

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

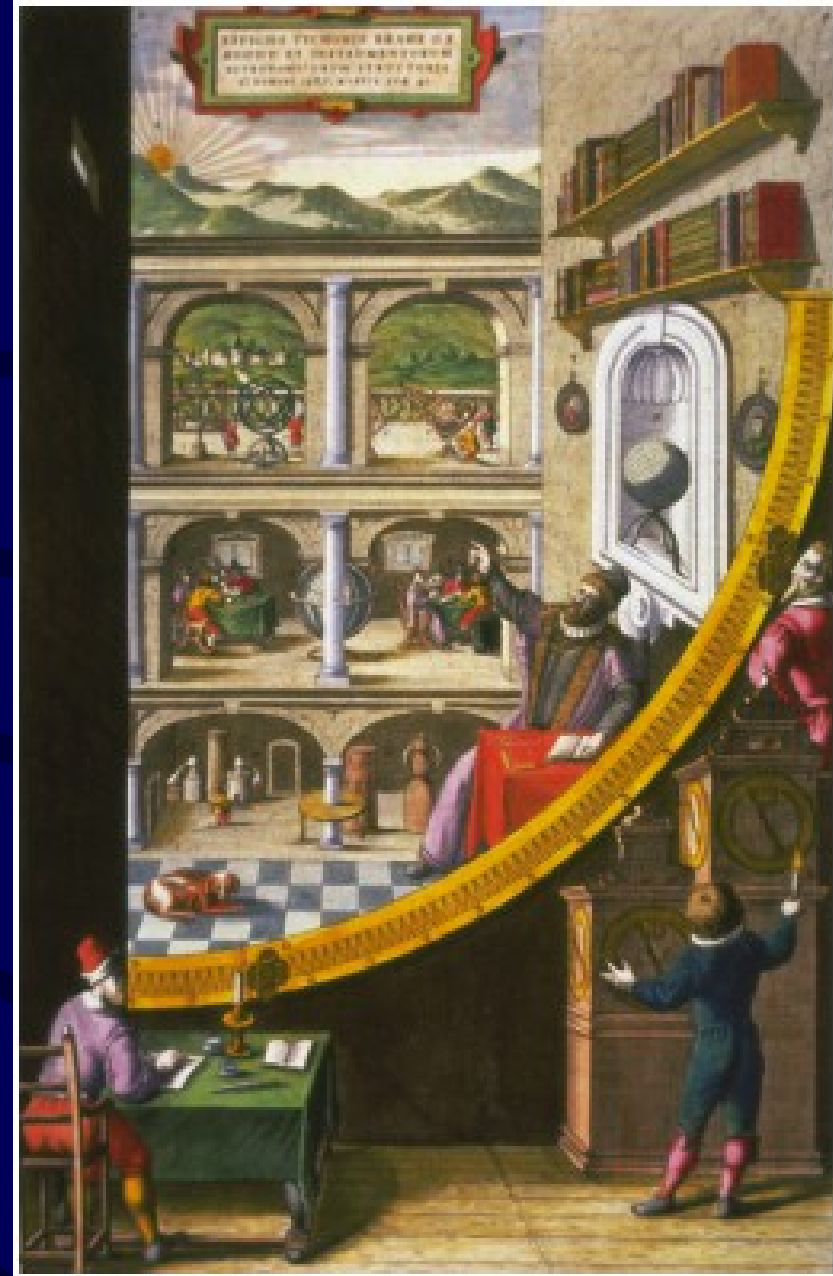


Tycho Brahe (1546–1601)



# 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)



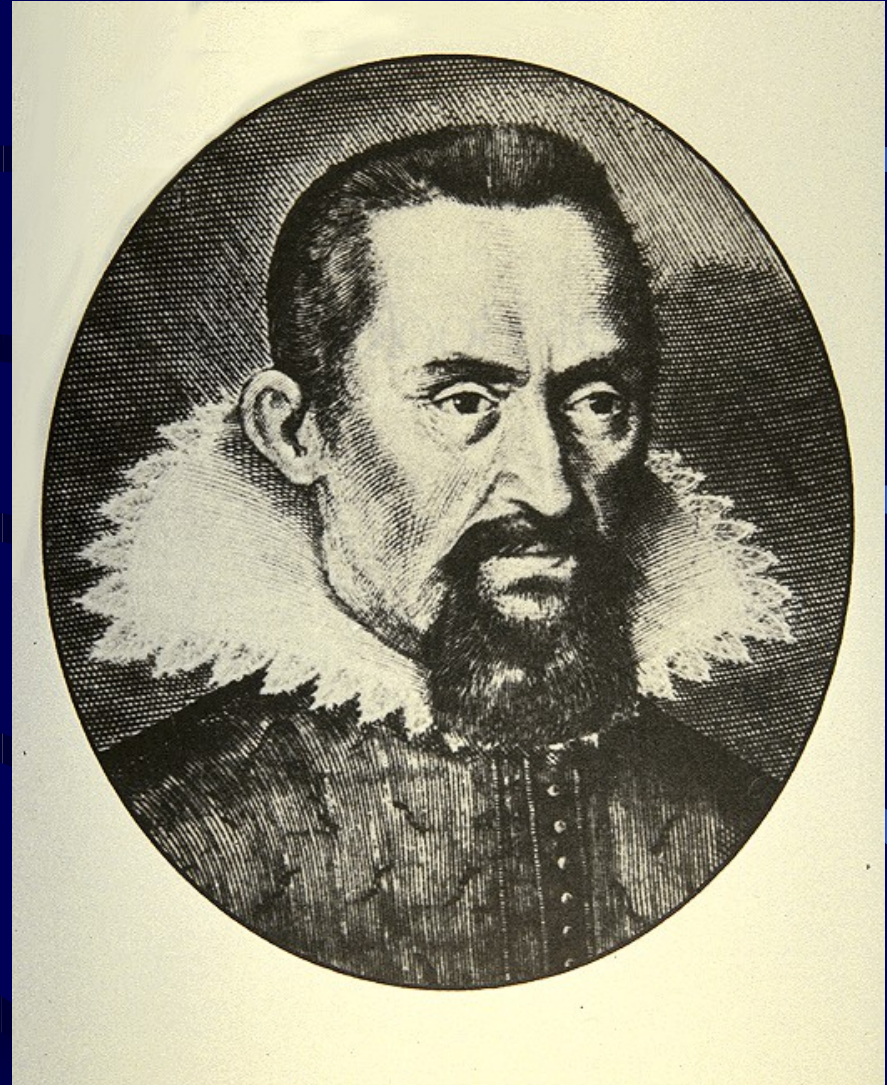
Tycho Brahe observing

# Johannes Kepler—The Phenomenologist

- Key question:  
How are things happening?

## Major Works:

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



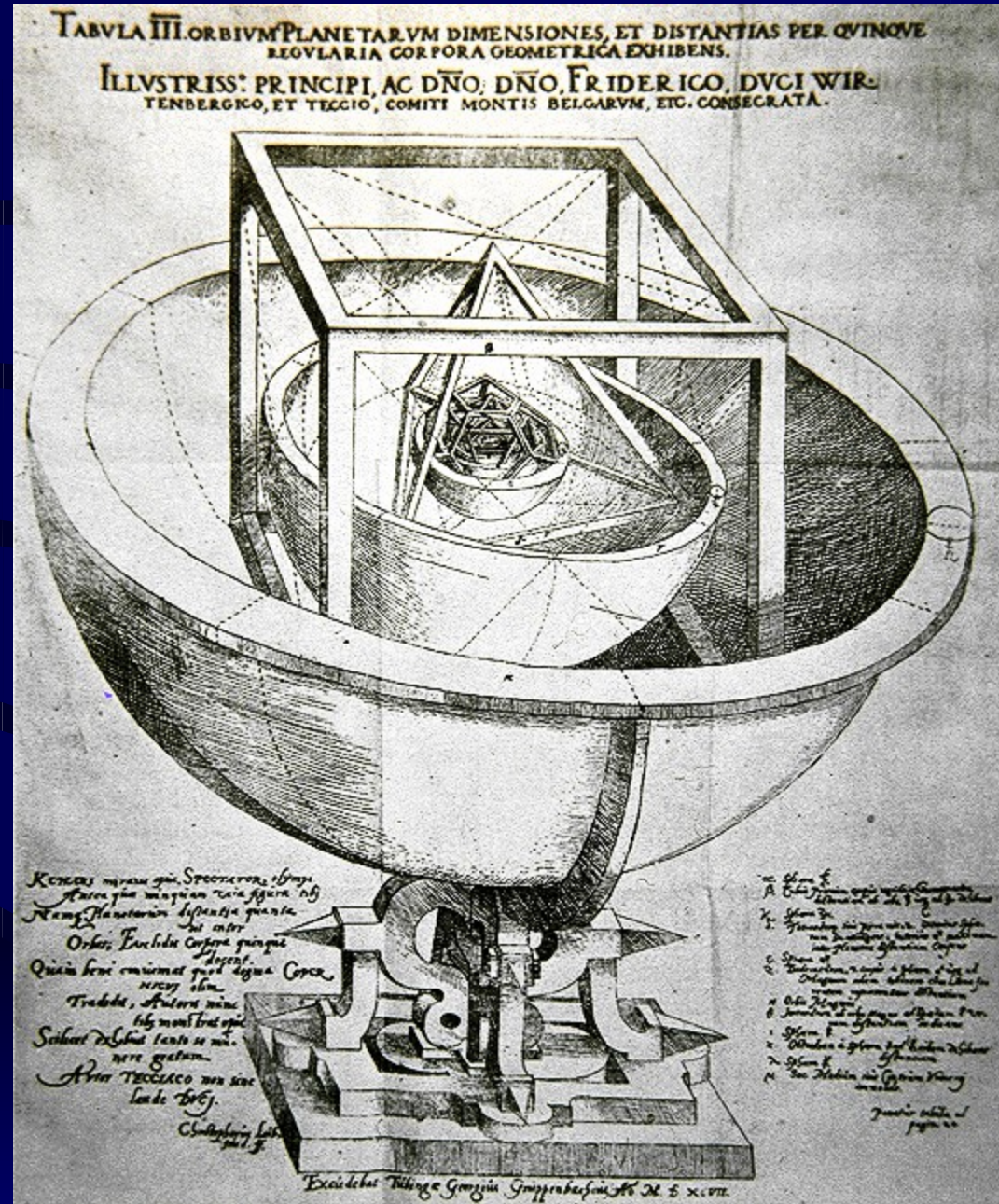
Johannes Kepler (1571–1630)



# Kepler's Beginnings

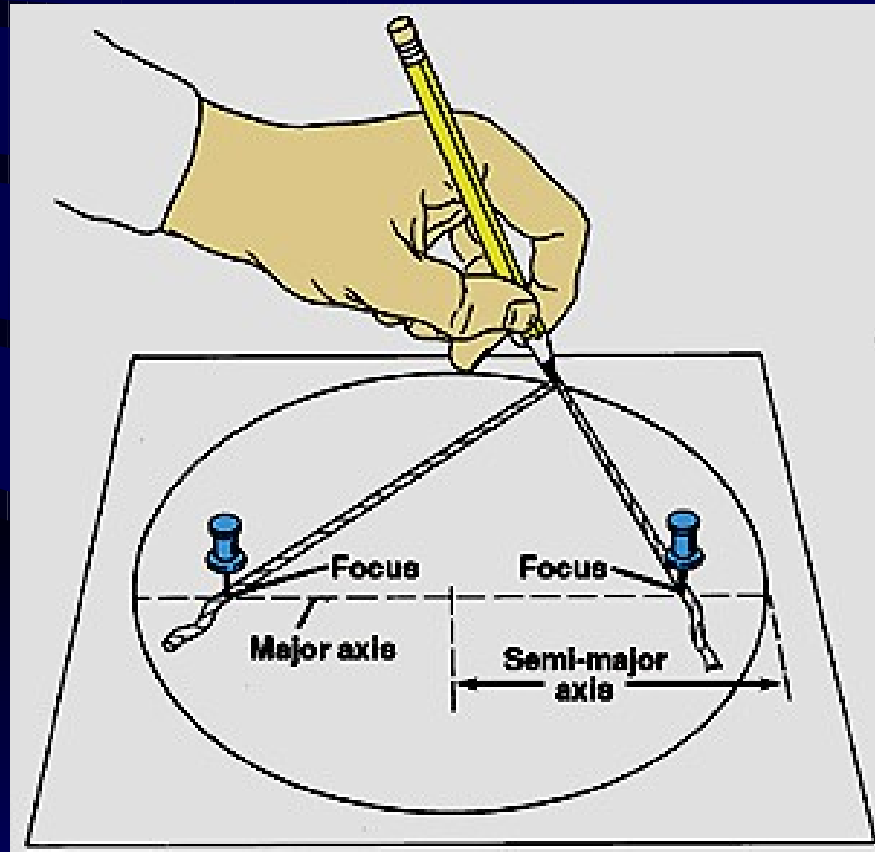
- Astrologer and Mystic
- Tried to find “music in the skies”
- Tried to explain distances of the 5 known planets by spheres resting on the 5 mathematical bodies

