The Cosmic Distance Ladder

— How do we really know the distance? —

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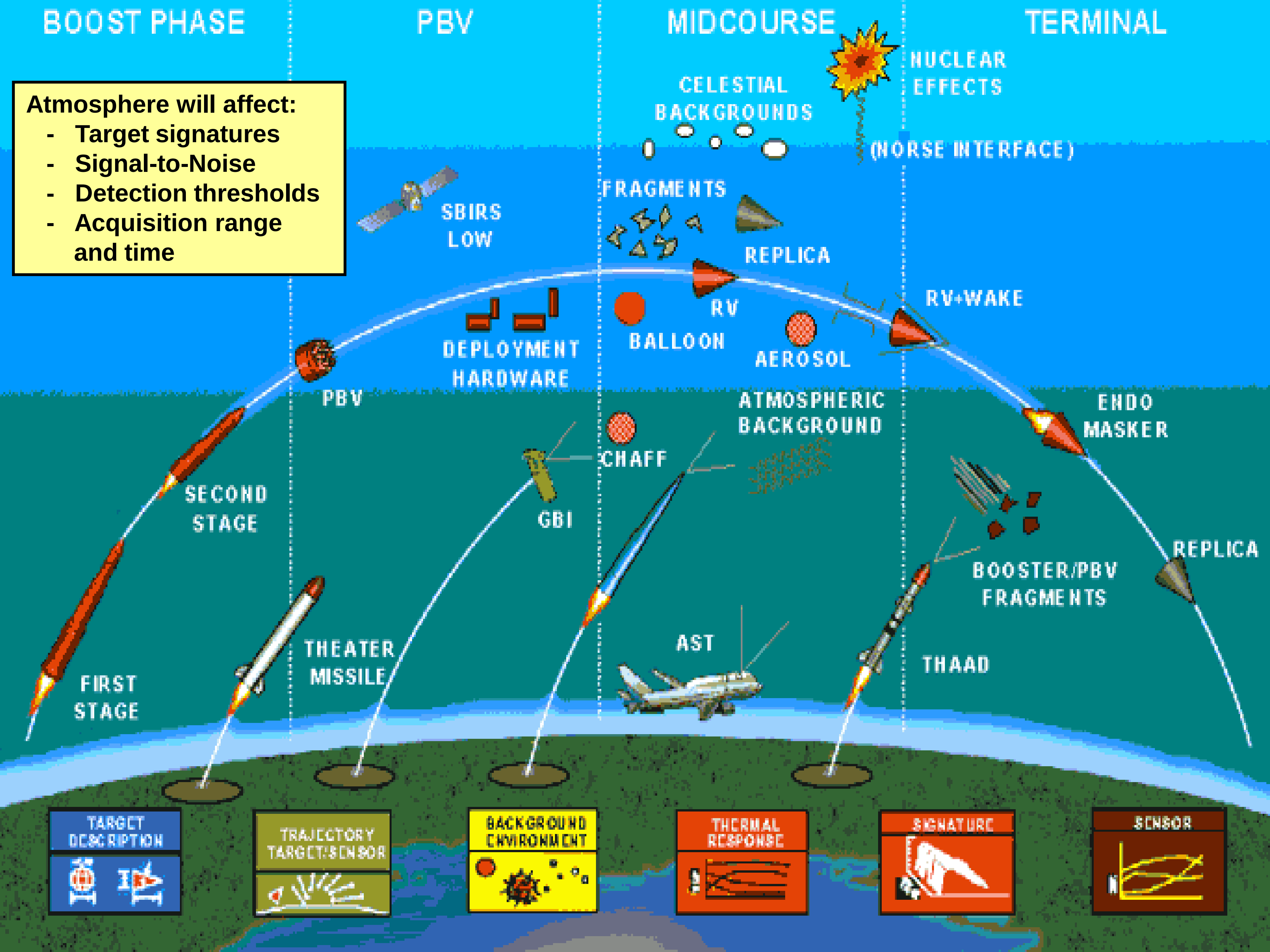
Presented to:
New Mexicans for Science and Reason (NMSR)
CNM Main Campus, SRC Room 204
10 January 2018

Atmosphere will affect:

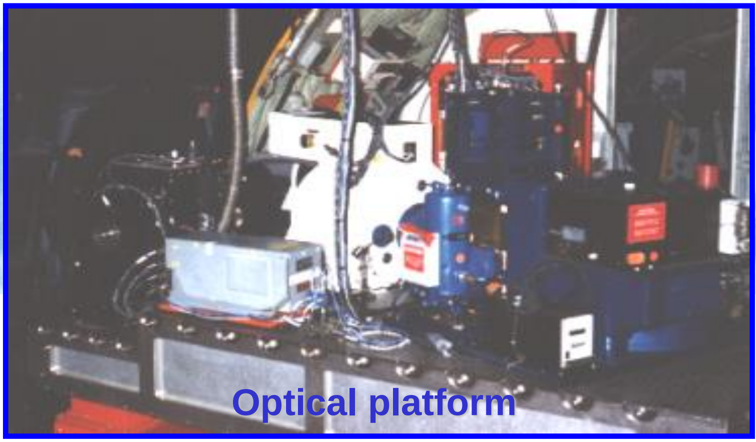
- Target signatures
- Signal-to-Noise
- Detection thresholds
- Acquisition range and time



Argus C-135E Electro-Optical Testbed

Argus was the only Air Force C-135E capable of flying extended missions up to 50,000 feet above the earth's surface, making it unique in the Air Force inventory. From 1986 to 2000, its mission was to collect data on rocket plume phenomena, reentry vehicle signatures, kill assessments, sensor checkout for SDI, and airborne laser remote sensing experiments.

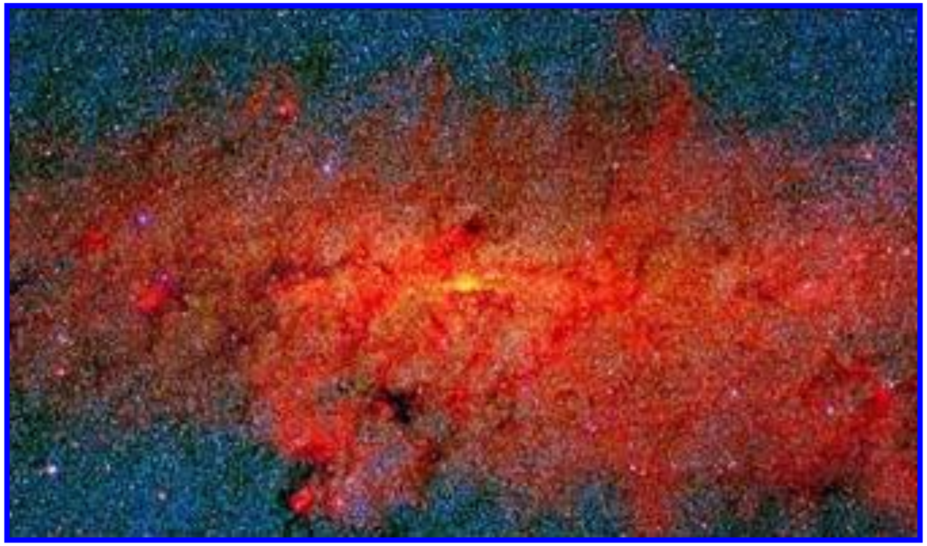
- Airborne Electro-optical Testbed
- Palletized optical benches
- UV/Visible Imagery & Spectroscopy
- MWIR/LWIR Imagery & Spectroscopy
- LIDAR & Laser Experiments
- Active/Passive remote sensing
- Hyperspectral Experiments

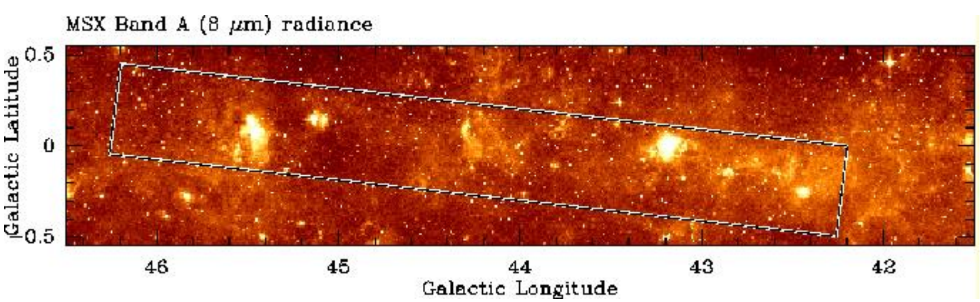

Optical platform

MSX SPIRIT III Sensor

Midcourse Space Experiment (MSX) was a Ballistic Missile Defense Organization satellite experiment to map bright infrared sources in space. MSX offered the first system demonstration of technology in space to identify and track ballistic missiles during their midcourse flight phase. Operational from 1996-97.

I developed the Sensor Off-Axis Radiance (SOAR) computer code, modeling Bidirectional Reflectance Distribution Function (BRDF) data to analyze the Mid-Course Space Experiment (MSX) SPIRIT III infrared sensor (5 IR bands).





http://irsa.ipac.caltech.edu/Missions/msx.html

The American Institute of Aeronautics and Astronautics (AIAA) Congressional Visits Day
Every year, AIAA members – engineers, scientists, researchers, students, educators, and technology executives – travel to Washington DC, for a day of advocacy and awareness with national decision makers. My group usually presents 2 key issues with recommendations:

- Aerospace & Defense Work-force Enhancement (& STEM)
- Aerospace & Defense Budget Funding and Procurement



In DC with **Ms. Cynthia Kaiser**, former Directed Energy Chief Engineer at AFRL, she is now involved with the AfterMath summer camp program for students; **Col. Mark Neice** (ret.), Executive Director of the Directed Energy Professional Society, Col. Neice was Chief of the Laser Division at AFRL when I was a civilian crew member on the Argus C-135E electro-optical testbed aircraft, he was the pilot for Argus on many missions that I flew on including a deployment to South Korea; and our group leader **Dr. James Horkovich** (Directed Energy advocate), and **Senator Martin Heinrich**.


https://www.facebook.com/marchforscienceABQ/
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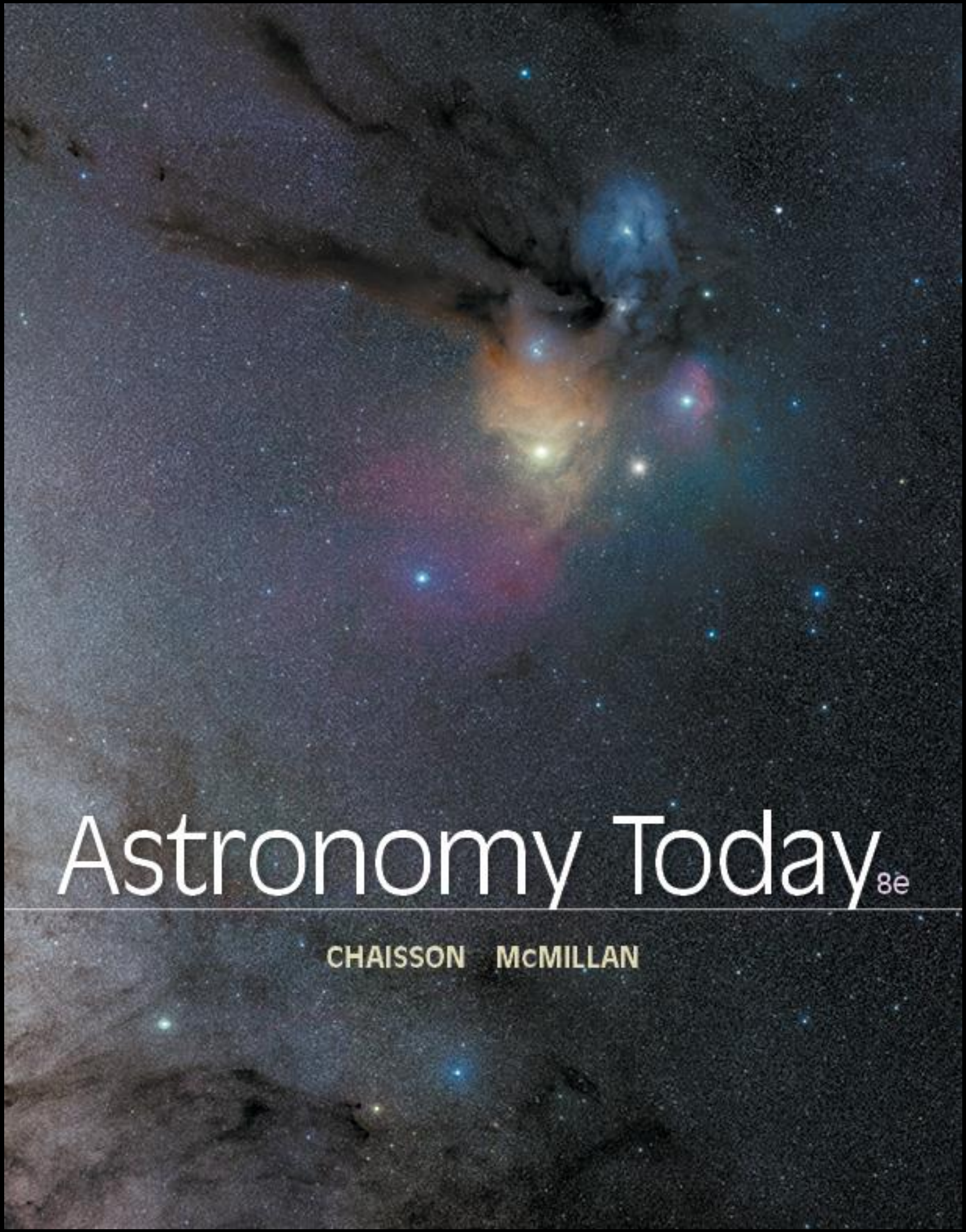
Photos
Videos
Liked
Following
Share
Send Email
Write something...
Cause



Astronomy Today, 8th ed
Chaisson/McMillan

Astronomy 1192
Lab Manual (CNM)
Dr. Erica Voges, et. al.

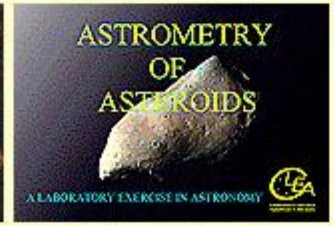
Project CLEA Software
http://www3.gettysburg.edu/~marschal/clea/CLEAhome.html

Sponsored by Gettysburg College and the National Science Foundation, Project CLEA,

Contemporary Laboratory Experiences in Astronomy,

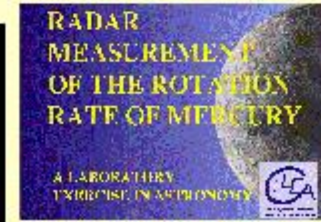
develops laboratory exercises that illustrate modern astronomical techniques using digital data and color images.

Radio Astronomy of Pulsars



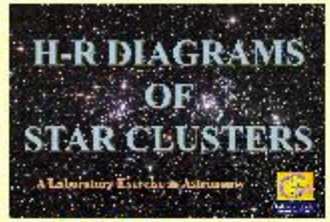
Astrometry of Asteroids

The Revolution of the Moons of Jupiter



The Rotation of Mercury by The Doppler Effect

Photoelectric Photometry of the Pleiades



HR Diagrams of Clusters

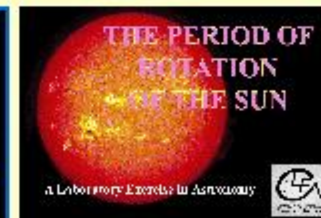
Spectral Classification of Stars

The Hubble Relation

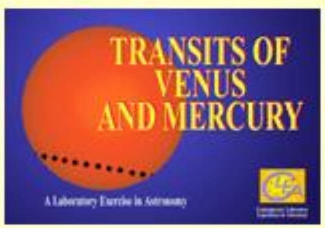
The Large Scale Structure of the Universe

Flow of Energy Out of the Sun

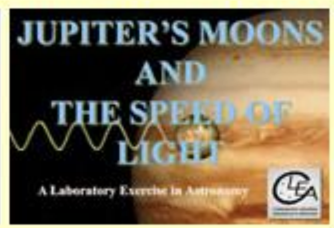
The Quest for Object X



Solar Rotation Using Images from the GONG Project

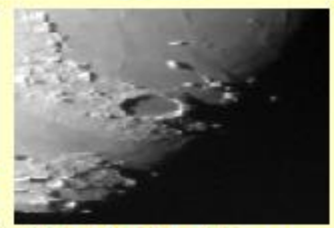


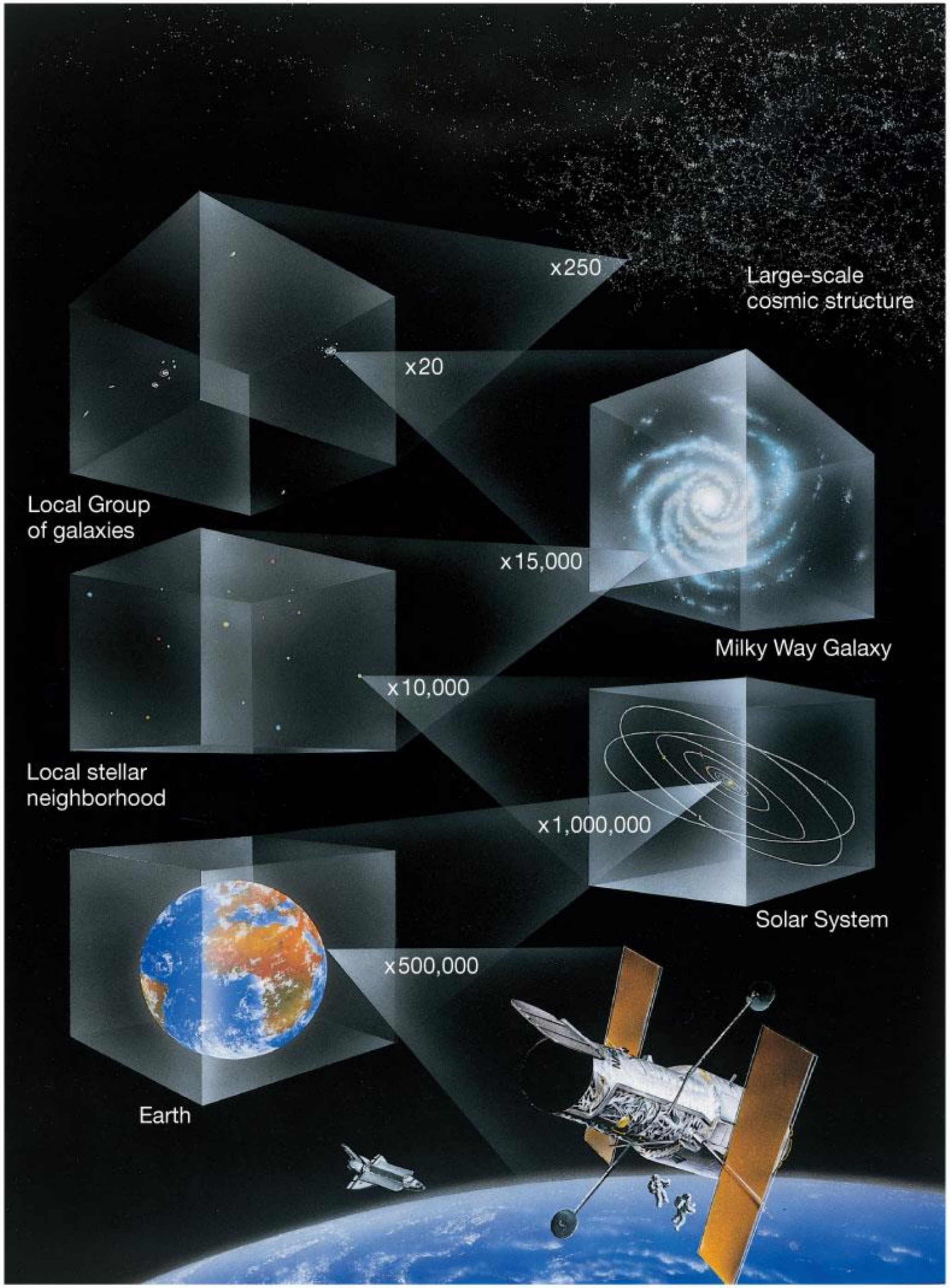
Transits of Venus and Mercury Using Images from the GONG project



Jupiter's Moons and the Speed of Light: The Classic Roemer Experiment

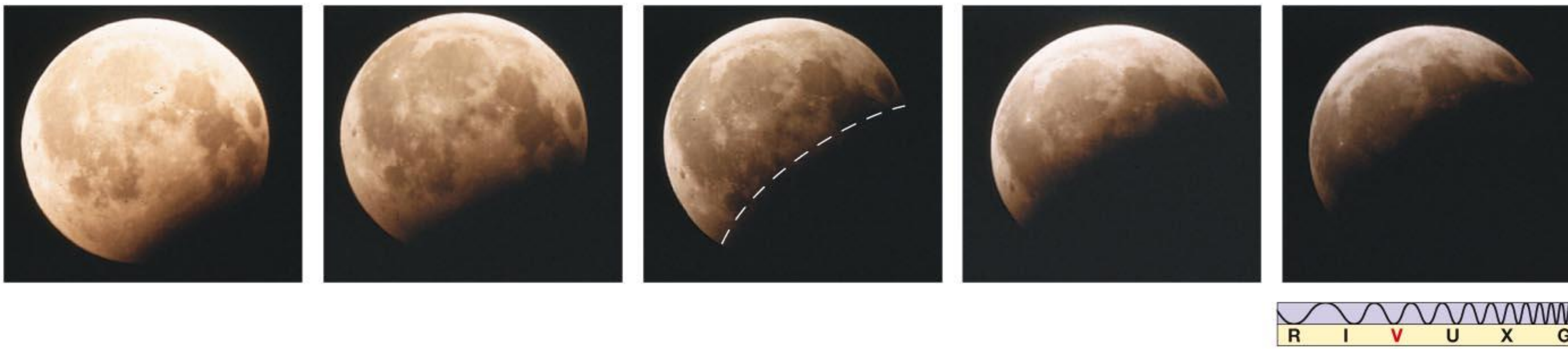
Dying Stars and the Birth of the Elements

