Ancient Astronomy

Lecture 4

Course website: www.scs.fsu.edu/~dduke/lectures

Lecture 4

- *Almagest* Books 7–8
- the stars
- precession
- the constellations
- rising and setting and the calendar
- the background

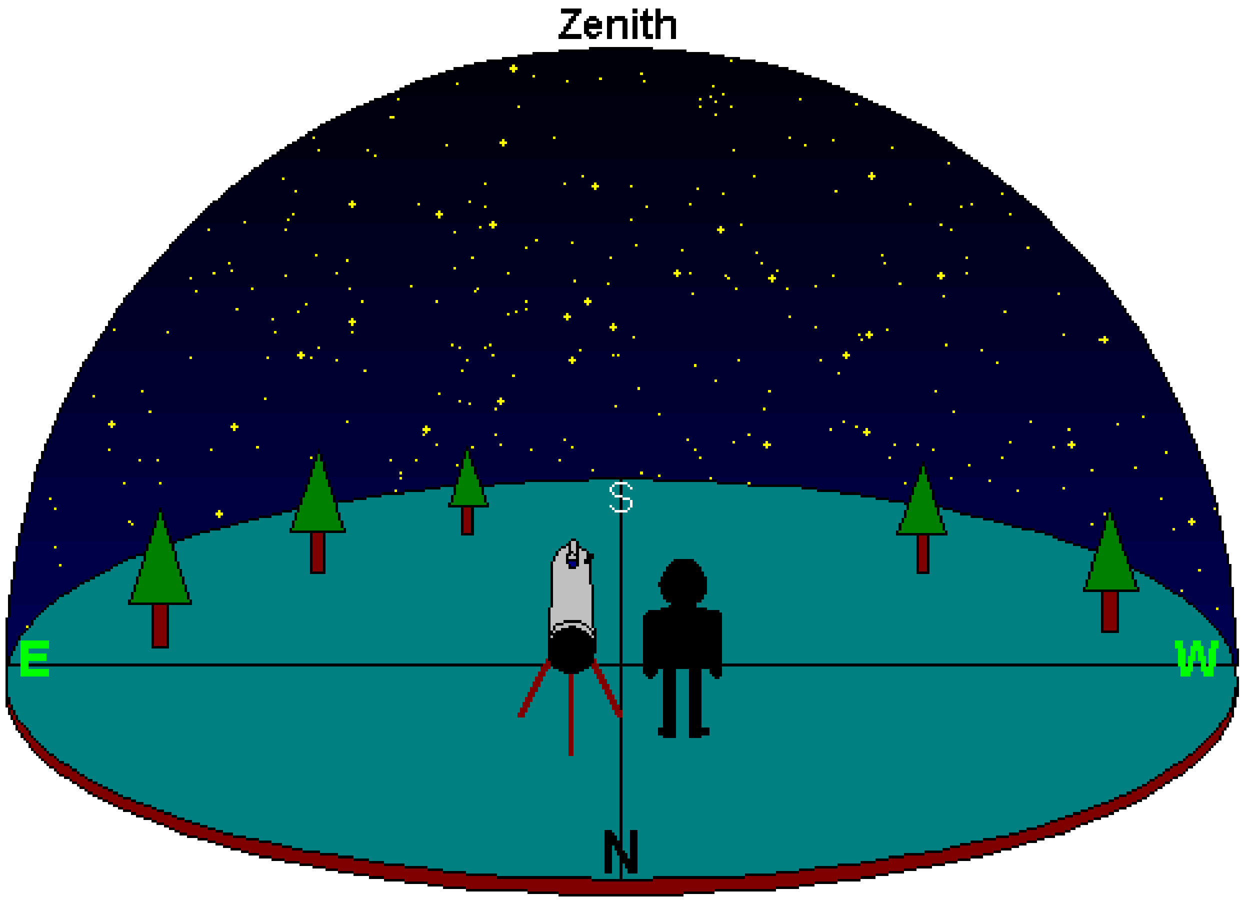
Ptolemy is now ready to discuss the stars. Recall that

- first, he measures the Sun w.r.t. the equinoxes and solstices
- then he measures the Moon w.r.t. the Sun
- now he will measure the stars w.r.t. the Moon
- next he will measure the planets w.r.t. the stars

But first he must deal with a small complication:

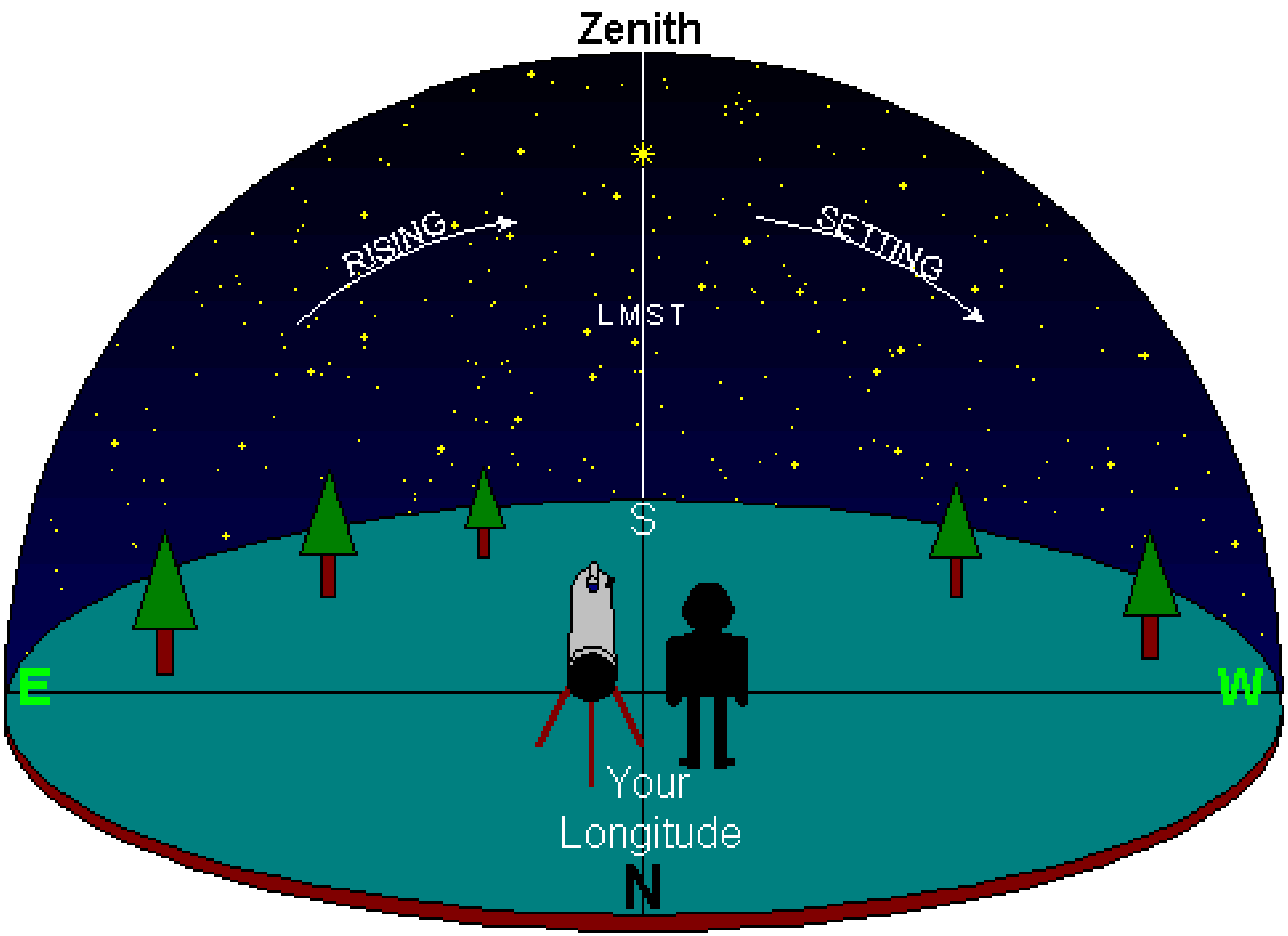
the stars move!

The goal is to measure the position of stars on the celestial sphere. Let’s see what is involved.



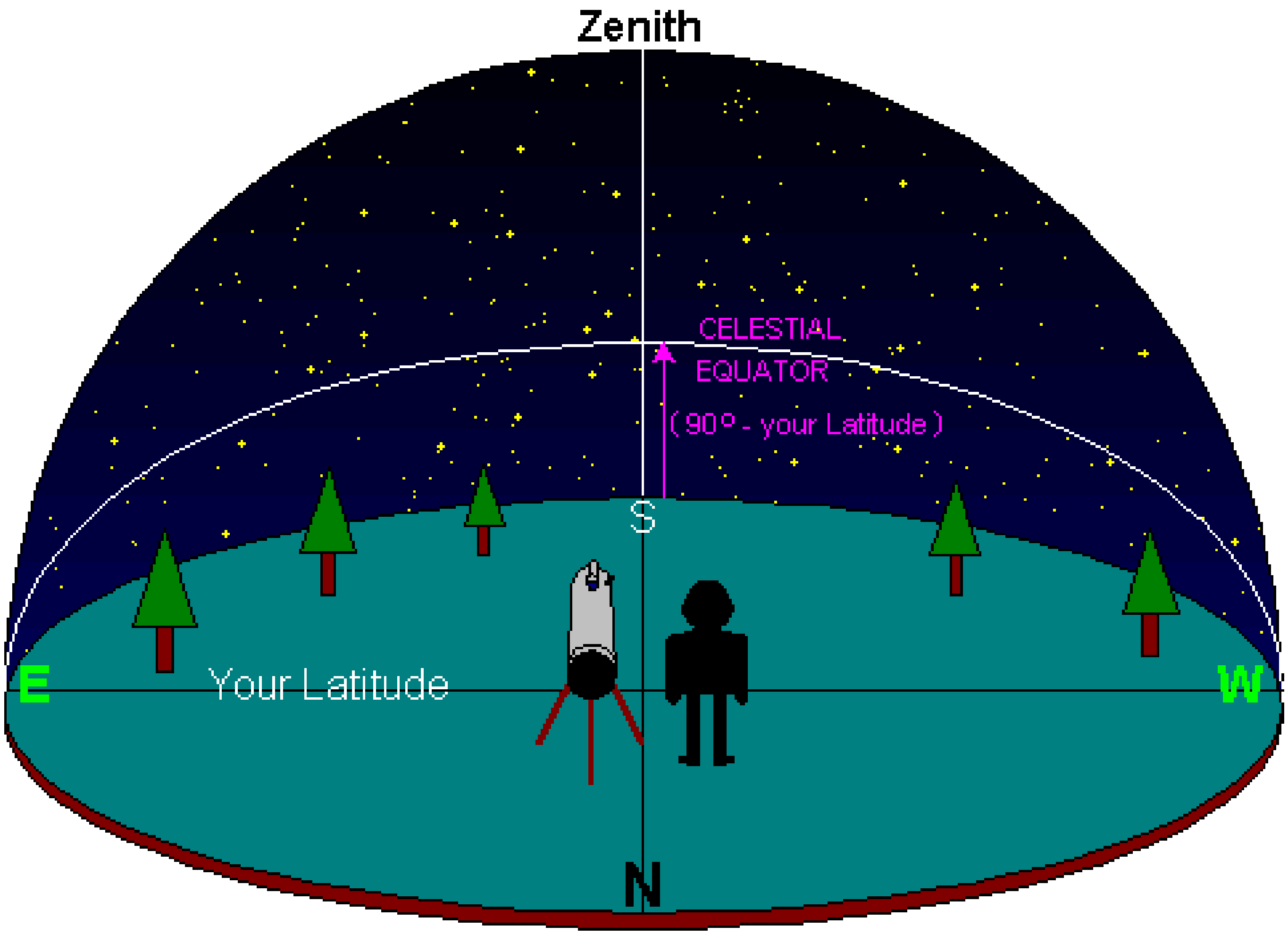
Pick Your Observing Location

Throughout each night the stars rise in the east and set in the west.

