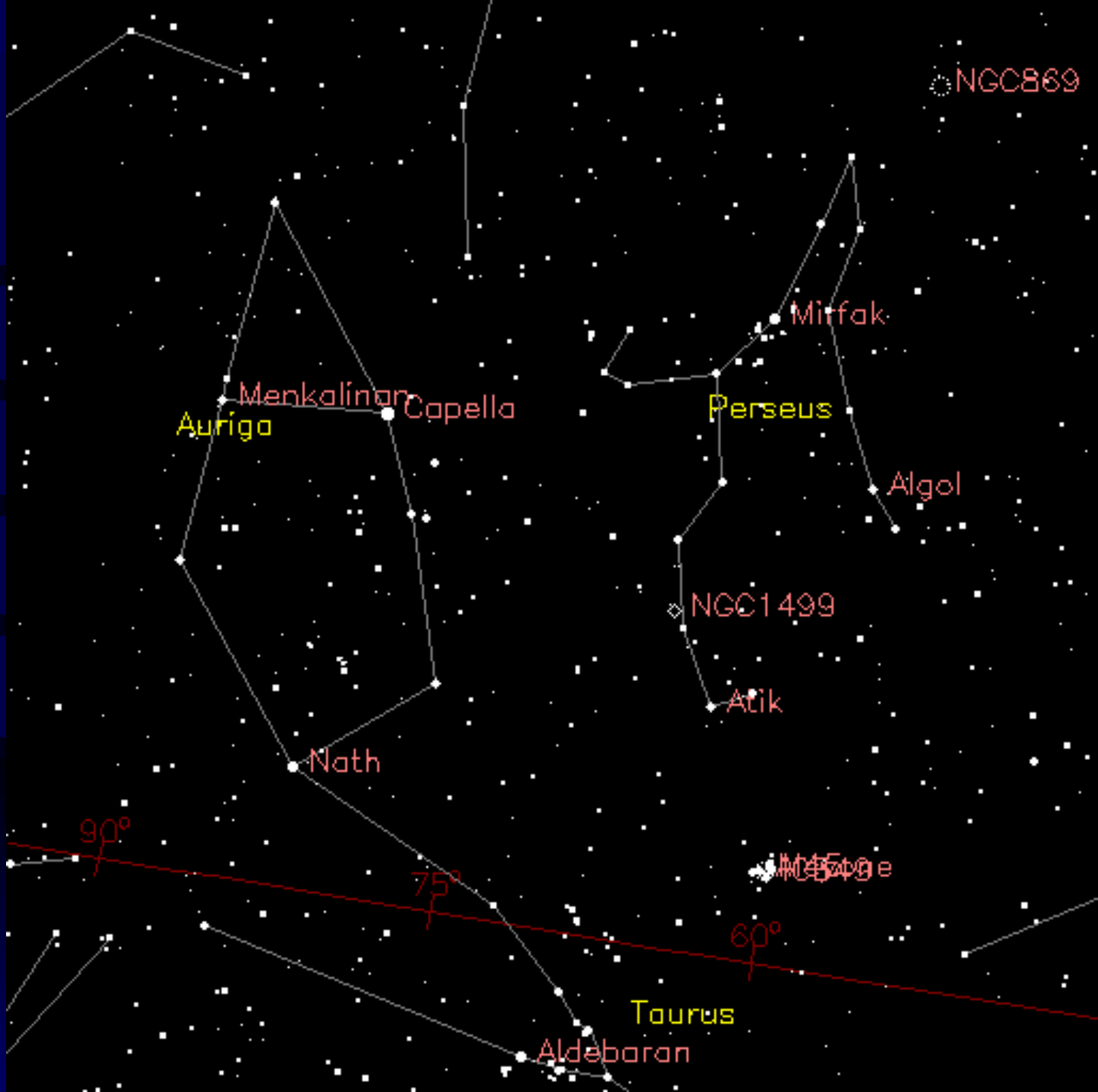
Big Dipper points to the north pole



West

Perseus and Auriga