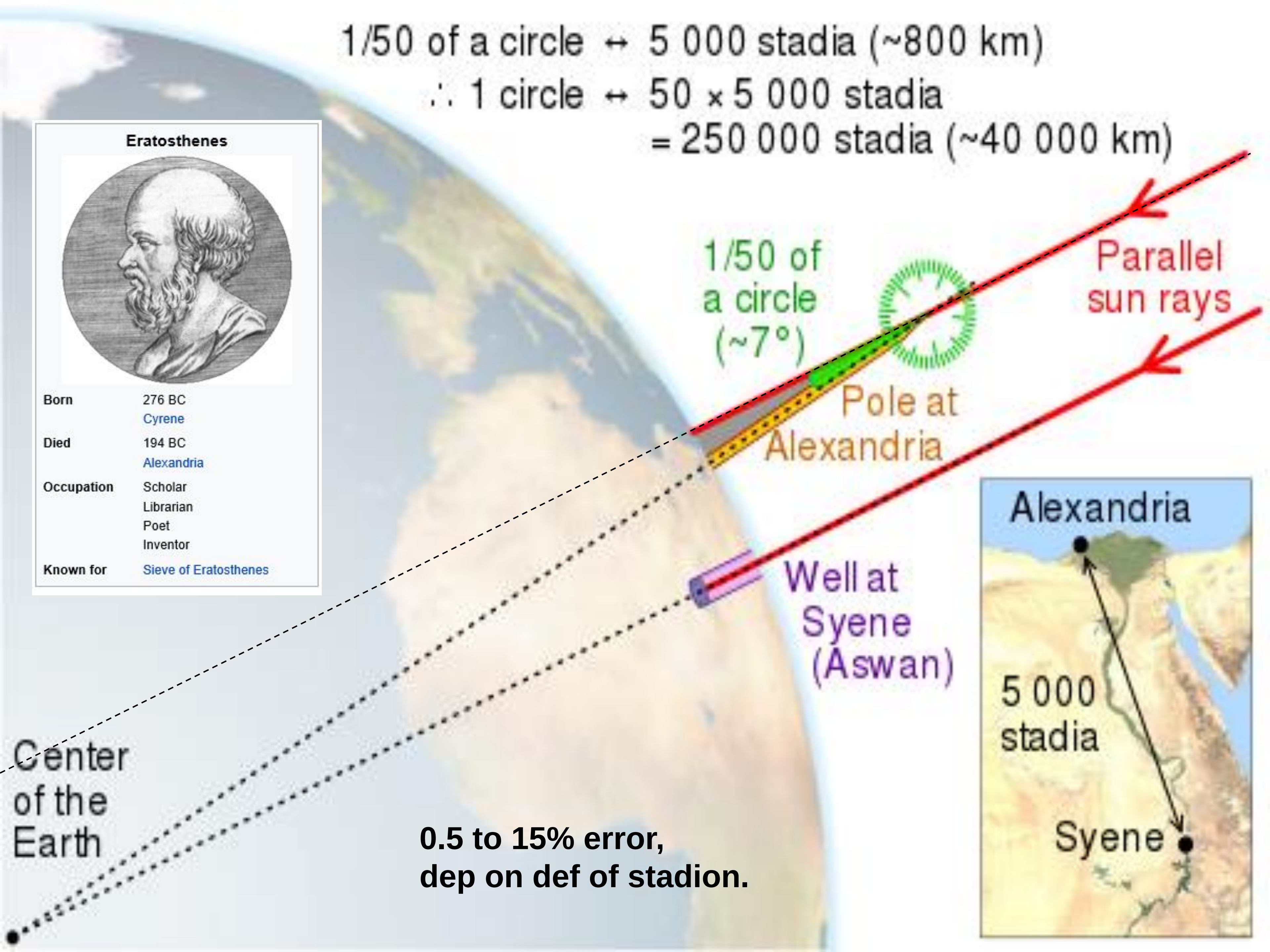

The Height of Lunar Mountains (From an associated NON CLEA DEVELOPER)



● **"Cosmic Voyage" (35 min), narrated by Morgan Freeman. Cosmic zoom from 6:35 to 11:40.**

https://www.youtube.com/watch?v=xEdpSgz8KU4

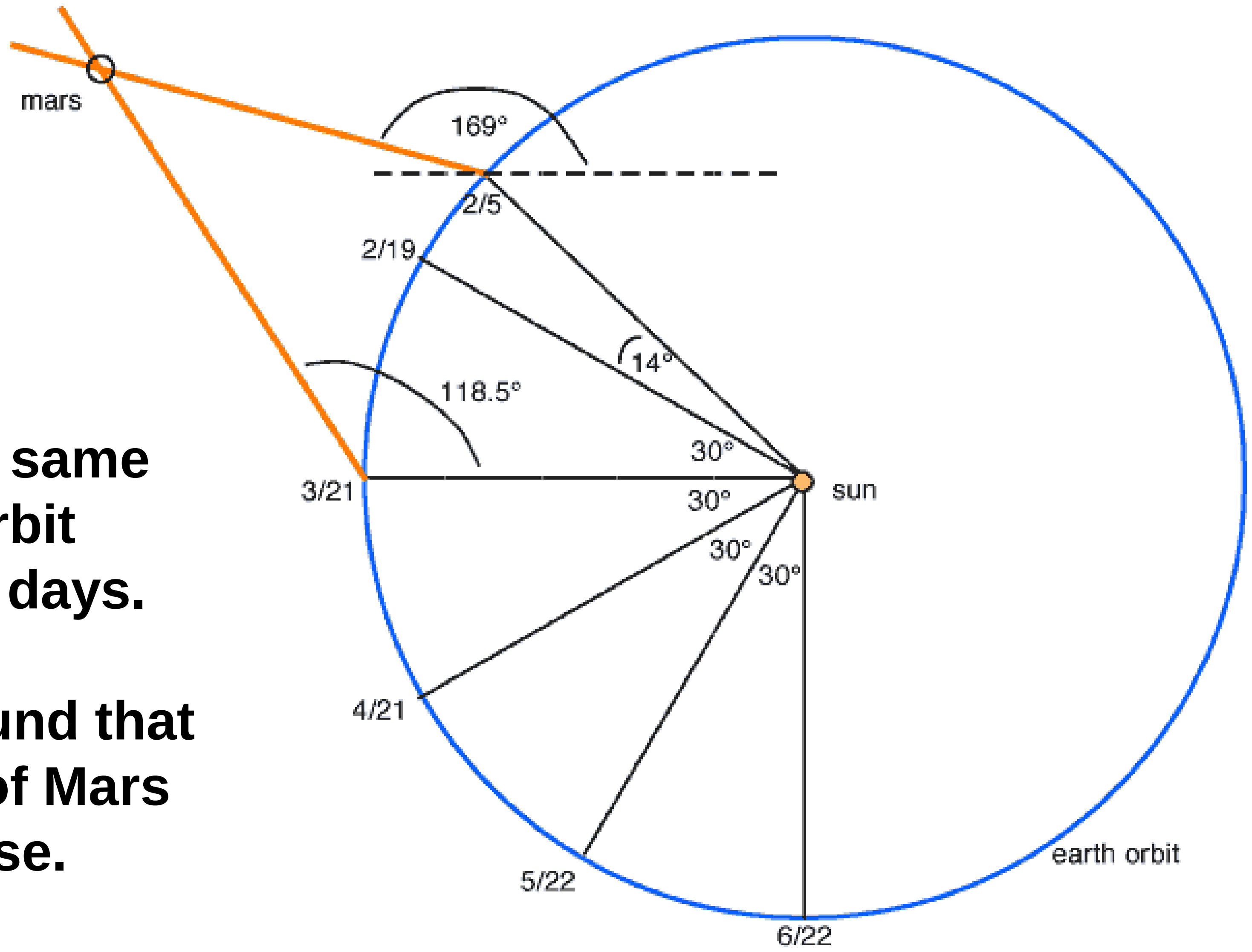

R I V U X G

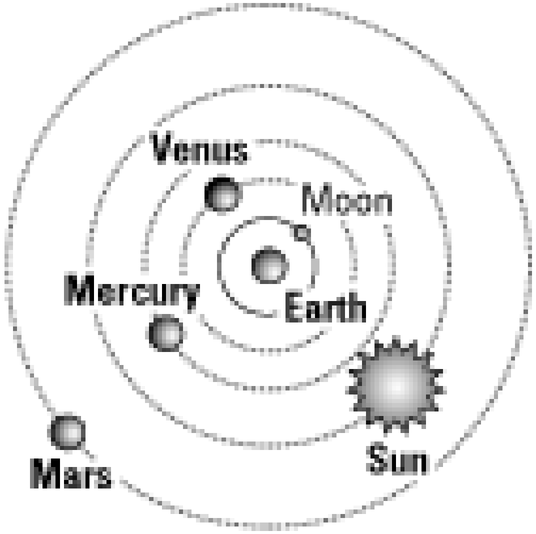


0.5 to 15% error,
dep on def of stadion.

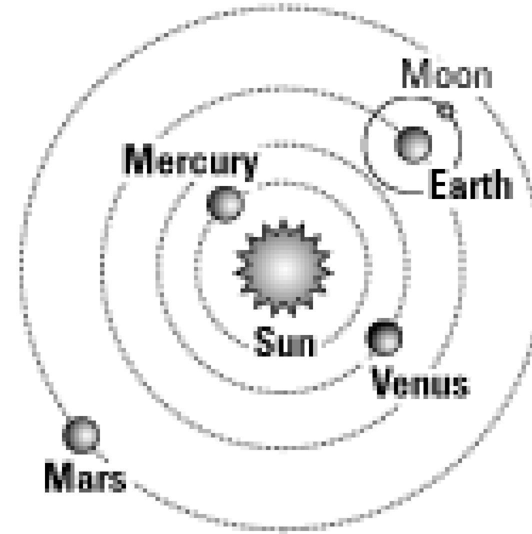
Mars is at same point in orbit every 687 days.

Kepler found that the orbit of Mars is an ellipse.

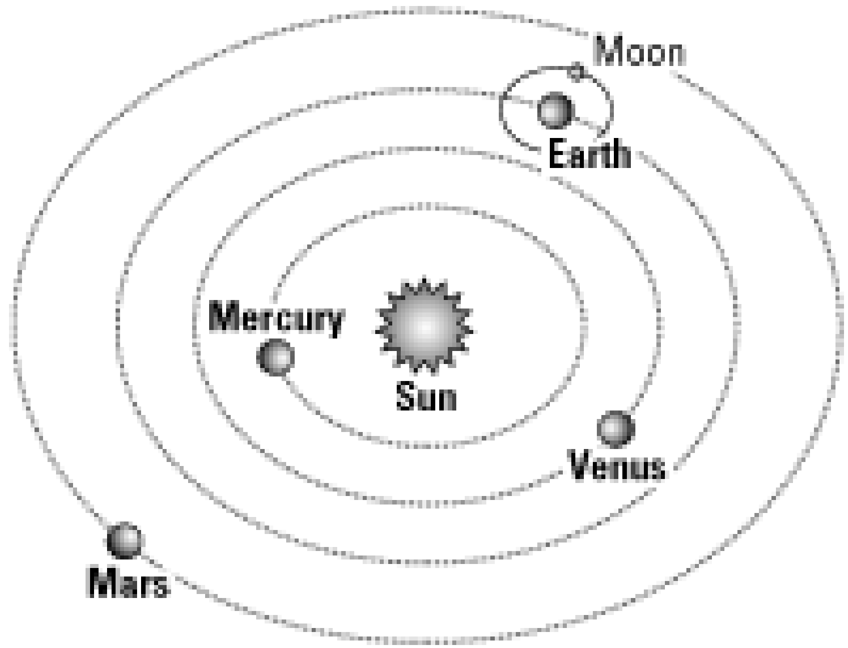




PTOLEMY



COPERNICUS



KEPLER

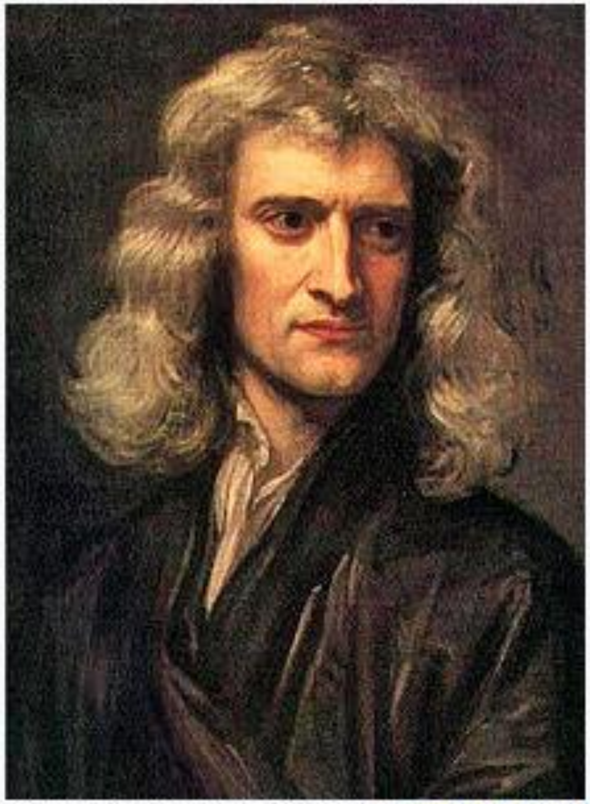
Johannes Kepler (1571 – 1630) found that orbits are ellipses, not circles. Developed Laws of planetary motion.

Planet	P(yr)	a(A.U.)	P^2	a^3
Mercury	0.241	0.387	0.058	0.058
Venus	0.615	0.723	0.378	0.378
Earth	1	1	1	1
Mars	1.881	1.524	3.537	3.537
Jupiter	11.862	5.203	140.7	140.8
Saturn	29.456	9.534	867.7	867.9

$$P^2 = a^3$$

P = Period (in years)
a = semimajor axis (in AU)

Sir Isaac Newton



Portrait of Newton in 1689 by Godfrey Kneller

Born	25 December 1642 [NS: 4 January 1643][1] Woolsthorpe, Lincolnshire, England
Died	20 March 1726/7 (aged 84) [OS: 20 March 1726 NS: 31 March 1727][1] Kensington, Middlesex, England

Newton modified Kepler's 3rd Law

$$P^2 = a^3 / M$$

P = Period (in years)
a = semimajor axis (in AU)
M = total mass in solar units

Newton's Universal Law Of Gravitation

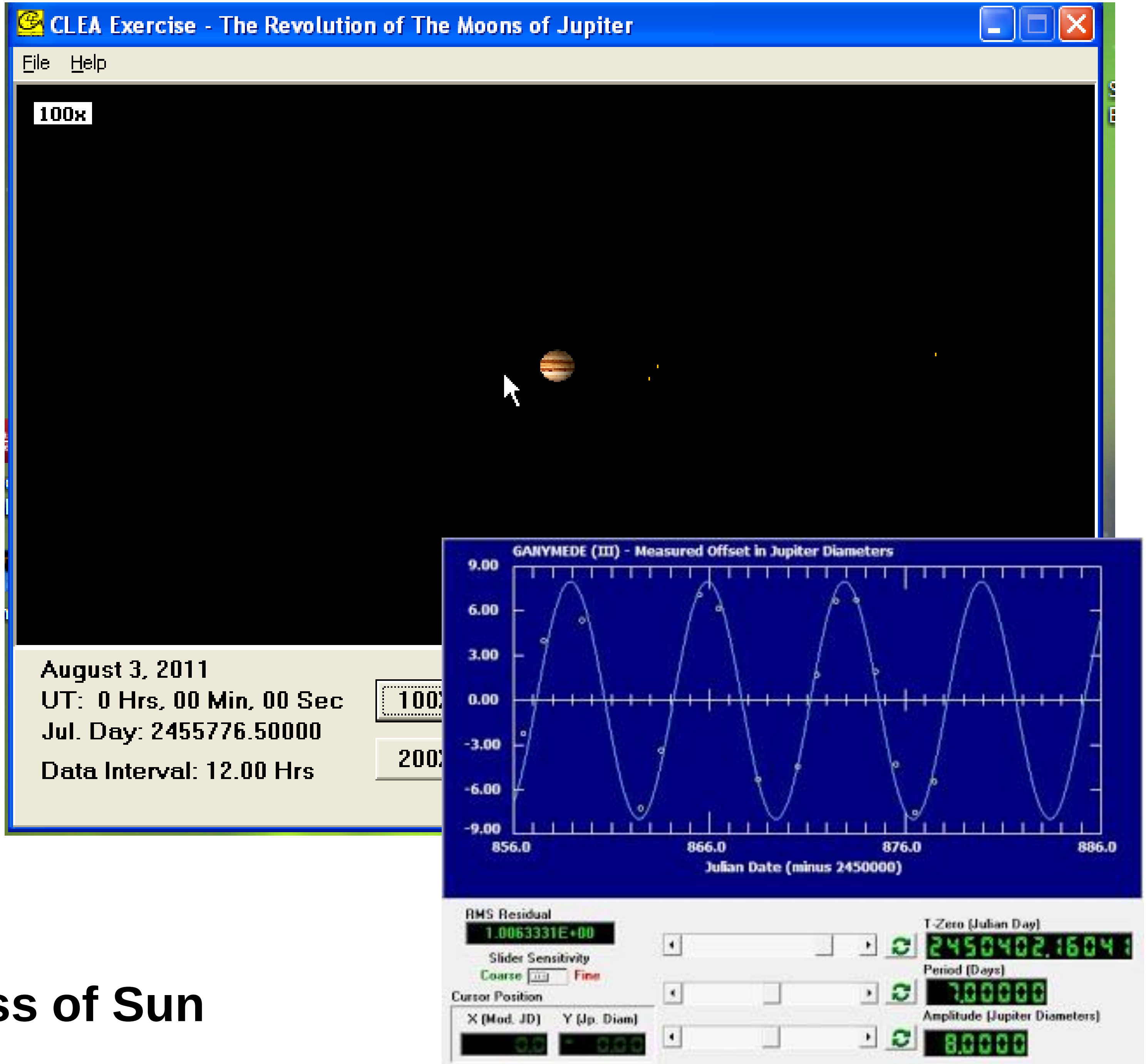
Newton's 2nd Law of Motion

$$F = GMm/r^2 \qquad F = ma$$

$$a = GM/r^2$$

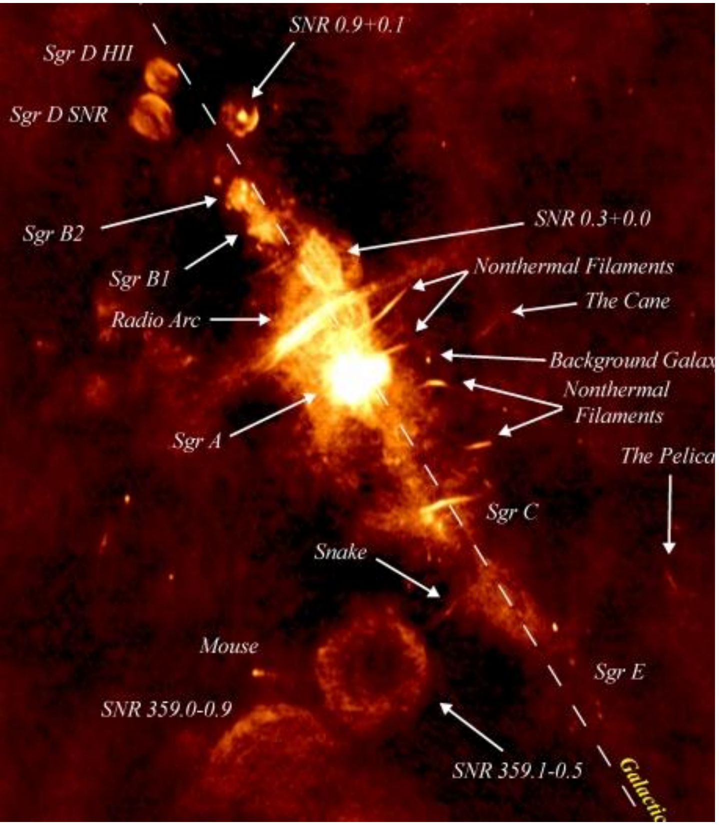
(Vector calculus in polar coordinates)

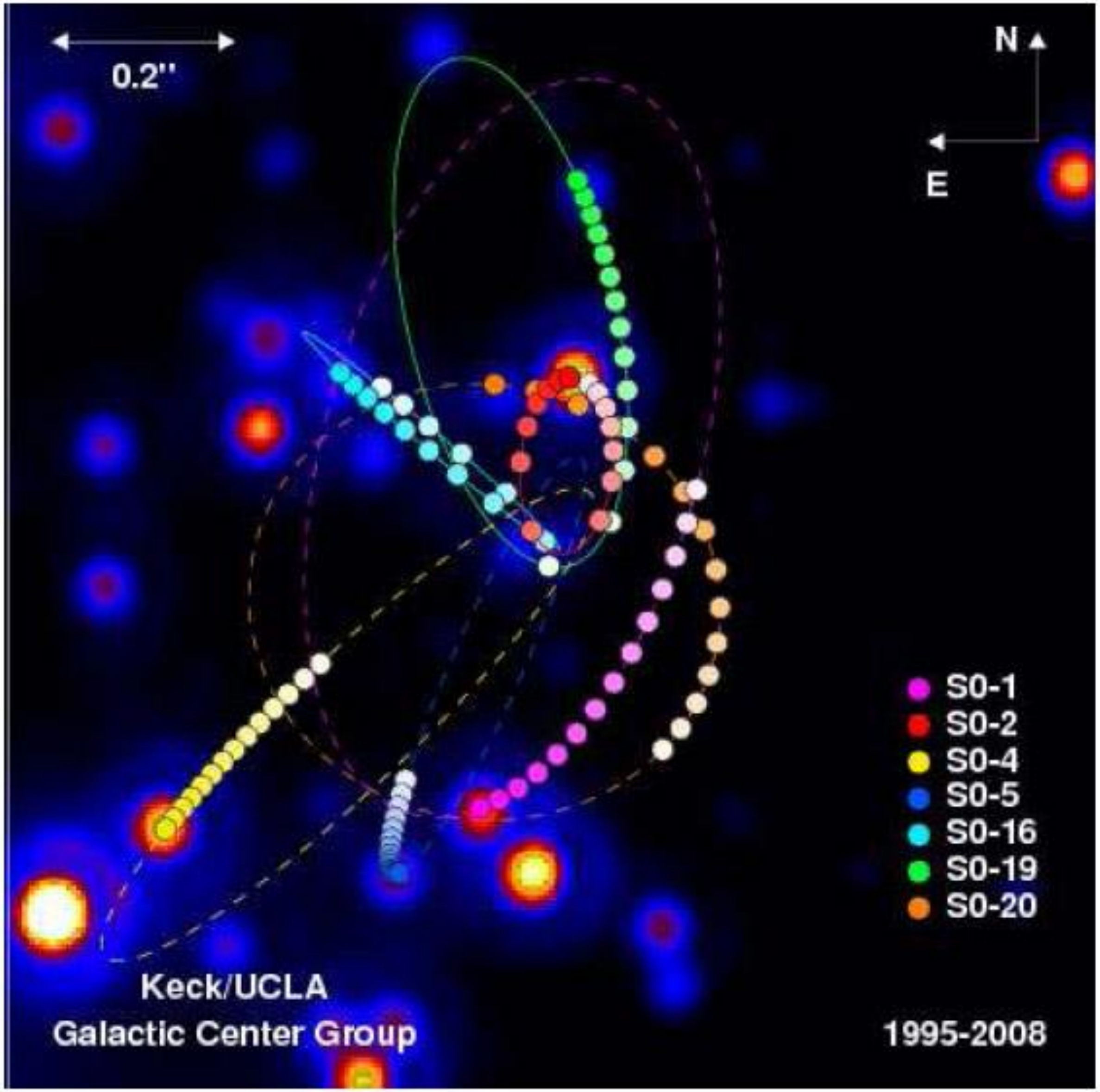
$$P^2 / a^3 = 4 \pi^2 / (M+m)$$



Jupiter
1/1047 mass of Sun

Supermassive black hole Sagittarius A*
4.3 million solar masses

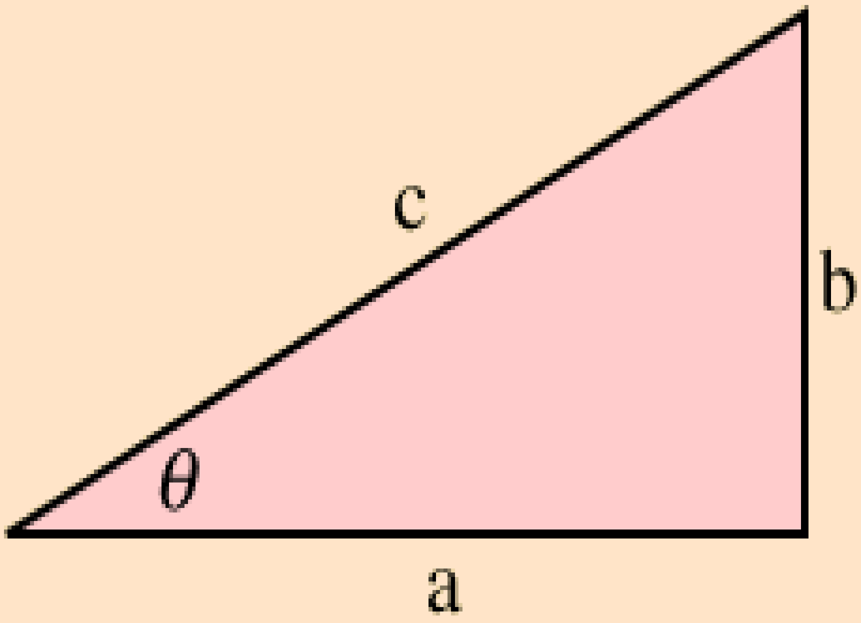




Star S2 reaching speeds exceeding 5000 km/s (11,000,000 mph, or 1/60 the speed of light)

