Exploring the cosmic infinite horizons of modern

Astronomy

Today.

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Goals for this course

1) Obtain knowledge about astronomy.

2) Obtain understanding of some basic physics concepts.

3) Get practice and gain confidence in problem solving and analytical reasoning.

4) Learn about science and how it differs from pseudosciences and other belief systems.

5) Expand your personal “theory of everything” - your cosmology.

Week 1 of Stellar and Galactic Astronomy

View the film "*Powers of 10 A Film About the Relative Sizes of Things*
1977
by Charles and Ray Eames
Narrated by Phillip Morrison

Pre-Questions
1) Note the largest scale achieved.
2) Note the smallest scale achieved.
3) In which powers of 10 do we find great "voids" where nothing new enters the view?

Also consider ...
4) In every 10 seconds, the view expands by a factor of 10. Could this entire journey be experienced while flying in a rocket ship?

Why do we need powers of 10?

Many quantities have a vast range of values in Astronomy ...

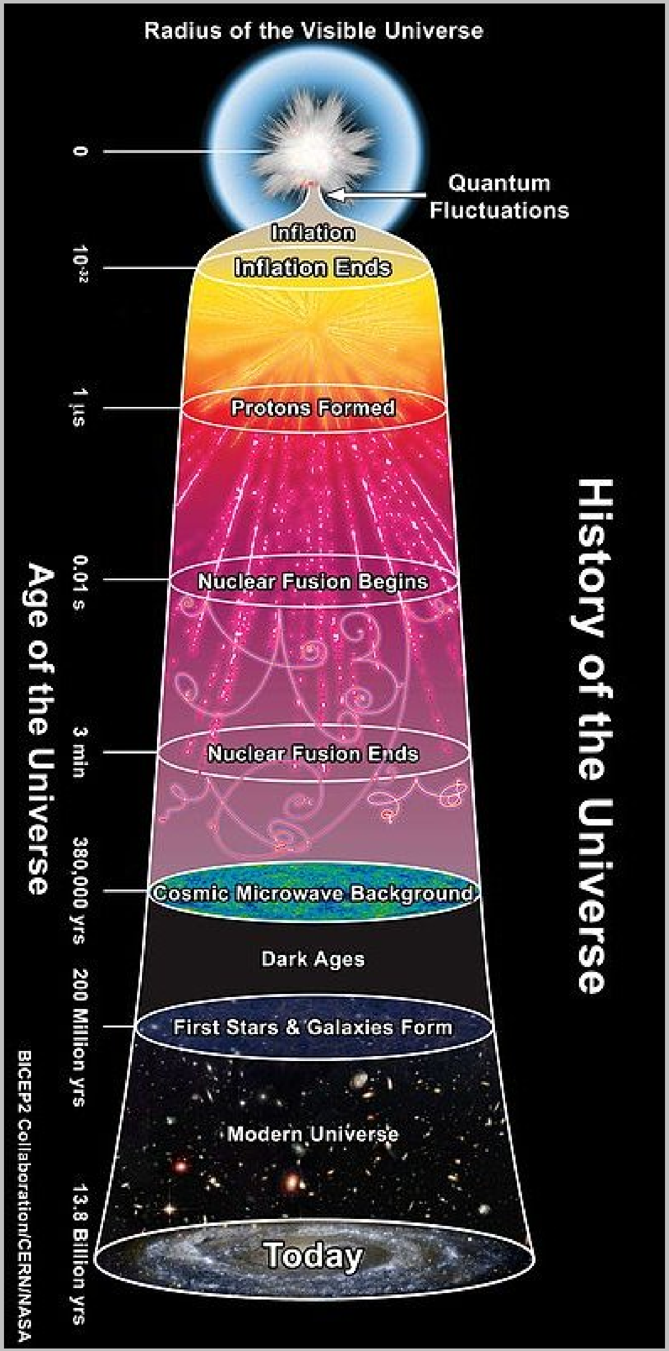
1) *Distances*. 10^{-16} to 10^{24} meters (actually $>10^{26}$) for the scale of an atomic nucleus compared to the scale of largest structures in the universe.