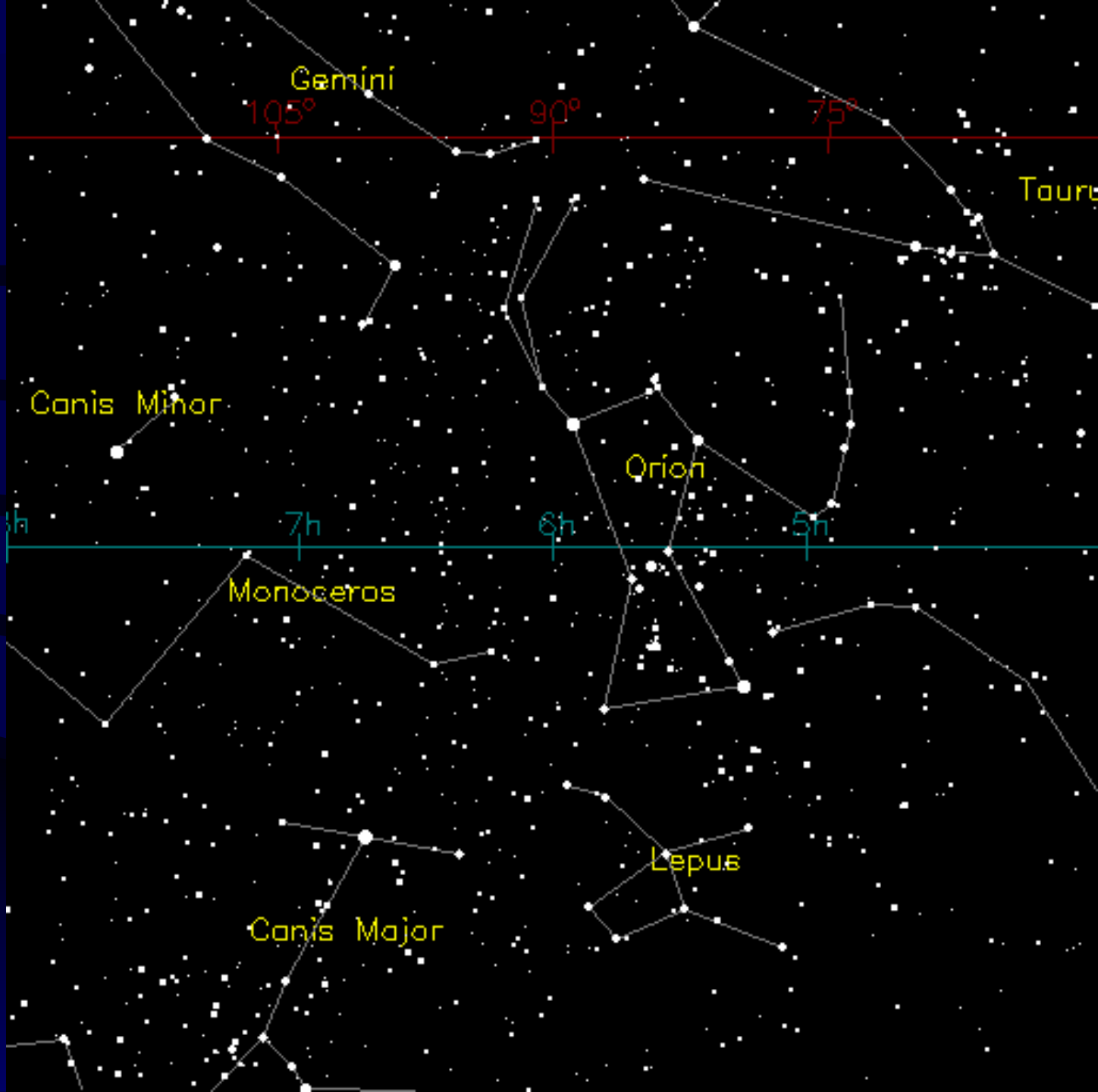
with Plejades and the Double Cluster



West

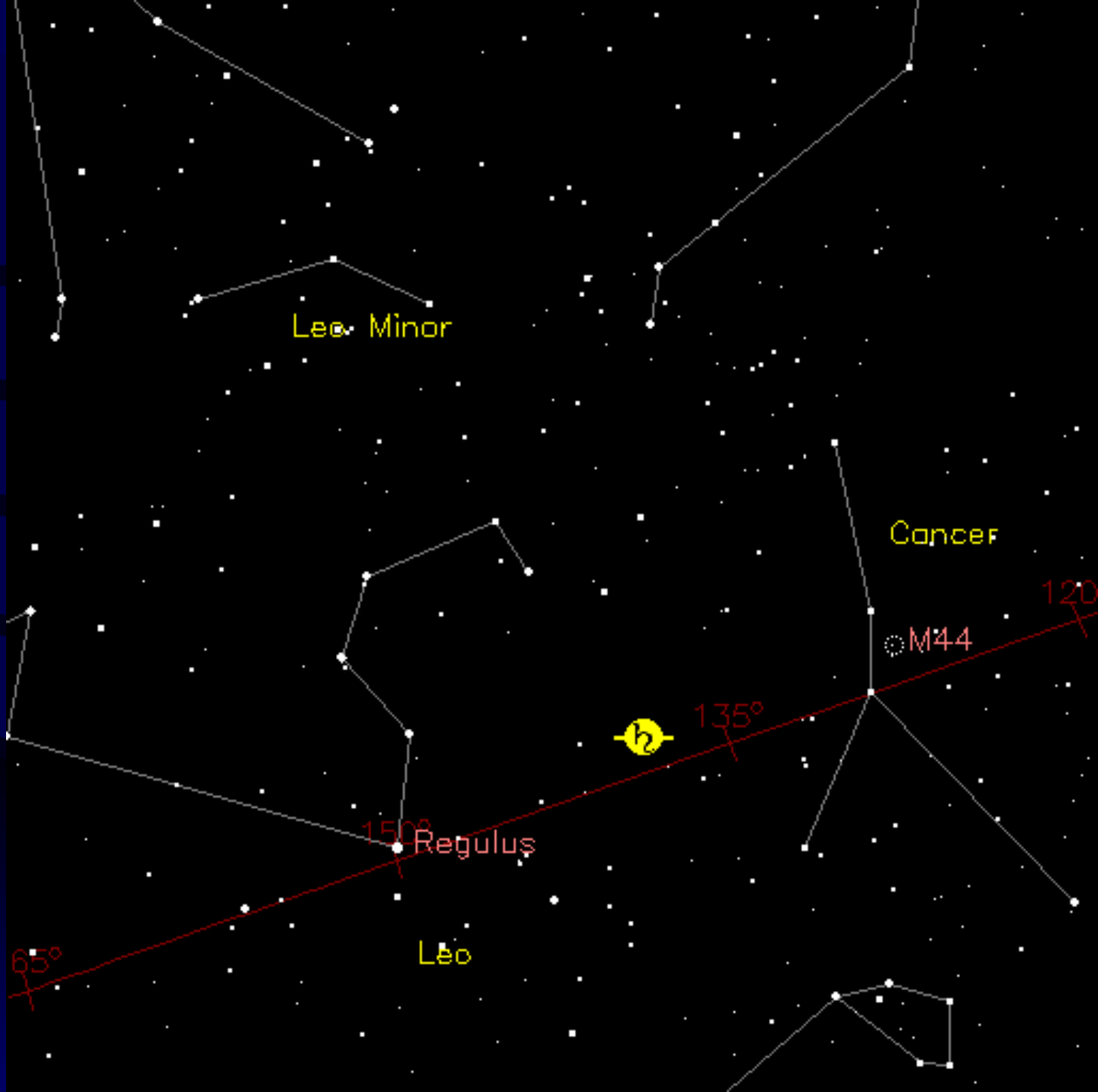