Basic Trigonometric Functions

The basic trigonometric functions can be defined in terms of a right triangle. For the angle θ at one apex of the right triangle the functions can be defined by:



$$\text{sine}: \sin\theta = \frac{b}{c} = \frac{\textit{side opposite } \theta}{\textit{hypotenuse}}$$

$$\text{cosine}: \cos\theta = \frac{a}{c} = \frac{\textit{side adjacent } \theta}{\textit{hypotenuse}}$$

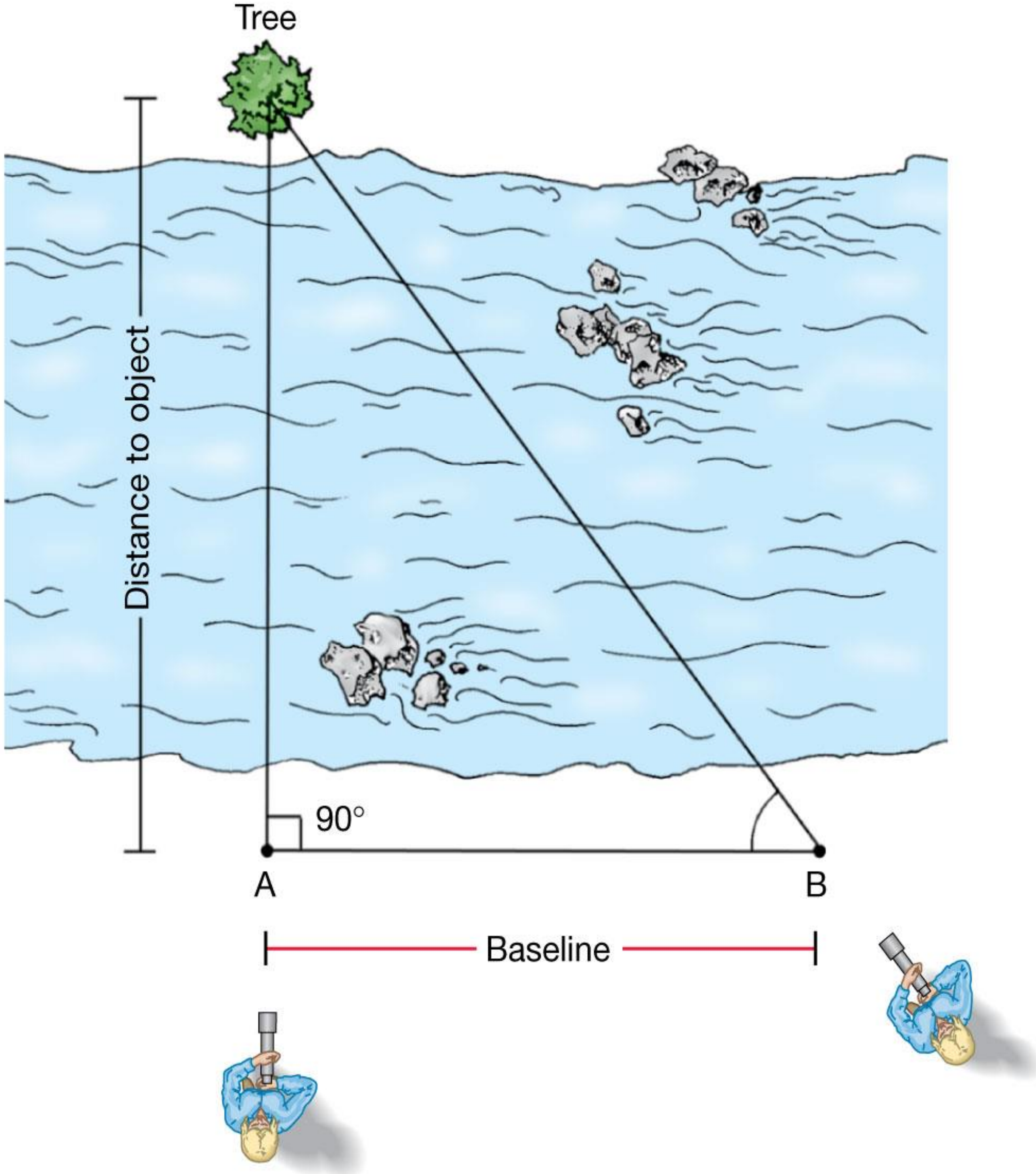
$$\text{tangent}: \tan\theta = \frac{b}{a} = \frac{\textit{side opposite } \theta}{\textit{side adjacent } \theta} = \frac{\sin\theta}{\cos\theta}$$

Triangulation: Measure baseline and angles, can calculate distance

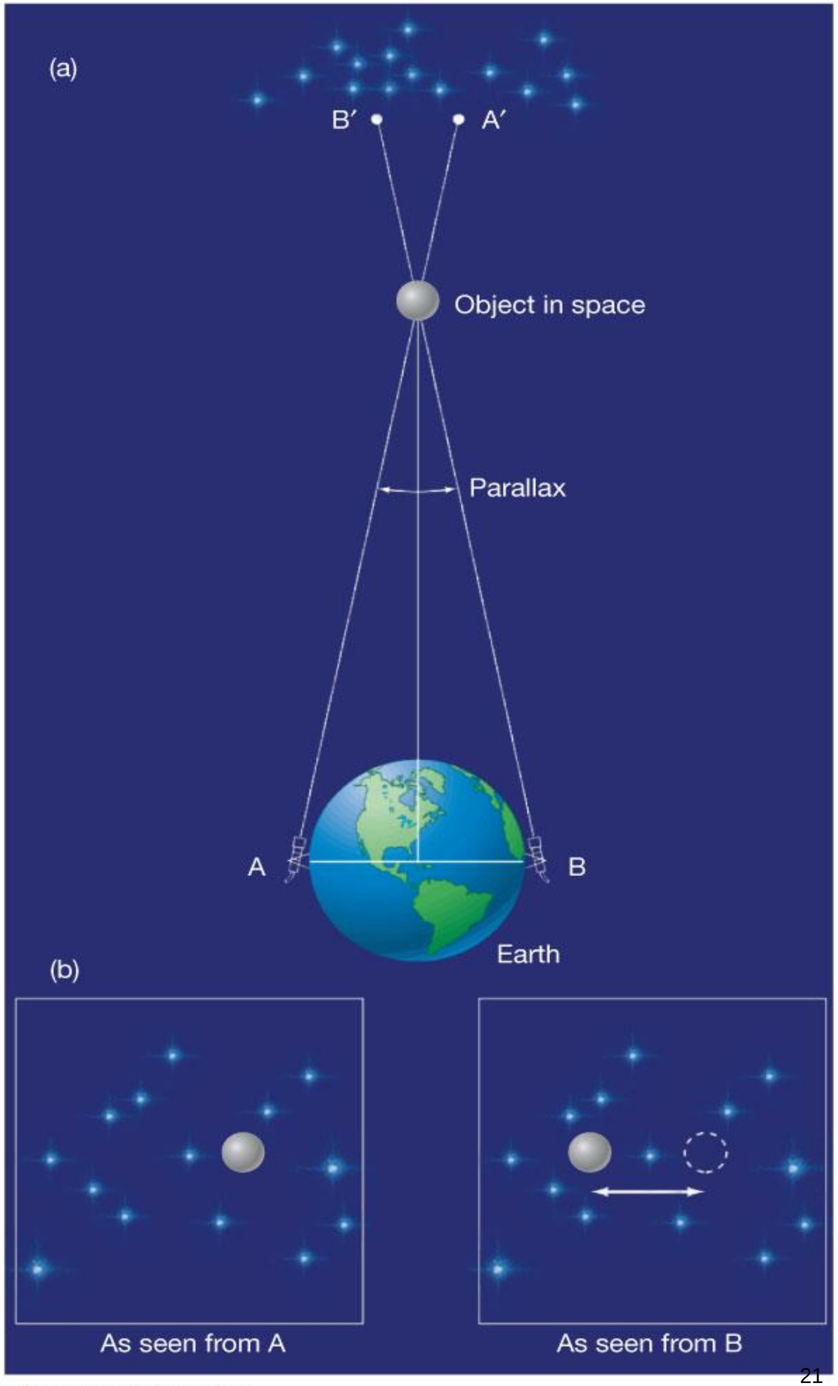
B = 100 m
θ = 60º

$\tan(\theta) = D / B$

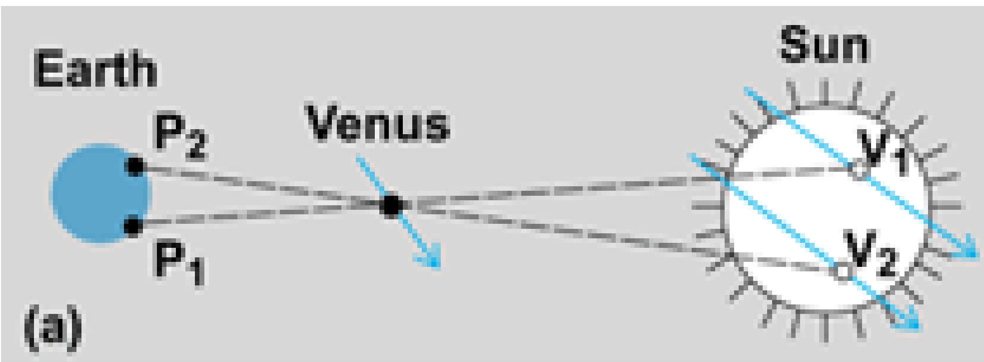
$D = B \tan(\theta)$
$= (100m) \tan(60º)$
$= (100m)(1.732)$
$= 173$ m

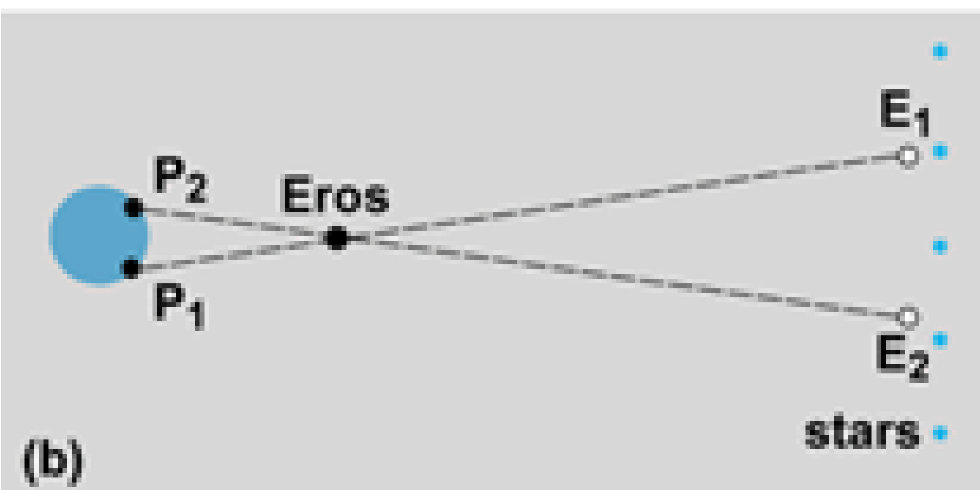


Parallax: Similar to triangulation, but look at apparent motion of object against distant background from two vantage points



Edmond Halley (1656 - 1743) first to propose method of finding AU by measuring the parallax of transits.



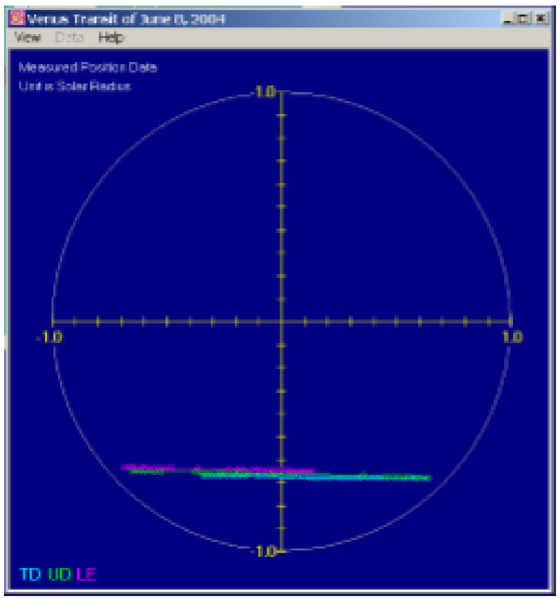


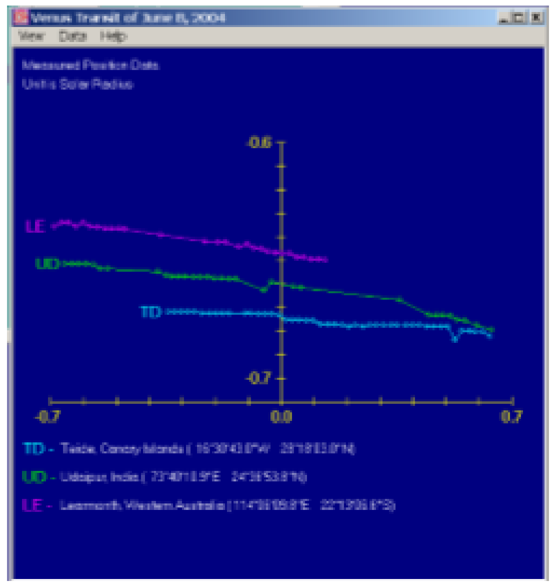
Transit – When inner planets pass between Earth and Sun

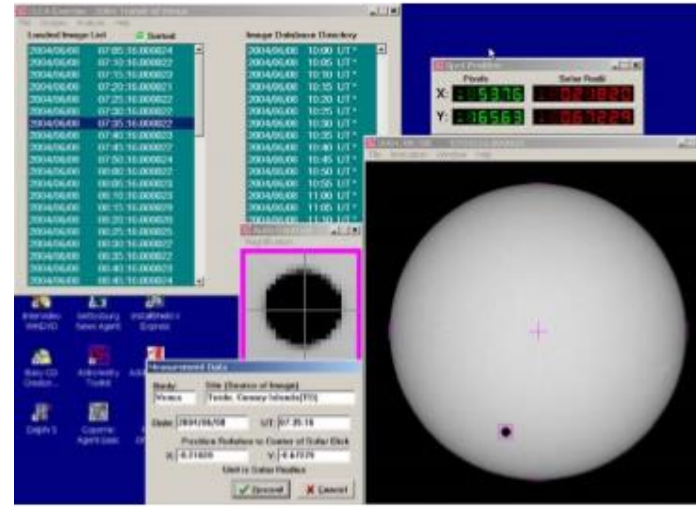
- **Mercury : 1 or 2 per decade**
- **Venus: about 1 pair per century**

1639
1761
1769
1874
1882
2004
2017

TABLE 1: GONG TELESCOPES OBSERVING THE TRANSIT OF VENUS, JUNE 8, 2004		
Site	***Latitude***	***Longitude***
Observatorio del Teide, Tenerife, Spain	+28°17.5'	-16°29.8'
Udaipur Solar Observatory, India	+24° 35.1'	+73°42.8'
Learmonth Solar Observatory Australia	-22°13.2'	+114°6.1'







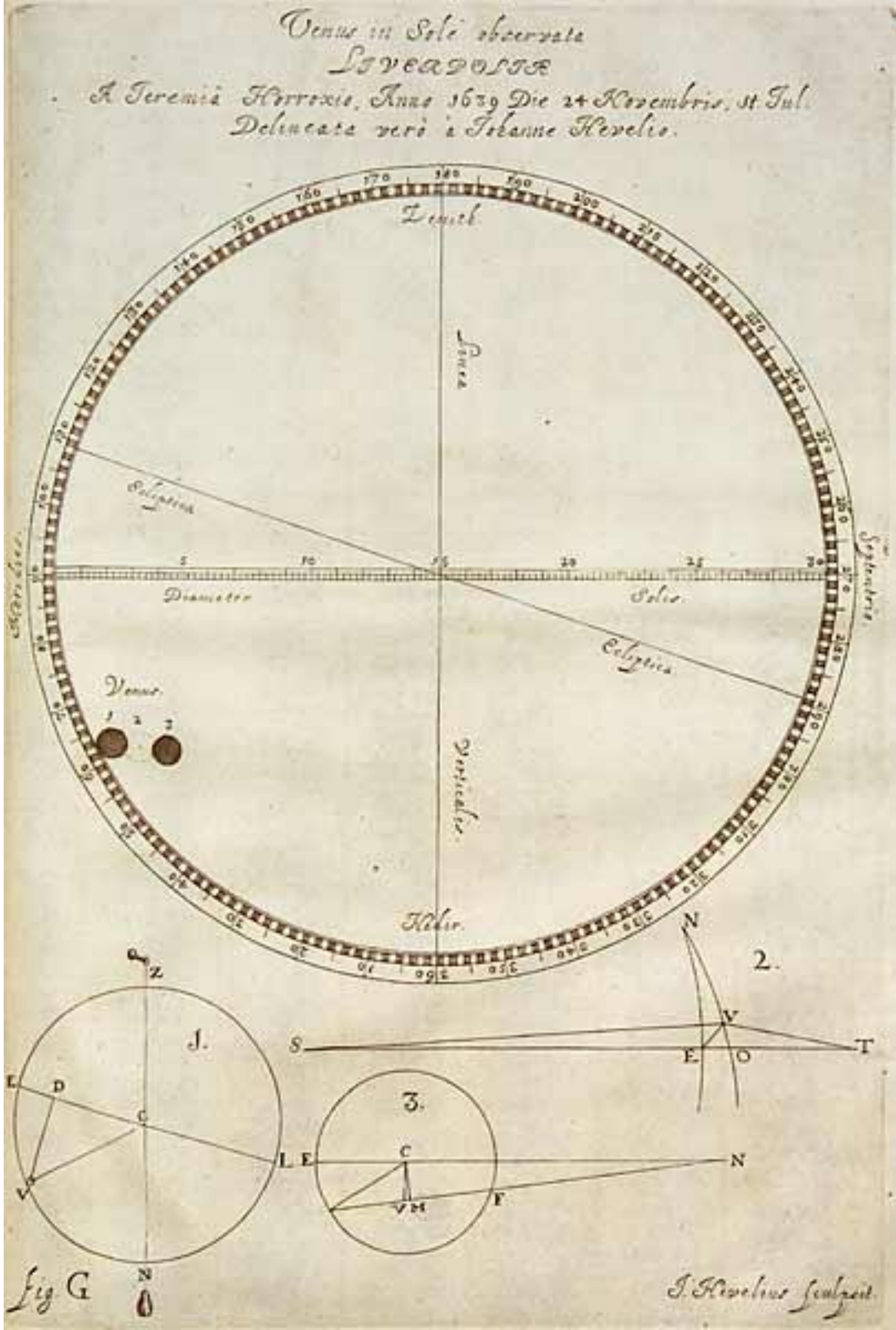
The simple formula you use to calculate the length of the Astronomical Unit **A** in km is:

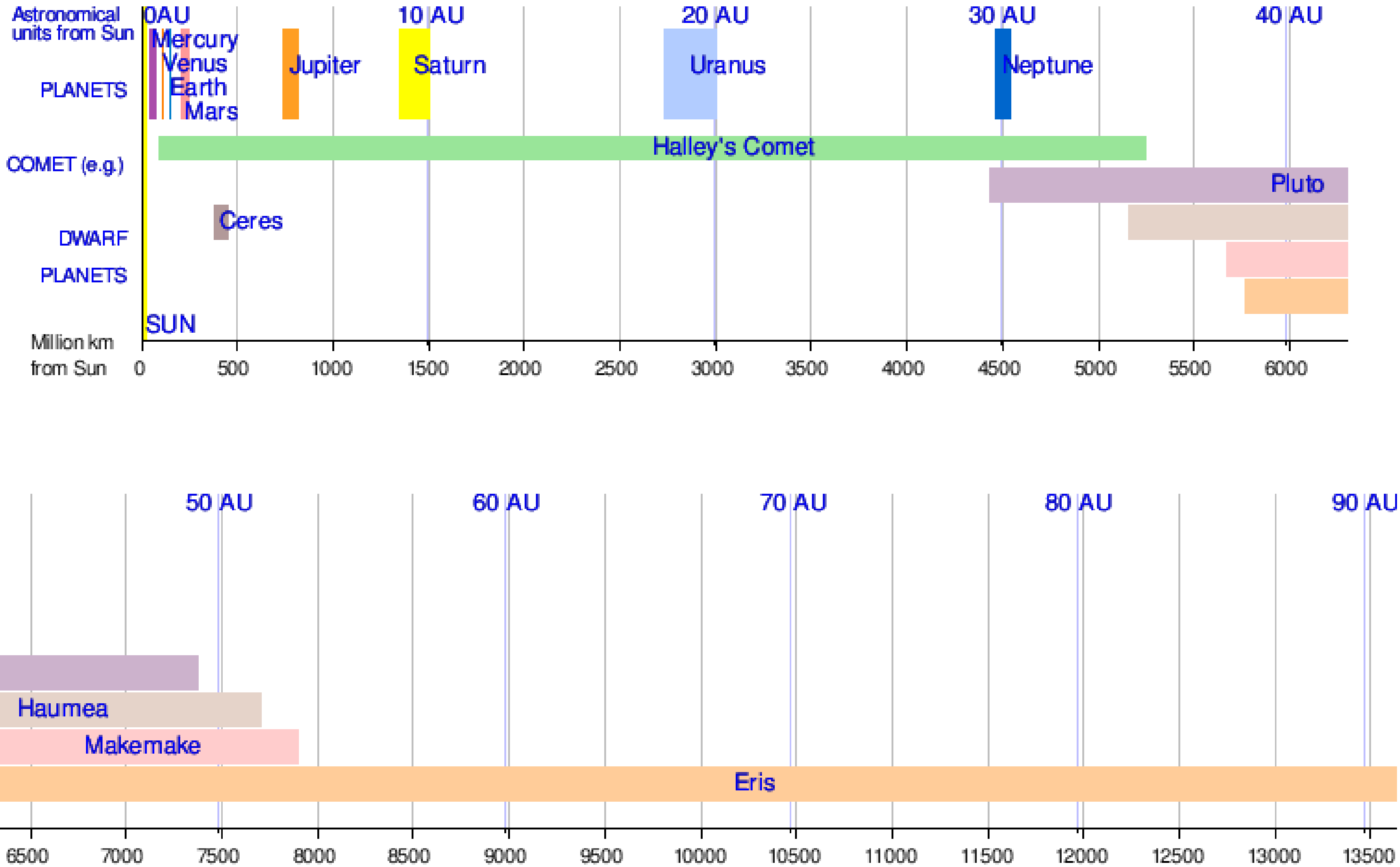
$$\mathbf{A} = \frac{\mathbf{B \cdot (D_{es} - D_{ev}) \cdot 206265}}{\mathbf{\pi_m \cdot D_{ev} \cdot D_{es}}}$$

CAUTION: Be sure your units are correct before you plug into this formula. B is in km, D_{ev} and D_{es} are both in AU, and π_m is in arc seconds!