2) *Time.* 10^{-46} second to 10^{16} seconds (10^{9} yrs) for the Planck time to the age of the universe.

3) *Masses:* 10^{-31} kg (electrons) to 10^{45} kg (clusters of galaxies)

4) *Energies:* and 10^{-19} Joules for H-alpha photon to 10^{+39} Joules for Gamma-Ray Bursts.

5) Speeds: continental drift (cm/yr) to the speed of light 300,000,000 m/s.



And that's why we use "powers of 10" -- to make them more manageable!

Understanding Powers of 10, orders of magnitude, and Scientific Notation

Scientific Notation: a way of writing a number in which the decimal point Is placed to the right of the most significant digit, and this is multiplied by 10^P where P=an integer (the exponent, or "power of 10")

Exponential Notation Format: Coefficient X Base ^{exponent} (where Base=10)

Example: $58400 = 5.84X10^4$

Example: $0.01093 = 1.093x10^{-2}$

Example: The average Earth-Sun distance is 93,000,000 miles or 9.3×10^7 miles.

Power of 10: one can approximate a number by giving only the exponent of that number expressed in scientific notation, rounded up or down depending on the coefficient.

Example: $5.84x10^4 = 10^{4.7664} \sim 10^5 = 10x10x10x10x10 = 100,000$.

Example of usage: The distance to the Sun from the Earth is about 10^8 miles.

Thus, the Earth-Sun distance is 8 powers of 10 greater than a mile.

Order of magnitude: the "order of magnitude" of a number is the same thing as a number's "power of ten", it is just used differently in sentences.

Example: "The Earth-Sun distance is 8 orders of magnitude larger than a mile.")

Example: "If you thought the US population was 3 million, you were off by 2 orders of magnitude."

<u>Understanding Powers of 10, orders of magnitude, and Scientific Notation</u>

Rounding to the nearest <u>power of 10</u>.

Previous example: $5.84 \times 10^{4} = 10^{4.7664} \sim 10^{5}$. But what if we had …
Example: $4.84 \times 10^{4} = 10^{4.6848} \sim 10^{5}$.
Example: $3.84 \times 10^{4} = 10^{4.5843} \sim 10^{5}$. Perhaps if the exponent dropped below 4.5 …
Example: $2.84 \times 10^{4} = 10^{4.4533} \sim 10^{4}$. Finally, we don't round up!

For which coefficient will the exponent be exactly 4.5? Answer: 3.162278 ($=\sqrt{10}$)

Example: $3.1623 \times 10^{4} \sim 10^{5}$.
Example: $3.1622 \times 10^{4} \sim 10^{4}$.

Try these:

Example: 9.99×10^{2} $\sim 10^{3}$
Example: 9.9×10^{-2} $\sim 10^{-1}$.
Example: 5.1×10^{-4} $\sim 10^{-3}$.
Example: 3.10×10^{6} $\sim 10^{6}$.
Example: 3.20×10^{9} $\sim 10^{10}$.

Example: 401,000 $\sim 10^{6}$.
Example: 301,000 $\sim 10^{5}$.
Example: 73,162,055,319 $\sim 10^{11}$.

Why do we need these new ways of expressing numbers?

1) To compress long numbers.

Example: mass of the Sun in kilograms:

$$1\ M_\odot = 2.0\times10^{30}\ \text{kg (sci notation)}$$

$$1\ M_\odot = 10^{30}\ \text{kg (nearest power of 10)}$$

(Now try writing this number as a 1 with 30 zeros!)

2) To simplify multiplication and division.

Example: if the Earth's mass is $6\text{x}10^{24}$ kg, how many Earth masses go into the Sun?

$$M_\odot/M_\oplus = 10^{30} \div 10^{25} = 10^{30-25} = 10^{5}$$ (actual $3.35\text{x}10^{5}$)

Example: if there are 86400 seconds per day, and 365 days in a year, roughly how many seconds are in a year?

$$10^{5} * 10^{2} = 10^{5+2} = 10^{7}$$ (actual $3.156\text{x}10^{7}$)

Simplified multiplication and division allows easy rough estimates called "order of magnitude calculations" or "back of the envelope calculations".

Summary:

With powers of 10 math, <u>division becomes subtraction</u> and <u>multiplication becomes addition</u>.