The Winter Constellations

- Orion
- Taurus
- Canis Major
- Gemini
- Canis Minor



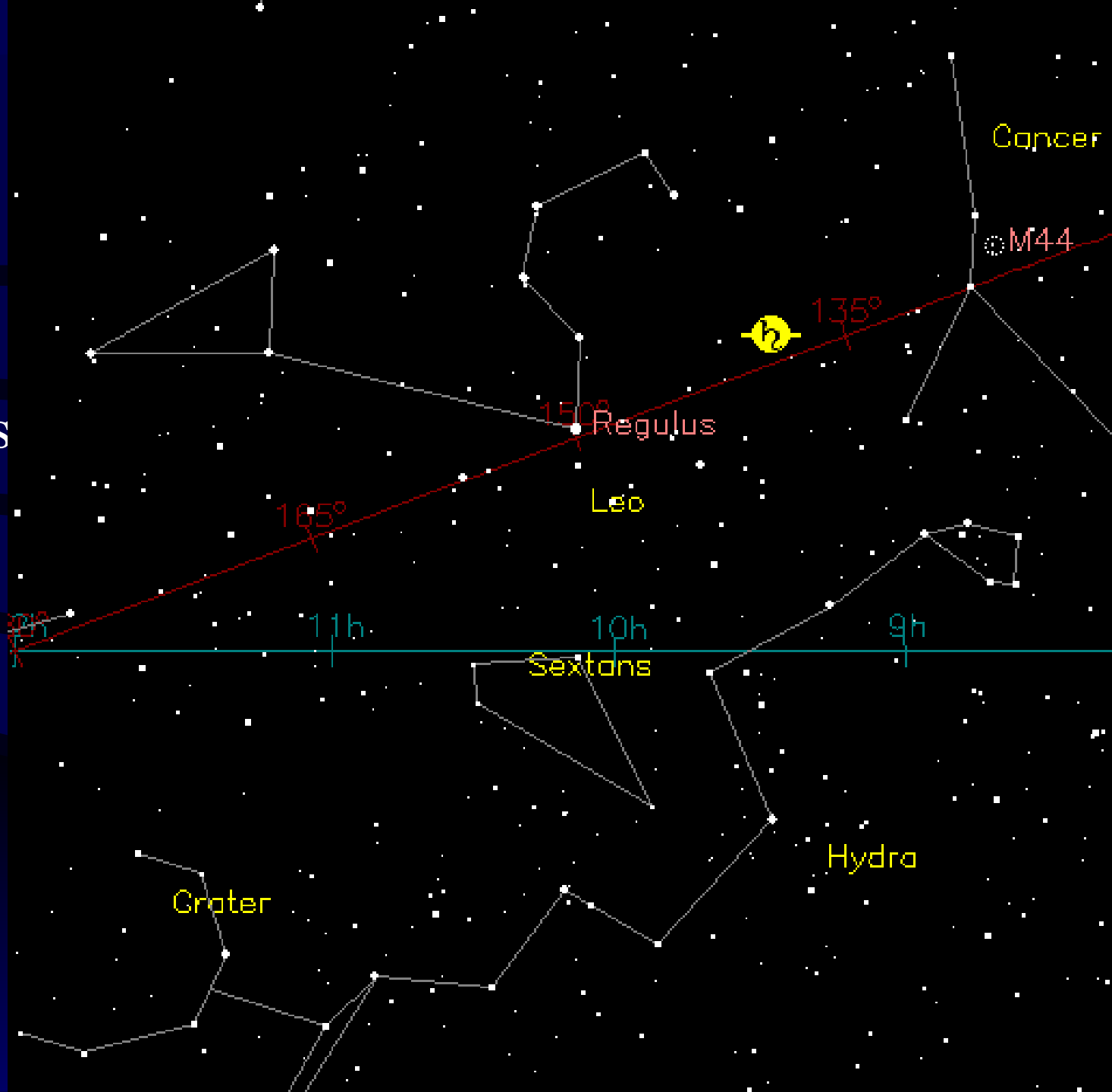
South

- Saturn near Praesepe (M44), an open star cluster



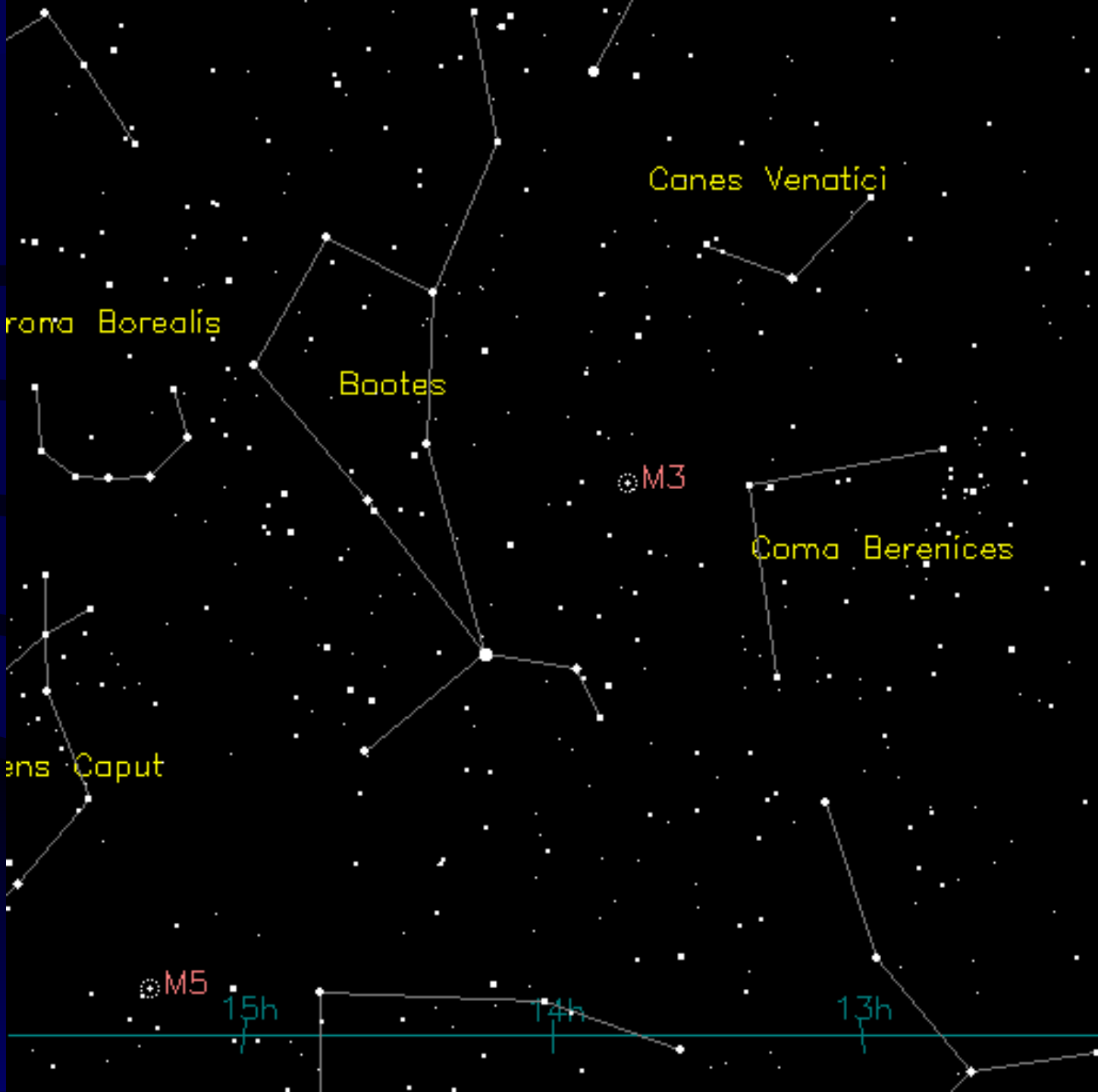