Transits were important to determine length of the Astronomical Unit (AU), the average distance from the Earth to the Sun.

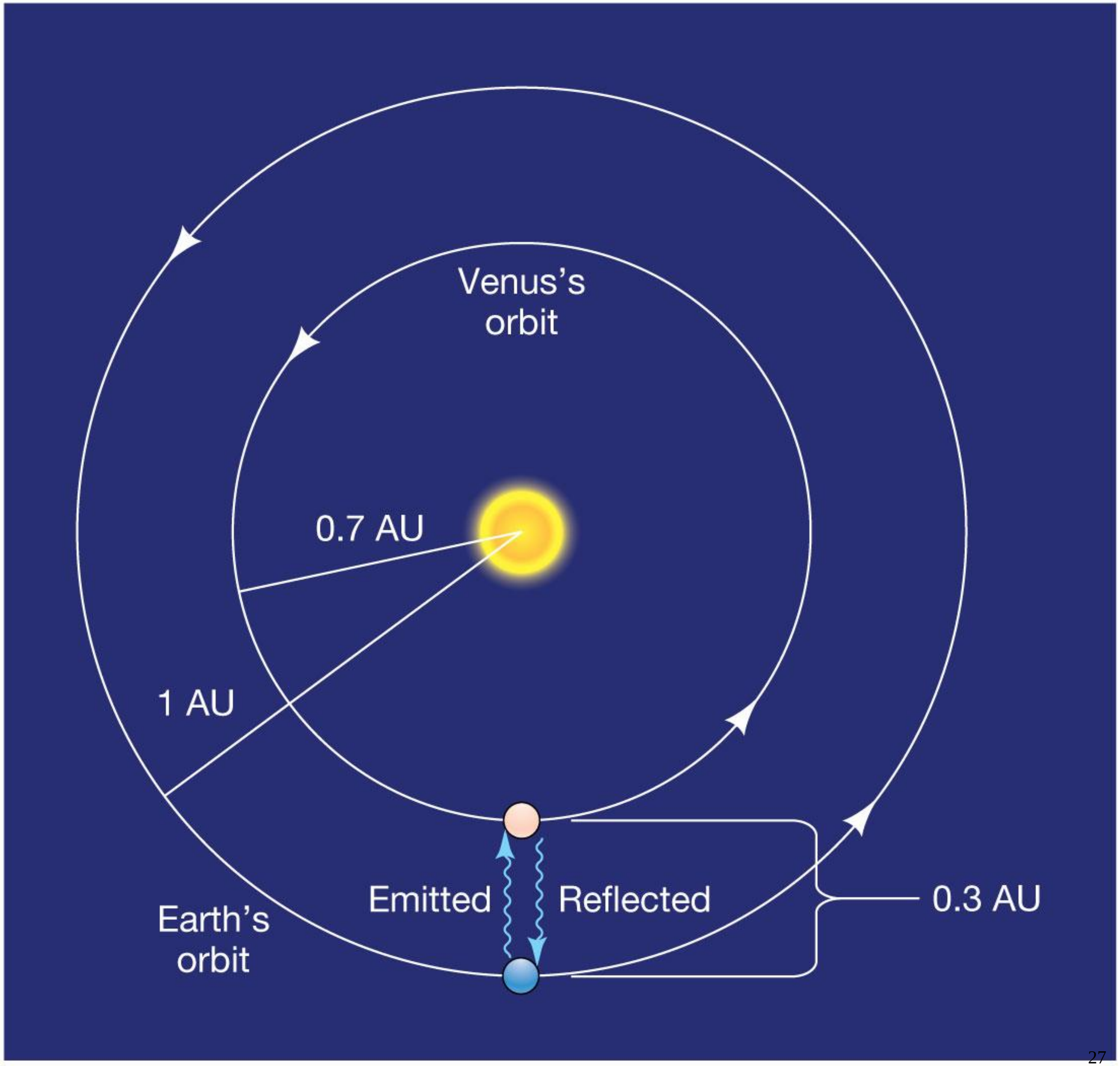
1 AU = 93 million miles
= 9.22956 x10^7 mi
= 1.49598 x10^8 km




Astronomical units from Sun
0AU
10 AU
20 AU
30 AU
40 AU
PLANETS
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
COMET (e.g.)
Halley's Comet
Pluto
Ceres
DWARF PLANETS
SUN
Million km from Sun
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
50 AU
60 AU
70 AU
80 AU
90 AU
Haumea
Makemake
Eris
6500
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500

The Dimensions of the Solar System

Now measured using radar. Ratio of mean radius of Venus's orbit to that of Earth is very well known.



A beam of light is depicted travelling between the Earth and the Moon in the time it takes a light pulse to move between them: 1.255 seconds at their mean orbital (surface-to-surface) distance. The relative sizes and separation of the Earth–Moon system are shown to scale.

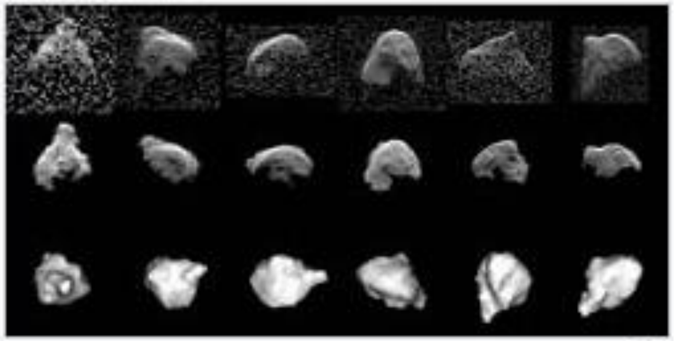
https://en.wikipedia.org/wiki/Speed_of_light#/media/File:Speed_of_light_from_Earth_to_Moon.gif

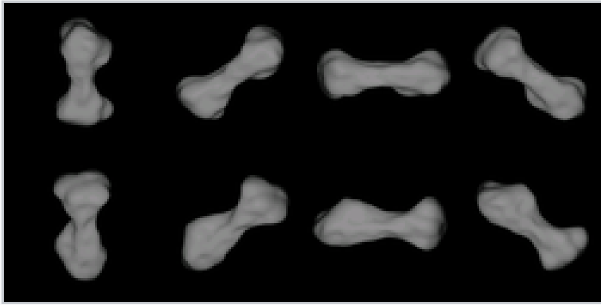
Planet	Distance from Sun in Astronomical Units	Light Travel Time
Mercury	0.38	3.2 minutes
Venus	0.72	6.1 minutes
Earth	1.00	8.5 minutes
Mars	1.52	12.9 minutes
Jupiter	5.20	44.2 minutes
Saturn	9.58	1.4 hours
Uranus	19.14	2.7 hours
Neptune	30.20	4.3 hours

Radar astronomy is a technique of observing nearby astronomical objects by reflecting microwaves off target objects and analyzing the reflections. This research has been conducted for six decades. Radar astronomy differs from radio astronomy in that the latter is a passive observation and the former an active one. Radar systems have been used for a wide range of solar system studies.

The combination of optical and radar observations normally allows the prediction of orbits at least decades, and sometimes centuries, into the future.
Radar provides the ability to study shape, size and spin state of asteroids and comets from the ground. Radar imaging has produced images with up to 7.5-m resolution. With sufficient data, the size, shape, spin and radar albedo of the target asteroids can be extracted.

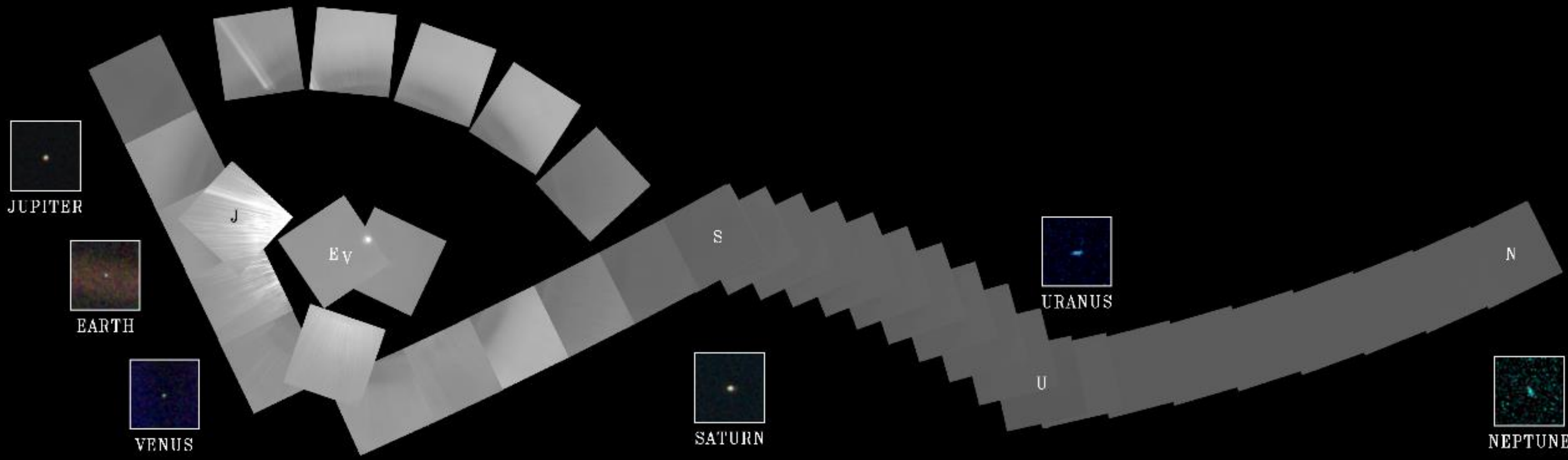
Only 19 comets have been studied by radar,[8] including 73P/Schwassmann-Wachmann. There have been radar observations of 612 Near-Earth asteroids and 138 Main belt asteroids.

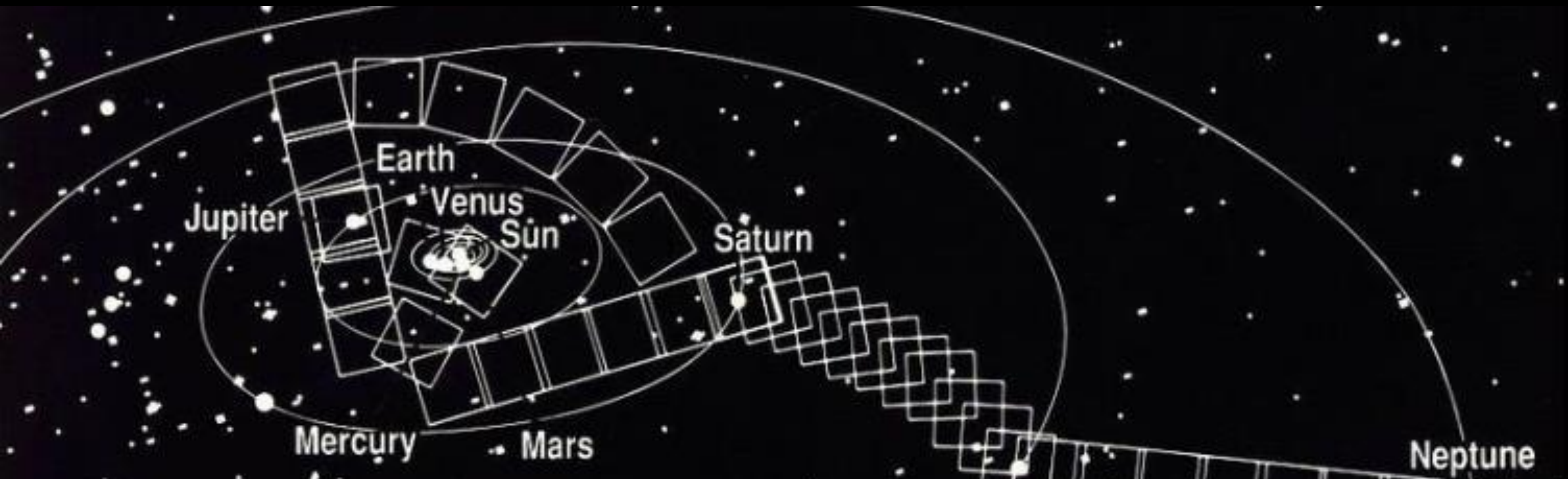

Radar images and computer model of asteroid 1999 JM8


Computer model of asteroid (216) Kleopatra, based on radar analysis.

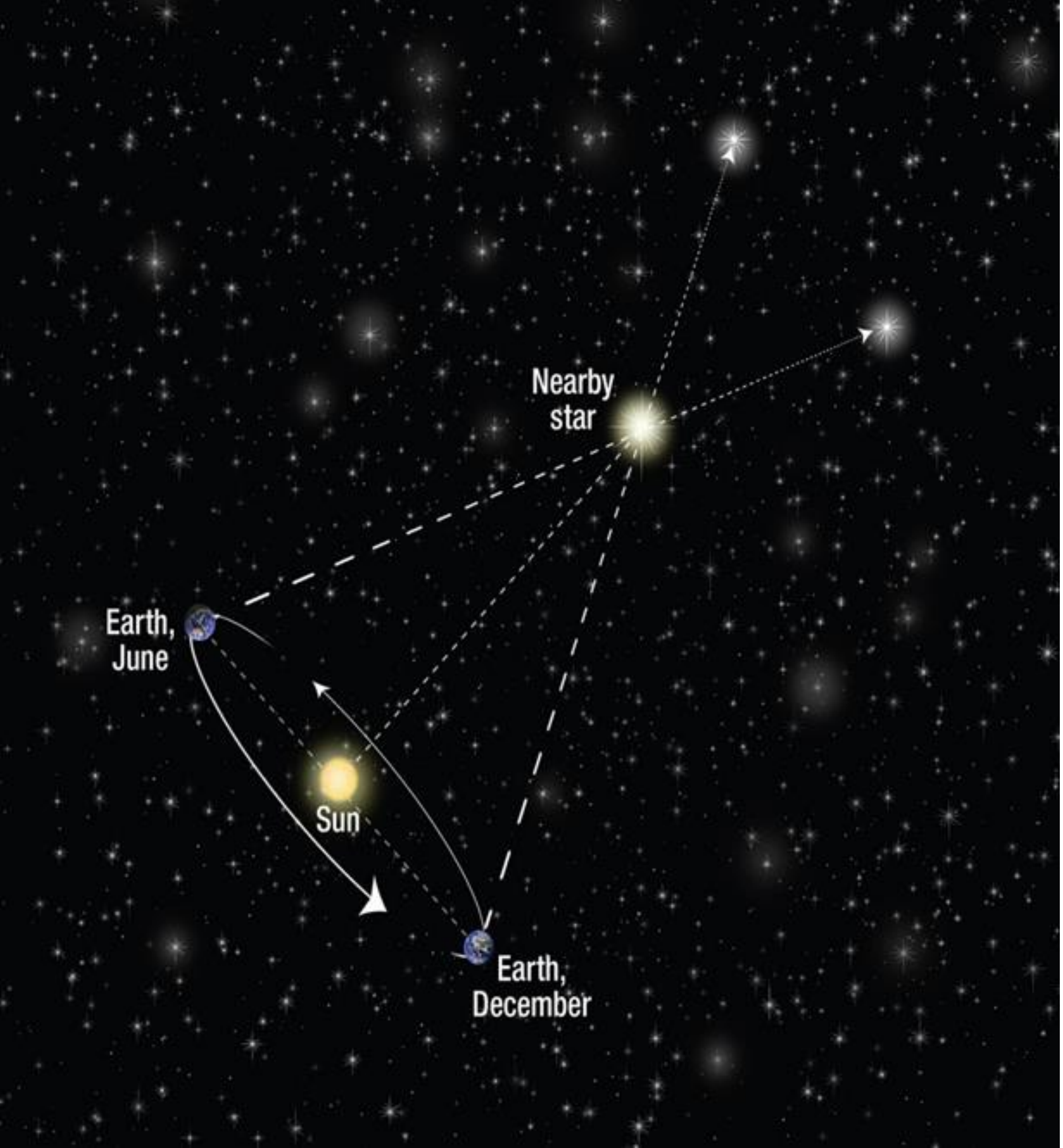

70 m antenna at Goldstone

"Family Portrait", 1990, Voyager 1.6 billion km





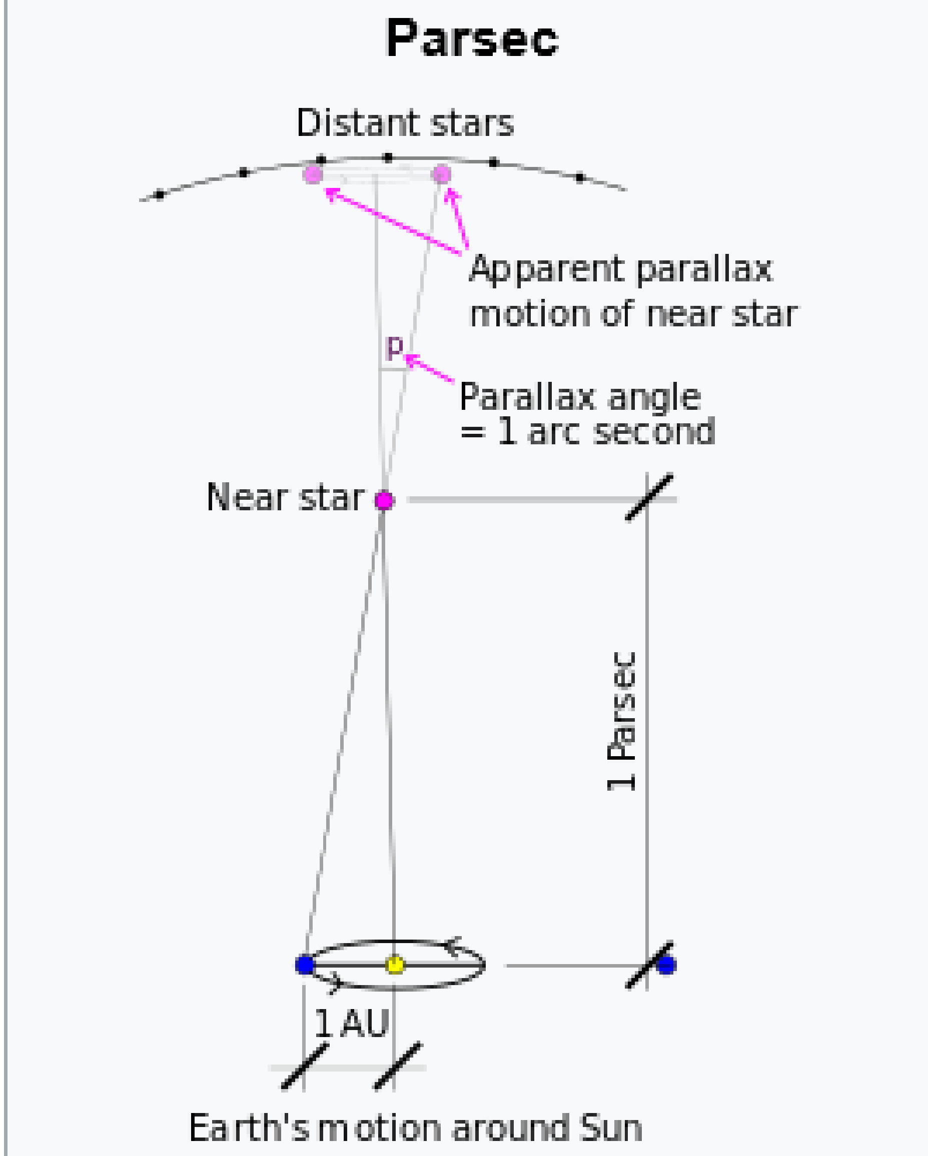
[The Pale Blue Dot - Cosmos: A Space Time Odyssey (3.5 min)](https://www.youtube.com/watch?v=GO5FwsblpT8)
https://www.youtube.com/watch?v=GO5FwsblpT8
https://en.wikipedia.org/wiki/Pale_Blue_Dot
https://en.wikipedia.org/wiki/Family_Portrait_(Voyager)
https://en.wikipedia.org/wiki/Cosmos:_A_Spacetime_Odyssey



Proper Motion of Ursa Major (the Big Dipper)
https://www.youtube.com/watch?v=txJH8RlIoXQ

Stellar Parallax (exaggerated)
https://www.youtube.com/watch?v=_D7sbn27arE

Parallax - Polaris, Big Dipper with proper motion (exaggerated)
https://www.youtube.com/watch?v=-scjpUI9ksA



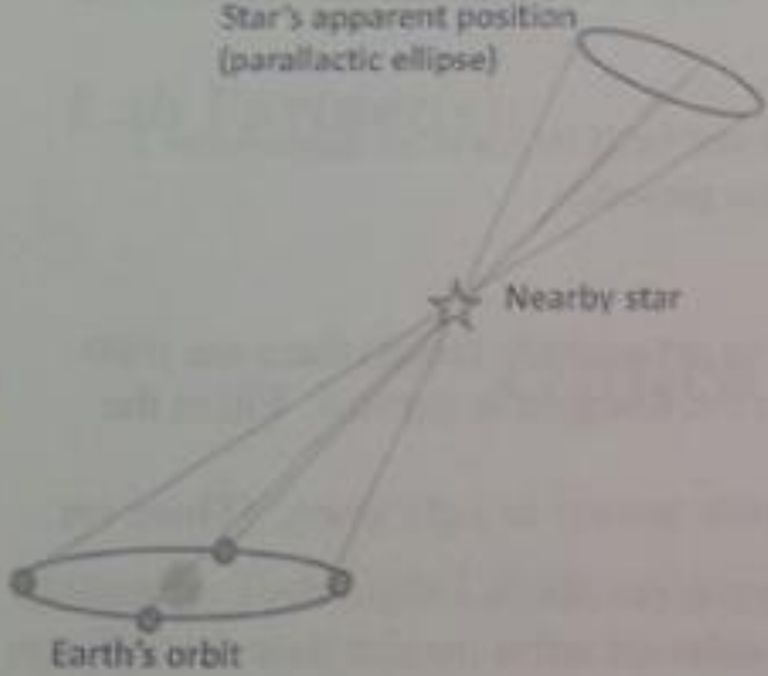
A parsec is the distance from the Sun to an astronomical object that has a parallax angle of one arcsecond (the diagram is not to scale).