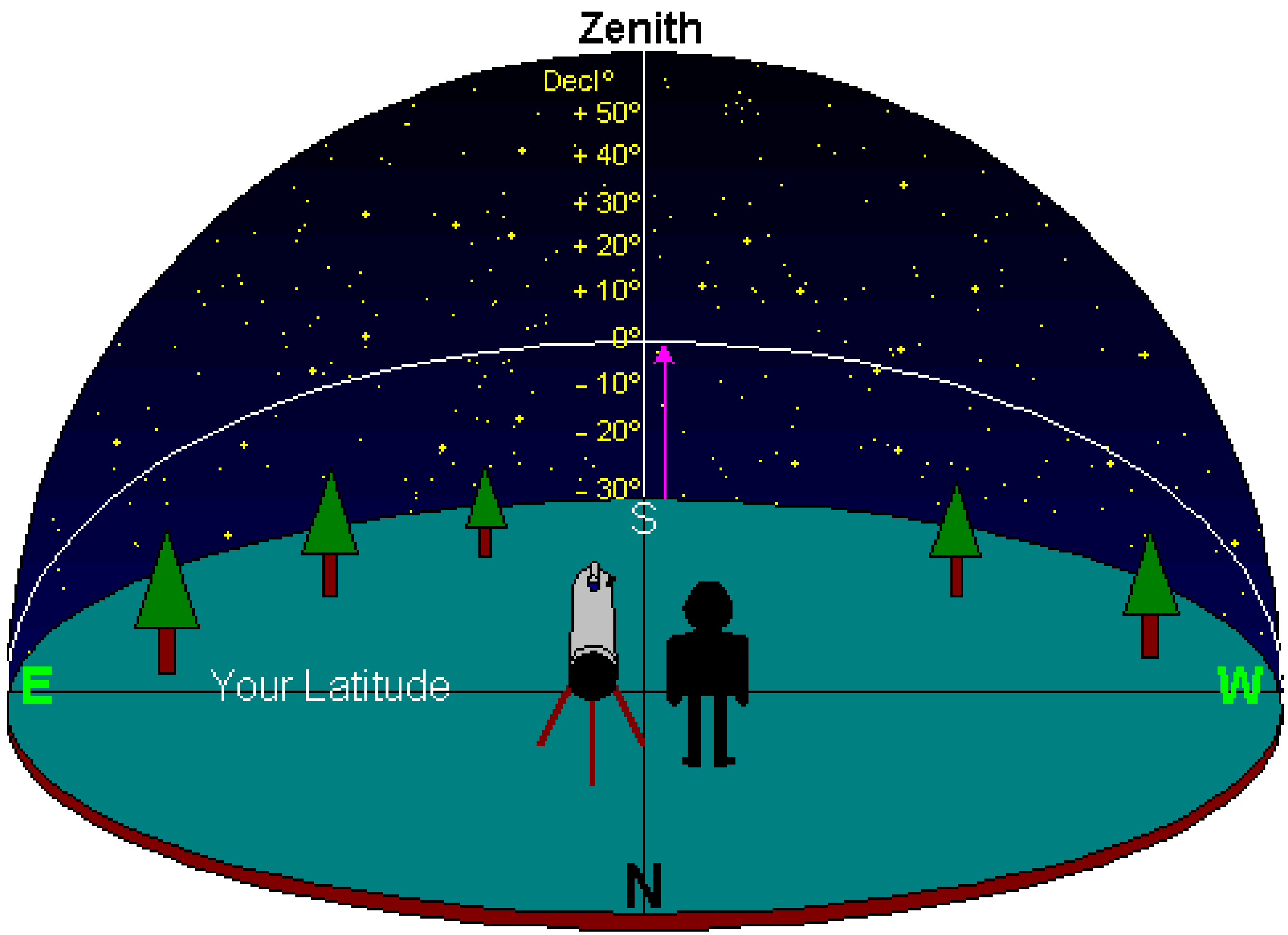


Your LMST - Local Mean Siderial Time - on your Meridian.

since the latitude of Alexandria is about 31° (similar to Tallahassee) the celestial equator is about 59° above the southern horizon.

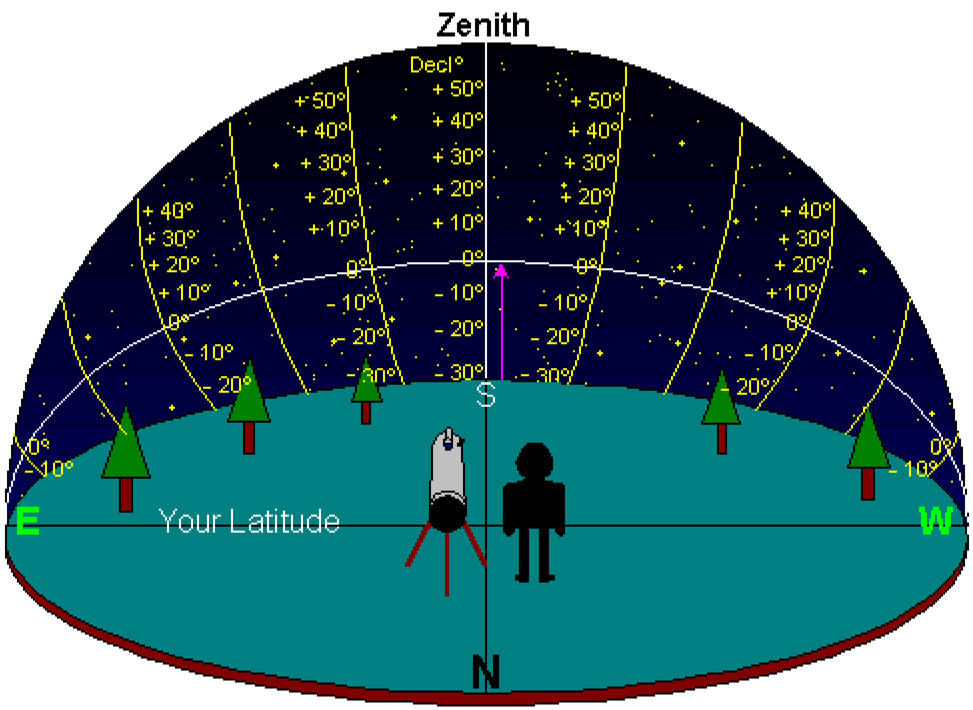


The Celestial Equator is up (90°- your Latitude) from the S horizon the *declination* coordinate is the distance of each star from the celestial equator. It is easiest to measure when the star crosses the southern meridian.

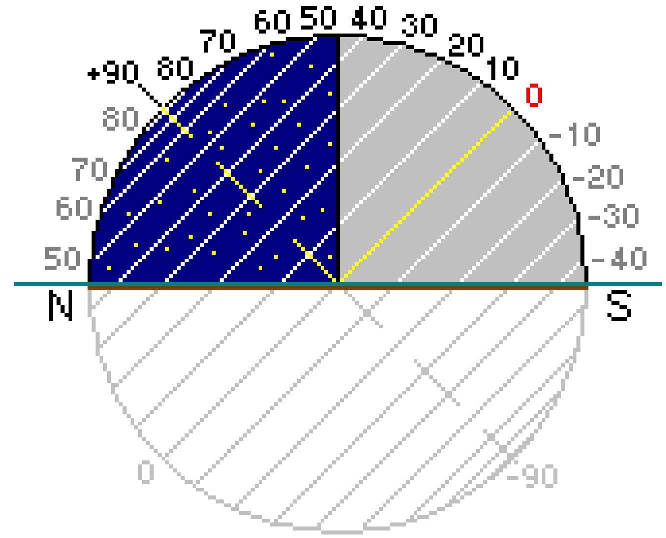


Declination is measured + (northerly) and - (southerly) from 0°

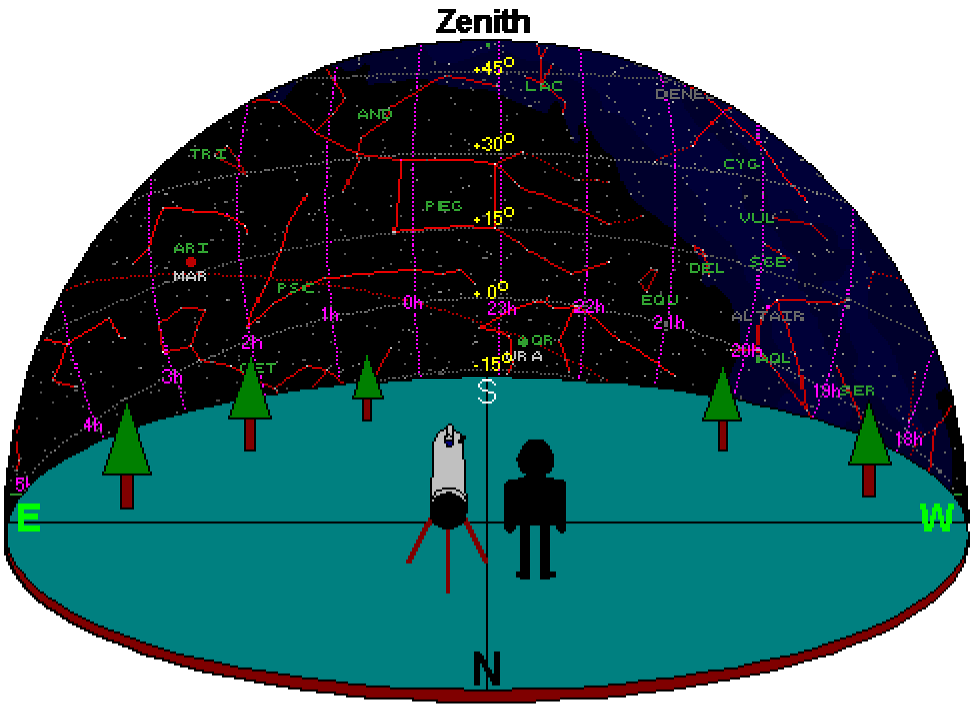
stars rotate along circles of constant declination parallel to the celestial equator



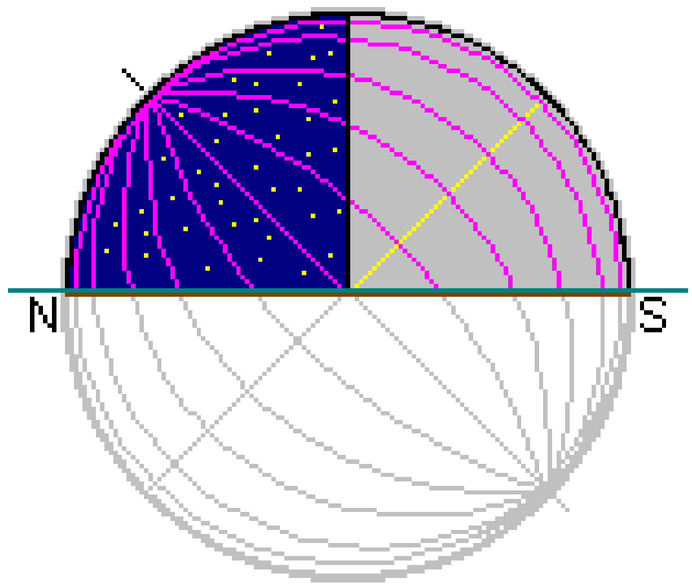
Declination is measured + and - from the Celestial Equator