South

- Spring constellations
  - Leo
  - Hydra
  - Crater
  - Sextans



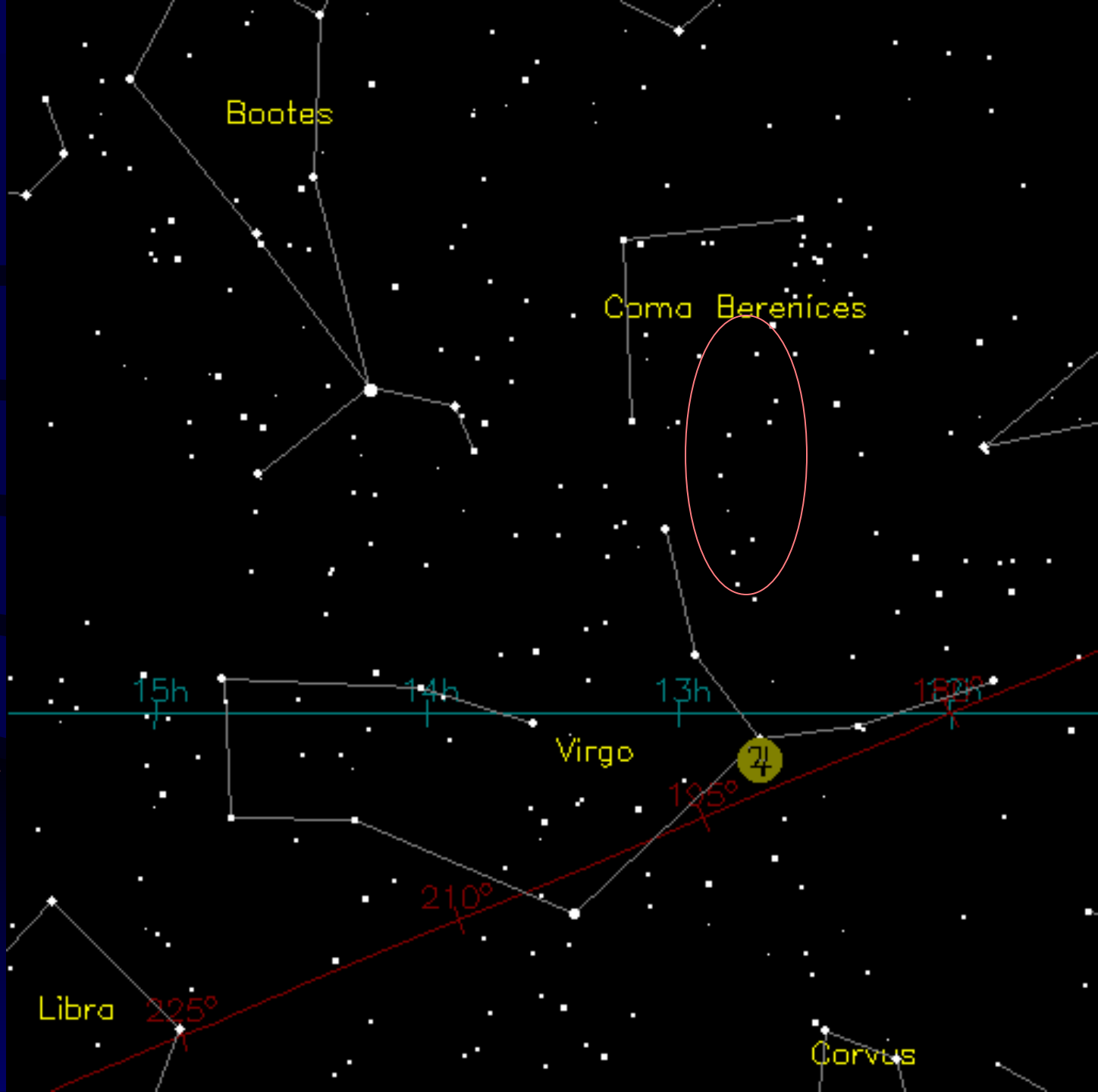
East

- Canes Venatici:
  - M51
- Coma-Virgo Cluster
- Globular Star Clusters
  - M3, M5