→ pre-scientific

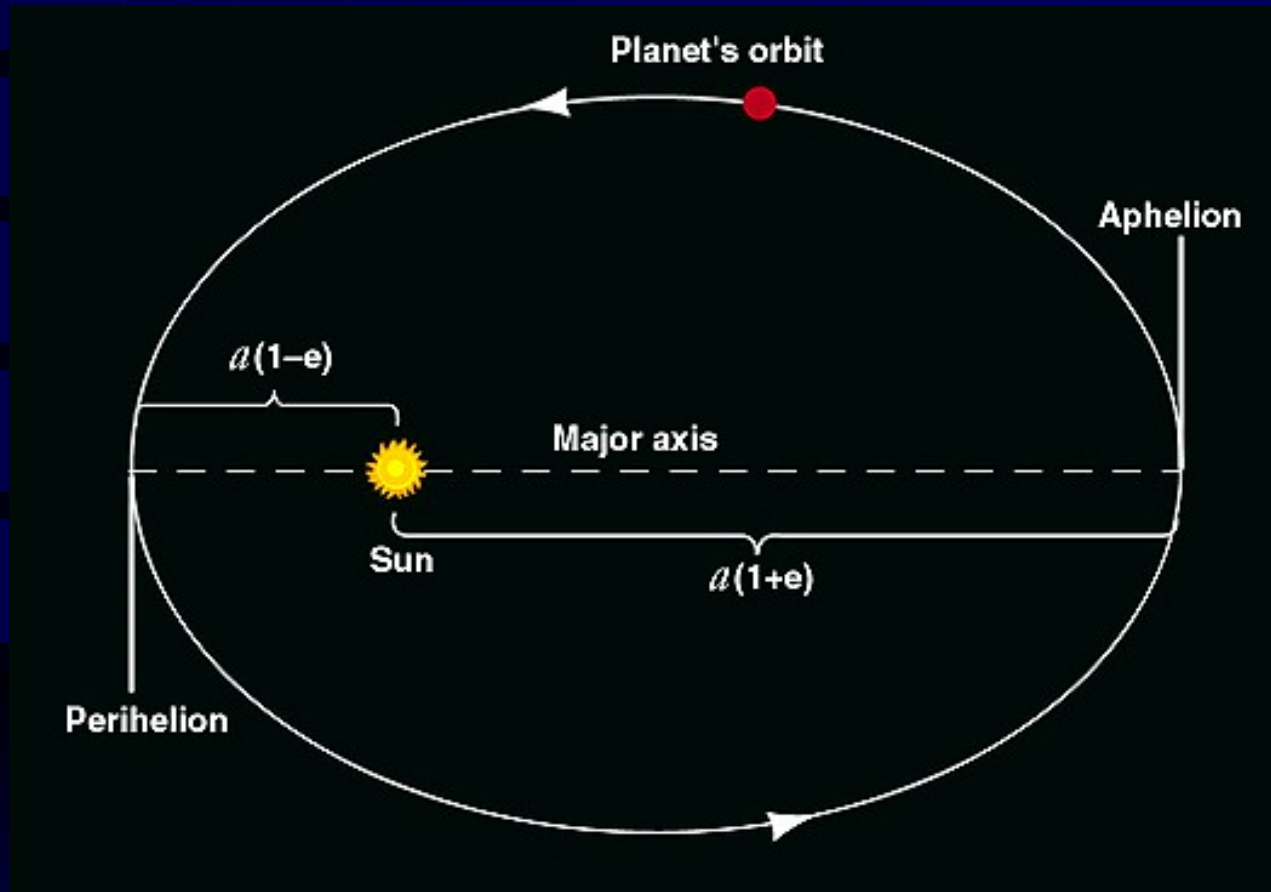


# Kepler's First Law

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

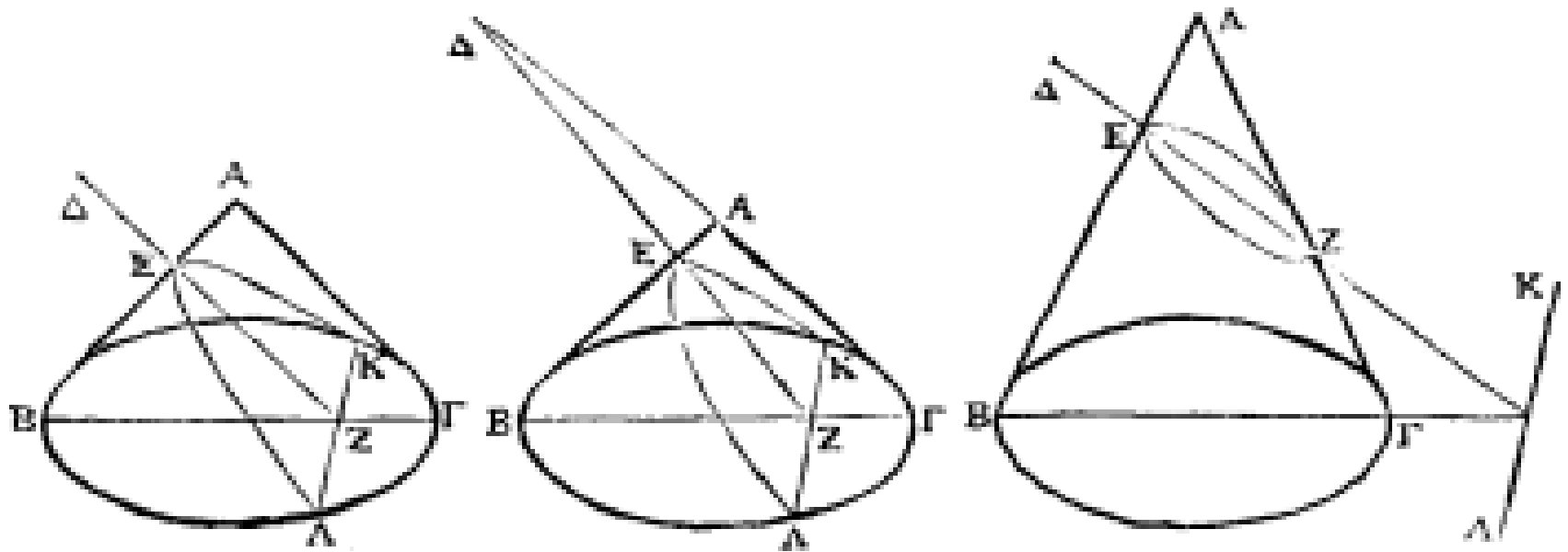


# Ellipses



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

# Conic Sections

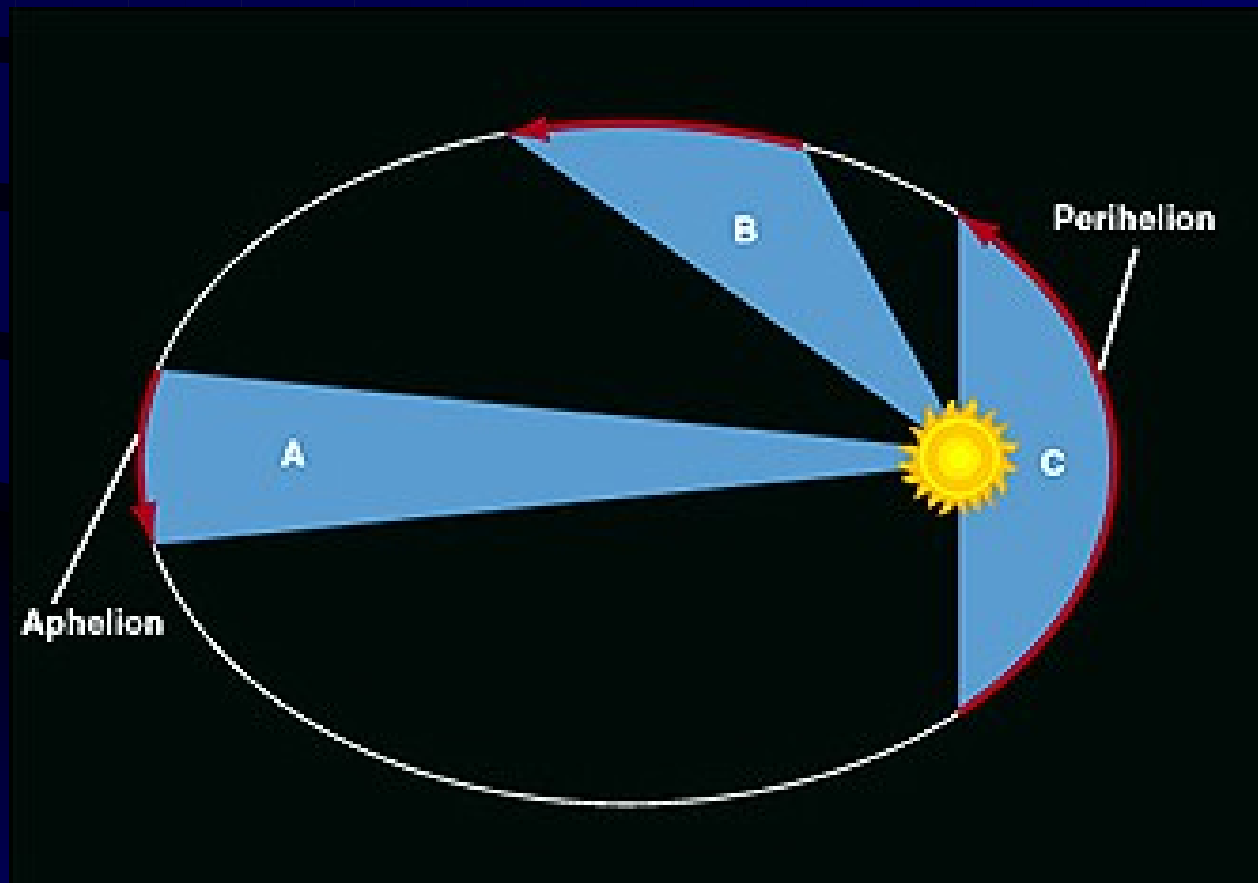


Aus der Konika-Ausgabe von E. Halley, Oxford, 1710.

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:

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

<b>Planet</b>	<b>a</b> <b>Orbital Semi-Major Axis</b>	<b>P</b> <b>Orbital Period</b>	<b>Eccentricity</b>	<b>P<sup>2</sup>/a<sup>3</sup></b>
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
	<b>(A.U.)</b>	<b>(Earth years)</b>		



# Galileo Galilei – The Experimentalist

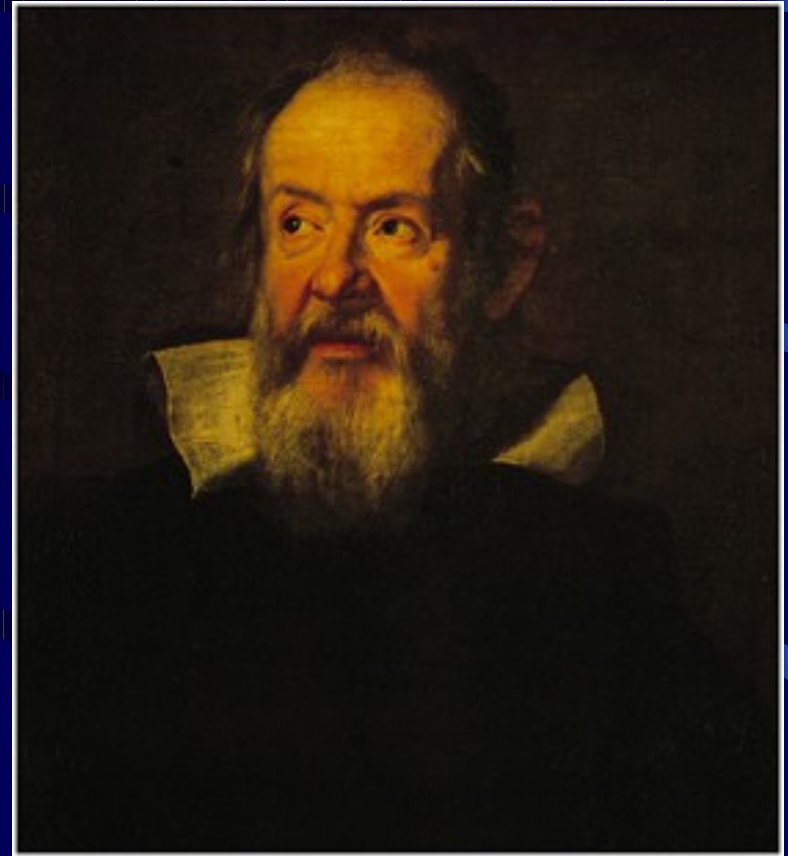
Did experiments (falling bodies) rather than studying Aristotle

## 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)

# SIDEREVSVN NCIVS

MAGNA, LONGEQVE ADMIRABILIA  
Spectacula pandens, suspiciendaque proponens  
vnicuique, praesertim verò

PHILOSOPHIS, atq; ASTRONOMIS, quæ à  
GALILEO GALILEO  
PATRITIO FLORENTINO

Patauini Gymnasij Publico Mathematico

PERSPICILLI

Nuper à se reperti beneficio sunt observata in 13<sup>or</sup> N<sup>or</sup> A. E. F. ACTE, FINIS TN;  
NUMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,

Apparete verò in

QVATVOR PLANETIS

Circa 10<sup>or</sup> VIS Sæclum obspicibus interualis, atque periodis, celesti  
tate mirabilis circumsculatus, quos, nemini in hanc vique  
diem cognovit, monstrum Auctores deprecas.  
hæcile primus; atque

MEDICEA SIDER A  
NVNCVPANDOS DECREVIT.