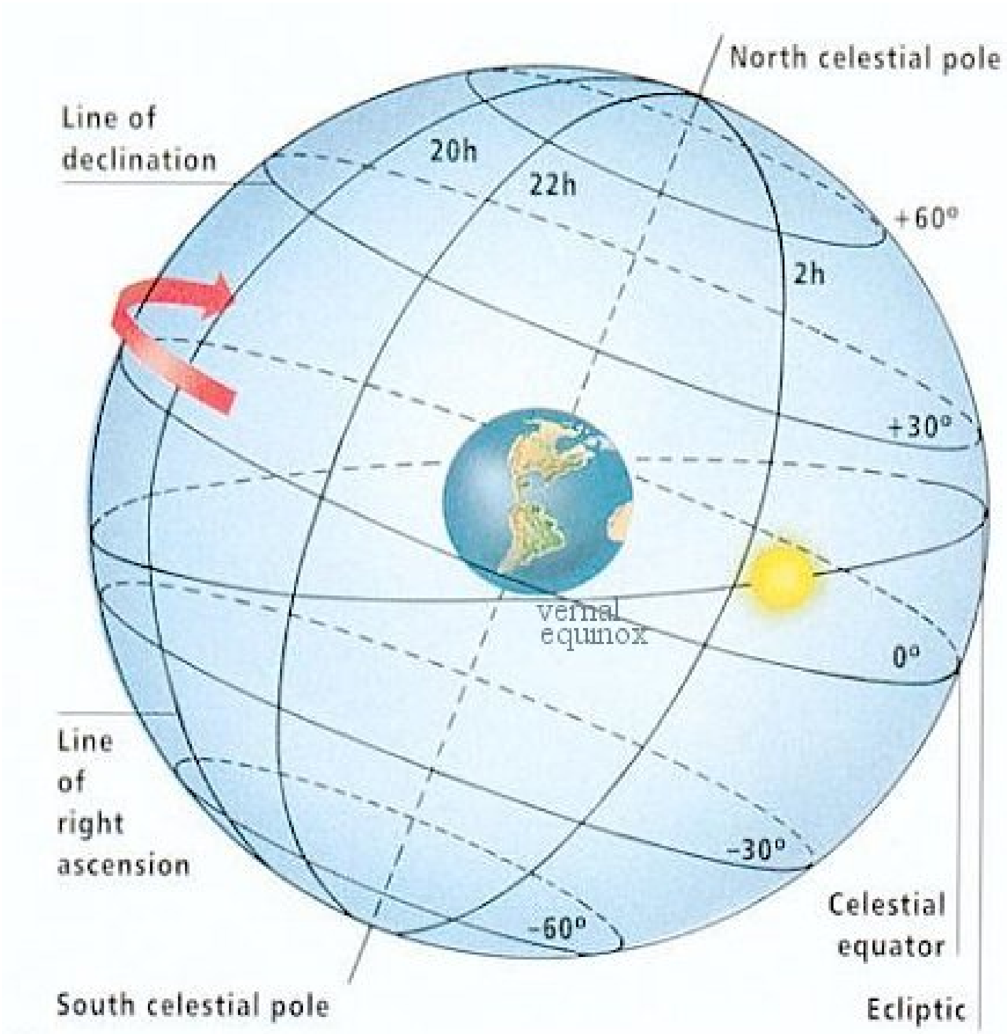
from north pole to south pole run parallel lines of constant *right ascension*, always perpendicular to the lines of declination.



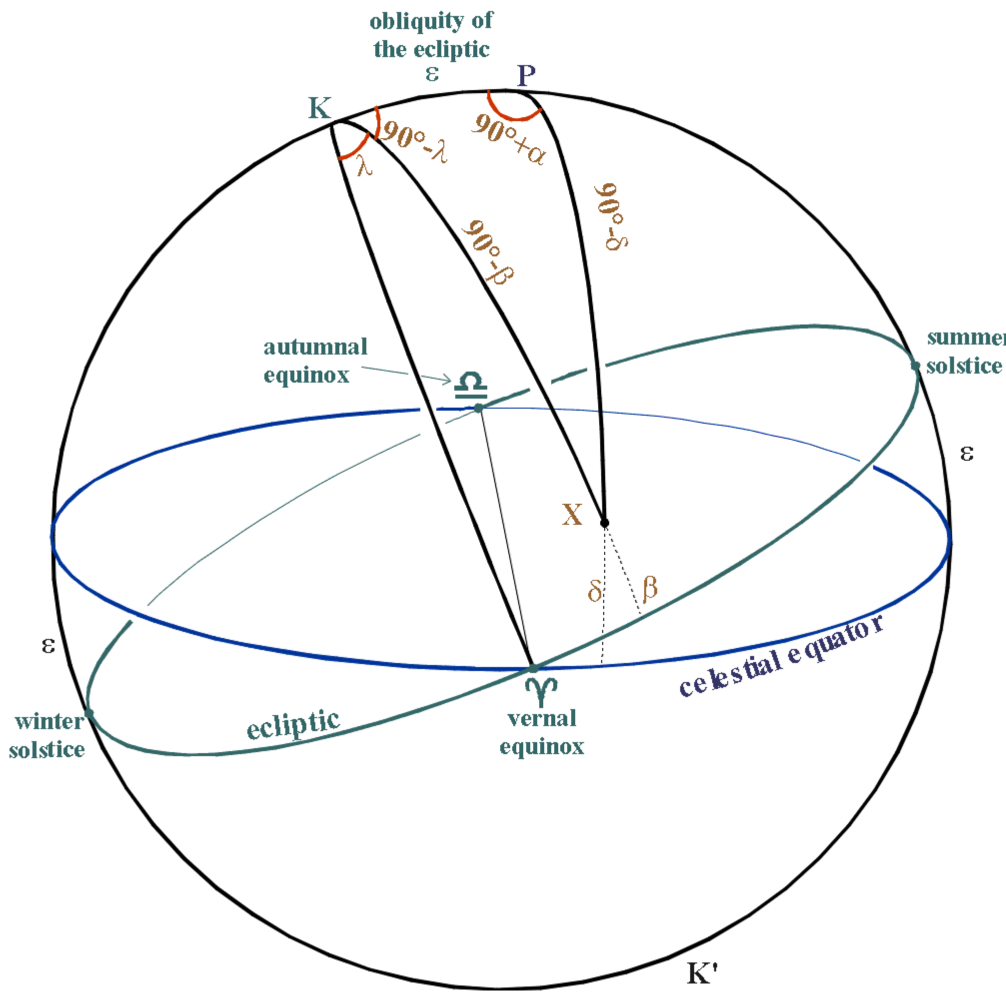
Lines of Right Ascension



so one convenient set of coordinates is (right ascension, declination).



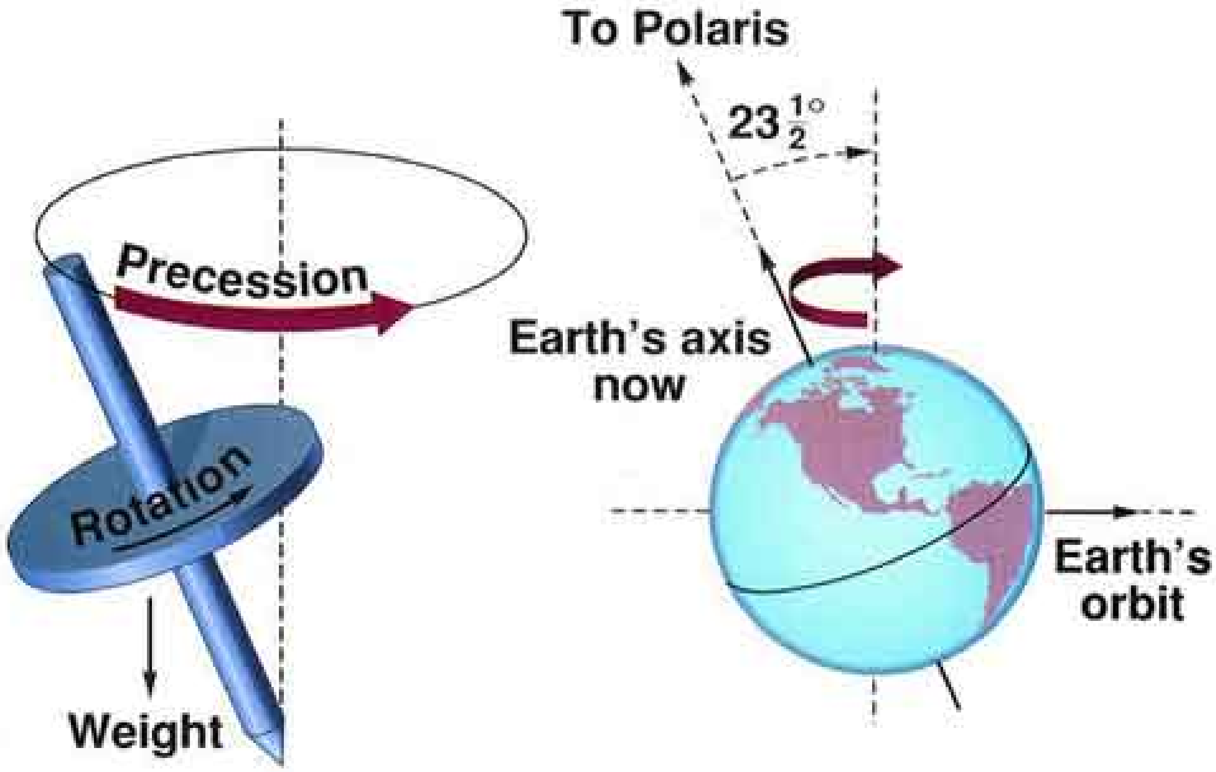
Another set is defined by the ecliptic, which is oblique to the equator:



This is the coordinate system used by Ptolemy

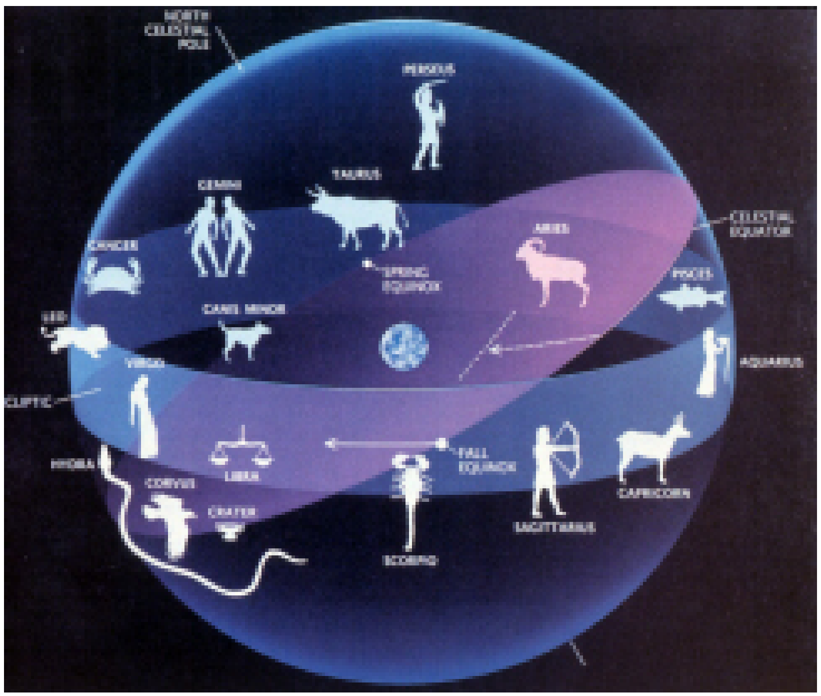
Ptolemy says he used an *armillary sphere* to measure the position of a star.

The problem is: these coordinate systems do not stay fixed w.r.t. each other.