Unit information	
Unit system	astronomical units
Unit of	length
Symbol	pc
Unit conversions	
1 pc in ...	*... is equal to ...*
metric (SI) units	3.0857×10^{16} m ~31 Petametres
imperial & US units	1.9174×10^{13} mi
astronomical units	2.0626×10^{5} au 3.261 56 ly

Small angles so use
d(pc) = 1 / p(arcsec)

Table 2. Parallaxes (Half-Angle) of Three Nearby Stars as Measured by Hipparcos [Extracted from Ref 5]

Name	Parallax (mas)	Parallax Std Error (mas)	Distance (parsecs)	Distance (light years)
Alpha Centauri	742.12	1.40	1.35	4.39
Vega (Alpha Lyrae)	128.93	0.55	7.76	25.3
Sirius (Alpha Canis Majoris)	379.21	1.58	2.64	8.62



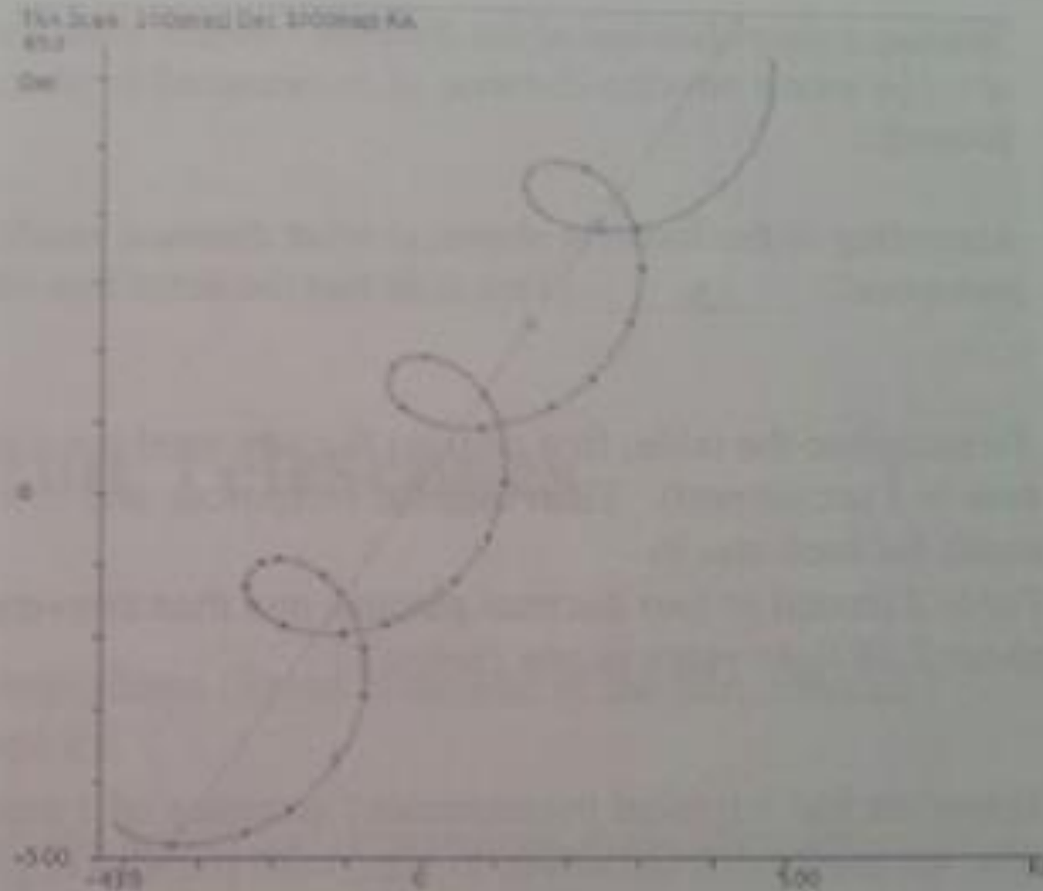
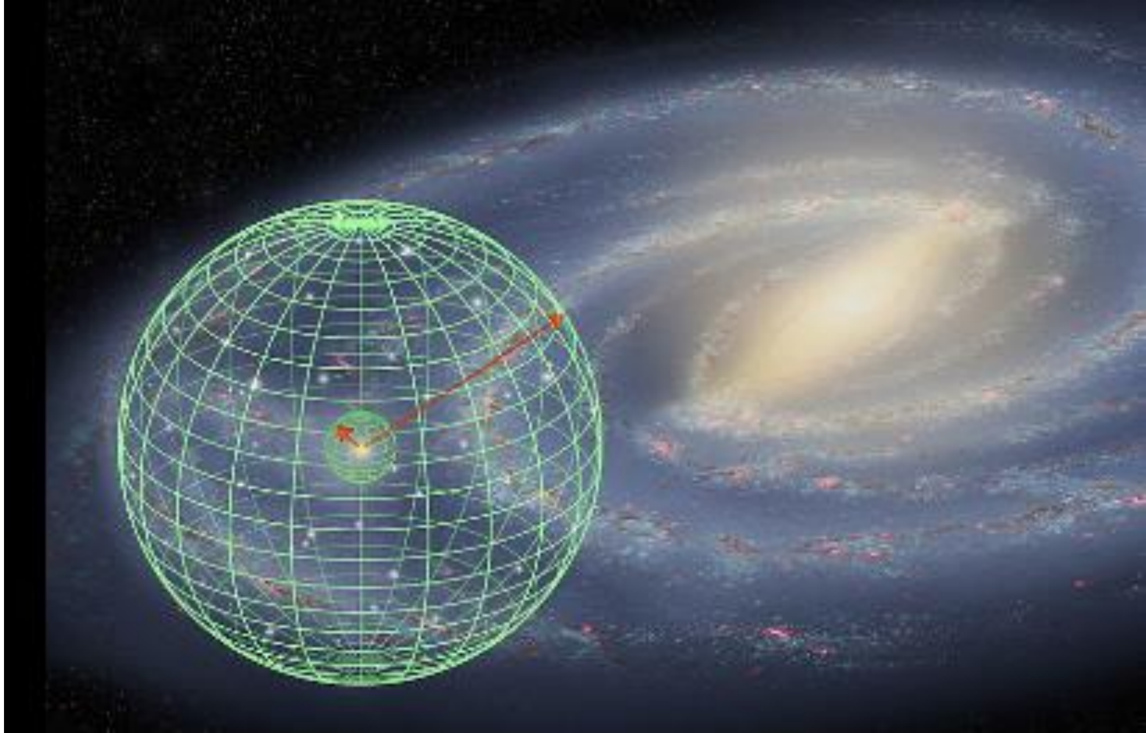


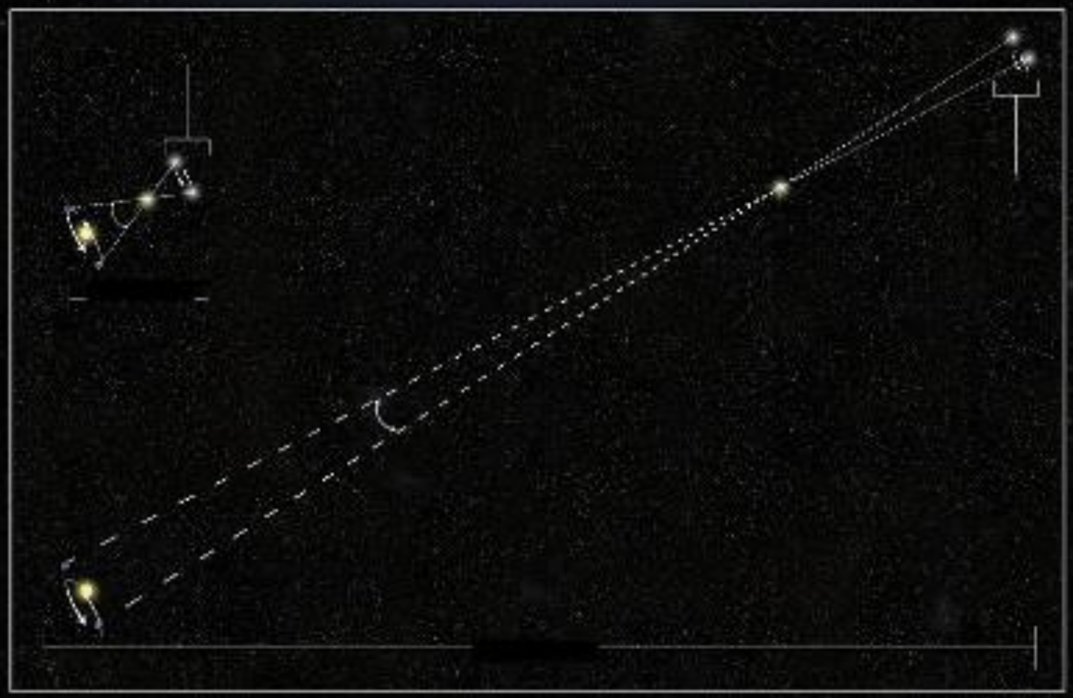
Figure 5. *Plot of position of the bright star Vega over a period of 3 years as measured by the Hipparcos satellite [from Ref 4]. The curlicue is due to a combination of the star's parallax (an ellipse for a stationary star) and its proper motion across the sky (straight line).*

Ground-based telescope measurements of parallax angle is limited to about 0.01 arcseconds, and thus to stars no more than 100 pc distant.

Hipparcos satellite, with an astrometric precision of about 0.97 milliarcseconds, obtained accurate measurements for stellar distances of stars up to 1000 pc away.

Gaia satellite, with precision of 20 microarcseconds, produces errors of 10% in measurements as far as the Galactic Centre, about 8000 pc away.





The Solar Neighborhood

The Solar Neighborhood

The 30 closest stars to the Sun

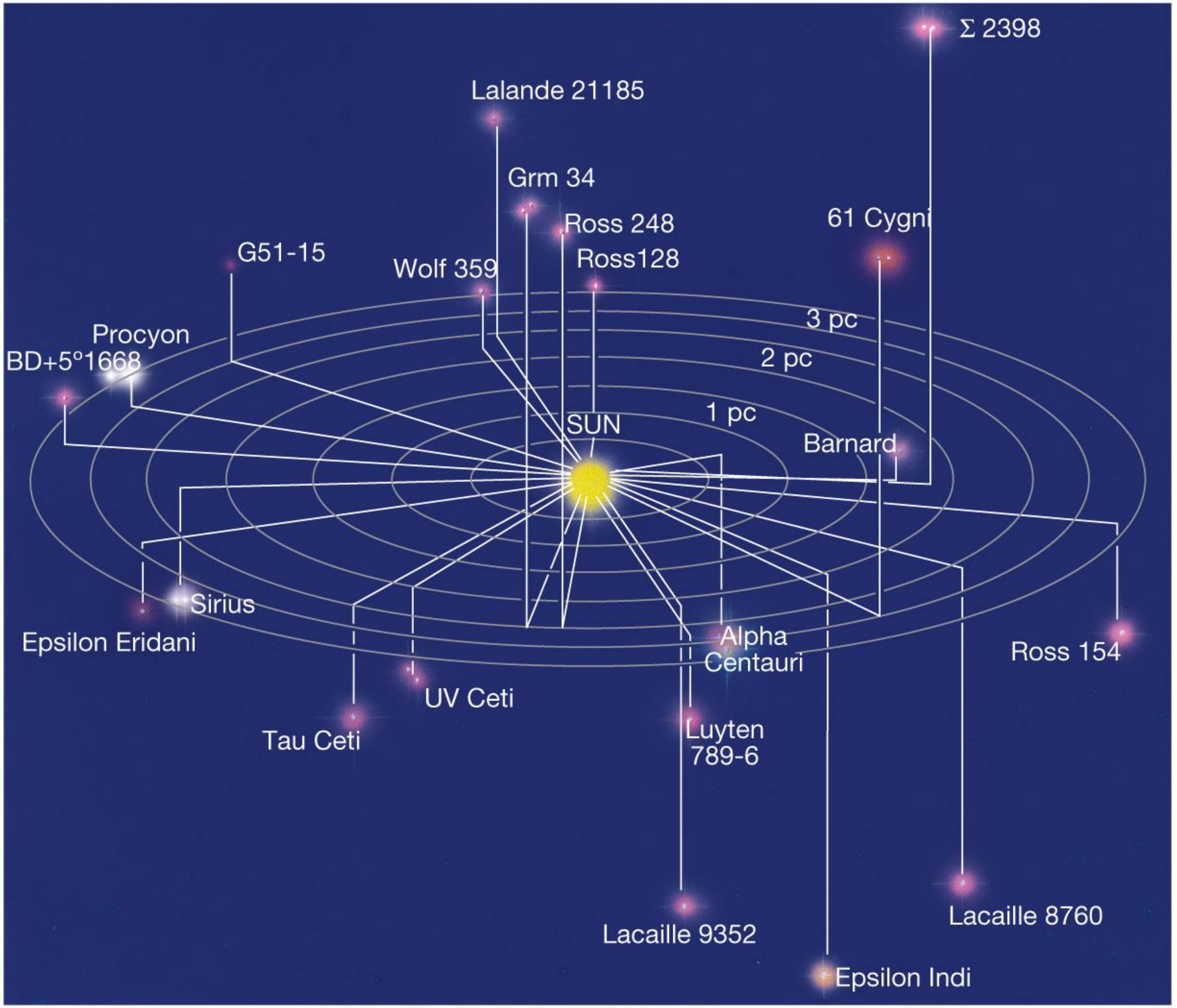
(within 4 pc or 13 ly)

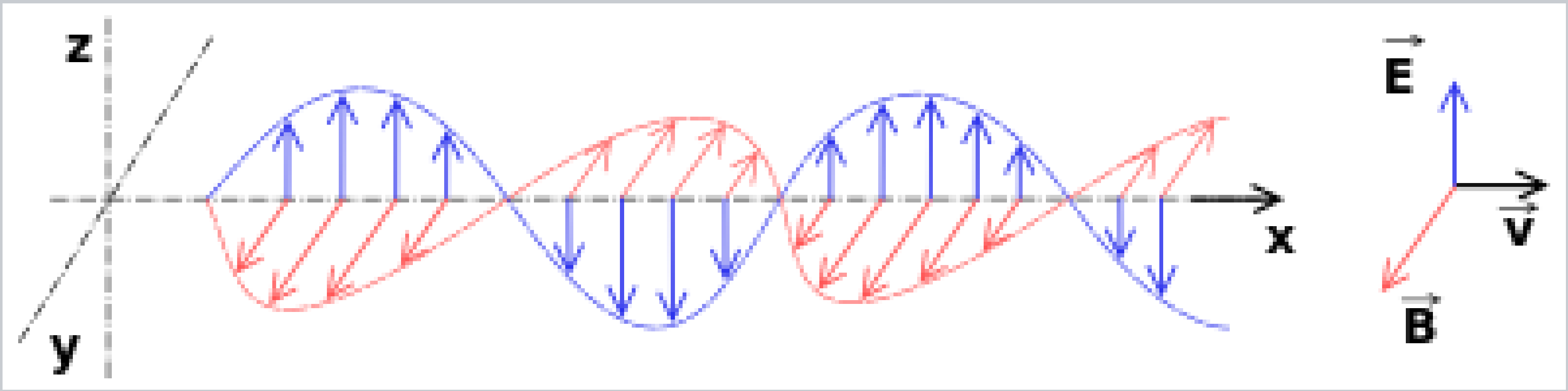
Proxima Centauri

parallax = 0.77”

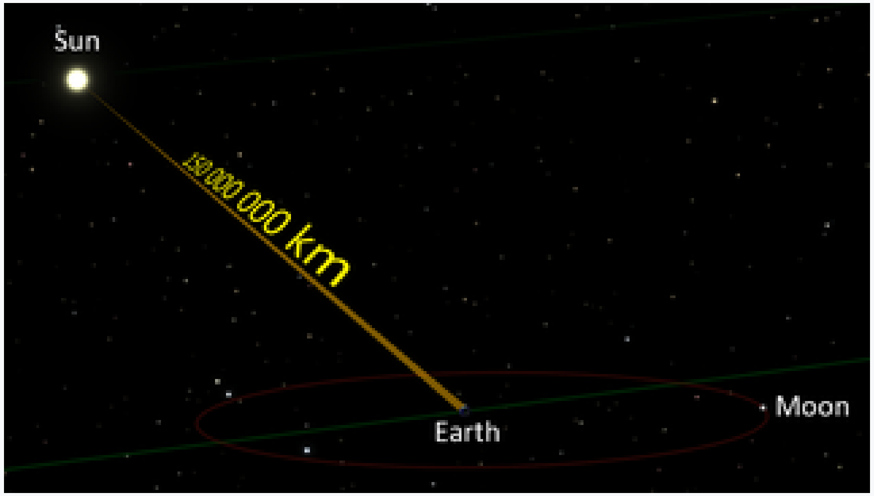
= 270,000 AU

= 4.3 light-years





The electromagnetic waves that compose electromagnetic radiation can be imagined as a self-propagating transverse oscillating wave of electric and magnetic fields. This diagram shows a plane linearly polarized EMR wave propagating from left to right (X axis). The electric field is in a vertical plane (Z axis) and the magnetic field in a horizontal plane (Y axis). The electric and magnetic fields in EMR waves are always in phase and at 90 degrees to each other.



Sunlight takes about 8 minutes 17 seconds to travel the average distance from the surface of the Sun to the Earth.

Exact values	
metres per second	299 792 458
Planck length per Planck time (i.e., Planck units)	1

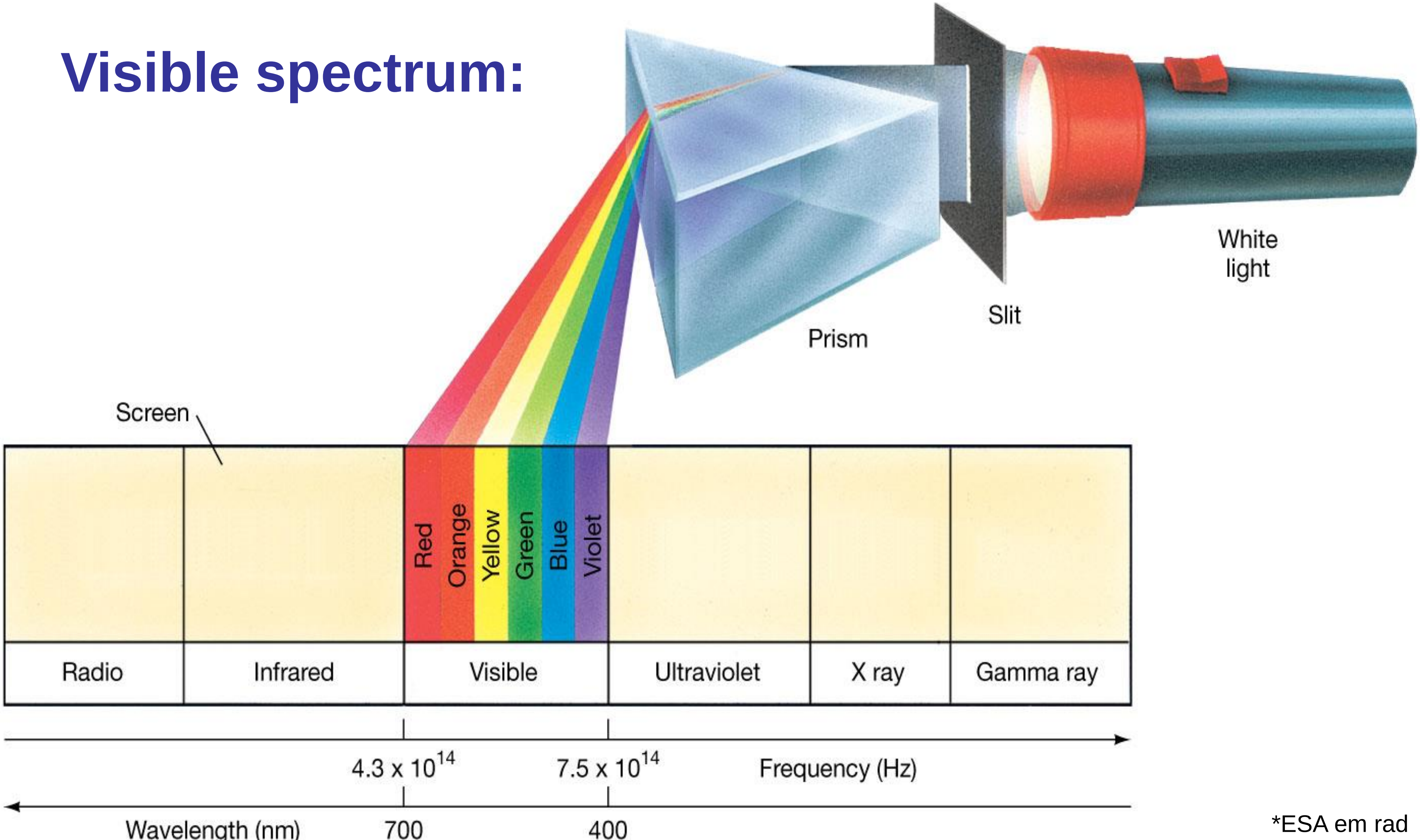
Approximate values (to three significant digits)	
kilometres per hour	1080 million (1.08×10^9)
miles per second	186 000
miles per hour[1]	671 million (6.71×10^8)
astronomical units per day	173[Note 1]
parsecs per year	0.307[Note 2]

Approximate light signal travel times

Distance	Time
one foot	1.0 ns
one metre	3.3 ns
from geostationary orbit to Earth	119 ms
the length of Earth's equator	134 ms
from Moon to Earth	1.3 s
from Sun to Earth (1 AU)	8.3 min
one light year	1.0 year
one parsec	3.26 years
from nearest star to Sun (1.3 pc)	4.2 years
from the nearest galaxy (the Canis Major Dwarf Galaxy) to Earth	25 000 years
across the Milky Way	100 000 years
from the Andromeda Galaxy to Earth	2.5 million years
from Earth to the edge of the observable universe	46.5 billion years