GROUP EXERCISE

Rank these lengths from smallest to largest. First guess using left column, then use data provided by the instructor to fill in right column.

Small to large - guess		Sizes	smallest to largest
1._H__	**A. Black Hole, 1 solar mass, (Schwarzschild radius)**	______	1._H__
2.____	**B. Cosmic Microwave Background (distance)**	______	2.____
3.____	**C. Distance between stars in Sun's neighborhood**	______	3.____
4.____	**D. Earth (diam)**	______	4.____
5.____	**E. Galaxies, Dwarf Ellipticals (diam)**	______	5.____
6.____	**F. Galaxies, Giant Ellipticals (diam)**	______	6.____
7.____	**G. Galaxies, Milky Way (diam)**	______	7.____
8.____	**H. Human (diam)**	______	8.____
9.____	**I. Jupiter (diam)**	______	9.____
10.___	**J. Local Group (diam)**	______	10.___
11.____	**K. Moon (diam)**	______	11.____
12.____	**L. Moon (distance)**	______	12.____
13.____	**M. Neptune (dist from Sun. size of sol sys)**	______	13.____
14.____	**N. neutron star (diam)**	______	14.____
15.____	**O. Rich clusters of galaxies (diam)**	______	15.____
16.____	**P. Star Clusters, globular (diam)**	______	16.____
17.____	**Q. Sun (diam)**	______	17.____
18.____	**R. Sun (distance)**	______	18.____
19.____	**S. Superclusters of galaxies (length)**	______	19.____
20.____	**T. White dwarf**	______	20.____

GROUP EXERCISE **NAME: ____________________**

Rank these lengths from smallest to largest. (Use lengths in meters.)

	Sizes	smallest to largest
A. Black Hole, 1 solar mass, (Schwarzschild radius)	$3x10^3$ m	1._H___
B. Cosmic Microwave Background (distance)	**_10^{26} m_**	2.____
C. Distance between stars in Sun's neighborhood	**_10^{16} m_**	3.____
D. Earth (diam)	**_10^7 m**	4.____
E. Galaxies, Dwarf Ellipticals (diam)	_10^{19} m	5.____
F. Galaxies, Giant Ellipticals (diam)	_10^{22} m	6.____
G. Galaxies, Milky Way (diam)	_10^{21} m	7.____
H. Human (diam)	**_10^0 m**	8.____
I. Jupiter (diam)	_10^8 m	9.____
J. Local Group (diam)	_10^{22} m	10.___
K. Moon (diam)	_10^6 m	11.____
L. Moon (distance)	_10^8 m	12.____
M. Neptune (dist from Sun. size of sol sys)	**_10^{13} m**	13.____
N. neutron star (diam)	_10^4 m	14.____
O. Rich clusters of galaxies (diam)	_10^{23} m	15.____
P. Star Clusters, globular (diam)	_10^{17} m	16.____
Q. Sun (diam)	**_10^9 m**	17.____
R. Sun (distance)	**_10^{11} m**	18.____
S. Superclusters of galaxies (length)	**_10^{24} m**	19.____
T. White dwarf	_10^7 m	20.____

Other ways to make large numbers manageable

1) Use prefixes

small: deci, centi, milli, micro, nano, pico, femto
10 to the: -1 -2 -3 -6 -9 -12 -15

large: kilo, mega, giga, tera, peta, exa
10 to the: 3 6 9 12 15 18

Example) What is a convenient unit for 10^{-6} seconds? Ans: a microsecond (1 μs).

2) Invent new units

In astronomy we have ... (red ones are new units)

a) The “solar mass”, 1 M⊙ = 2x10^30 kg

b) The “astronomical unit”, 1 AU = 1.5x10^8 km, 93,000,000 miles.
The average distance between the Earth and Sun.

c) The Light year, 1 LY = 9.5 x 10^12 km
The distance light travels through space in a year.
Good for distances between stars.

d) The parsec, 1 pc = 3.1 x 10^13 km.
The distance one must be from the Solar system so that the Earth-Sun separation appears to be 1 arcsecond.
Good for distances between stars.

e) The kiloparsec, 1 kpc = 1000 pc
Good for distances inside a galaxy

f) The megaparsec, 1 Mpc = 1000,000 pc
Good for distances between galaxies, clusters, superclusters.