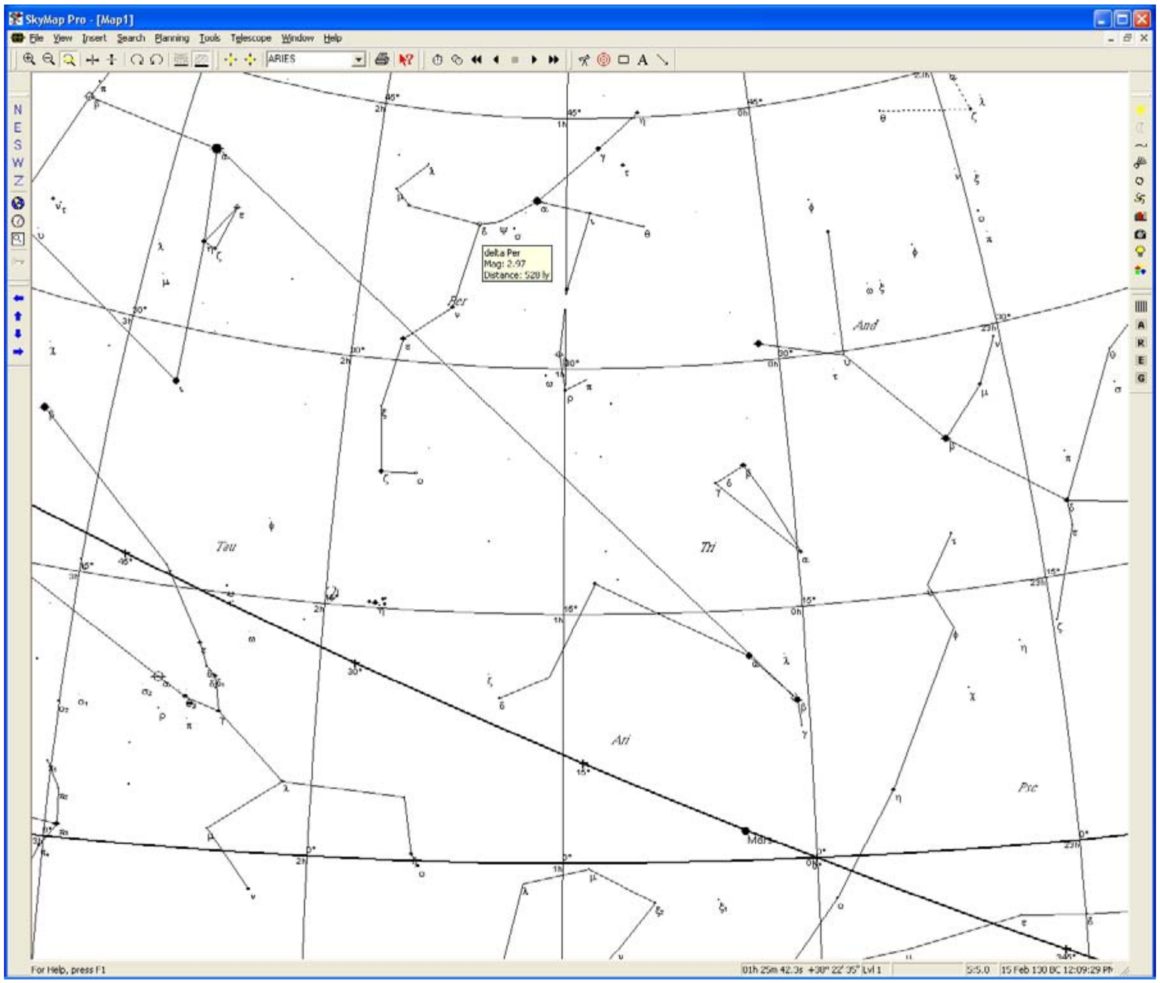


The real reason is that the Earth is like a spinning top, hence the name *precession*.

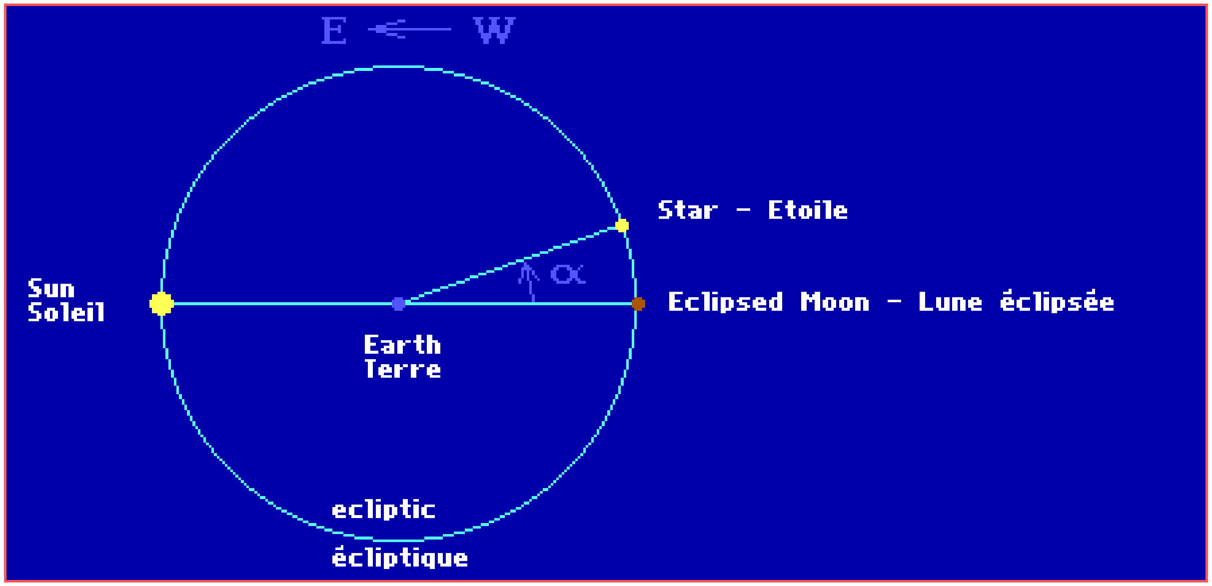
However, to the ancient observers precession shows up as the equinoxes and solstices, and the north celestial pole, moving with respect to the stars. But the speed is *very* slow: they estimated at least 1° per century (in fact, about 1° in 72 yrs).

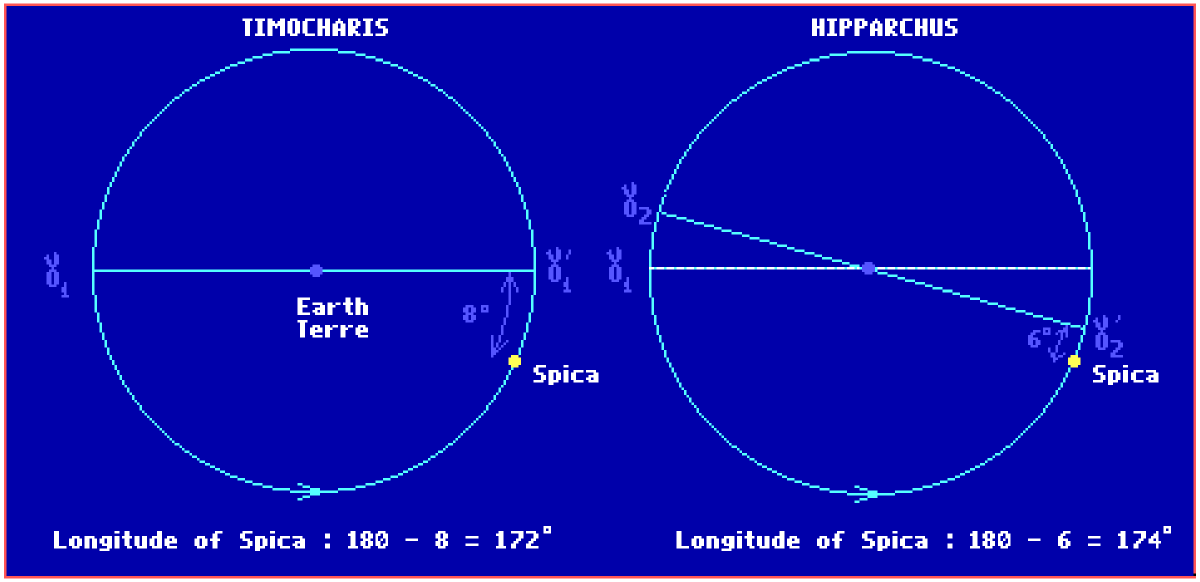


Ptolemy tells us that Hipparchus was quite careful about this, e.g. he wondered if just the stars near the ecliptic were involved, or all the stars? To test this he left a list of star alignments good in his time, and invited future observers to check them. Ptolemy did, and added some new ones:

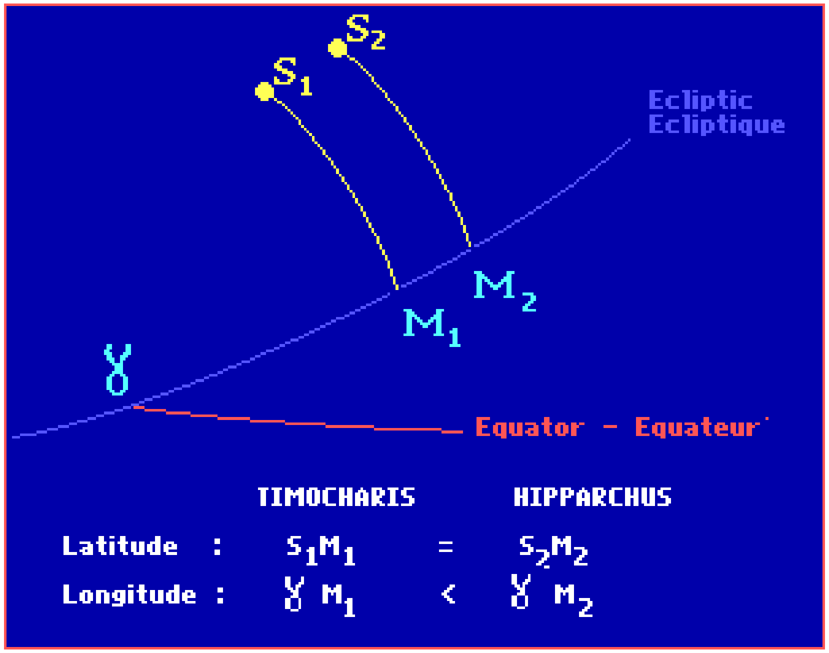


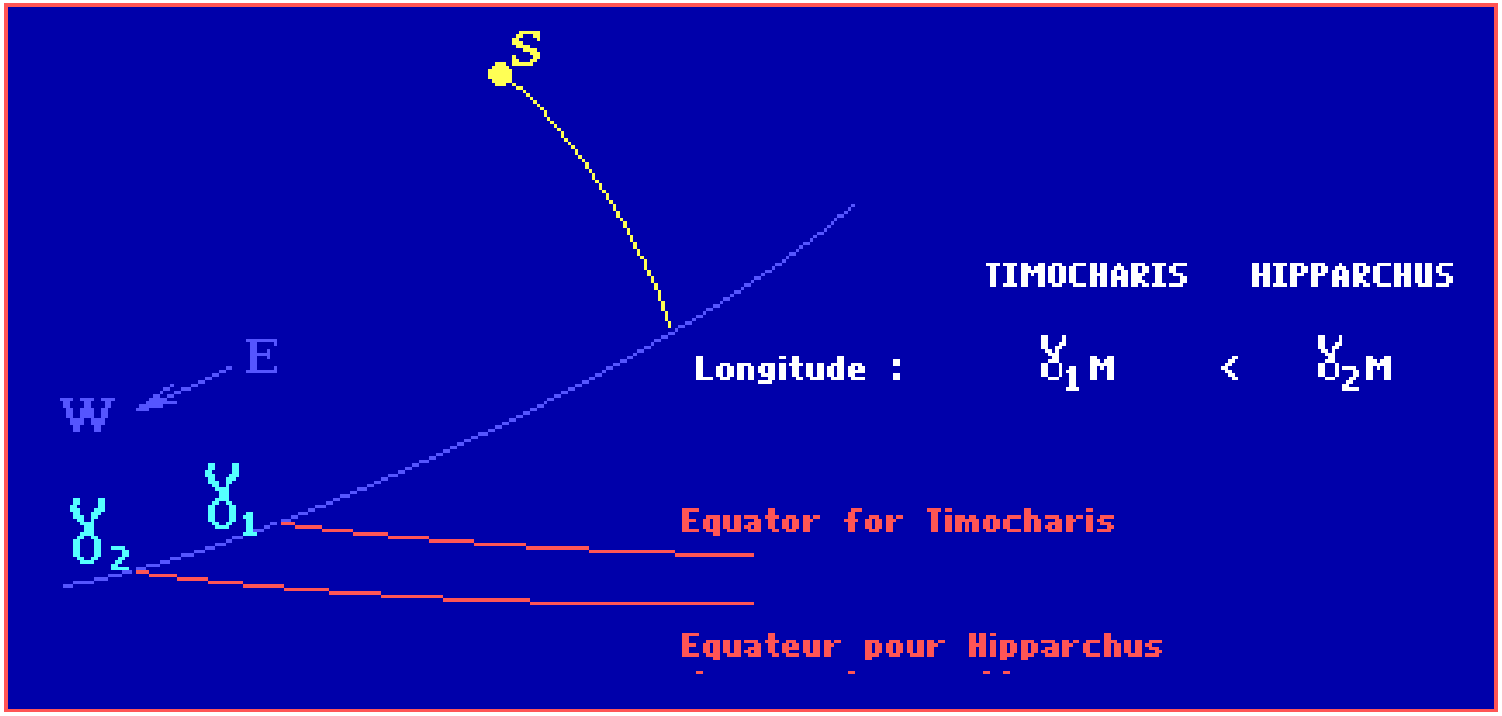
To determine the speed of precession several kinds of observations were used. First, eclipses when the Moon was near a star:





The changes in declination for stars near an equinox:

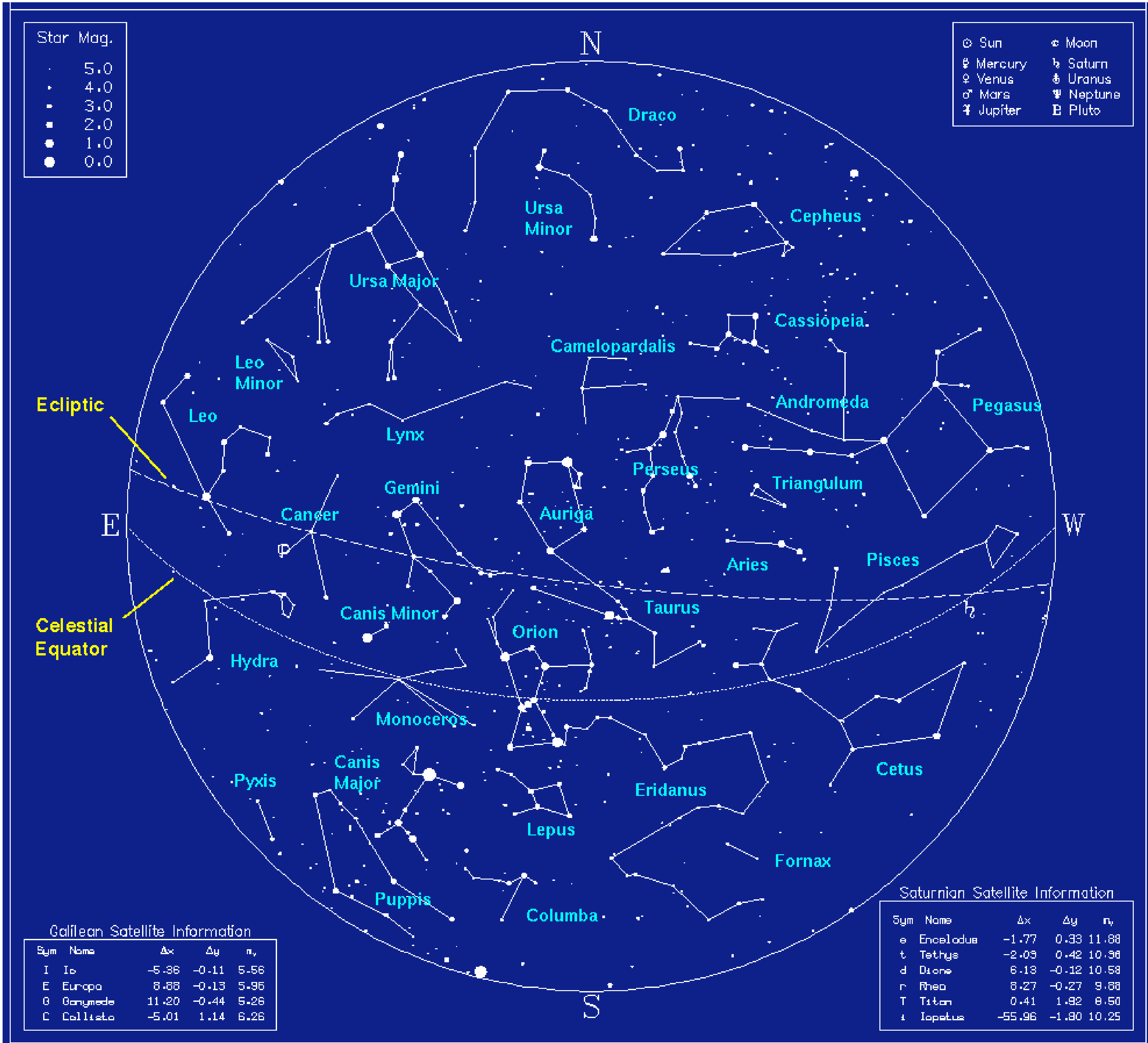




Lunar occultations of stars a few hundred years apart in time:

Ptolemy recognizes 48 constellations: 21 north of the zodiac, 12 in the zodiac, and 15 south of the zodiac. He gives the ecliptic longitude and latitude of 1,028 stars (including 3 duplicates shared by two constellations).

	Ursa Minor (Little Dipper)		**longitude**			**latitude**		**mag**	
	Description		**d**	**m**		**d**	**m**	**V**	**name**
1	The star on the end of the tai.	UMi 1 1	60	10	+	66	0	3	1Alp UMi
2	The one next to it on the tail	UMi 1 2	62	30	+	70	0	4	23Del UMi
3	The one next to that, before the place where the tail joins [the body]	UMi 1 3	70	10	+	74	20	4	22Eps UMi
4	The southernmost of the stars in the advance side of the rectangle	UMi 1 4	89	40	+	75	40	4	16Zet UMi
5	The northernmost of [those in] the same side	UMi 1 5	93	40	+	77	40	4	21Eta UMi
6	The southern star in the rear.side	UMi 1 6	107	30	+	72	50	2	7Bet UMi
7	The northern one in the same side	UMi 1 7	116	10	+	74	50	2	13Gam UMi
8	The star lying on a straight line with the stars in the rear side [of the rectangle] and south of them	UMi 1 8 i	103	0	+	71	10	4	5 UMi



Galilean Satellite Information

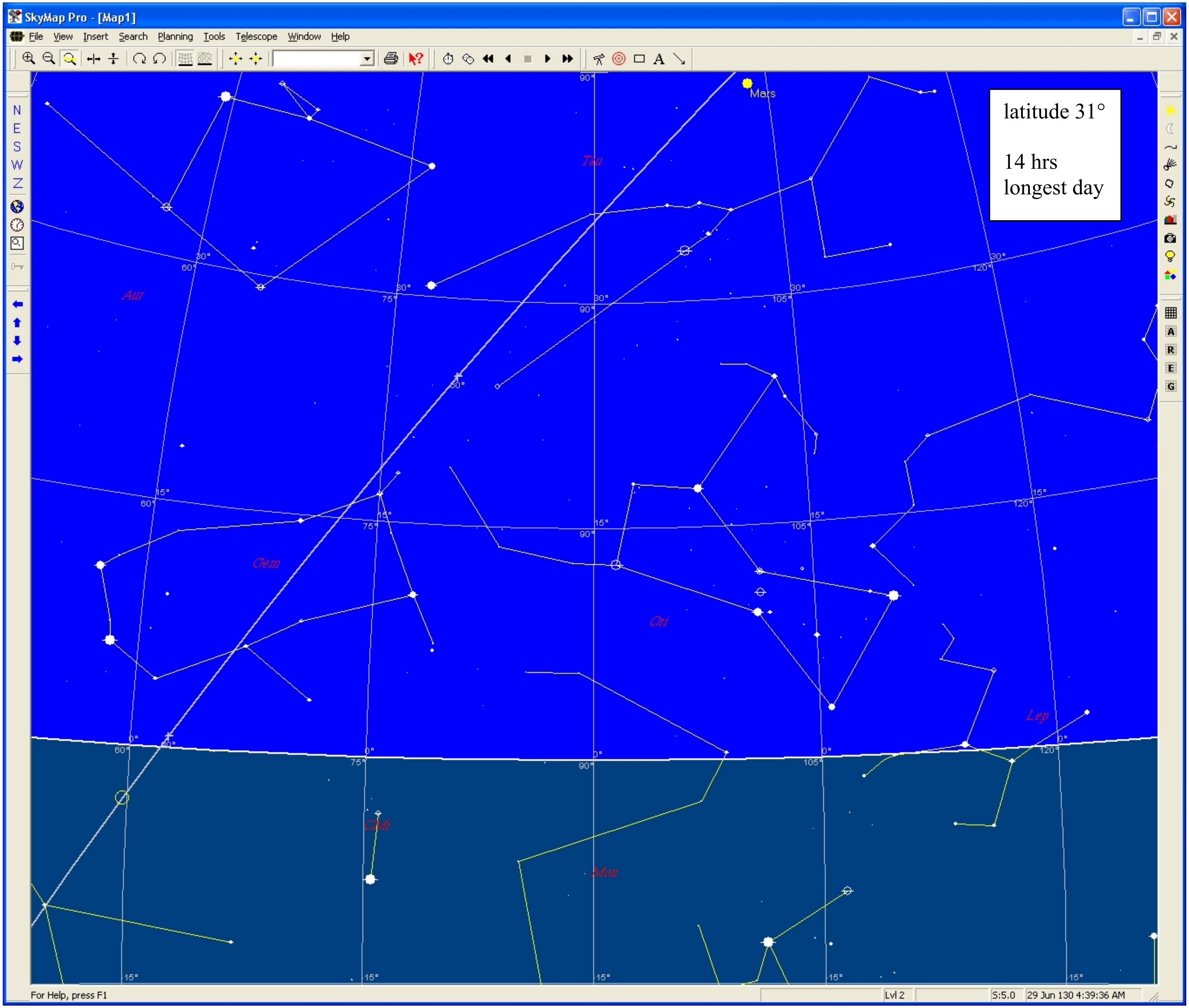
Sym	Name	Δx	Δy	m_v
I	Io	-5.36	-0.11	5.56
E	Europa	8.88	-0.13	5.96
G	Ganymede	11.20	-0.44	5.26
C	Callisto	-5.01	1.14	6.26

Saturnian Satellite Information

Sym	Name	Δx	Δy	m_v
e	Enceladus	-1.77	0.33	11.88
t	Tethys	-2.09	0.42	10.98
d	Dione	6.13	-0.12	10.58
r	Rhea	8.27	-0.27	9.88
T	Titan	0.41	1.92	8.50
i	Iapetus	-55.96	-1.80	10.25

For most people in antiquity the real interest in the stars resulted from their relation to the annual calendar. Ptolemy and many people before him published something like this (e.g. 14 hrs is the longest day at latitude 31°):

Epiphi (*the 11th month)*.
1. Summer solstice. 13 ½ hours: the middle one of the belt of Orion rises.
14 hours: the one on the trailing shoulder of Orion rises.
2. 15 ½ hours: the bright one of Perseus rises in the evening.
5. 14 hours: the one common to Eridanus and the foot of Orion rises. 15 hours: the one on the leading shoulder of Orion rises.
6. 13 ½ hours: the one on the head of the leading twin [of Gemini] rises.
14 hours: the middle one of the belt of Orion rises, and the last one of Eridanus rises, and the one on
the head of the leading twin [of Gemini] rises.
7. 14 ½ hours: the bright one of Corona Borealis sets in the morning.
8. 15 hours: the one on the head of the leading twin [of Gemini] rises. 15 ½ hours: the one common to Pegasus and Andromeda rises in the evening.
9. 15 ½ hours: the one on the head of the leading twin [of Gemini] rises.