VENETIIS, Apud Thomam Baglionum. M DC X.

Superiorum Privilegiis. & Privilegiis.

# DIALOGO D I

GALILEO GALILEI LINCEO  
MATEMATICO SOPRAORDINARIO

DELLO STUDIO 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'una, quanto per l'altra parte.*

CON PRI



VILEGI.

IN FIRENZA, Per Gio:Batista Landini MDCXXXII.

CON LICENZA DE' SUPERIORI.

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.

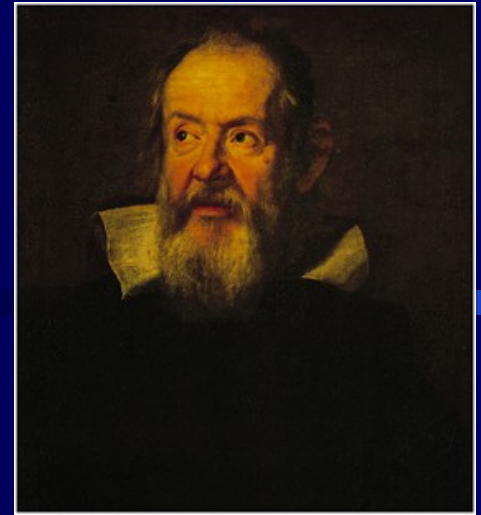


# Galileo's Telescopes



- 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

- 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

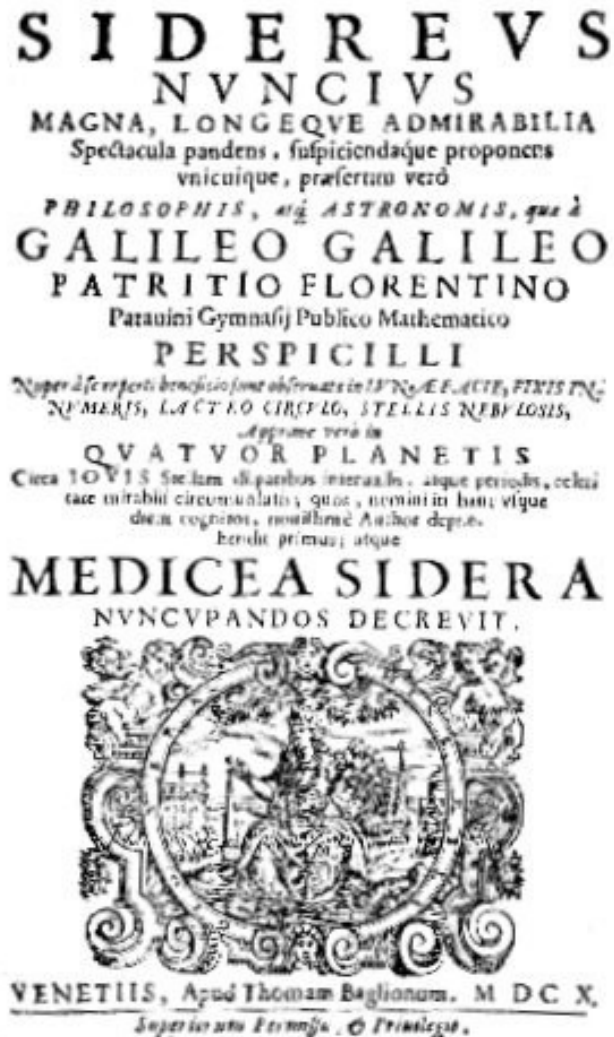
With the aid of a Spyglass recently invented by him

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 one before the Author recently perceived them and decided that they should be named

**THE MEDICEAN STARS**

Venice, 1610





# S I D E R E V S N V N C I V S

MAGNA, LONGEQVE ADMIRABILIA

Speſtacula pandens, ſuſpiciendaq̃ue proponens  
vnicuique, præſertim verò

*PHILOSOPHIS, atq̃ue ASTRONOMIS, quæ à*

**GALILEO GALILEO**

**PATRITIO FLORENTINO**

Parauiſi Gymnaſij Publico Mathematico

**PERSPICILLI**

*Nuper à ſe reſcripti beneſiſſio ſunt obſervati in 13<sup>to</sup> N<sup>o</sup> A. E. F. A. C. T. E, FINIS T. N. L.  
N. M. E. R. I. S, L. A. C. T. O. C. I. R. C. U. L. O, S. T. E. L. L. I. S. N. E. B. U. L. O. S. I. S,*

*Apparete verò in*

**QVATVOR PLANETIS**

*Circa IOVIS. Sæcũ ſcilicet diſparibus interuallis, atque periodis, cœliſſi-  
tate mirabili circumuolutis; quæ, nemini in hanc vique  
diem cognitæ, nouiſſimè Authoꝝ deſcriptæ.  
hæcũ primũ; atque*

**MEDICEA SIDER A**

NVNCVPANDOS DECREVIT.



**VENETIIS, Apud Thomam Baglionum. M DC X.**

*Superiorum Permiſſu. & Præſcripto.*

## The Medicean Stars

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

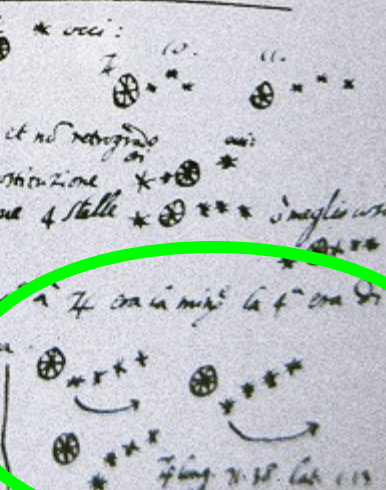


Sc. Principale.

Galileo Galilei, Humilis. Seruo della Ser. V. inuigilante.  
Io assistuando et di ogni spirito p. potere ho solam satisfare  
altario che nome della stessa di Mathematici nelle sue  
Vie di Padova,

Inuere Dauere determinato di presentare al Ser. Principe  
l'Orchiale et di essere di giuamenti inaspettabile p. ogni  
negotio et in iura marittima o terrestre stans di tenere pul.  
ito nuovo artificio nel maggior segreto et usque a disposizione  
di v. ser. L'Orchiale auuto dalle piu u. d. ite speculazioni di  
prospettua ha l'uantaggio di scoprire Legni et Vele dell' inimico  
p. u. h. et p. di tempo prima di esse senopra noi et distinguendo  
il numero et la qualita de i Vasselli giudicare la sua forte  
pallottarsi alla caccia al combattimento o alla fuga, o pure uale  
nella battaglia aperta uedere et particolarmente distinguere ogni suo  
moto et propriamente.

Adi 7. di Gennaio  
Giove si uede con  
Adi 8. con  
Adi 12. si uede in tale costituzione  
Adi 13. si uedono uiciniss. a Giove 4 stelle  
Adi 14. è angelo  
Adi 15. la prima  
stante dalla 3. il doppio  
L'orbita delle 3. uidevoli nel  
maggiore del diametro di 7. et  
sono in linea retta.



Adi 7. di Gennaio 1610 Giove si uede con la lampone con  
3. stelle p.ffe. con \* \* \* della quali se il uenire  
minore si uede con \* a di 8. appariva con \* \* \* era dug.  
diretto et no retrogrado come sogliono i calculatori.  
Adi 9. fu nubo. a di 10. si uede con \* \* \* di 11. è di.  
giu. la più occidentale si che la uideua p. gnato a suo credere.  
Adi 12. era in questa guida \* \* \* et la stella più uicina  
a Giove era la metà minore dell'altra, et uicinissima all'altra  
come che le altre pare erano le dette stelle apparse tutte tre  
di equal grandezza et tra di loro equal. Dal che  
appare intorno a Giove esser 3. altre stelle erranti uicinissime ad  
ogni uno sino a questo tefe.  
Adi 13. si uede in tale costituzione \* \* \* era la stella  
occidentale poco minor dello orientale, et giove era in mezzo tra  
da l'una et dall'altra quoto il suo diametro e uide: o forse era  
una terza mediana et uiciniss. a 7. uerso oriente; anzi pur in era  
uicini h. uide io si più diligente osservato, et uide più imminente  
notte.  
Adi 13. hauendo ben. formato lo scrum. si uedono uiciniss. a Giove  
4. stelle in questa costituzione \* \* \* è meglio con \* \* \*  
e tutte apparivano della med. grandezza, le glorio delle 3. occidentali  
ad era maggiore del diametro di 7. et erano più di loro notabili  
più uicine che le altre tre; ne erano in linea retta equidistanti come  
p. uide m. la media delle 3. occidentali era il poco eleuata, uero la  
più occidentale alquanto depressa; sono queste stelle tutte molto uide bene  
finitiss. et altre due et appariscono della med. grandezza ad essere  
con splendore.  
Adi 14. fu nubo. Adi 15. era con \* \* \* in pross. a  
7. era la minore et le altre dimano erano maggiori: gli interstizii  
tra 7. et la 3. seguati erano, quoto il diametro di 7. ma la 4. era di  
v. uide dalla 3. il doppio di uide: ad fine  
4. lung. 71. 38. lat. 1. 13. uano iteram linea retta, ma uero marcia  
l'esempio, erano al tutto uidevoli. Se le più  
le, et niente uideuano come uideuano.

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



but to et prepetuamente.

Adi 7. di Gennaio

Gione si vede a N

Adi 8. a N

era duy diretto et no retrogrado

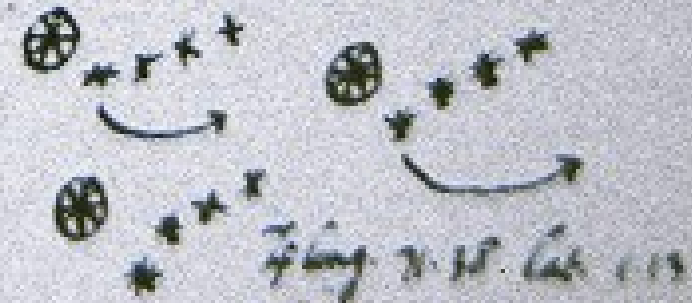
Adi 12. si vede a N tale costituzione

Il 13. si vedono vicino a Gione 4 stelle

Adi 14. è angelo

Il 15. la pross<sup>a</sup> a 4 ora in mig<sup>li</sup> la 4<sup>a</sup> ora di-  
stante dalla 3<sup>a</sup> il doppio tanto

Lo spazio delle 3 antiche ad ora  
maggiore del diametro di 7<sup>o</sup> et c.  
sono in linea retta.