East

Virgo and Coma with the Virgo-Coma galaxy cluster



Virgo-Coma Cluster

- Lots of galaxies within a few degrees

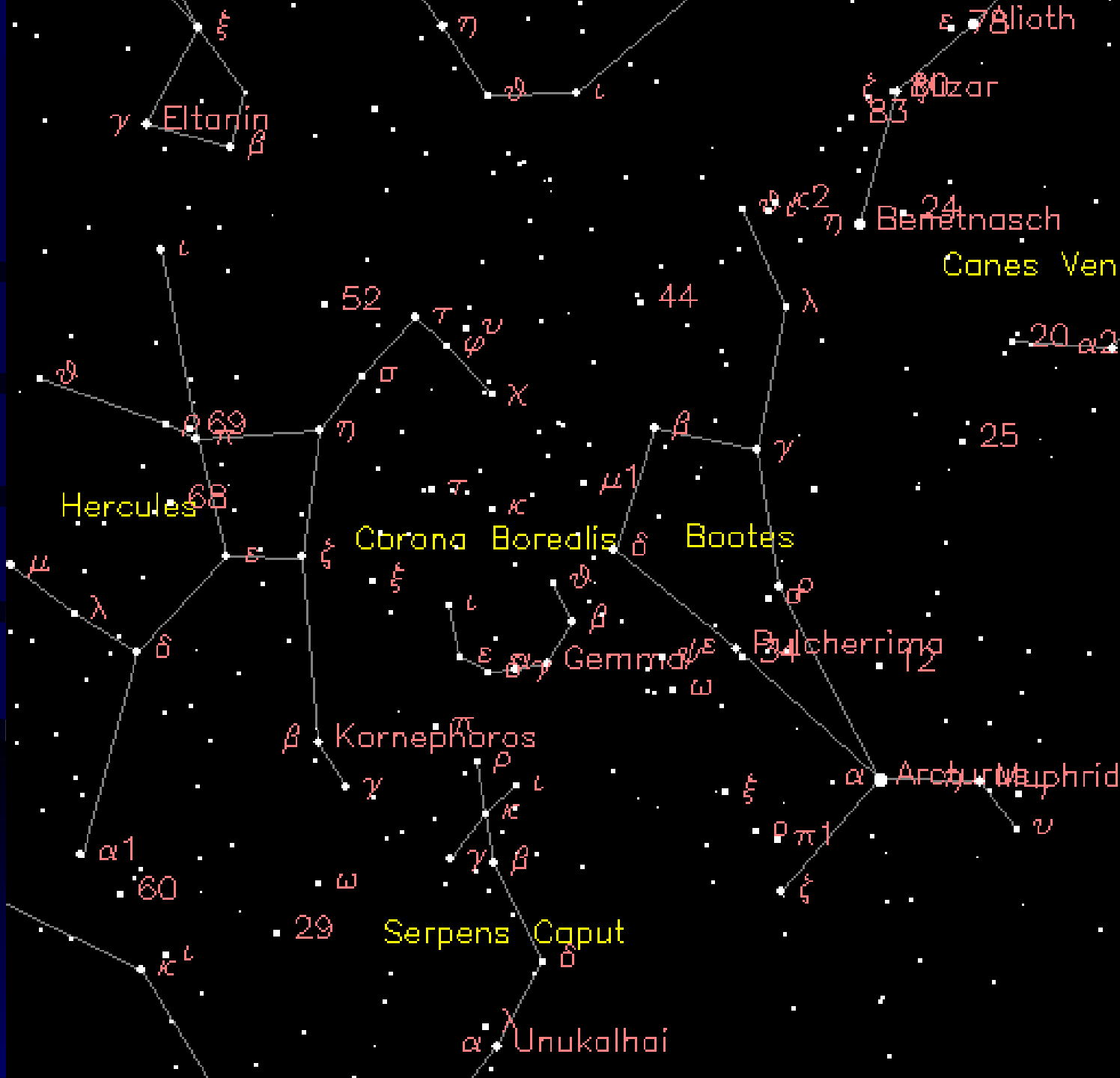
M87, M88 and M91

East

- Hercules
- Corona Borealis
- Bootes

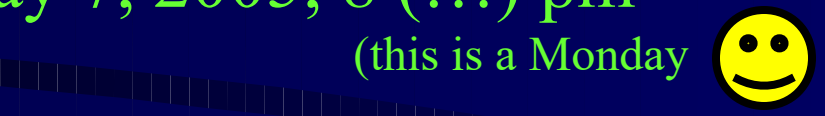
Globular Star Clusters:

- M 3
- M 13
- M 92



M13: Globular Cluster

Mark your Calendars!

- Next Starry Monday: May 7, 2005, 8 (!!!) pm
  (this is a Monday )
- Observing at Prairie Oaks Metro Park:
  - Friday, April 27, 2007, 8:30 pm
  - Friday, May 25, 2007, 9:00 pm
- Web pages:
  - http://www.otterbein.edu/dept/PHYS/weitkamp.asp (Obs.)
  - http://www.otterbein.edu/dept/PHYS/ (Physics Dept.)

Mark your Calendars II

- Physics Coffee is every Wednesday, 3:30 pm
- Open to the public, everyone welcome!
- Location: across the hall, Science 256
- Free coffee, cookies, etc.