SkyMap Pro - [Map1]
File View Insert Search Planning Tools Telescope Window Help
latitude 31°
14 hrs
longest day
Mars
Tau
Aur
Gem
Ori
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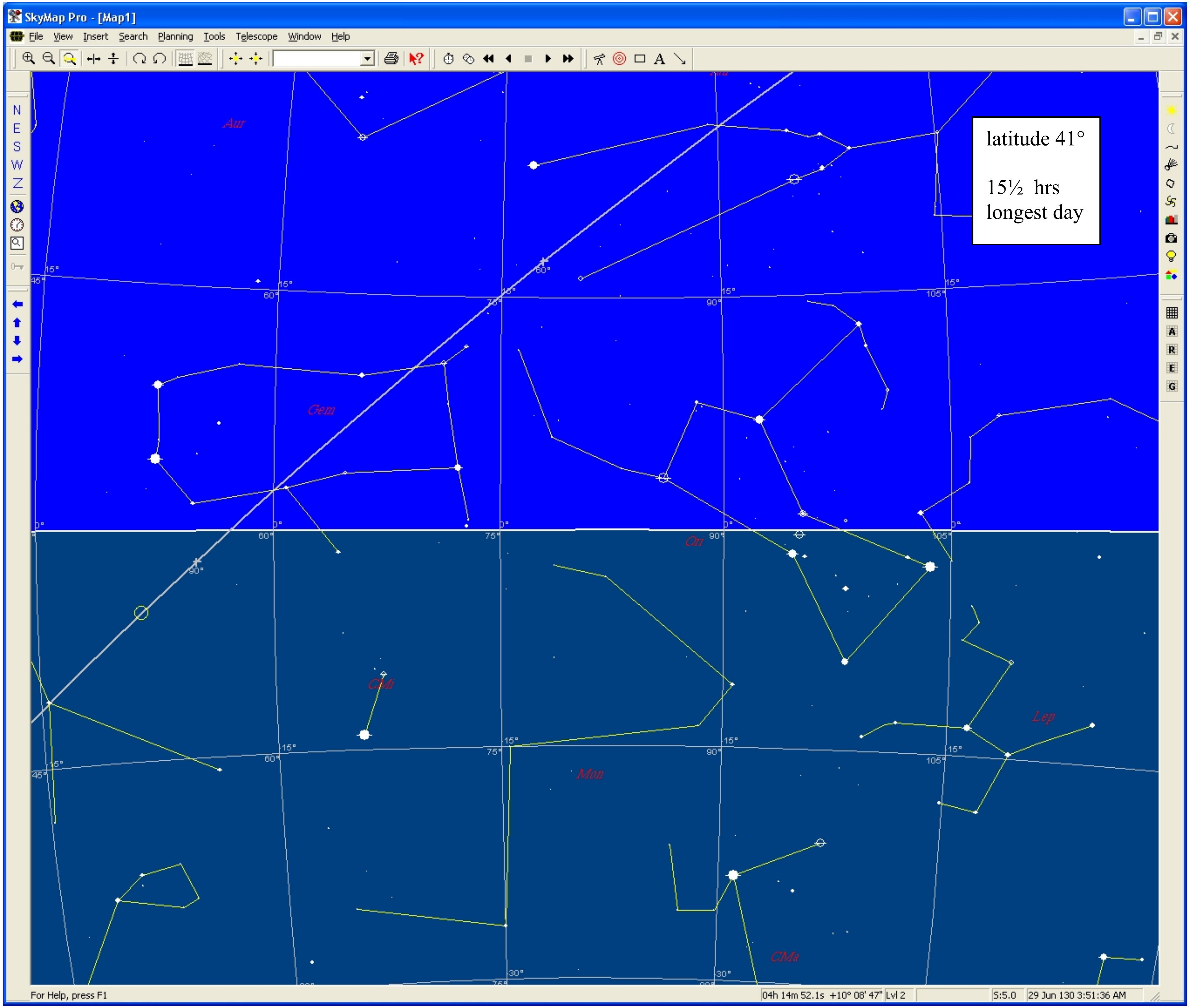
Lvl 2
S:5.0
29 Jun 130 4:39:36 AM


SkyMap Pro - [Map1]
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latitude 41°
15½ hrs
longest day
Aur
Gem
Ori
CMi
Mon
Lep
CMa
For Help, press F1
04h 14m 52.1s +10° 08' 47" Lvl 2
S:5.0
29 Jun 130 3:51:36 AM

a few relics survive:

The inscriptions have peg-holes next to lines of text.
(This explains the word *parapegma*, which means "peg beside")

Part of the text on this block:

30

•*The sun is in Aquarius.*

•*... begins setting the morning and Lyra sets.*

• •

•*Cygnus begins to set acronychally.*

• • • • • • • • • •

•*Andromeda begins rising in the morning.*

• •

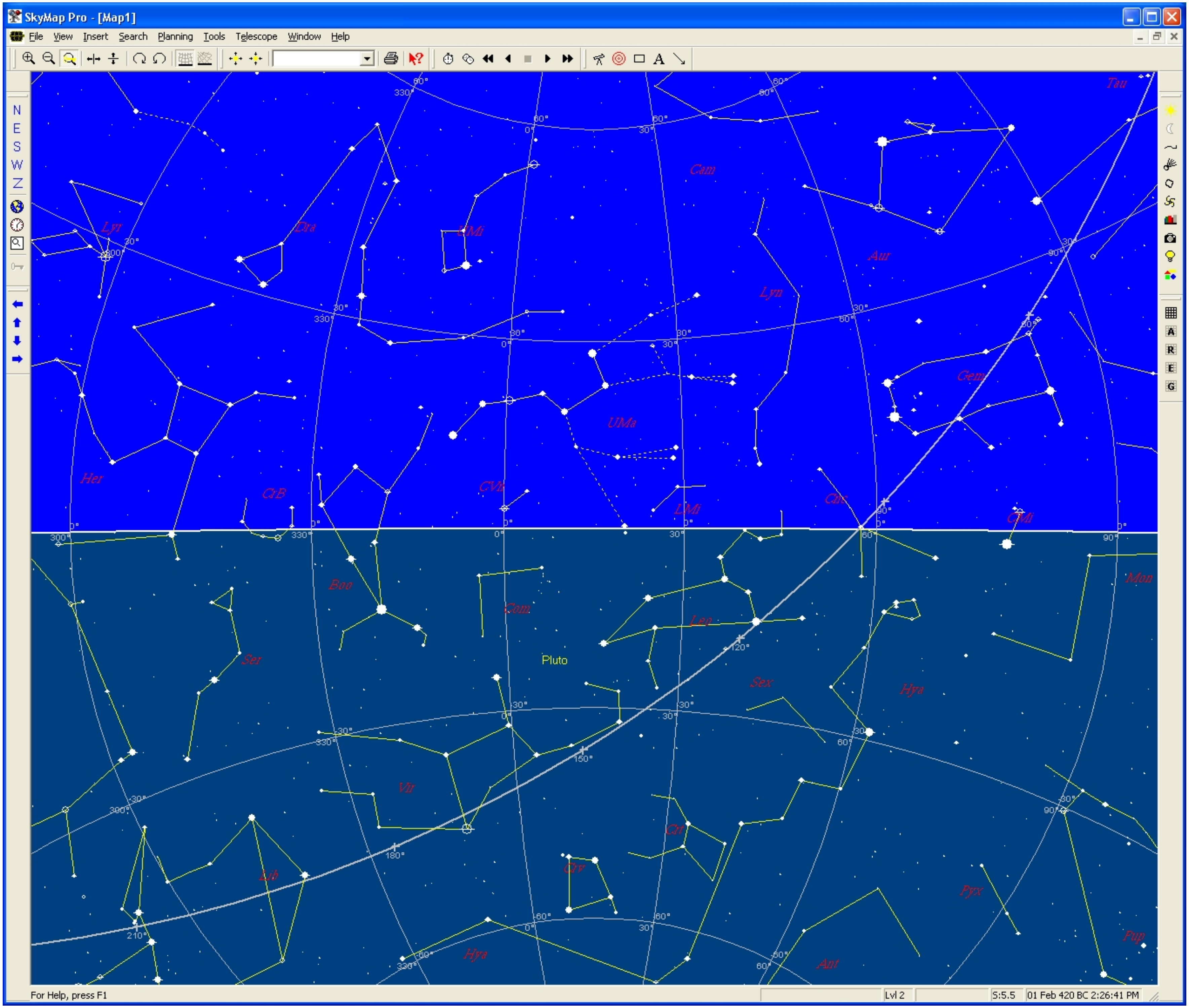
•*Aquarius is in the middle of rising.*

The Background

Constellations were known to the Babylonians. Many but not all are related to the Greek versions.

The constellations were well-organized in Greece no later than 380 B.C. and probably considerably earlier. We know this from the famous poem of Aratus written about 270 B.C. that was derived from two works by Eudoxus.

Not the faintest, when the Crab rises, are the circling stars that lie round the ocean to east and west, some setting, some rising from the other horizon. Setting is the Crown, and setting the Fish as far as its spine; half of the setting Crown you can see in the sky, while half is already cast down by the world's edge. The backward-turned figure, in the parts up to the lower belly, is not yet set, but the upper parts move in darkness. The Crab also brings down the toiling Ophiuchus from knees to shoulders, and brings down the Serpent close to the neck. No more will Bootes bulk large above and below the horizon, the lesser part being above, and the greater already in darkness. It takes four signs of the Zodiac together for the ocean to receive Bootes' setting. When he is sated with daylight, he occupies more than half of the passing night in the loosing of his oxen, in the season when he begins setting as the sun goes down. These nights are named after his late setting. So these constellations set, while opposite them no meagre one, but brilliant with his belt and two shoulders,


SkyMap Pro - [Map1]
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N
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Cam
Aur
Lyr
Dra
UMi
Lyn
Gem
UMa
Her
CrB
CVn
LMi
Cnc
CMi
Mon
Boo
Com
Leo
Ser
Pluto
Sex
Hya
Vir
Crt
Lib
Crv
Pyx
Pup
Ant
For Help, press F1
Lvl 2
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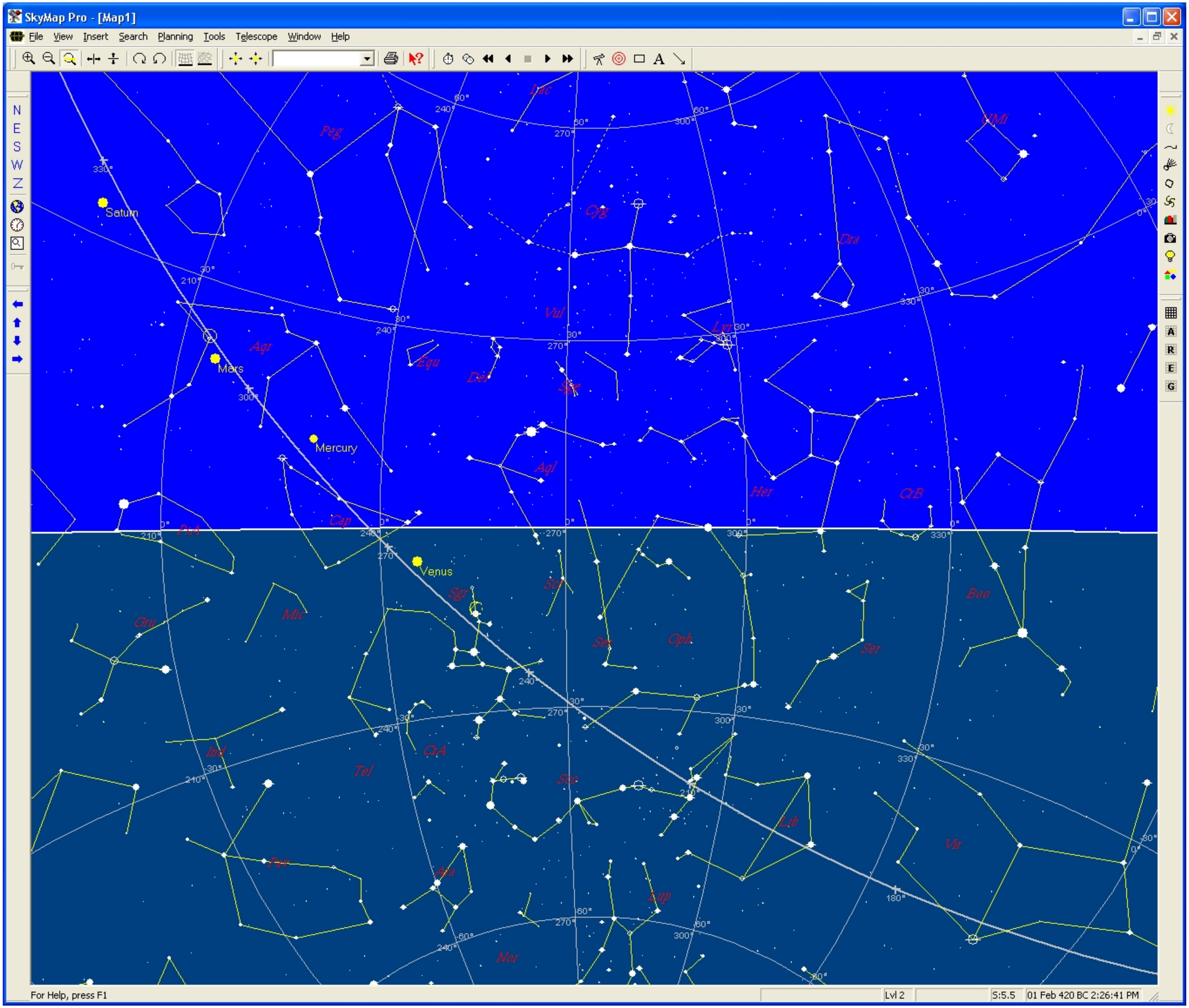
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Saturn
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Mercury
Venus
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In about 130 B.C. Hipparchus wrote a *Commentary to Aratus and Eudoxus* that, for the most part,

(a) severely criticized most earlier astronomers for not being accurate enough, and

(b) gave Hipparchus' own version of the rising and setting of constellations that established a new level of accuracy and precision.