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

# Phases of Venus

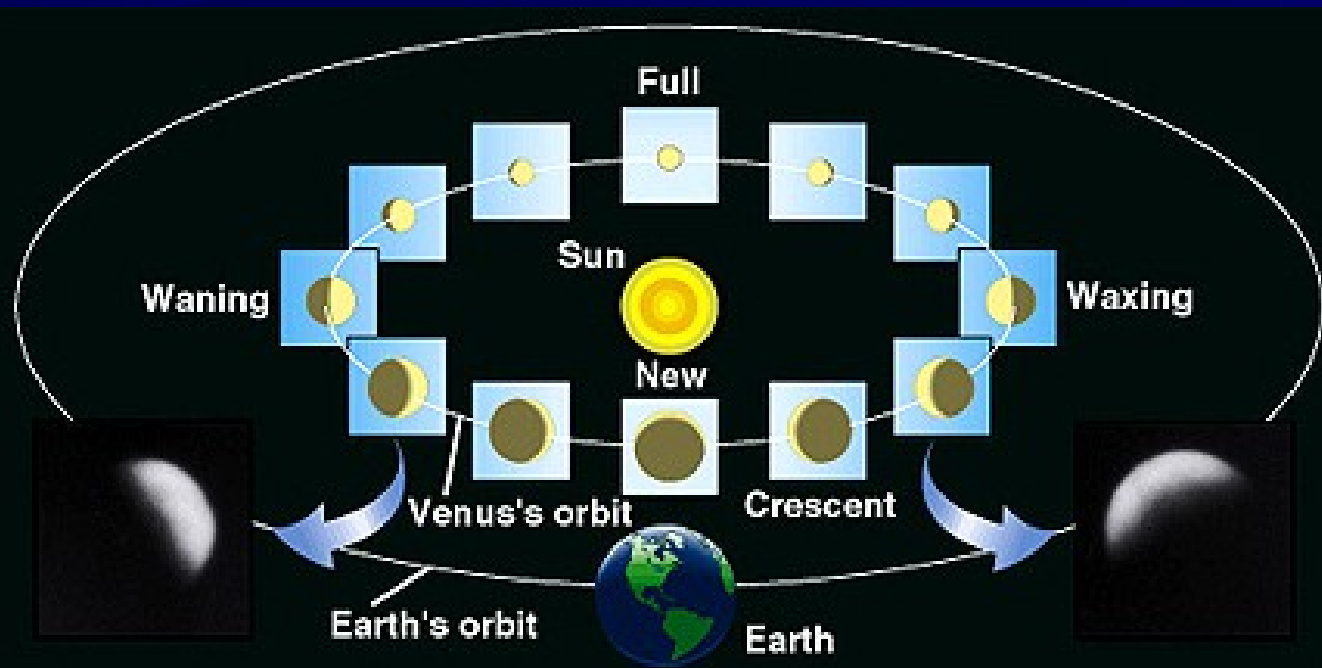


# Geocentric vs Heliocentric: How do we know?

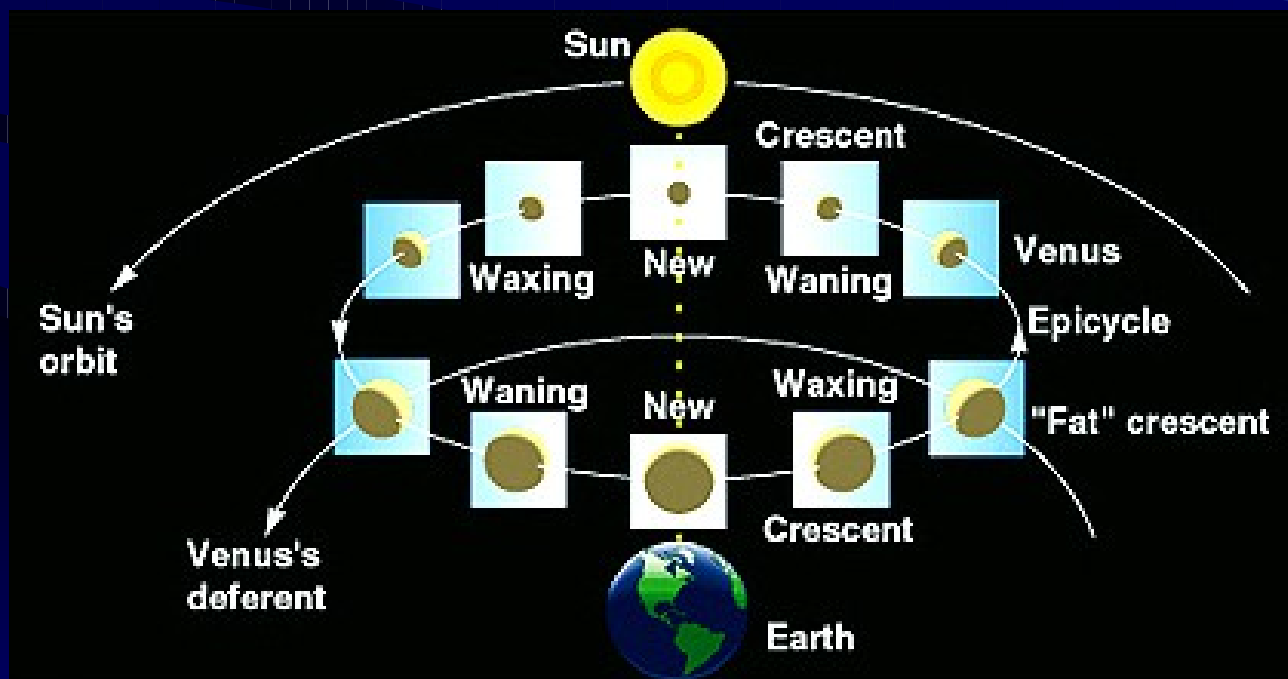
- Is the Earth or the Sun the center of the solar system?
- How do we decide between these two theories?
- Invoke the scientific methods:
  - both theories make (different) predictions
  - Compare to observations
  - Decide which theory explains data

# Phases of Venus

Heliocentric

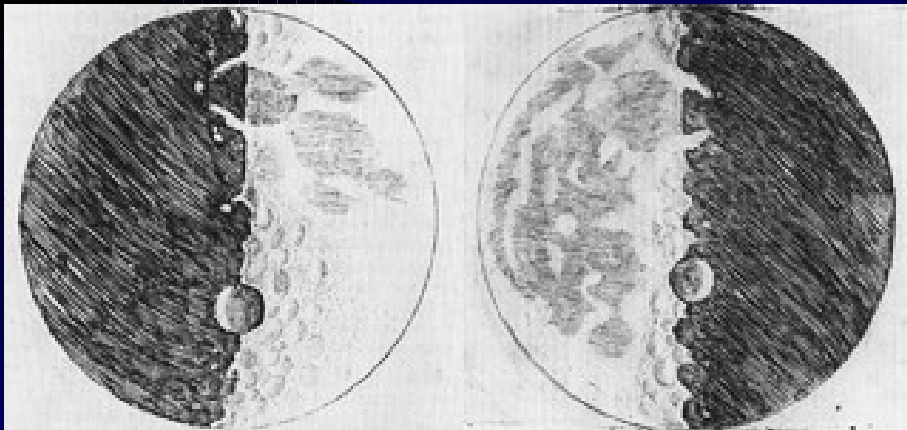
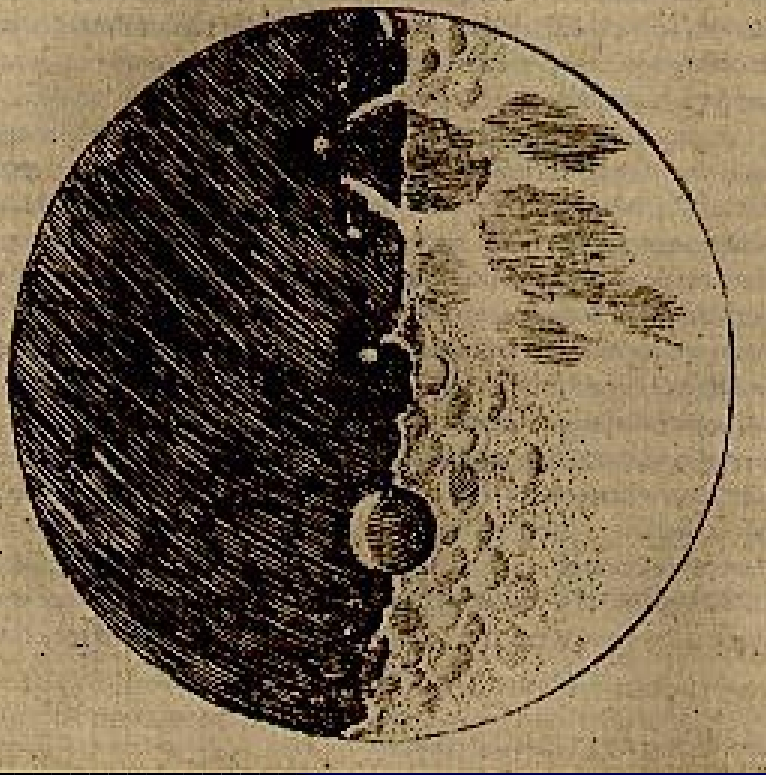