Side notes on astronomical distances / sizes

1) The magic number, 110.

110 (roughly) comes up many times in distance ratios.
110 = DiamSun/DiamE = distSun/DiamSun = distMoon/DiamMoon

2) The AU and Light Year.
There are 63,000 AU in 1 LY.
Coincidentally, there are 63,000 inches in a mile!

3) The distance to the Moon is 240,000 miles. A good car typically lasts about 240,000 miles. So you *might* be able to drive to the Moon if there were a direct route from Earth!

4) The ratio 400.
400 = DistSun/distMoon = DiamSun/diamMoon
Because of this coincidence the Sun and Moon subtend about the same angle in the sky (½ degree) and we can observe both total and annular solar eclipses.

The Naked – Eye Universe

Astronomical things that we can see with the naked eye

1. Sun
2. Moon
3. 5 planets (+Uranus, just visible)
4. 6500 stars (down to +6.0 mag)
5. 3 galaxies (M31,LMC,SMC. Some can see M33)
6. Comets
7. Supernovae, novae
8. Meteors (in our atmosphere)
9. Aurora (in our atmosphere)

The Naked – Eye Universe

The Top Ten Brightest Objects in the Sky

1. Sun
2. Moon
3. Venus
4. Mars
5. Jupiter
6. Mercury
7. Sirius
8. Saturn
9. Canopus (in Carina, Southern Hem)
10. Arcturus (Bootes)

Rigil Kent (Alpha Cen), Vega, and Capella are almost a tie for 11th!

The Naked – Eye Universe

Constellations and Asterisms

Constellation: a designated region in the sky containing one or more historical star patterns.

Examples) Orion, Taurus, Ursa Major (see next slides)

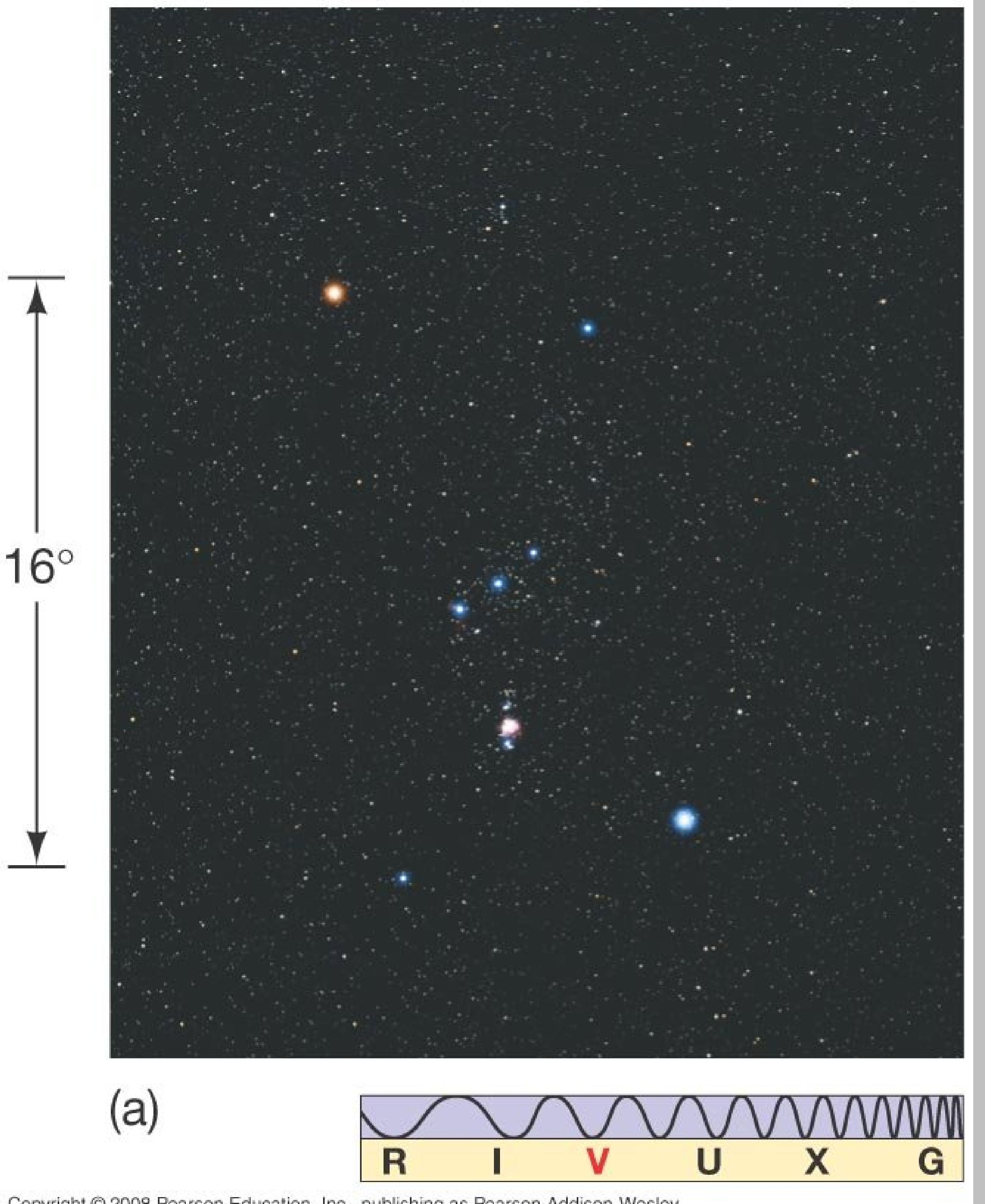
Asterism: a recognizable pattern of stars.