For example, Hipparchus wrote:

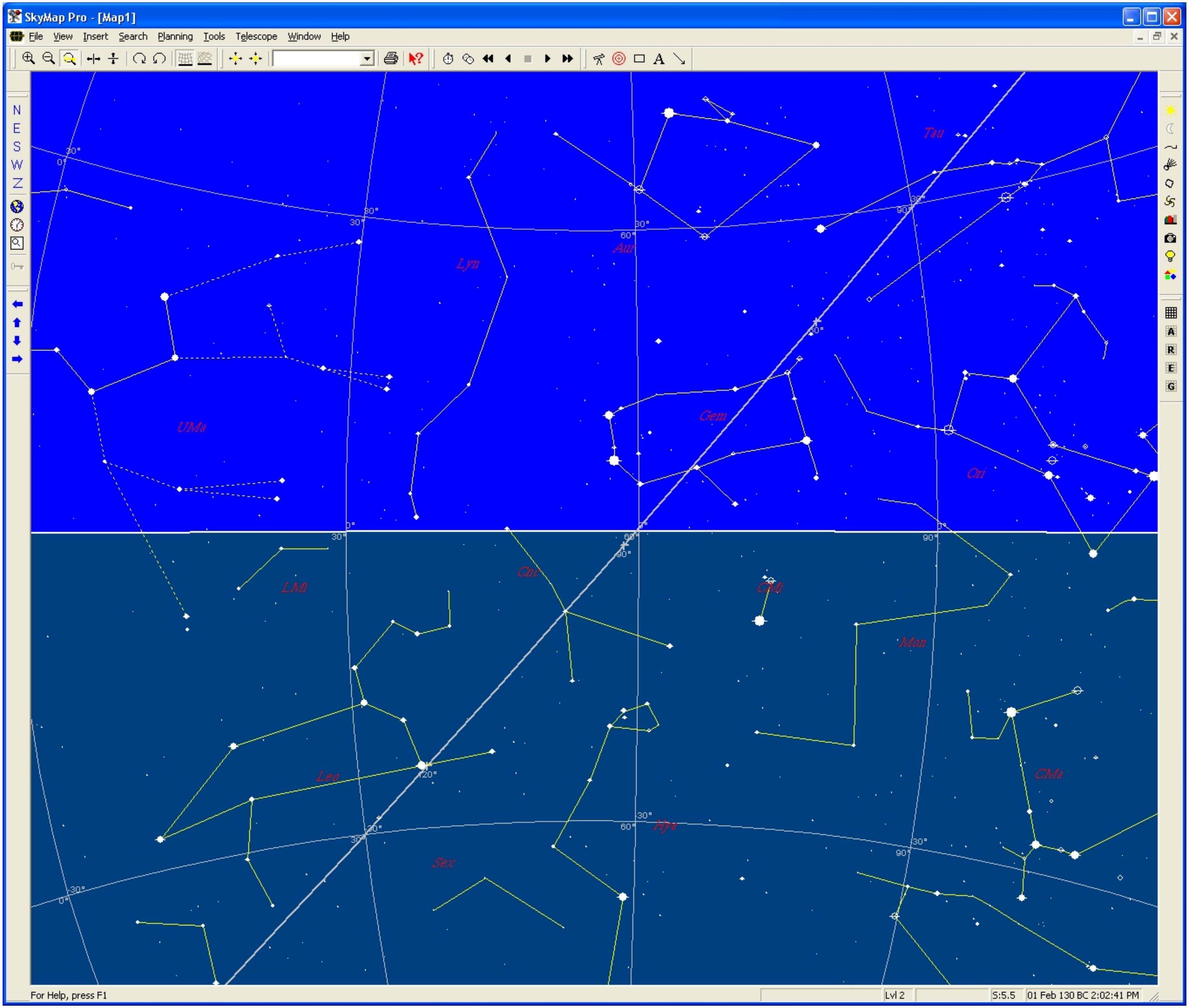
1.1.5 Since I observe that even on the most important points Aratus conflicts both with phenomena and with the things that really happen, but that in practically all details not only other commentators but even Attalus agree with him, I thought it good — for the sake of your learning and the common benefit of others — to make an accounting of the things that seem to me to be erroneous. I undertook to do this not because I chose to enhance my image by refuting others. That is hollow and altogether mean; indeed, I think, on the contrary, that we must give gratitude to all who engage in taking upon themselves rigorous tasks for the common benefit. However, I undertook this so that neither you nor others who seek wisdom might stray from scientific knowledge concerning phenomena in the universe. Many have suffered this; and it is easy to understand why. For the charm of poems acquires for their statements a certain reliability, and almost everybody who has commented upon this poet submits to his statements.

1.1.8 Eudoxus treated the same material concerning phenomena as did Aratus, but with greater understanding. Naturally, then, the poetry is also regarded as trustworthy because so many great mathematical astronomers concur. And yet, it is not appropriate that one assail Aratus, even if he happens to err in certain points. For he wrote the *Phaenomena* closely following Eudoxus' material, but without observing for himself and without promising to report the opinion of mathematical astronomers in matters concerning the heavens; this is where Aratus makes mistakes in his *Phaenomena*.

Hipparchus' own version of the rising of the Crab:

3.3.1b When the Crab is rising, together with it rises the zodiac from 23° of the Twins until 18° of the Crab. On the meridian is the portion from 5° of the Fishes until 1m° of the Ram. And the first star to rise is the one in the tip of the northern Claw; the last is that in the tip of the southern Claw.
Of others on the meridian, the first is the bright star in Andromeda's head; the last is the leading star of the three in the Ram's head, and the bright, unassigned star lying toward the south along the middle of the Sea-monster's body, and the southern of the following stars in the quadrilateral of the Sea-monster, and Andromeda's left foot which is a little short of the meridian.
The Crab rises in 1⅔ hours.

In fact this is pretty accurate in 130 B.C.:


SkyMap Pro - [Map1]
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UMa
Lyn
Aur
Tau
Gem
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CMi
Mon
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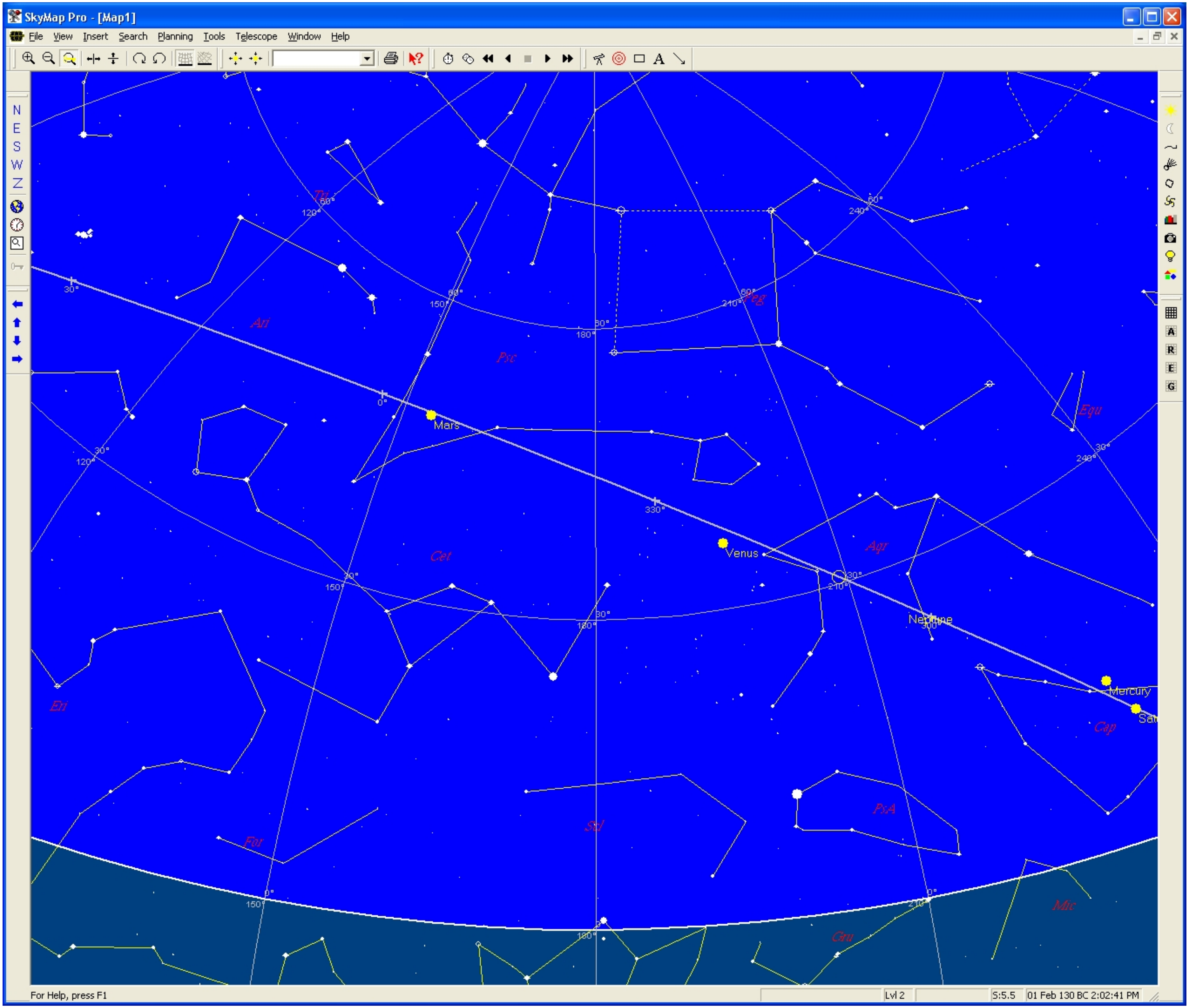