Geocentric

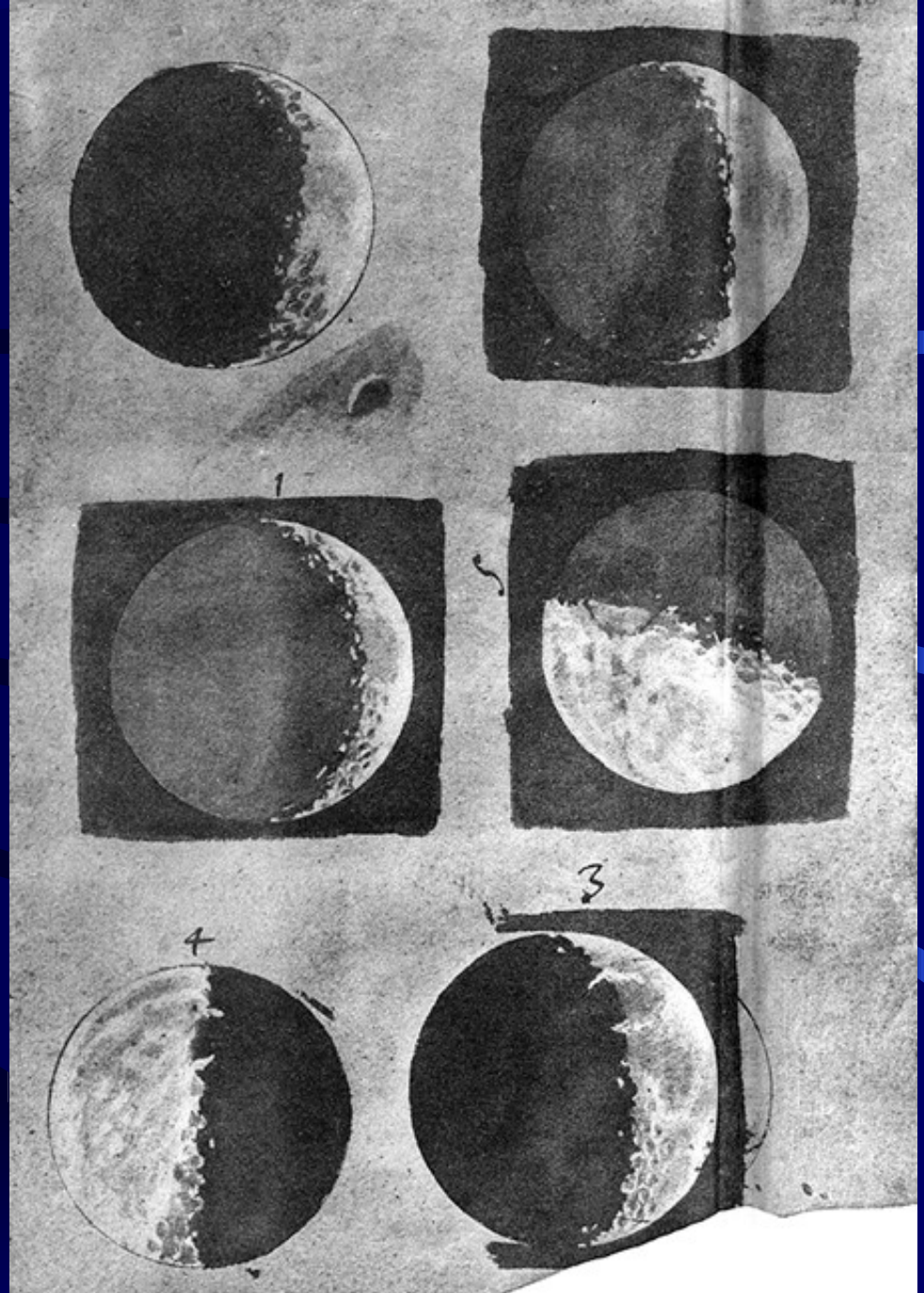


# Mountains on the Moon

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

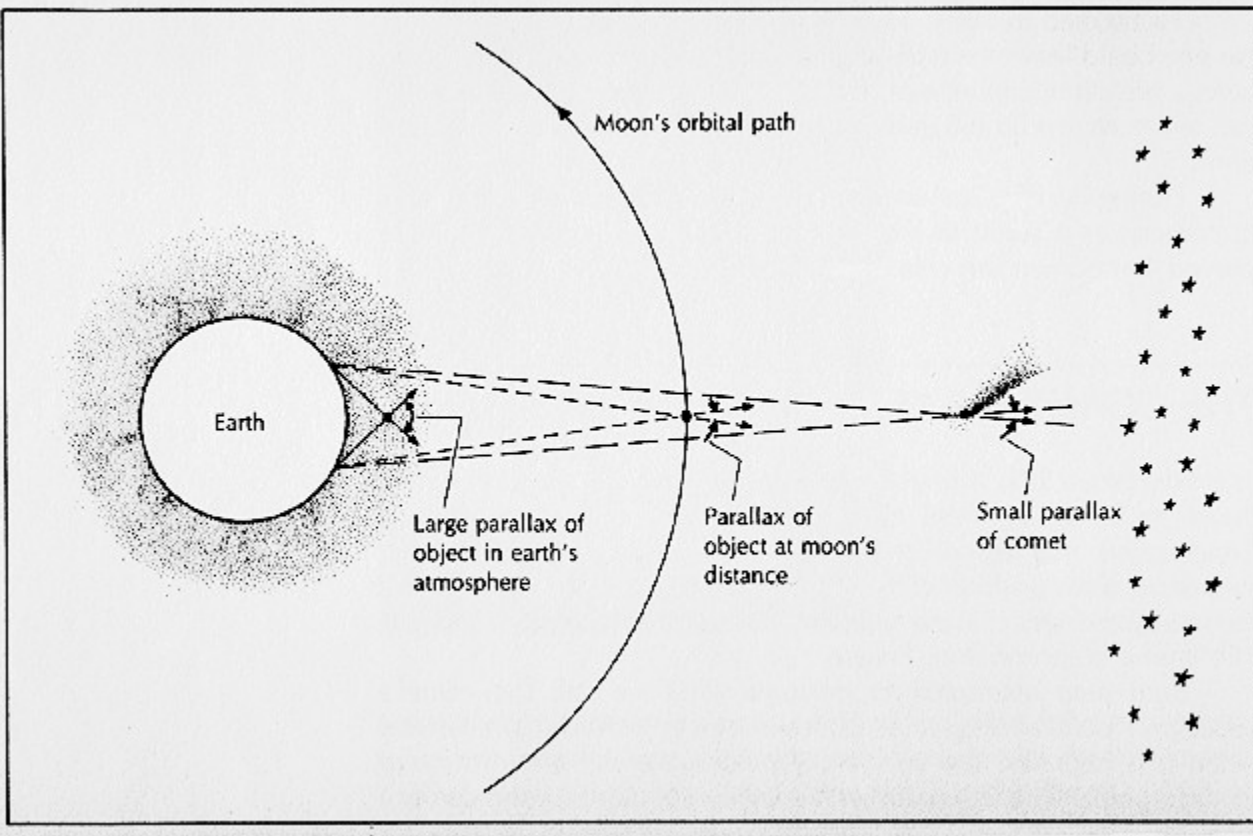


# Artsy eyepiece sketches



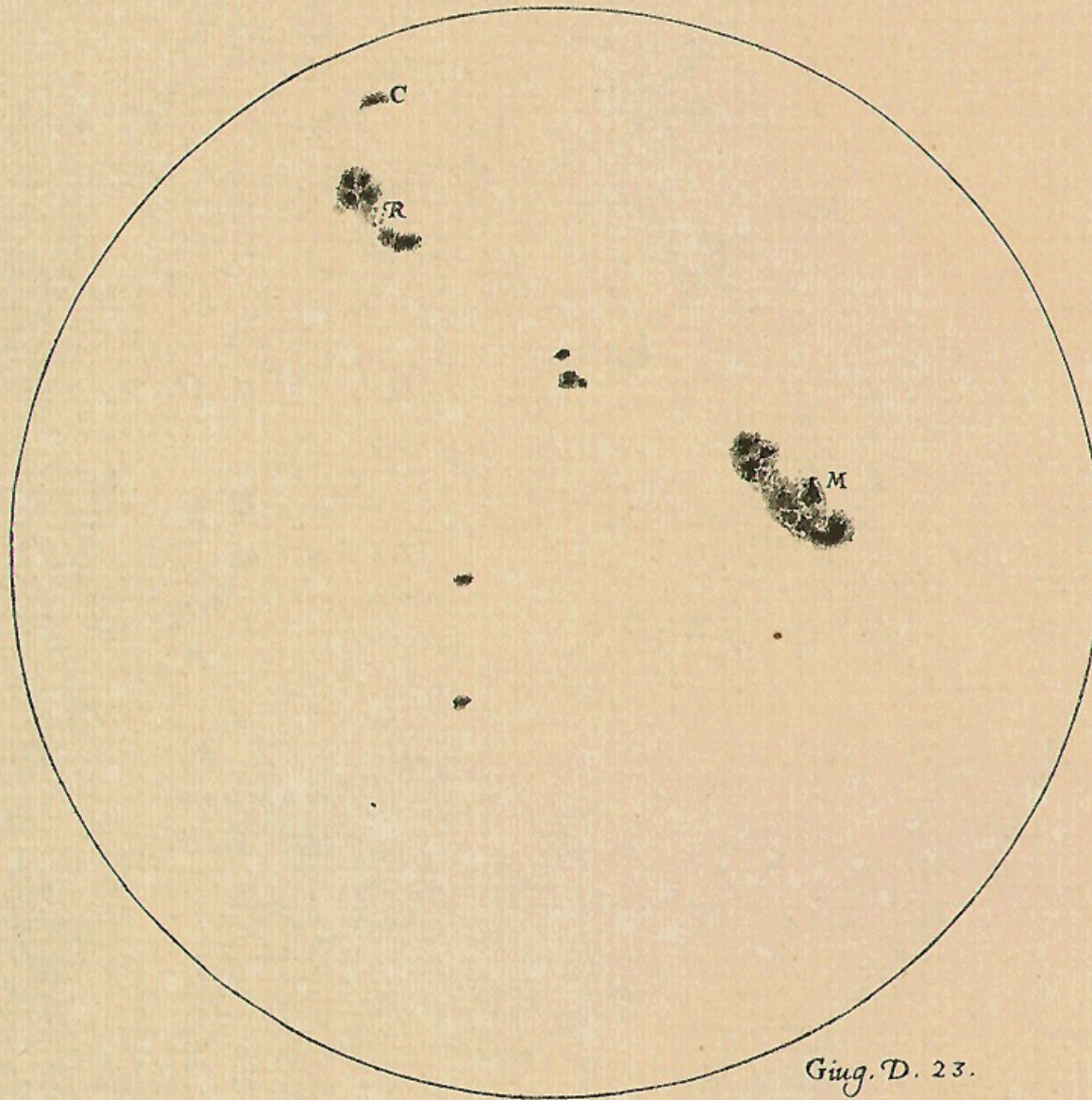


# Measuring distances with the Parallax



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

# Sunspots



*Giug. D. 23.*

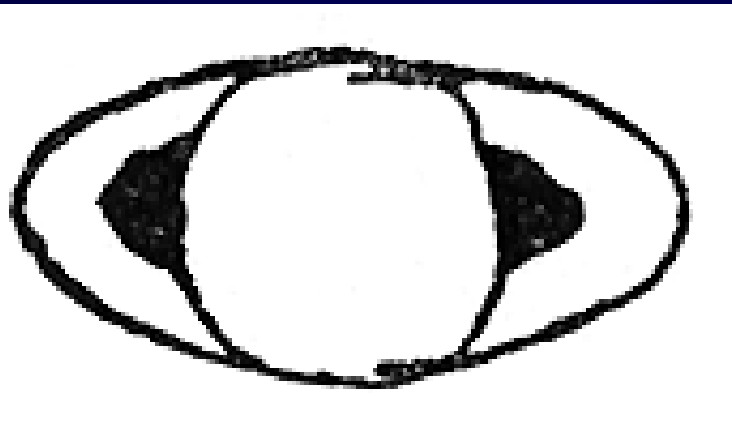
MPEG video from  
(June 2 – July 8,  
1613)

# 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

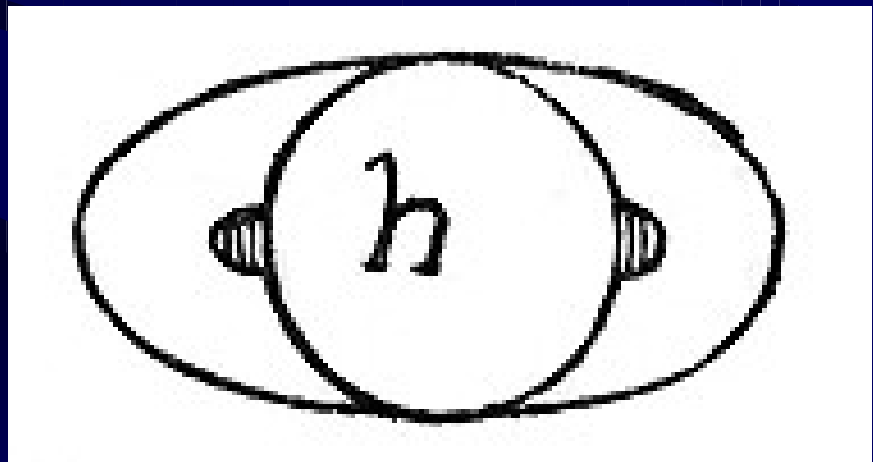
# Galileo's Genius – Applied to Sunspots

- 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  $R_E = 6.4 \times 10^3$  km, we find  $M_E = 6 \times 10^{24}$  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:  $M_S = r_{Orbit} v_{Orbit}^2 / G = 2 \times 10^{30} \text{ kg}$ 
  - 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)

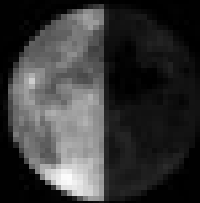
# The Night Sky in April

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

# Moon Phases



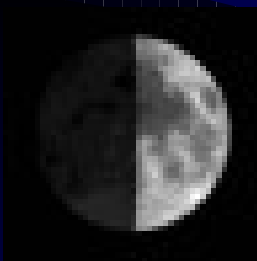
- **Today: Full Moon**



- 4 / 10 (Last quarter Moon)



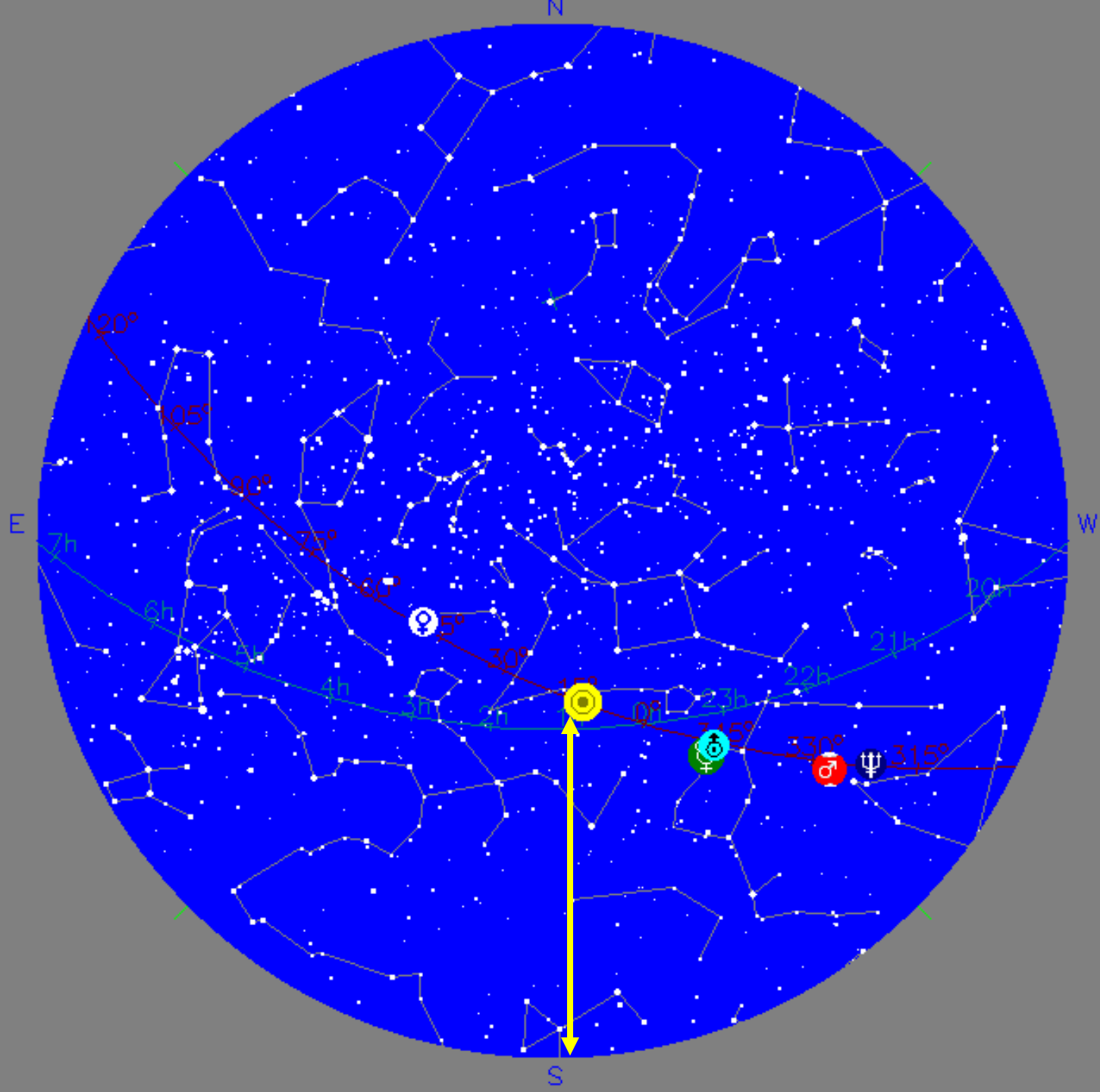
- 4 / 17 (New Moon)



- 4 / 24 (First Quarter Moon)