Ex) Orion, the hunter
Ex) Taurus, the bull; the Pleiades; the Hyades
Ex) Ursa Major (the great bear); the Big Dipper; La Cassarole
Ex) The Summer Triangle
Ex) The Coathanger (Brocchi's cluster)

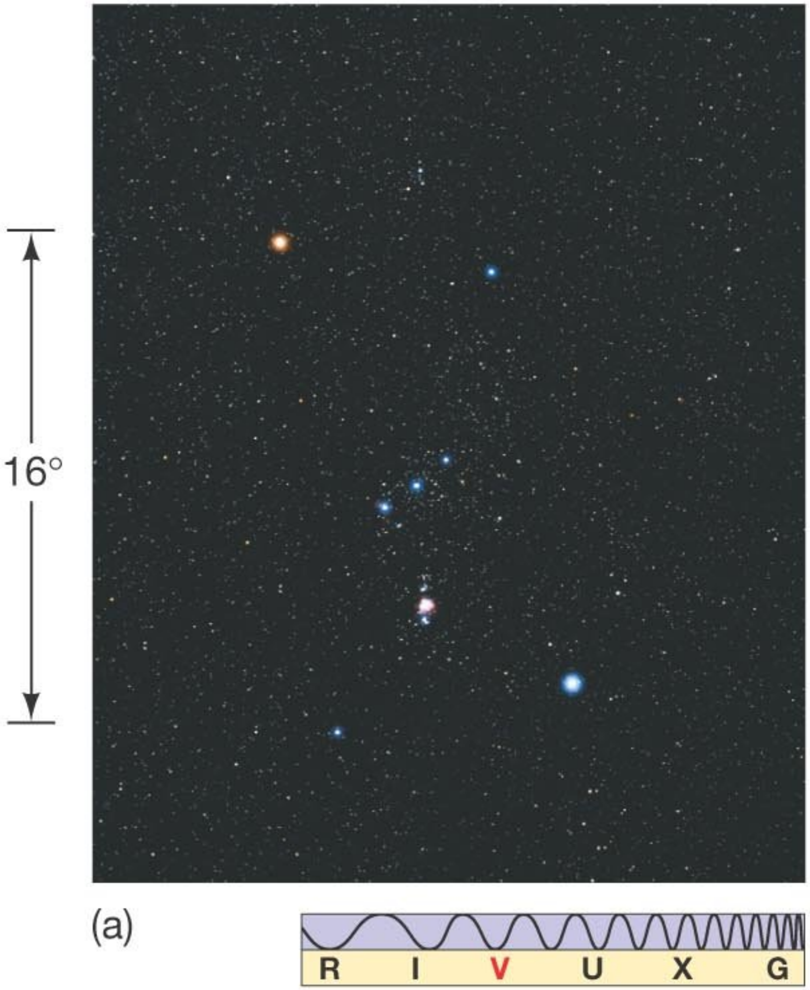
* 88 total constellations
* More than 88 asterisms
* Northern constellations named after Greek Mythological characters

Example: Orion.