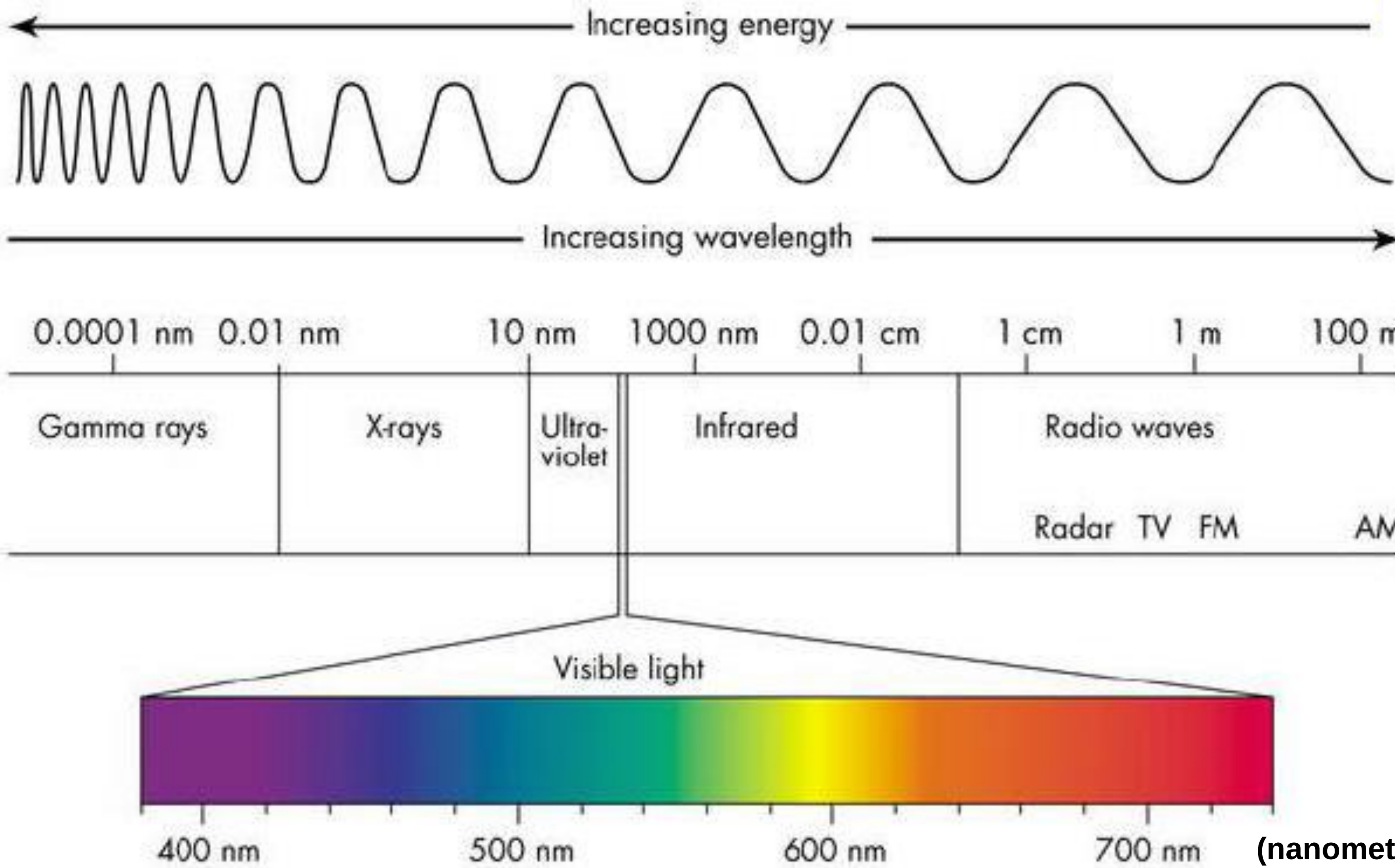
3.1 Information from the Skies

Visible spectrum:



*ESA em rad
*vio?

Electromagnetic Spectrum



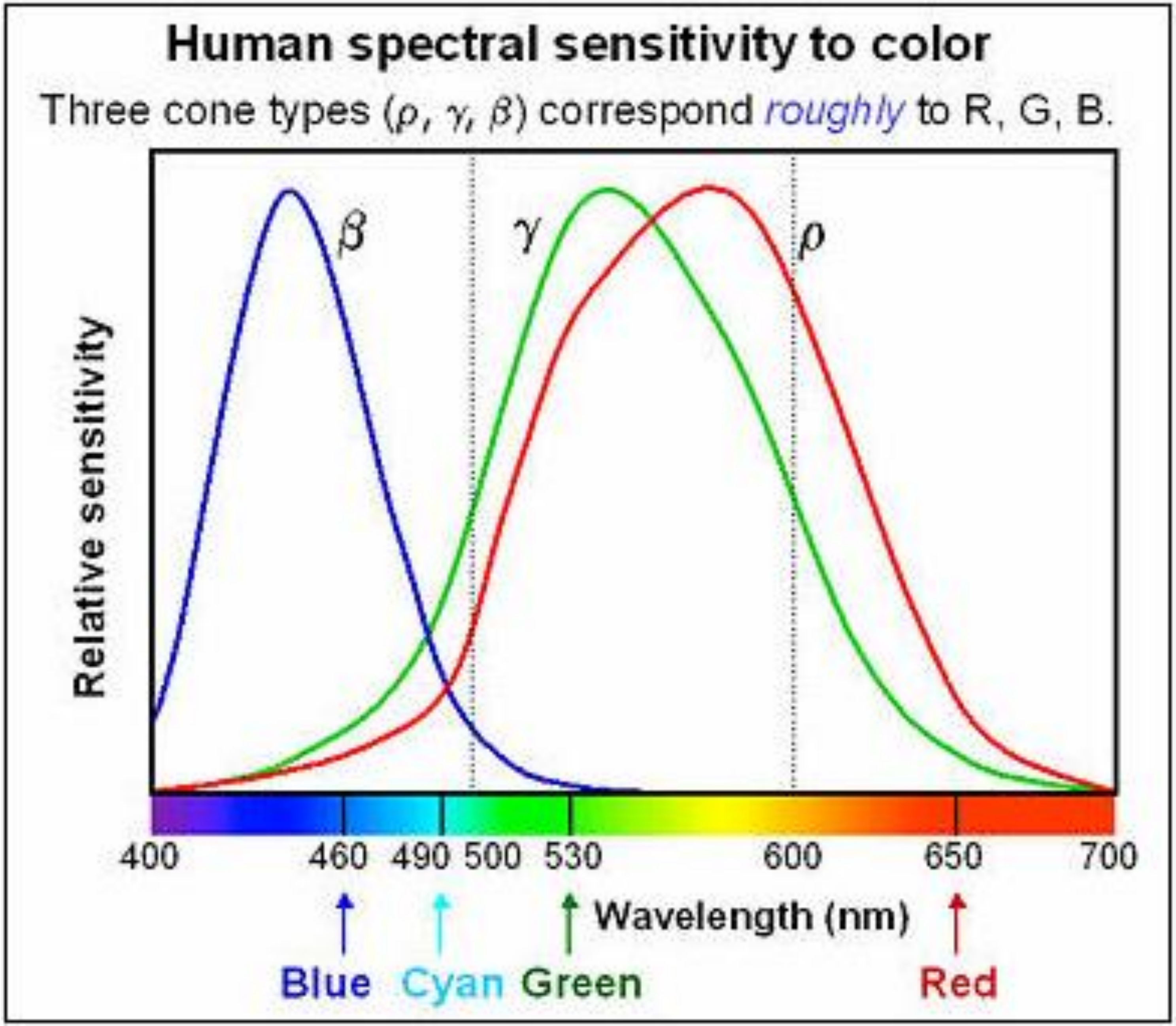
(nanometers)

4000 Å 5000 Å 6000 Å 7000 Å (angstroms)

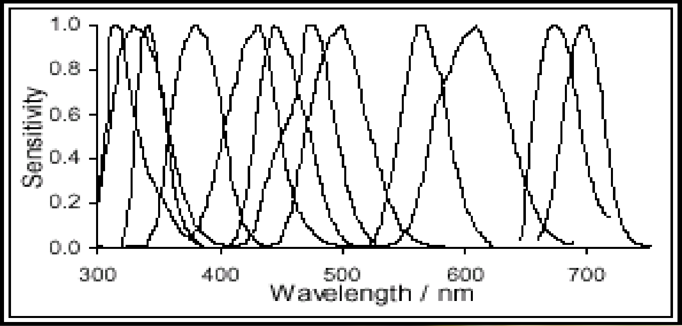
0.4 μm 0.5 μm 0.6 μm 0.7 μm (microns)

(1 micron = 10^{-6} meters, 1 nanometer = 10^{-9} meters , 1 angstrom = 10^{-10} meters)

Human Vision



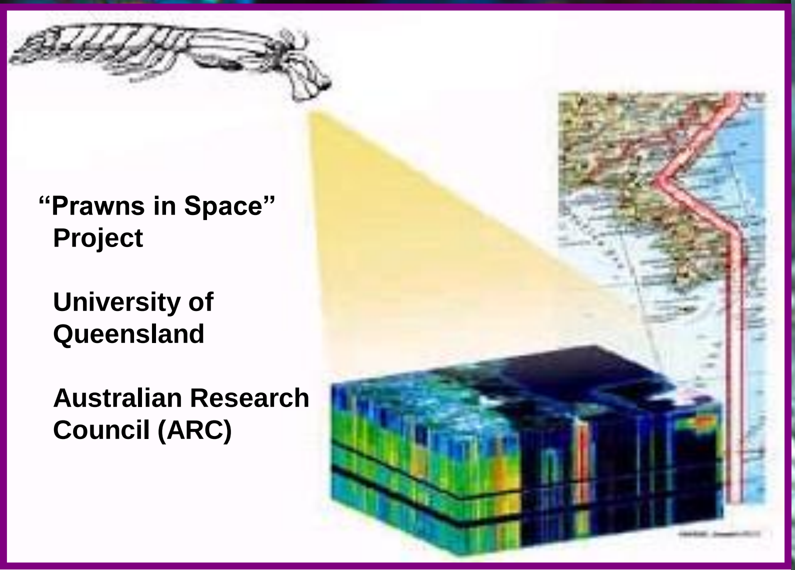
Biological Hyperspectral Remote Sensing System



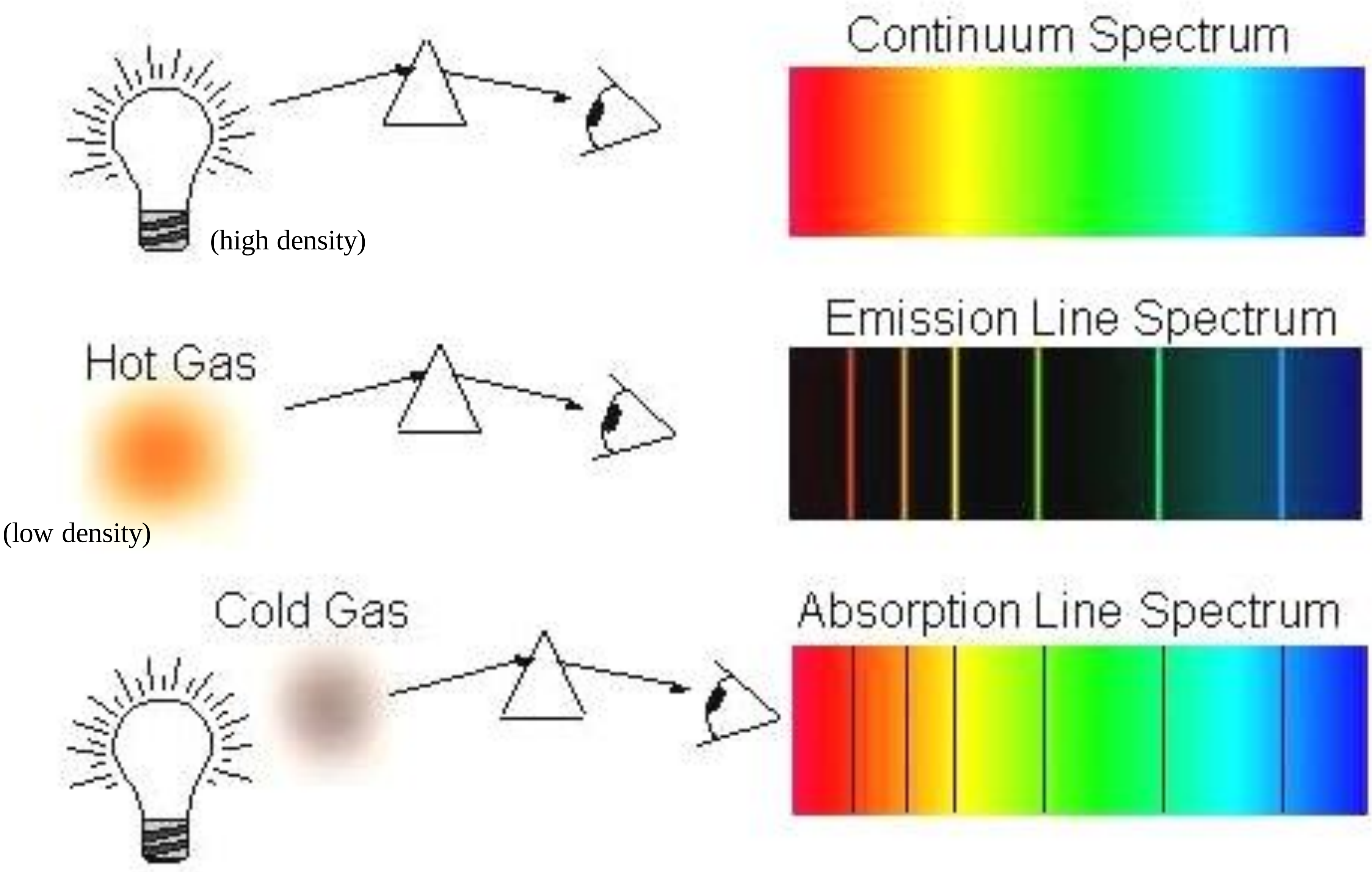
Mantis Shrimp (Stomatopod)

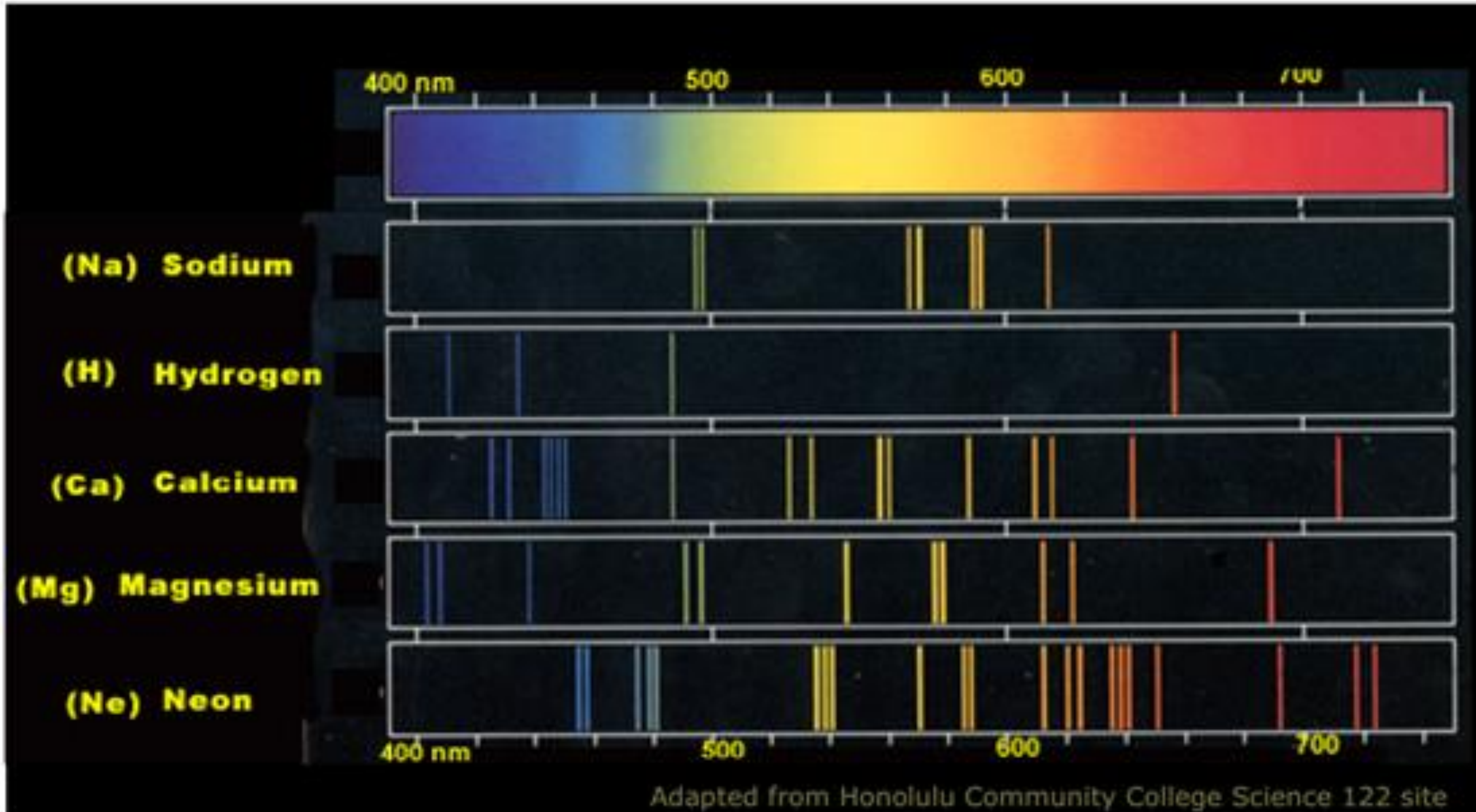
- Most complex vision system in nature
- Hyperspectral
  - Photoreceptors for 16 bands
  - Humans & primates see 3 bands (RGB)
  - Birds see 4 bands
- Ultraviolet / Visible / Near-Infrared range
  - 300 to >700 nm
- Detects 3 linear polarizations
  - E-vectors at 0°, 45°, 90° (~500 nm)
- 360° push-broom scanning mode
- Each eye is trinocular
  - 3 pupils in each eye
  - Both eyes result in “hexnocular” vision
- Nervous system integrates:
  - Spatial / Spectral / Temporal / Polarization
- Evolved from crustaceans 400 M years ago
  - Vision system developed 40 M years ago

Mantis Shrimp (Stomatopod)



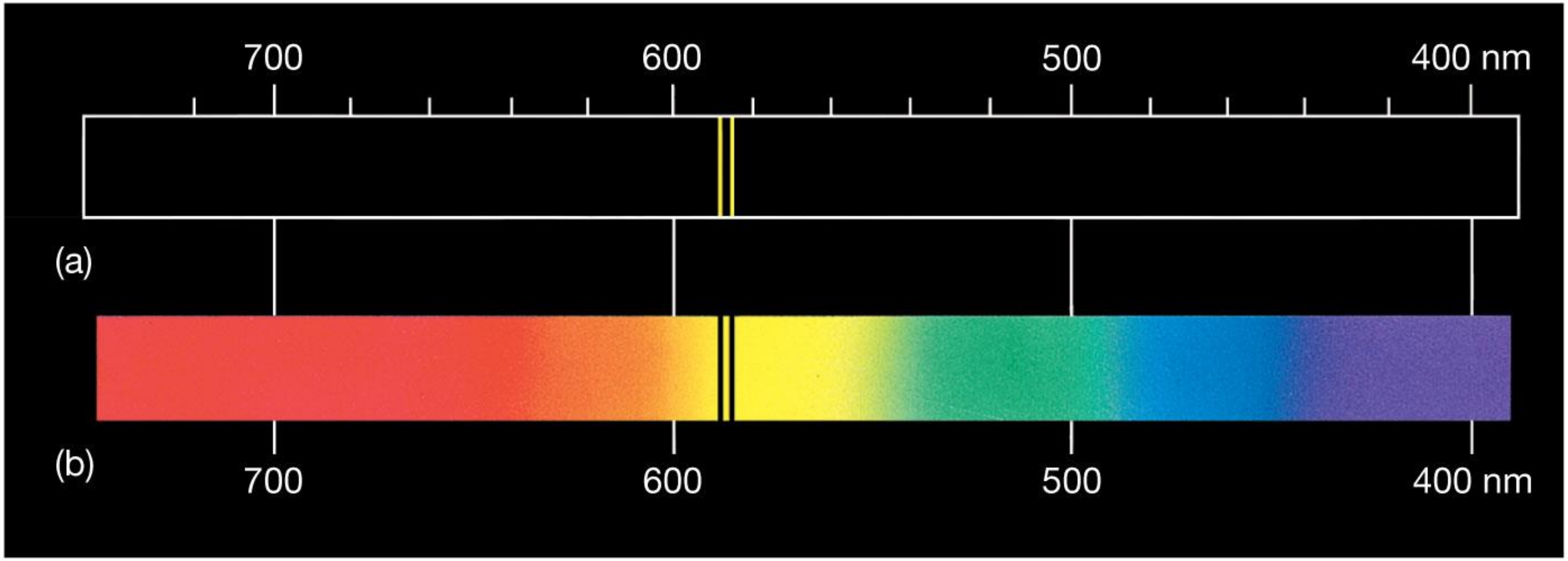
Kirchoff’s Laws

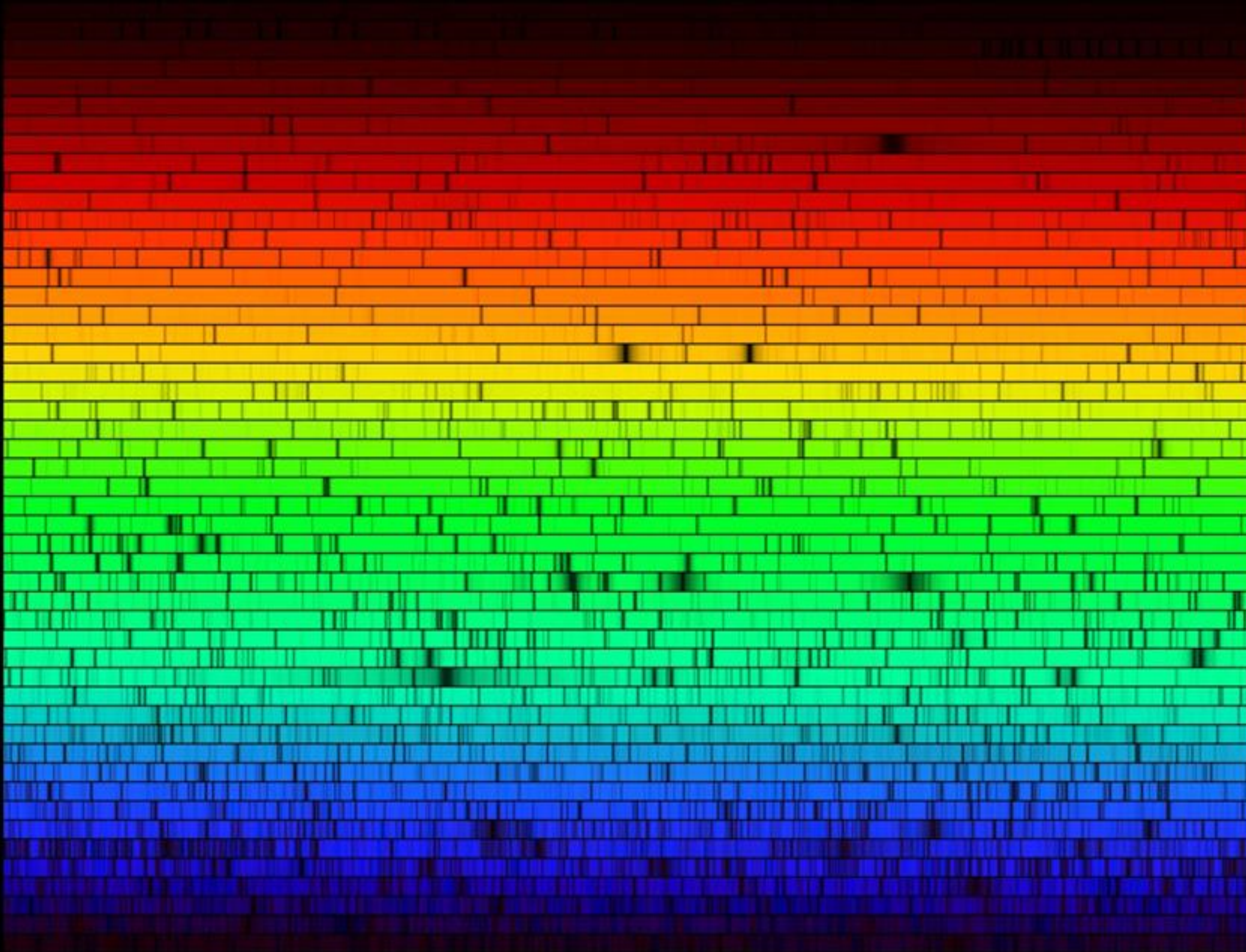



400 nm
500
600
700
(Na) Sodium
(H) Hydrogen
(Ca) Calcium
(Mg) Magnesium
(Ne) Neon
400 nm
500
600
700
Adapted from Honolulu Community College Science 122 site