Today  
at  
Noon

Sun at  
meridian,  
i.e.  
exactly  
south

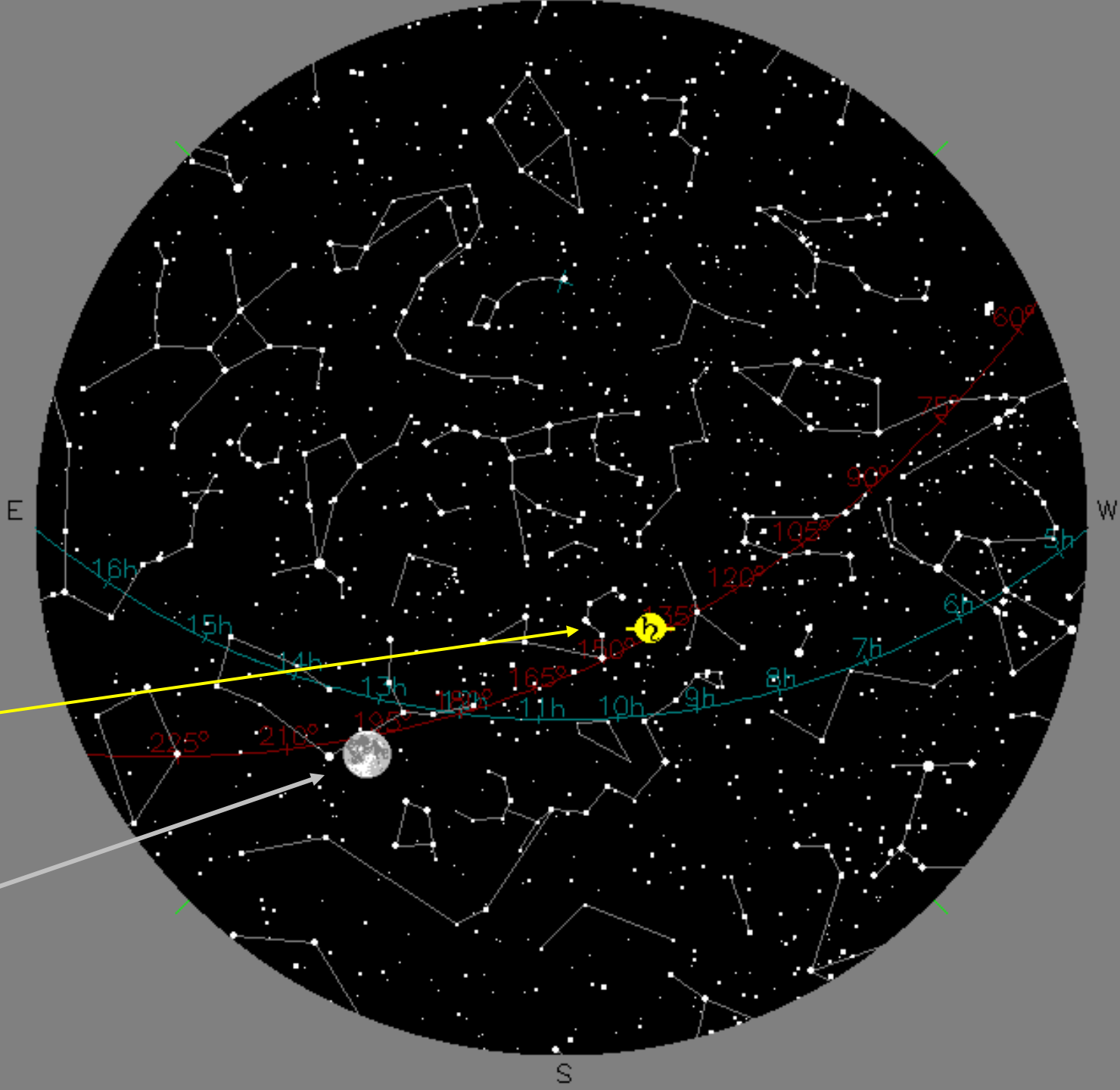


10 PM

Typical  
observing  
hour,  
early  
April

Saturn

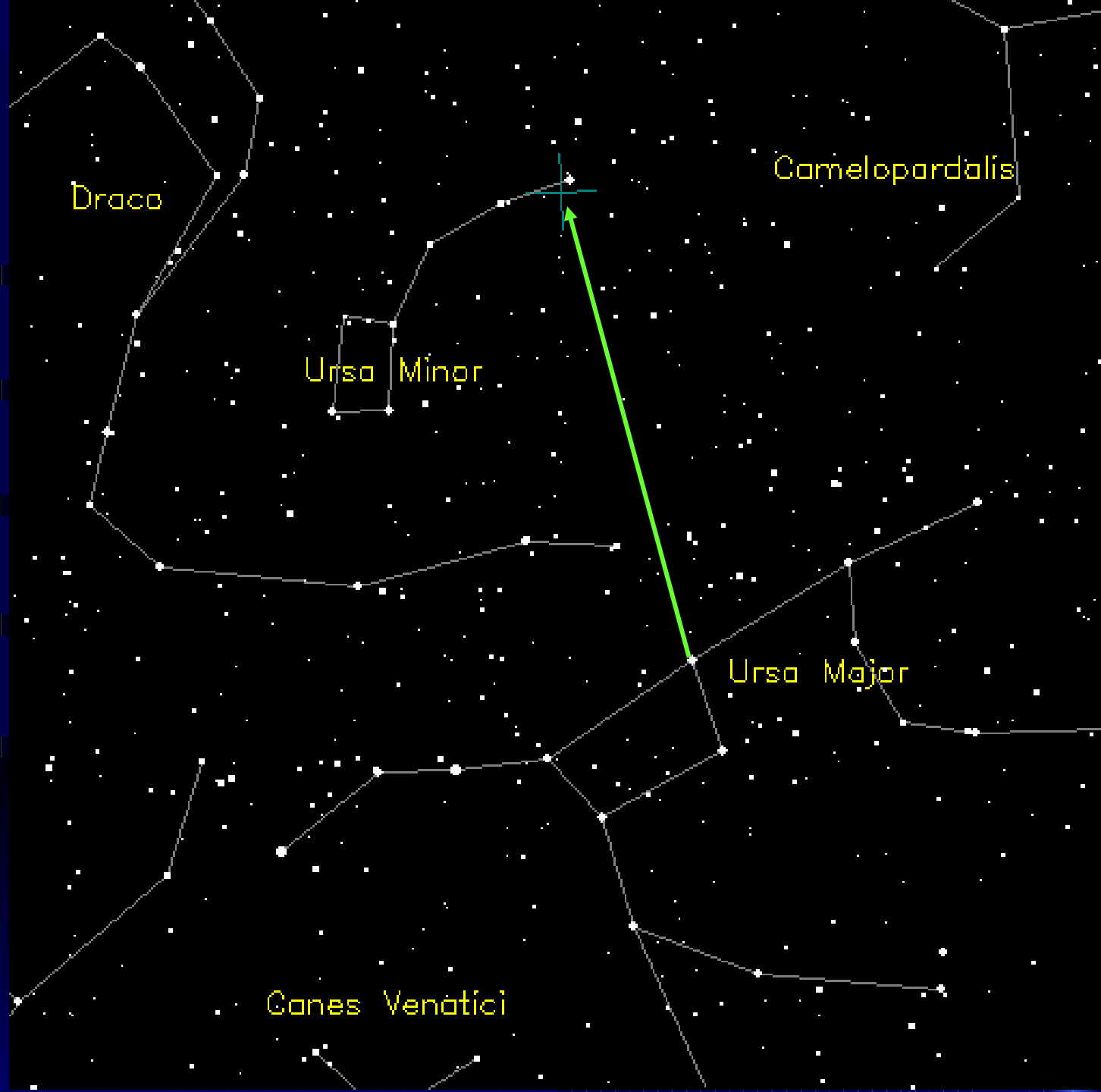
Moon





# Zenith

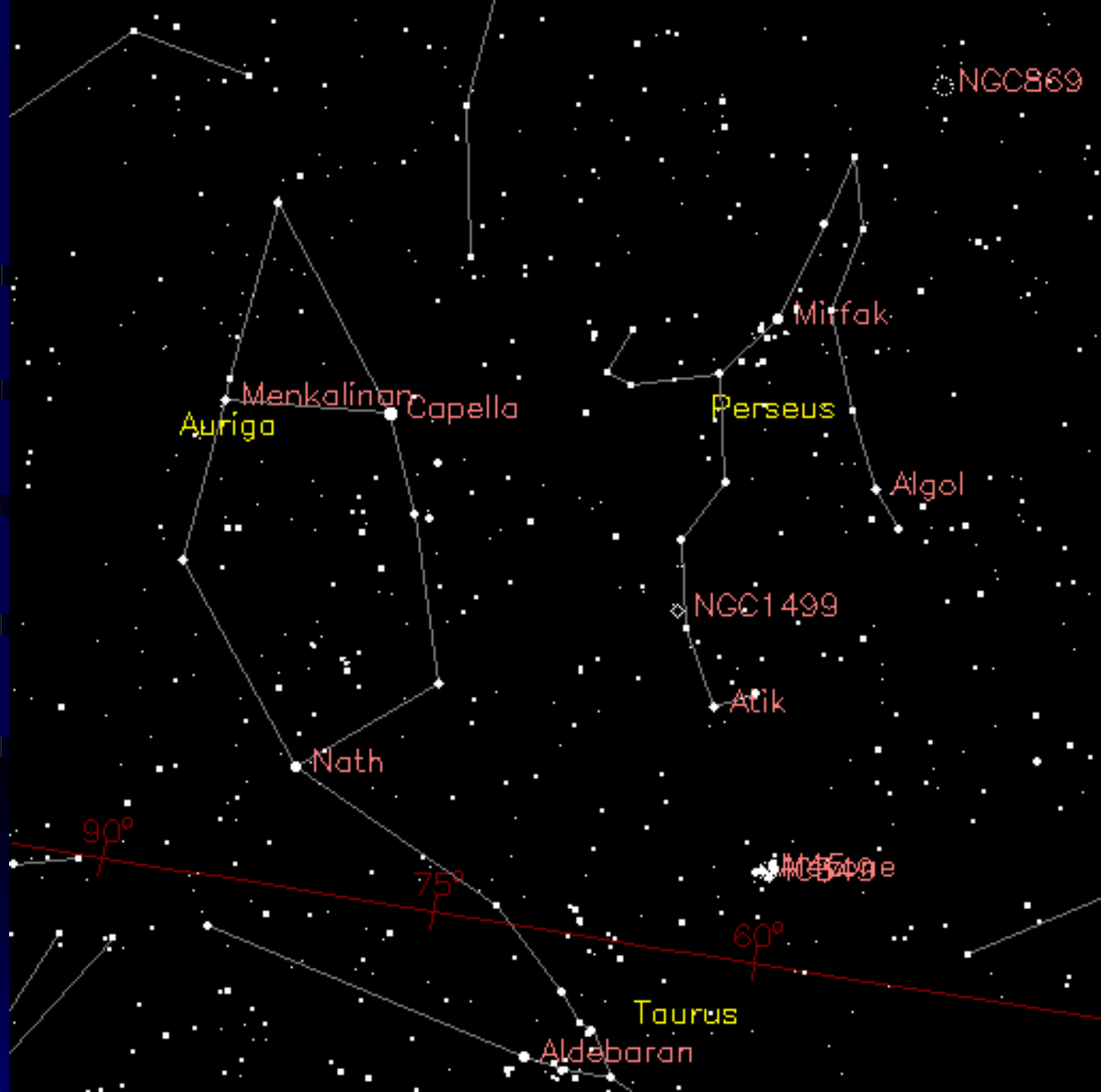
Big Dipper  
points to the  
north pole



West