SkyMap Pro - [Map1]
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Tri
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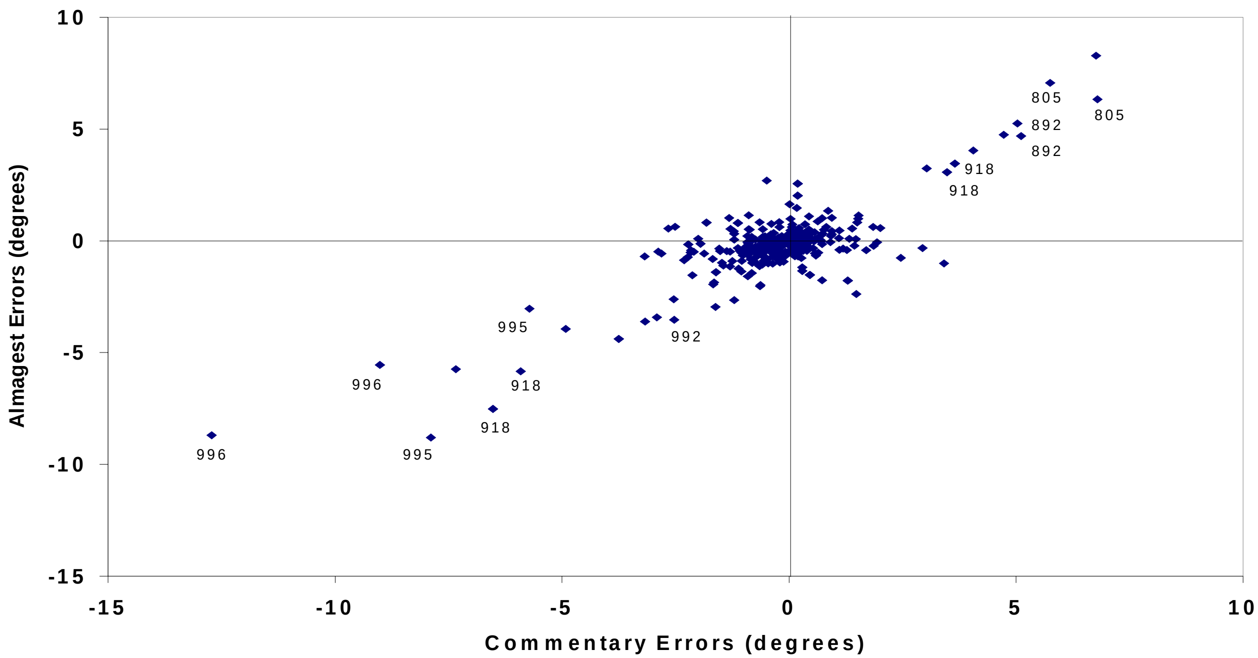
01 Feb 130 BC 2:02:41 PM

It turns out that using all the data that Hipparchus gives we can
(a) conclude that he had an extensive catalog of star coordinates, and
(b) figure out the errors on many of his star positions.

The correlation of the *Commentary* and *Almagest* errors should be small if the catalogs are independent, but large if the catalogs share a common heritage.

It is clear that Ptolemy copied his star coordinates from Hipparchus.



What Ptolemy almost certainly did was take Hipparchus' coordinates, probably in equatorial right ascension and declination, convert them to ecliptical longitude and latitude, and then add $2\frac{2}{3}^\circ$ to the longitudes to account for 265 years of precession at 1° per 100 years.

This in spite of his explicit claim:

> Hence, again using the same instrument [as we did for the moon, V 1], (because the astrolabe rings in it are constructed to rotate about the poles of the ecliptic), we observed as many stars as we could sight down to the sixth magnitude. [We proceeded as follows.] We always arranged the first of the above-mentioned astrolabe rings [Fig. F,5] [to sight] one of the bright stars whose position we had previously determined by means of the moon, setting the ring to the proper graduation on the ecliptic [ring (Fig. F,3) for that star], then set the other ring [Fig. F,2], which was graduated along its entire length and could also be rotated in latitude towards the poles of the ecliptic,[87] to the required star, so that at the same time as the control star was sighted [in its proper position], this star too was sighted through the hole on its own ring. For when these conditions were met, we could readily obtain both coordinates of the required star at the same time by means of its astrolabe ring [Fig. F,2]: the position in longitude was defined by the intersection of that ring and the ecliptic [ring], and the position in latitude by the arc of the astrolabe ring cut off between the same intersection and the upper[88] sighting-hole.

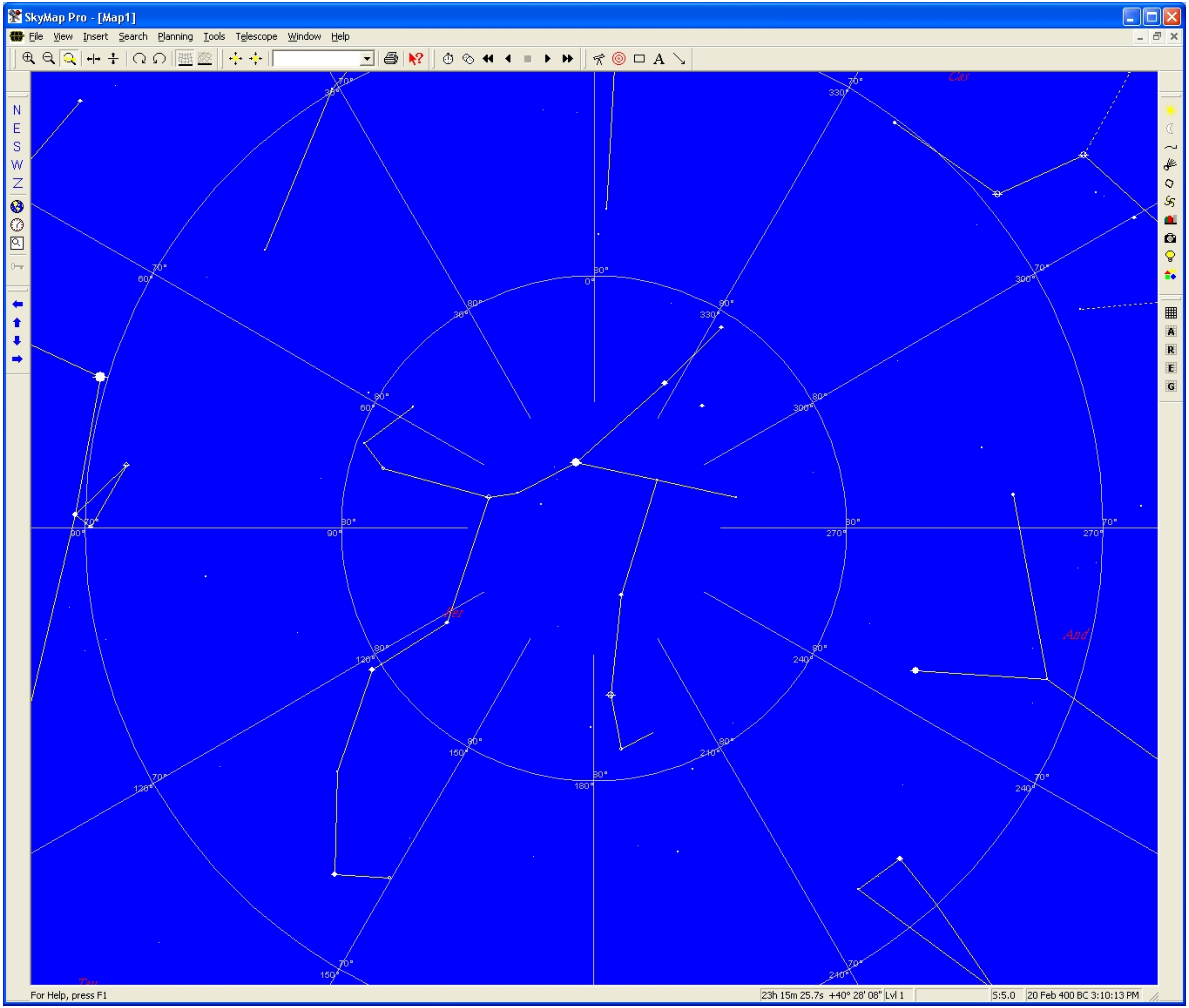
Hipparchus does have some strange things, though:

1.4.1 Eudoxus is in ignorance concerning the North Pole, when he says this:

> There is a certain star which remains ever in the same spot; and this star is the Pole of the world.

Upon the pole lies not even one star; rather it is an empty place beside which lie three stars. With these the point on the Pole forms nearly a square, according to Pytheas of Massilia.

It is difficult to know what Eudoxus or Hipparchus is referring to, though: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23h 15m 25.7s +40° 28' 08" Lvl 1
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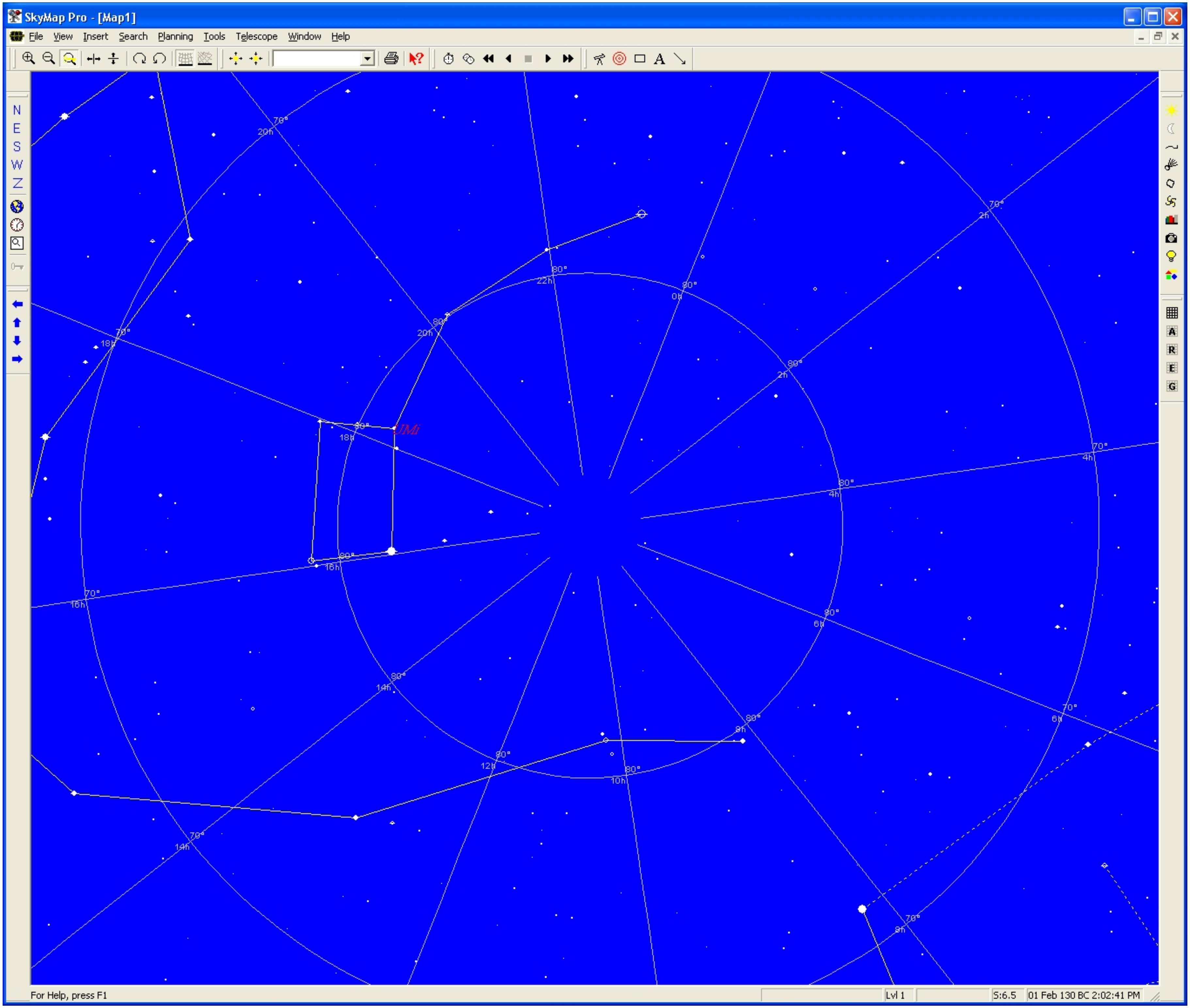
20 Feb 400 BC 3:10:13 PM



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There were probably a number of other star catalogs around. Star globes seem to have been popular, and two very nice originals have survived: the Farnese Atlas and the Mainz Globe.

Lectures 5-6

- *Almagest* Books 9–13
- geocentric vs. heliocentric point of view
- the wandering stars, or planets
- the two anomalies
- the eccentric plus epicycle and its problems
- the equant
- latitude
- the background