Spectral Lines

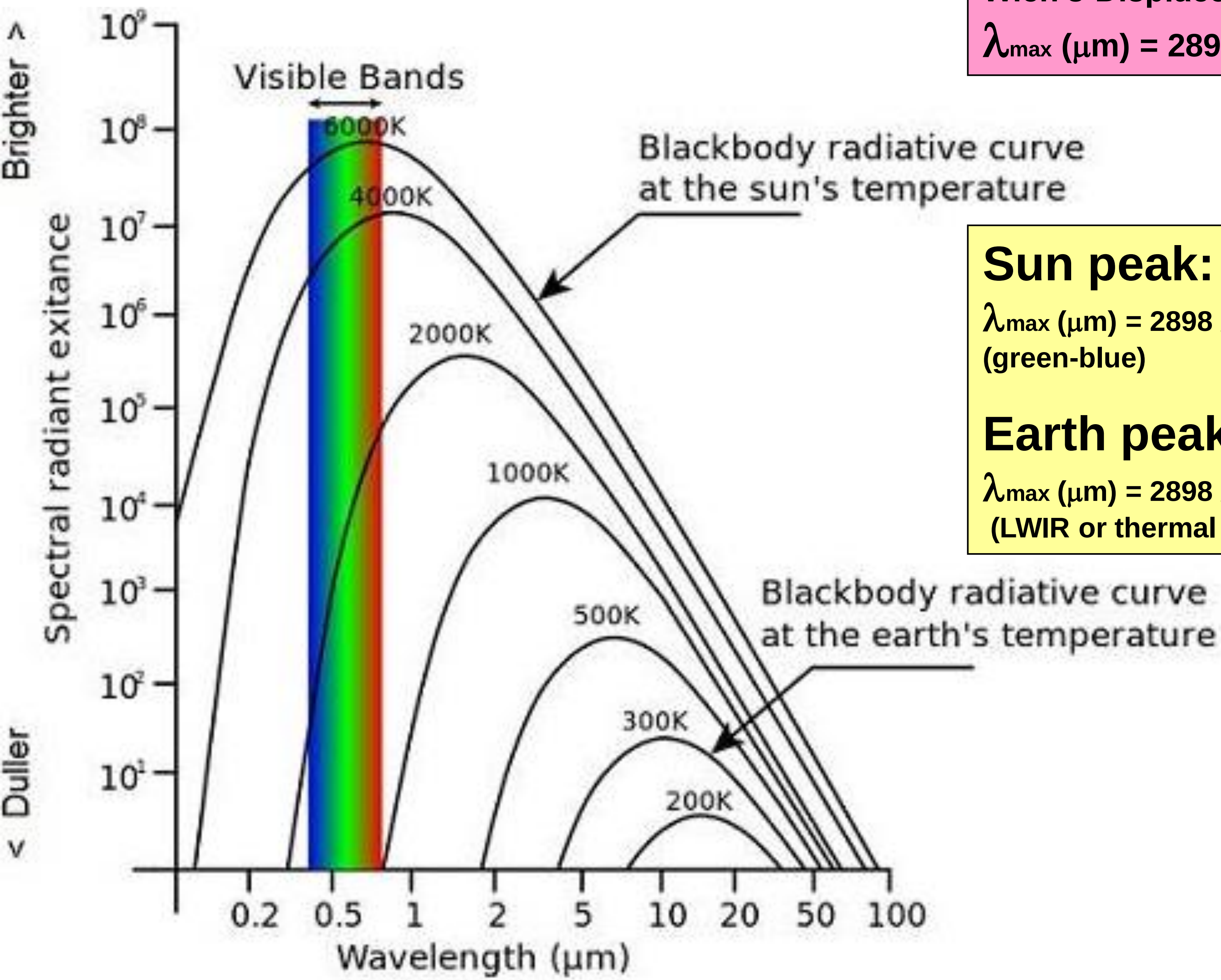
An absorption spectrum can also be used to identify elements. These are the emission and absorption spectra of sodium:





Photospheric composition (by mass)	
Hydrogen	73.46%[9]
Helium	24.85%
Oxygen	0.77%
Carbon	0.29%
Iron	0.16%
Neon	0.12%
Nitrogen	0.09%
Silicon	0.07%
Magnesium	0.05%
Sulfur	0.04%

Blackbody Radiation



Wien's Displacement Law

λ_{max} (μm) = 2898 / T (K)

Sun peak:

λ_{max} (μm) = 2898 / 5800 = 0.5 μm (green-blue)

Earth peak:

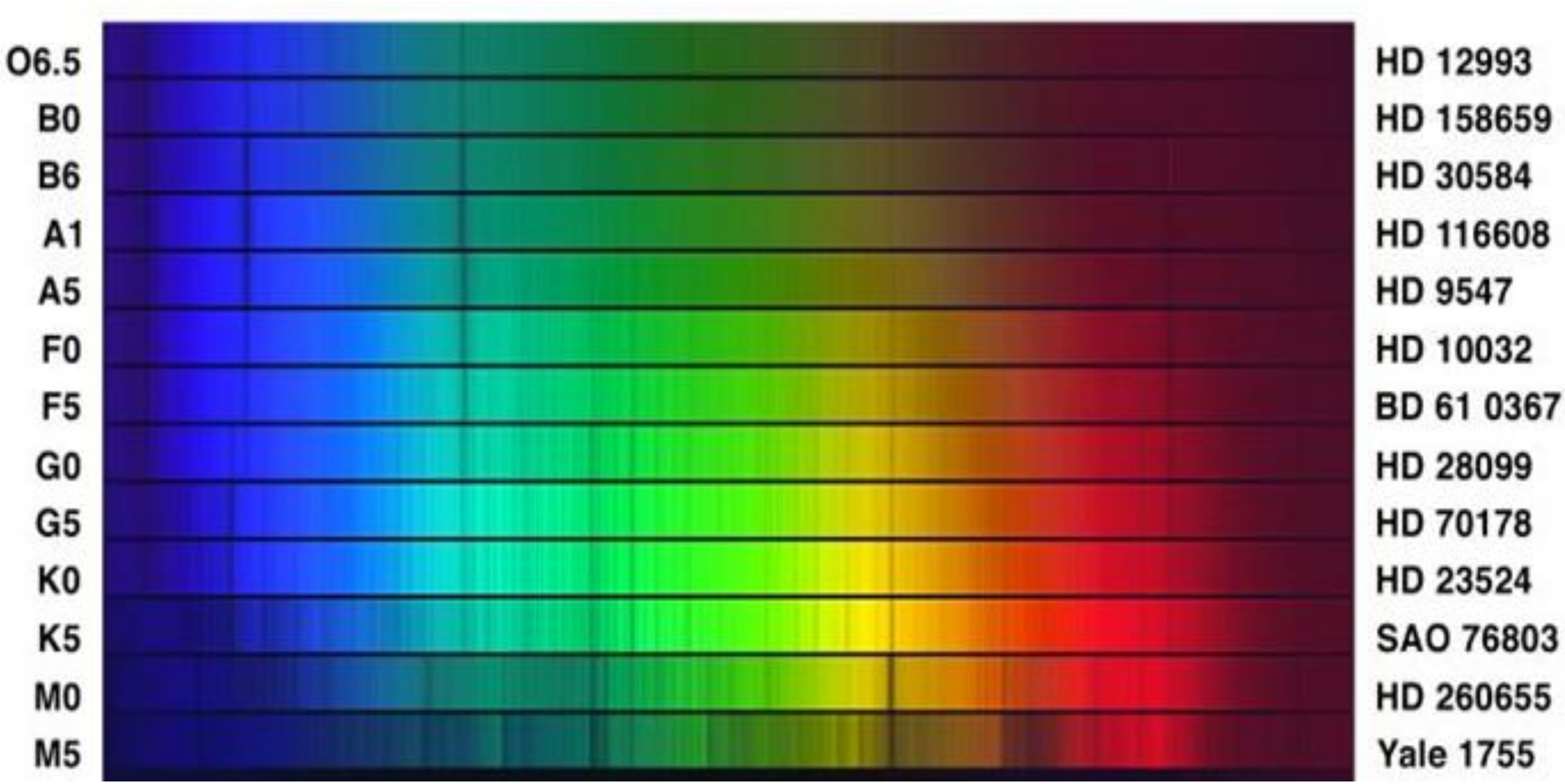
λ_{max} (μm) = 2898 / 295 = 9.8 μm (LWIR or thermal band)

Harvard Spectral Classification

Class	Temperature[8] (kelvins)	Conventional color	Mass[8] (solar masses)	Radius[8] (solar radii)	Hydrogen lines	Fraction of all main sequence stars[12]
O	≥ 33,000 K	blue	≥ 16 $M_\odot$	≥ 6.6 $R_\odot$	Weak	~0.00003%
B	10,000–33,000 K	blue to blue white	2.1–16 $M_\odot$	1.8–6.6 $R_\odot$	Medium	0.13%
A	7,500–10,000 K	white	1.4–2.1 $M_\odot$	1.4–1.8 $R_\odot$	Strong	0.6%
F	6,000–7,500 K	yellowish white	1.04–1.4 $M_\odot$	1.15–1.4 $R_\odot$	Medium	3%
G	5,200–6,000 K	yellow	0.8–1.04 $M_\odot$	0.96–1.15 $R_\odot$	Weak	7.6%
K	3,700–5,200 K	orange	0.45–0.8 $M_\odot$	0.7–0.96 $R_\odot$	Very weak	12.1%
M	≤ 3,700 K	red	≤ 0.45 $M_\odot$	≤ 0.7 $R_\odot$	Very weak	76.45%

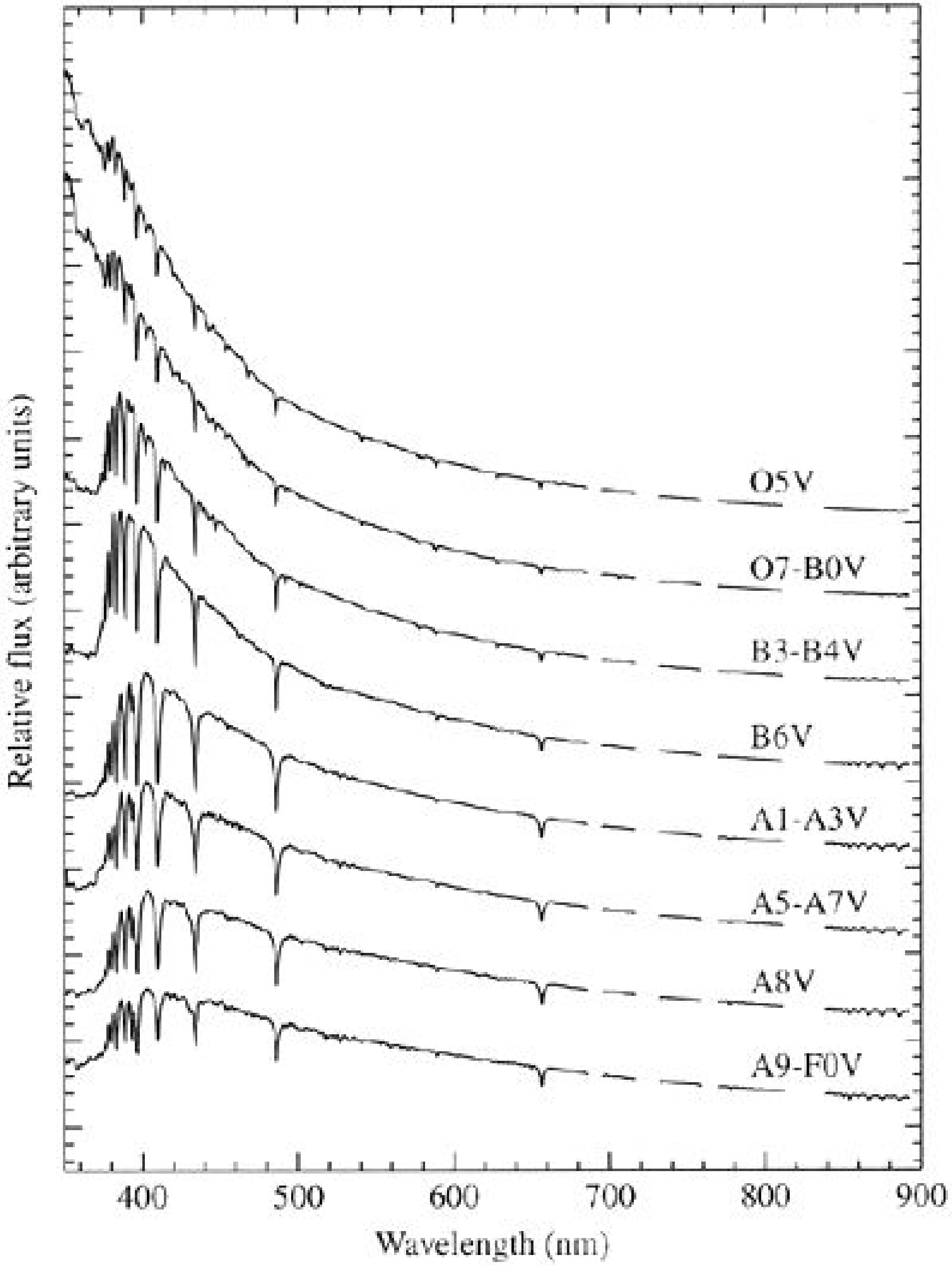
Each spectral type further subdivided into 10 divisions,
O0 to O9 through M0 to M9.
Our Sun is spectral type G2 (Surface T ~ 5800 K ~ 10,000 F)

Example Stellar Spectra

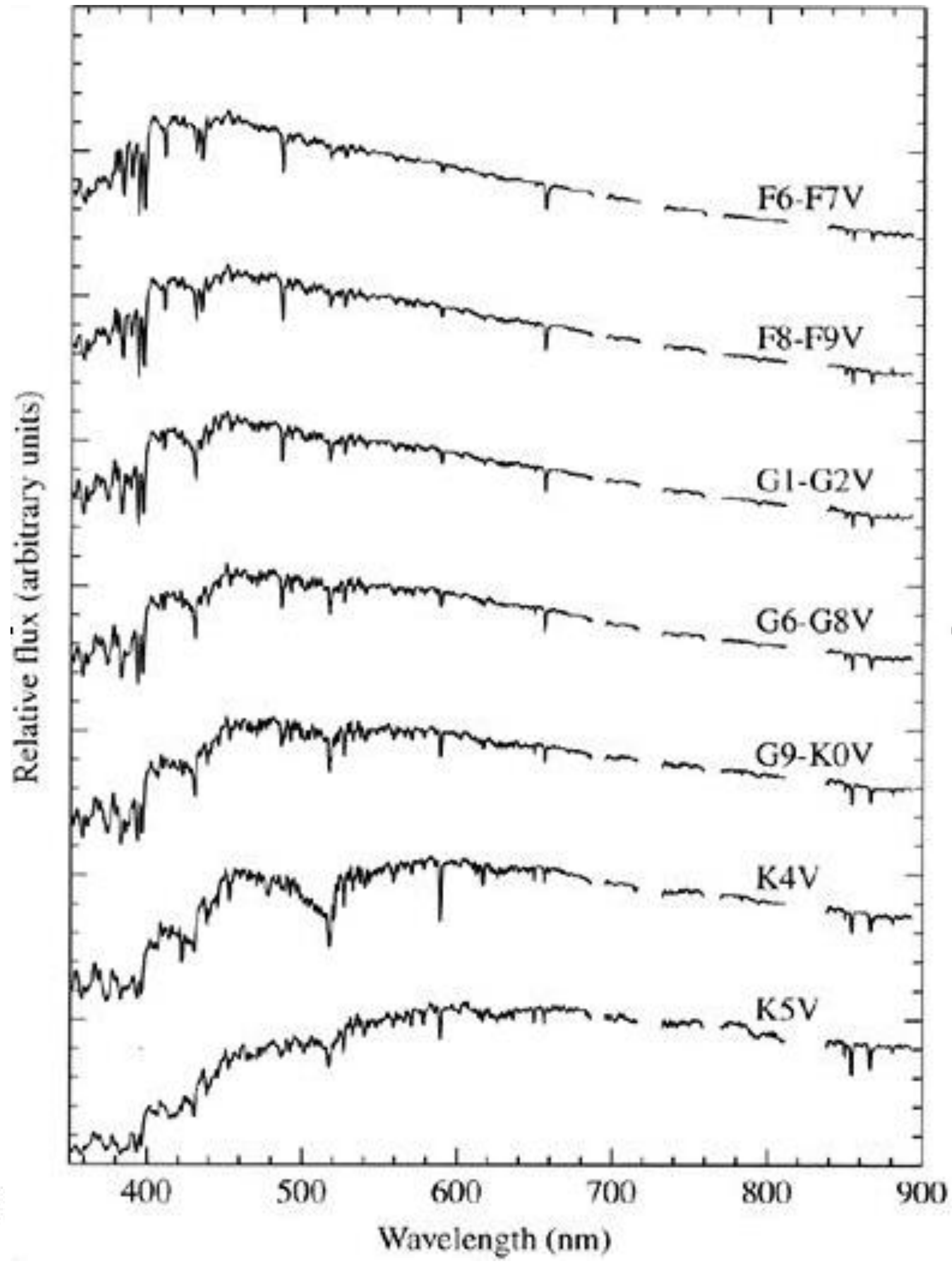


4000 Å 5000 Å 6000 Å
7000 Å

Our Sun is spectral type G2V
(Surface T ~ 5800 K ~ 10,000 F, main-sequence star)

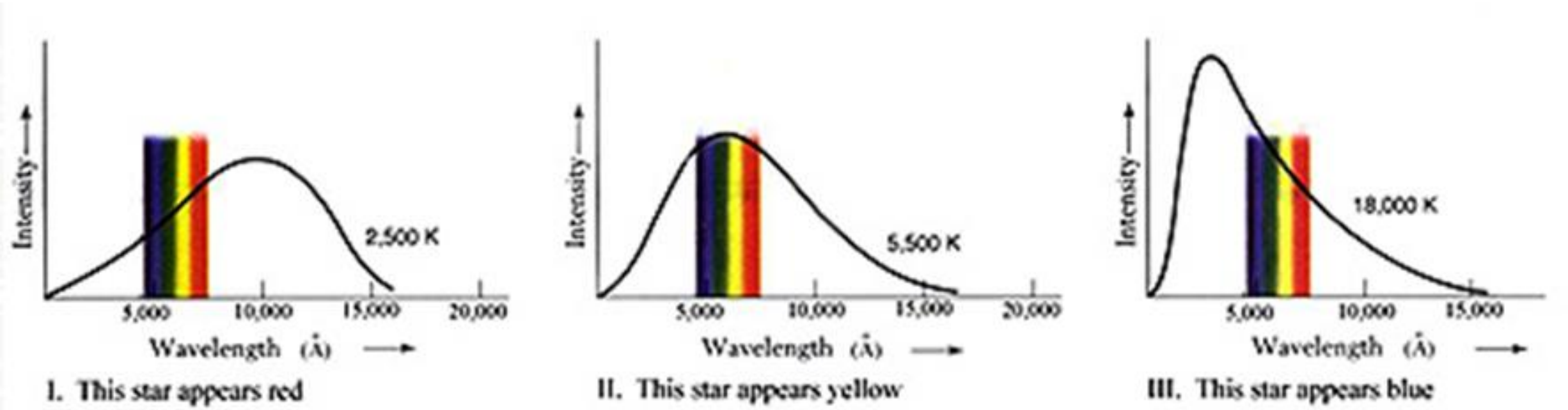


Relative flux (arbitrary units)
O5V
O7-B0V
B3-B4V
B6V
A1-A3V
A5-A7V
A8V
A9-F0V
400
500
600
700
800
900
Wavelength (nm)



Relative flux (arbitrary units)
F6-F7V
F8-F9V
G1-G2V
G6-G8V
G9-K0V
K4V
K5V
400
500
600
700
800
900
Wavelength (nm)

Blackbody Curve (Intensity vs Wavelength at temperature):
Peak Intensity shifts left for higher temperature.
Peak Intensity shifts right for lower temperature.