# Perseus and Auriga

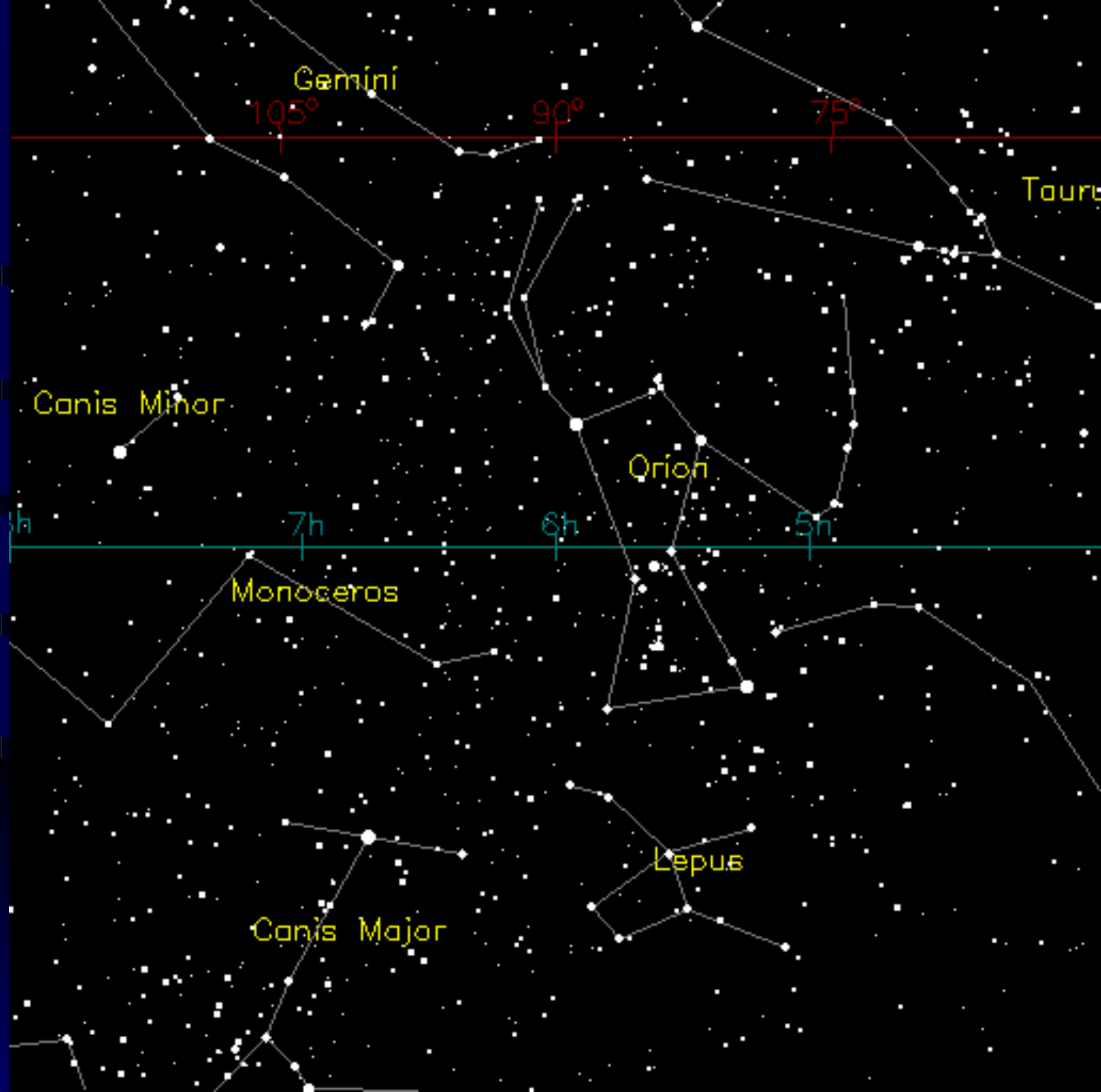
with Plejades  
and the  
Double  
Cluster



# West

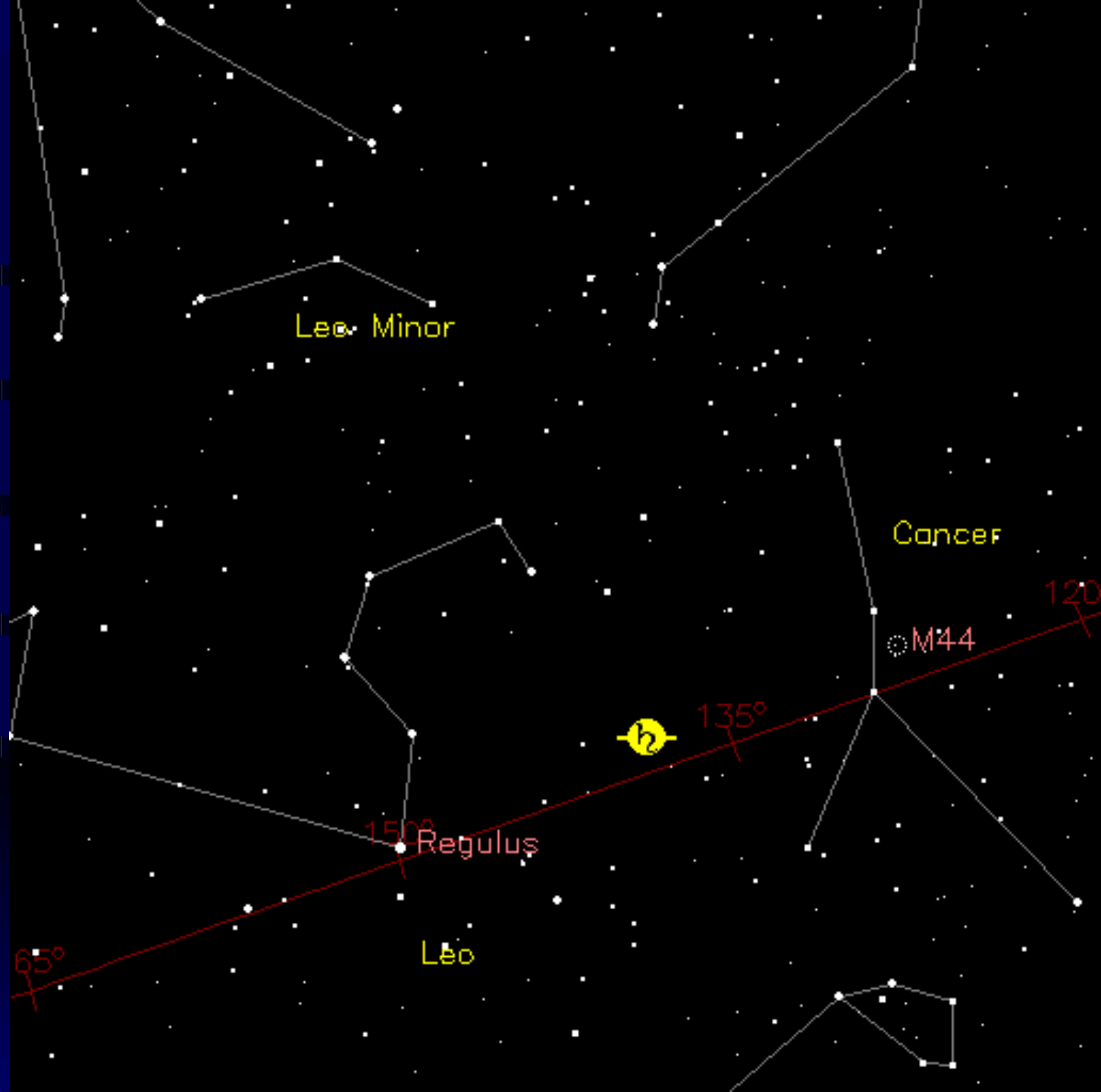
## The Winter Constellations

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



# South

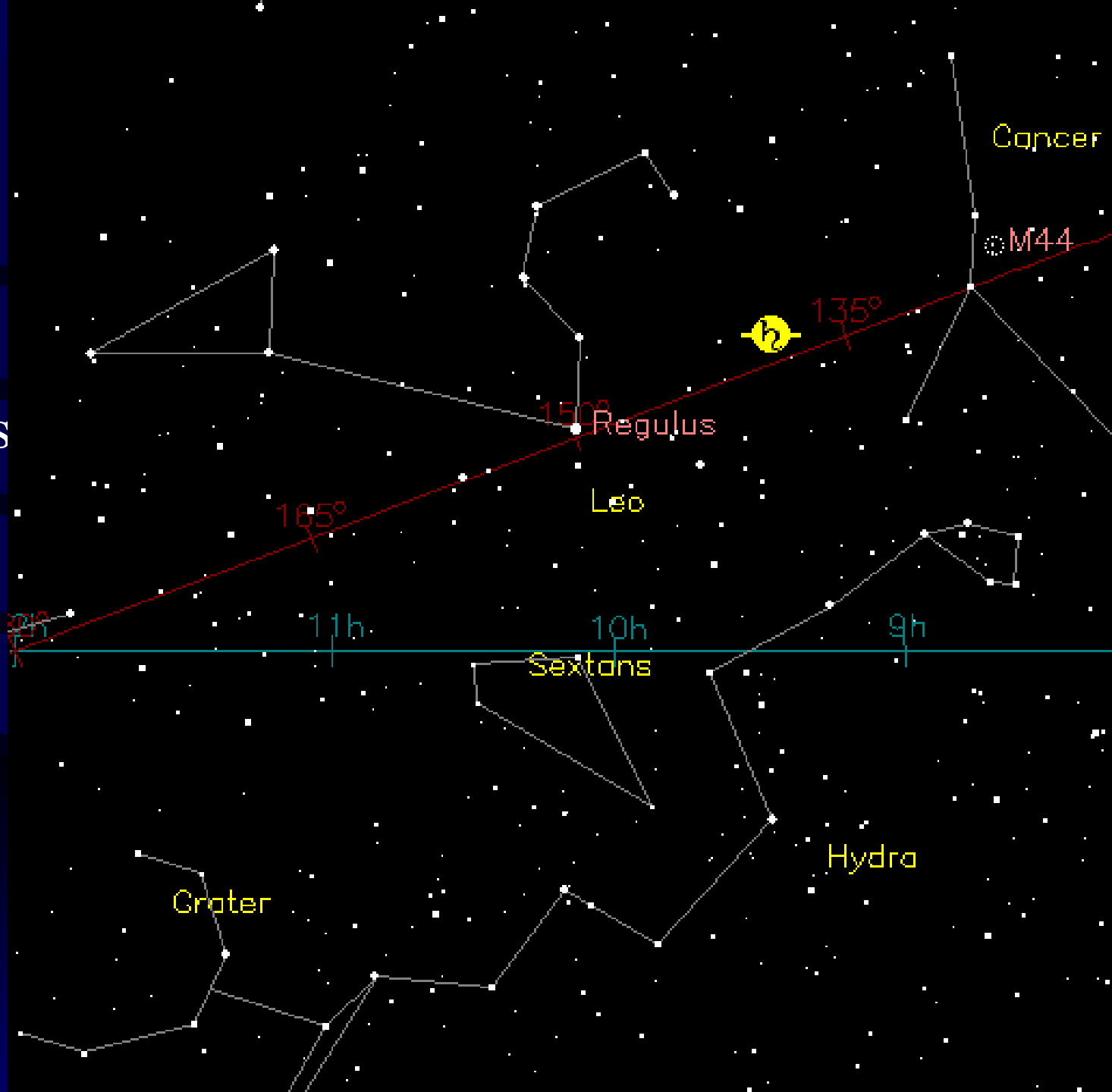
- Saturn  
near  
Praesepe  
(M44), an  
open star  
cluster