An easily recognized constellation!

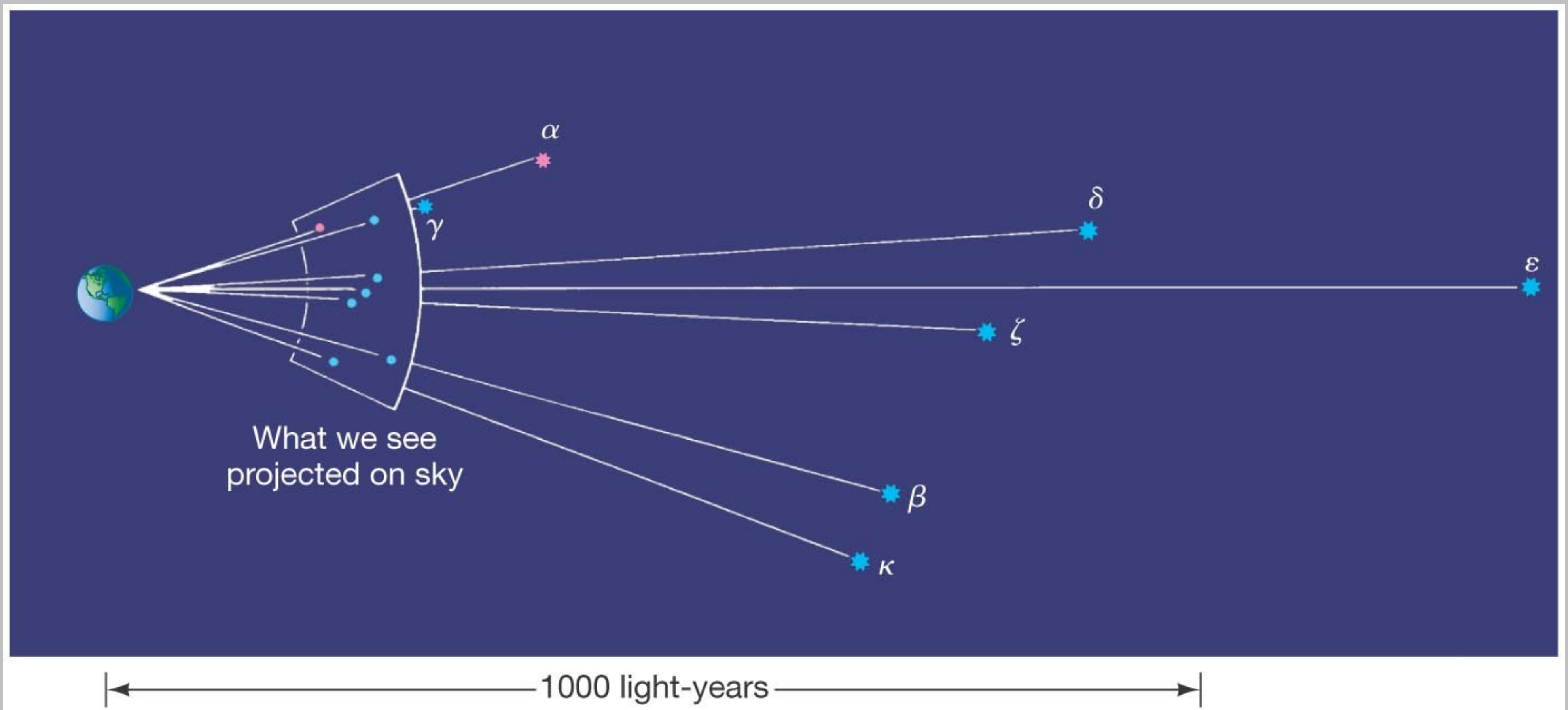


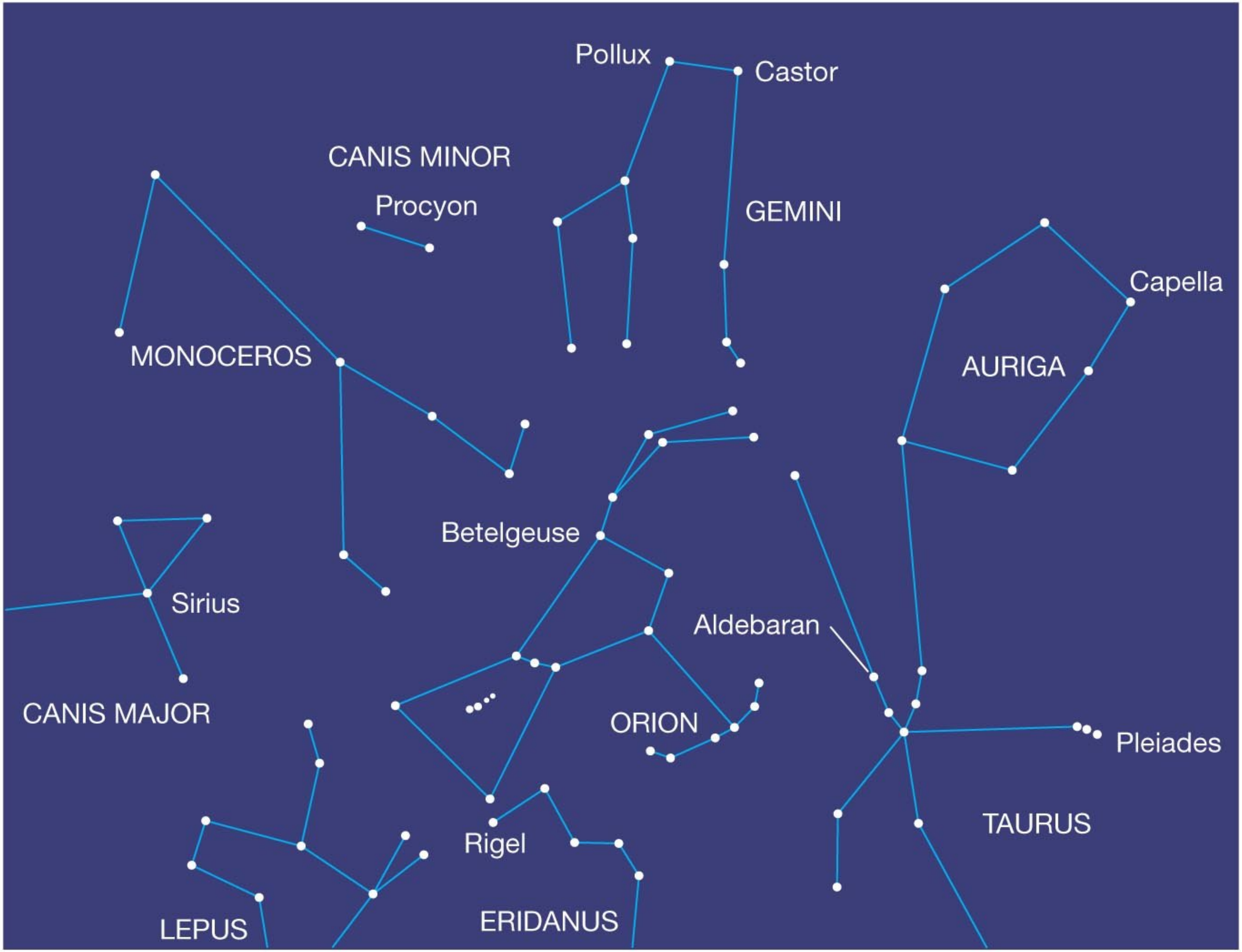
(a)



(a)

(b)


α
δ
ε
γ
ζ
β
κ
What we see
projected on sky
1000 light-years



Try a planetarium program like "Stellarium" or "Celestia" to see the sky in motion.