# South

## Spring constellations

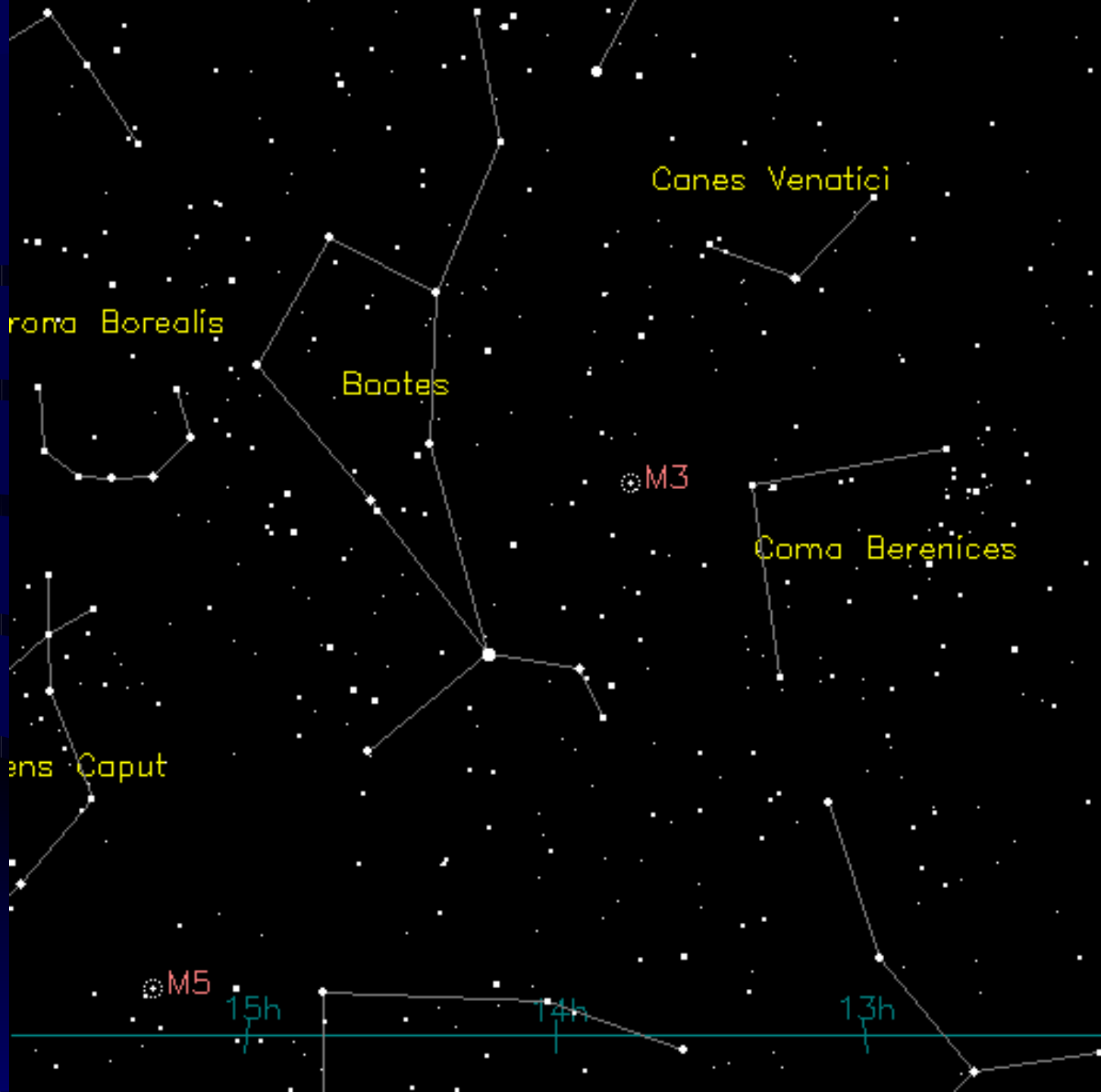
- Leo
- Hydra
- Crater
- Sextans





# East

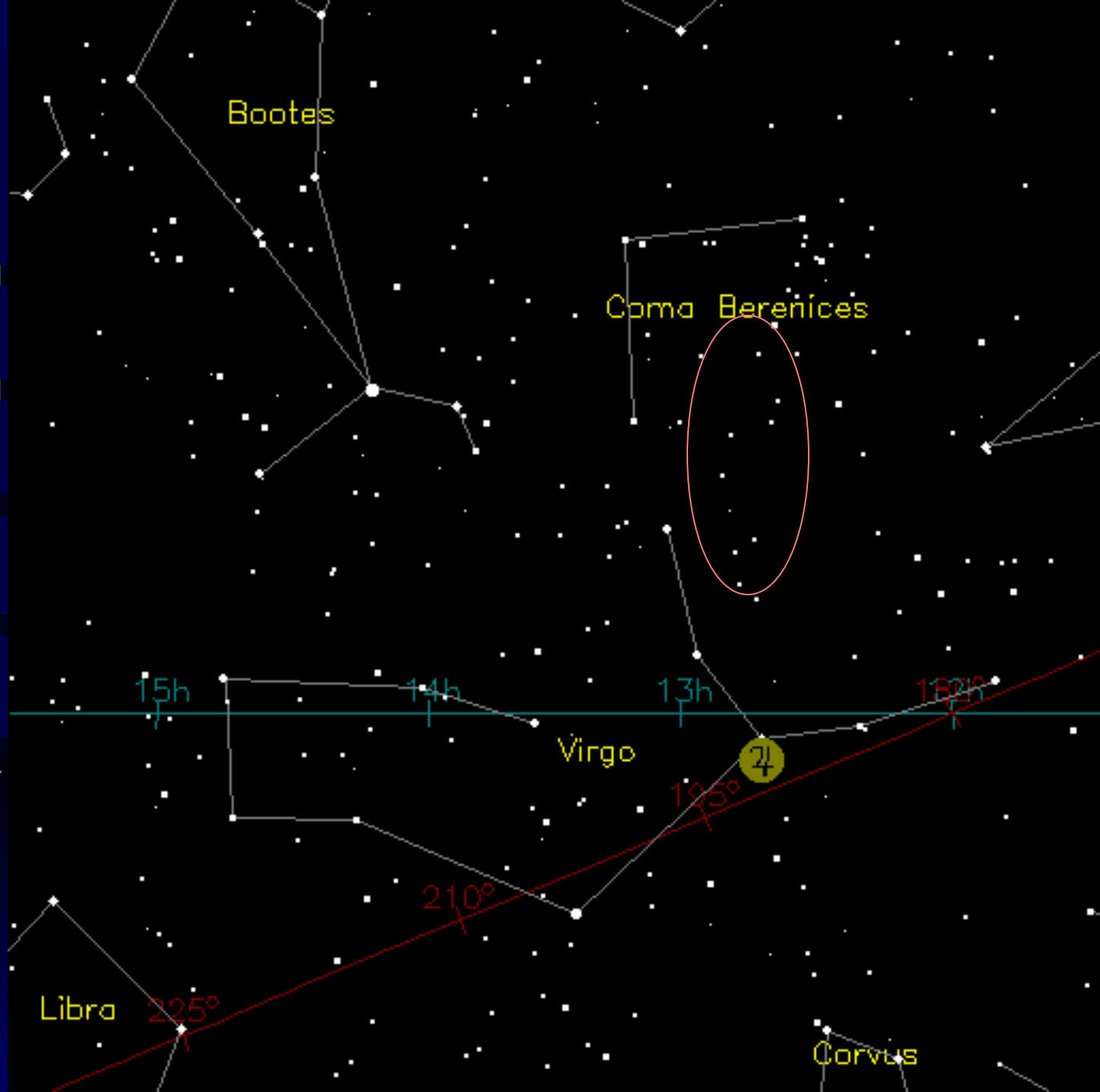
- Canes Venatici:
  - M51
- Coma-Virgo Cluster
- Globular Star Clusters
  - M3, M5



East

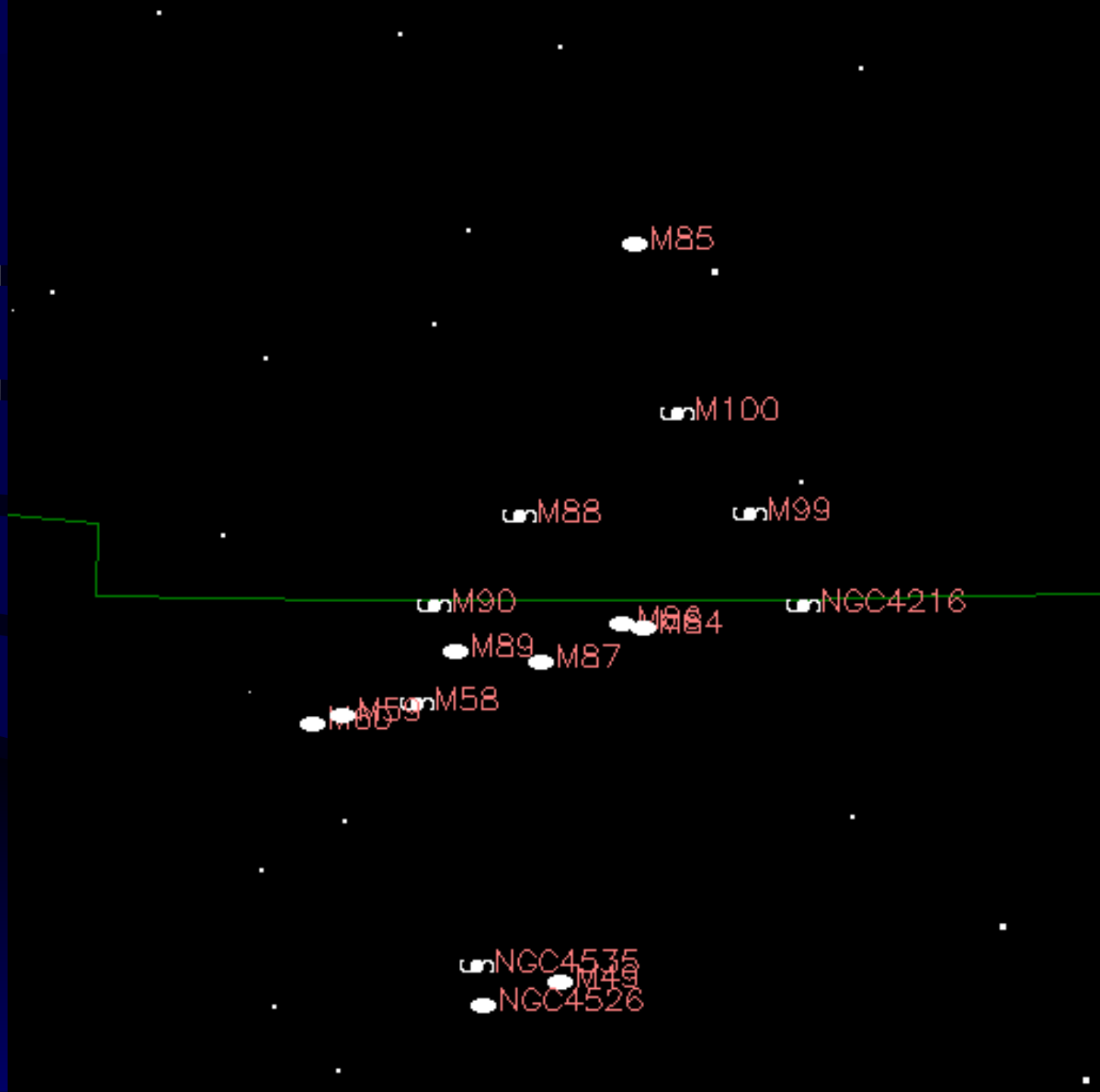
Virgo and  
Coma

with the  
Virgo-Coma  
galaxy  
cluster



# Virgo-Coma Cluster

- Lots of galaxies within a few degrees



# M87, M88 and M91



M87 © Anglo-Australian Observatory  
Photo by David Malin



# East

– Hercules

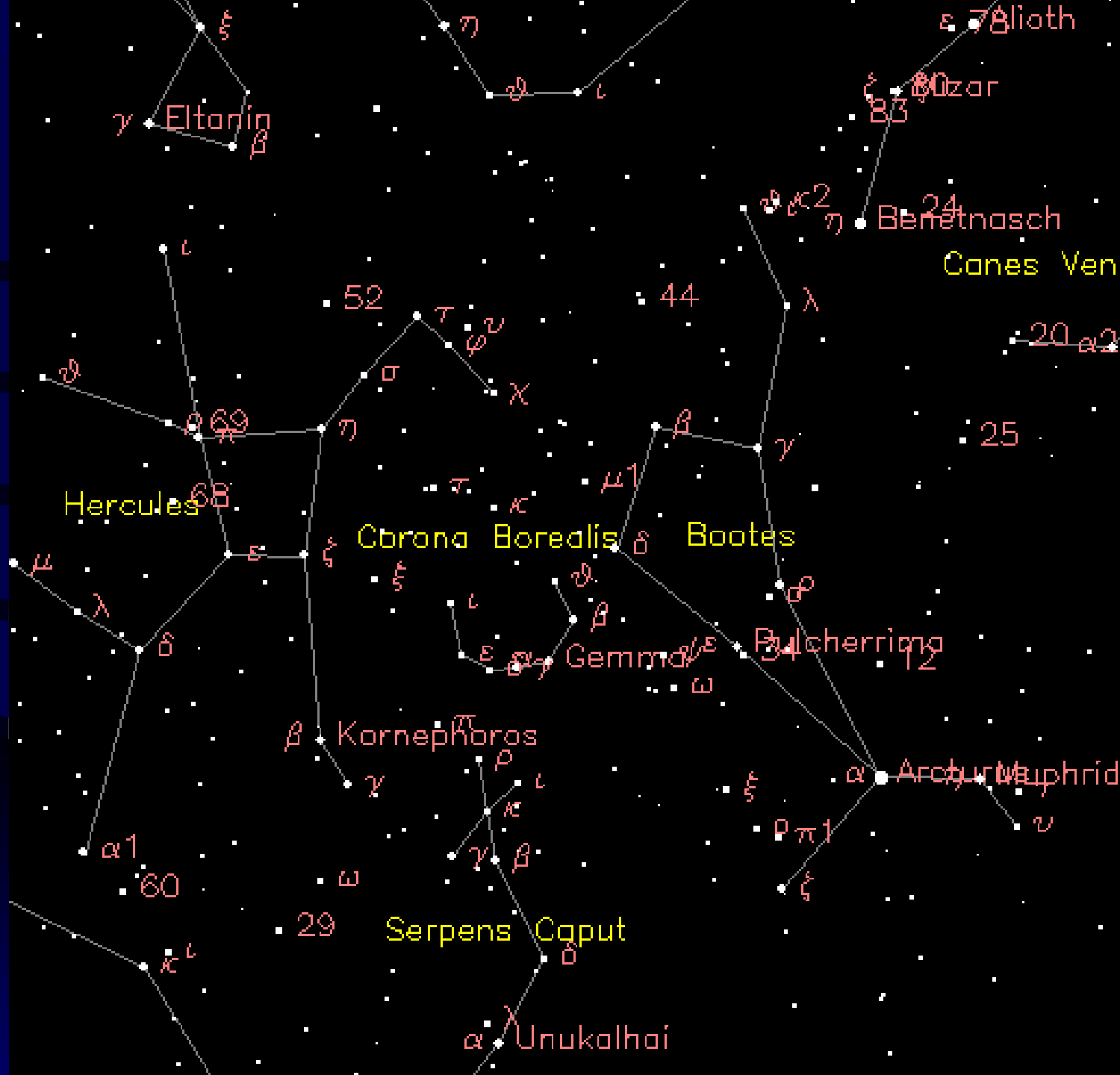
– Corona

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.