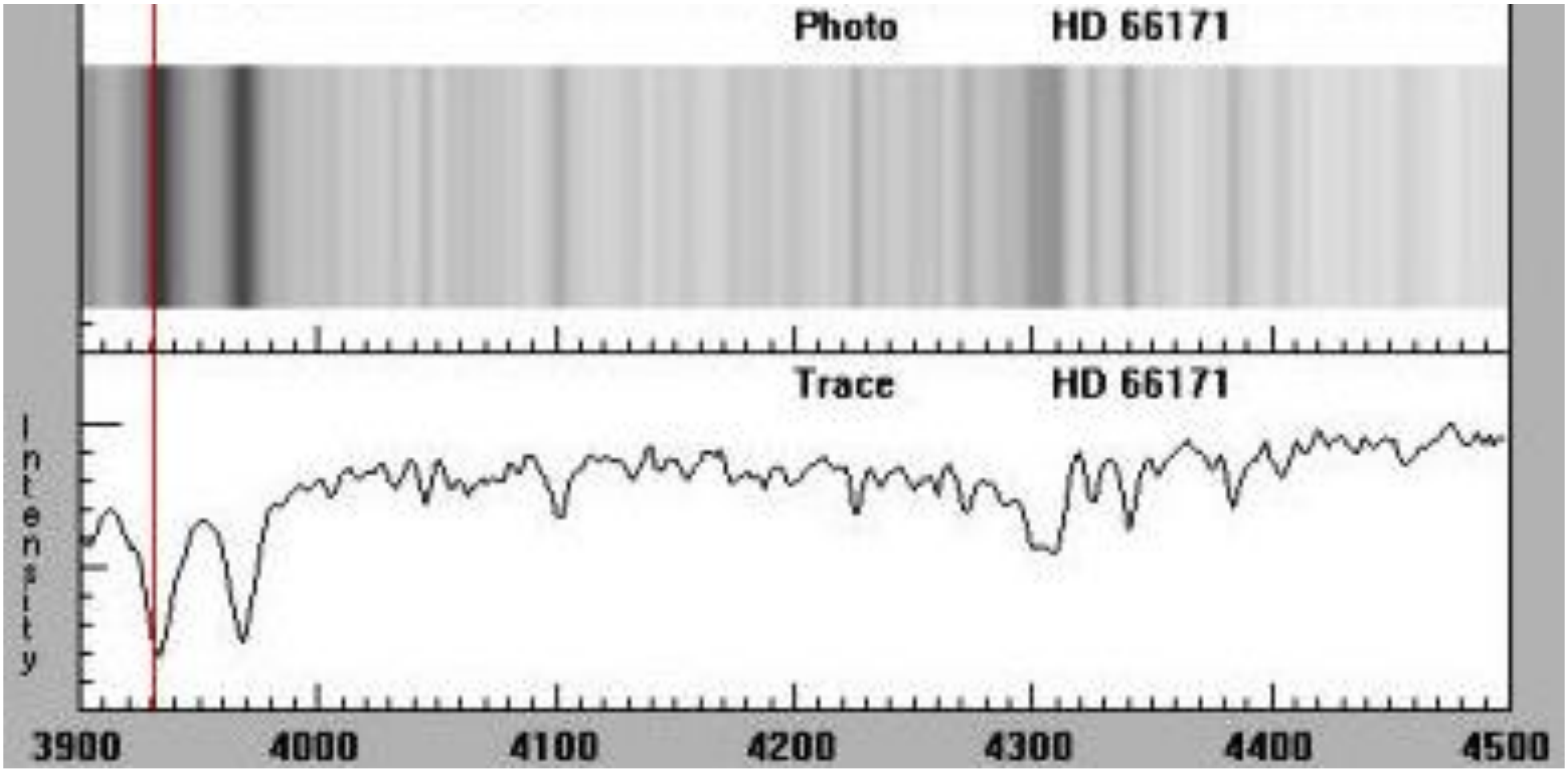
Wien's Law gives wavelength of maximum intensity for a given temperature.

$$\lambda_{max}\ (\text{Å}) = 2.9 \times 10^7 / T\ (K)$$

Our Sun: $\lambda_{max} = 2.9 \times 10^7 / (5800\ K) = 5000\ \text{Å}$

Spectral Image (photo) compared to Spectral Data Plot (Intensity vs Wavelength)

Absorption lines.

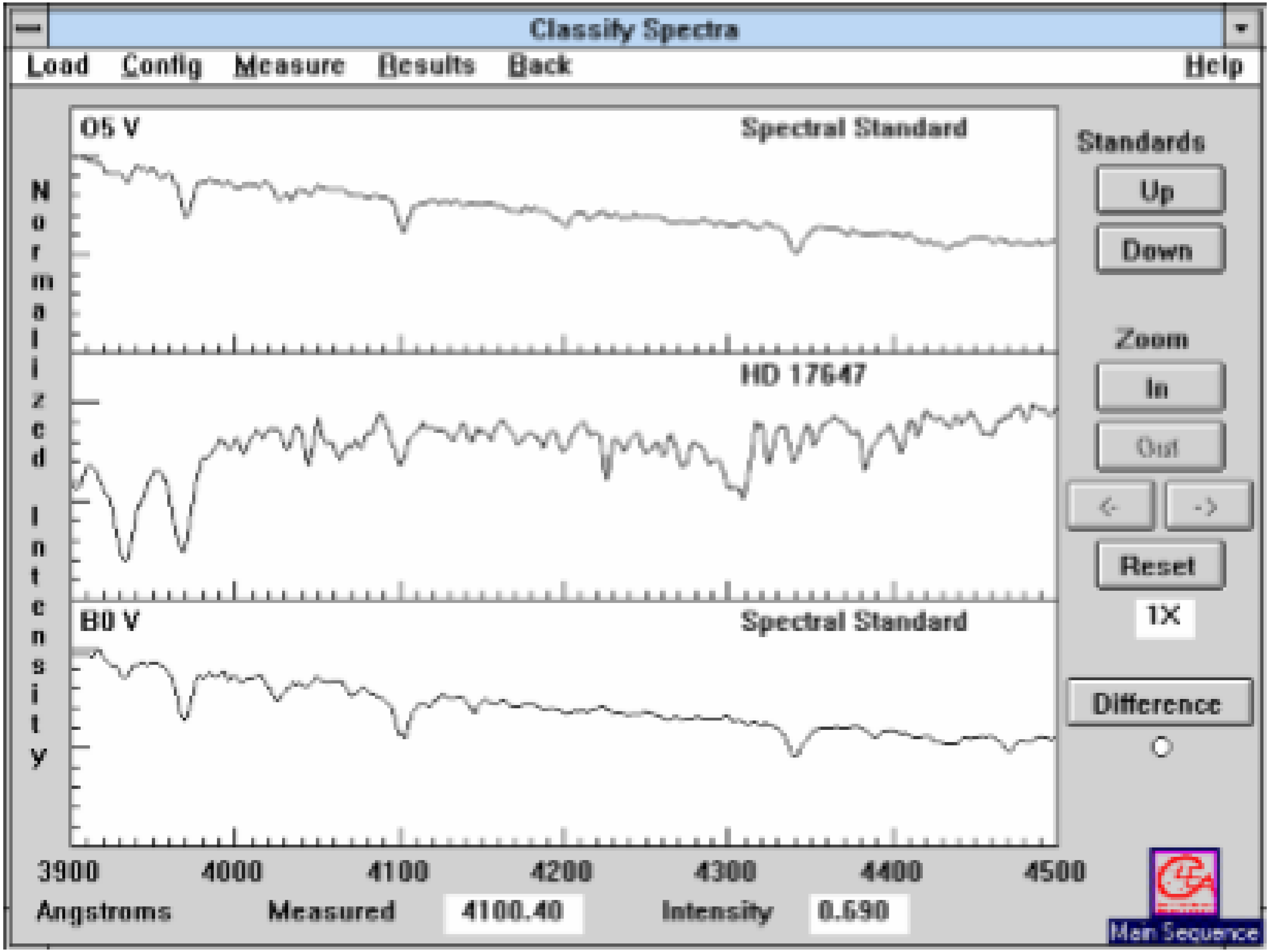


Wavelength (Å)

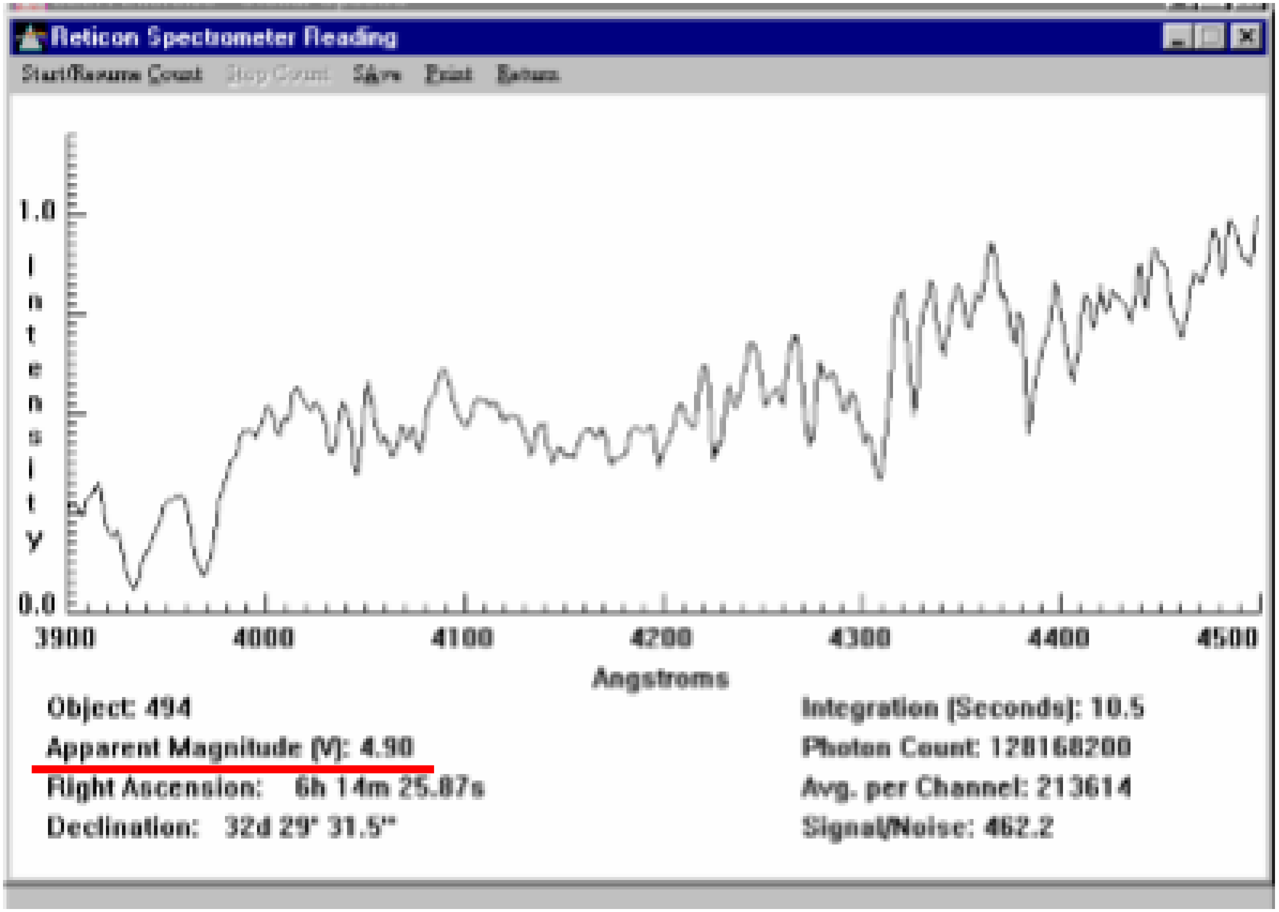
Intensity is "Normalized" to 1.

(1 angstrom = 10^{-10} meters)

Classification of Stellar Spectra



Get absolute magnitude (M) from spectral type, Get apparent magnitude (m) from measurement.



Main Sequence Stars, Luminosity Class V

Spectral Type	Absolute Magnitude, M
O5	-5.8
B0	-4.1
B5	-1.1
A0	+0.7
A5	+2.0
F0	+2.6
F5	+3.4
G0	+4.4
G5	+5.1
K0	+5.9
K5	+7.3
M0	+9.0
M5	+11.8
M8	+16.0

Apparent and Absolute Magnitude

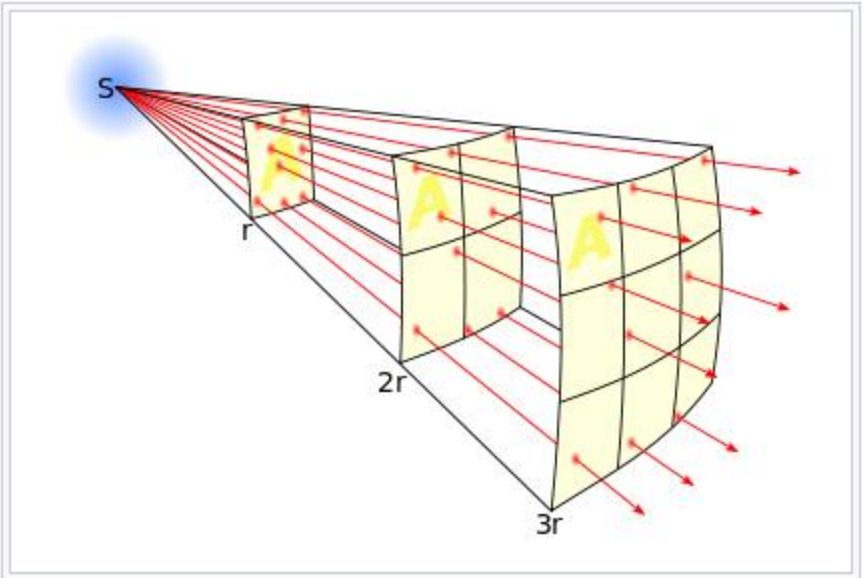
The apparent magnitude (m) of a celestial body is a measure of its brightness as seen by an observer on Earth.

The absolute magnitude (M) of a celestial body (outside of the solar system) is the apparent magnitude it would have if it were 10 parsecs (~32.6 light years) away.

(The brighter the object appears, the lower its magnitude.)

http://en.wikipedia.org/wiki/Apparent_magnitude

Inverse-square law.
Intensity drops as $1/r^2$.



Spectroscopic Parallax Method

$\log D = (m - M + 5)/5$ **(m-M is "Distance Modulus")**

$D = 10 \wedge [(m - M + 5)/5]$

D = distance to star in parsecs

(1 parsec = 3.26 light years = 3.08 x 10^{13} km ~ 19 trillion miles)

m = apparent magnitude (from your spectral plot)

M = absolute magnitude (from Main Sequence Chart, p.23)

Example: M = -2.1, m = 10.5, D = ?

Example:

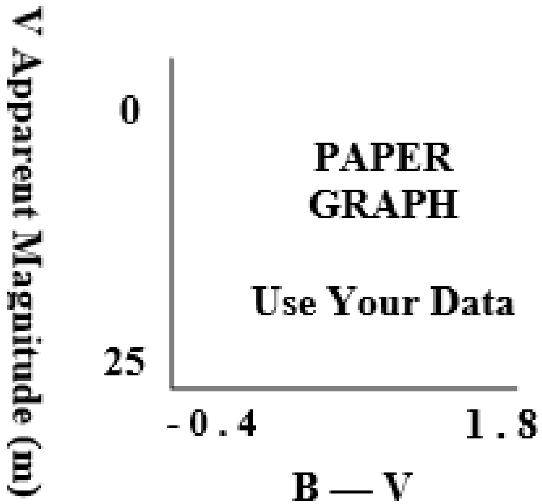
m = 10.5 (apparent magnitude)
M = -2.1 (absolute magnitude)

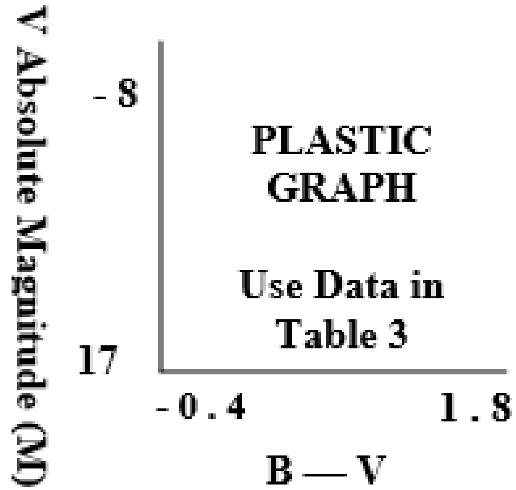
D = 10 ^ [(m – M + 5)/5]

D = 10 ^ [(10.5 – (-2.1) + 5)/5]
= 10 ^ [12.6 + 5)/5]
= 10 ^ [17.6 /5]
= 10 ^ [3.52]
= 3311 parsecs (x 3.26 ly/pc = 10,793 ly)

Identify spectral type to get M,
measure intensity to get m,
use distance modulus to calculate distance.

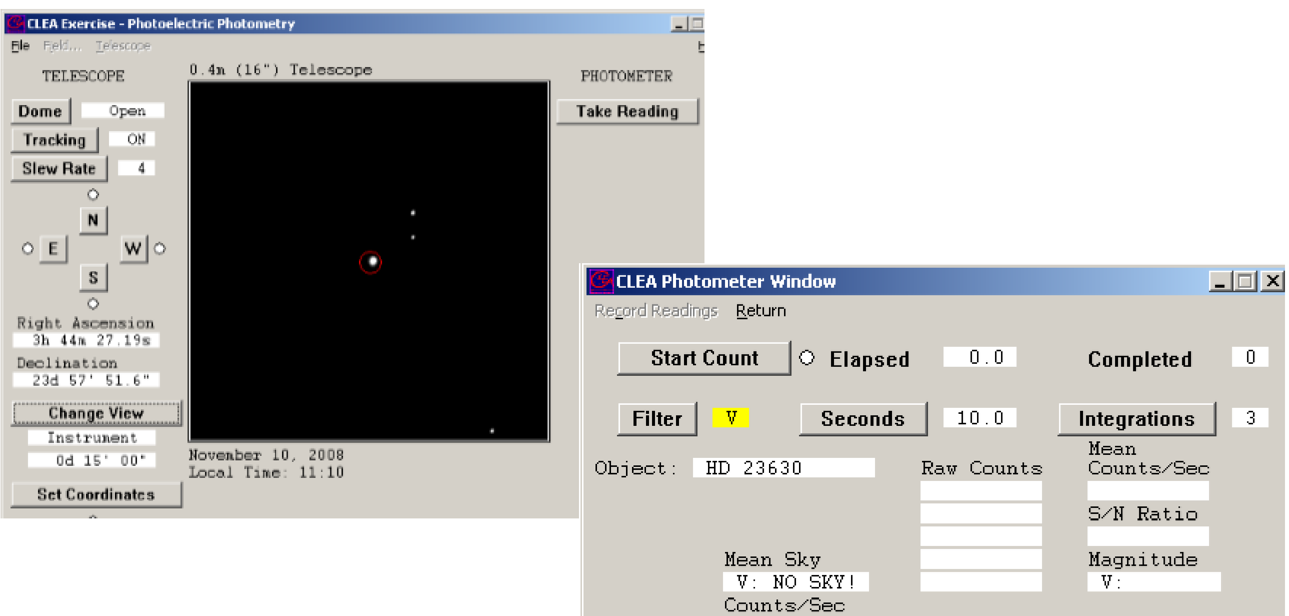
Photoelectric Photometry of the Pleiades





Main Sequence Stars, Luminosity Class V

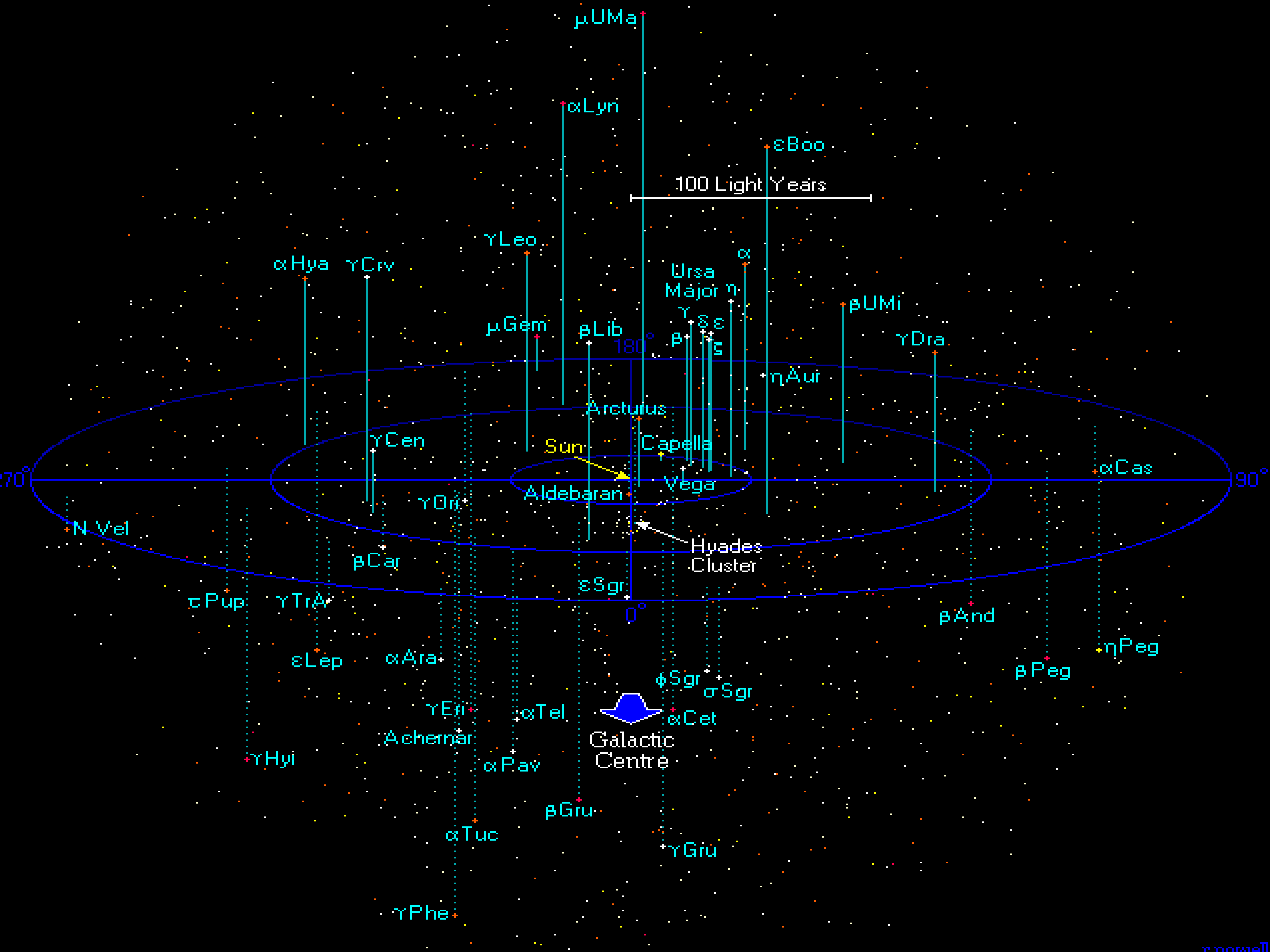
Spectral Type	Absolute Magnitude, M
O5	-5.8
B0	-4.1
B5	-1.1
A0	+0.7
A5	+2.0
F0	+2.6
F5	+3.4
G0	+4.4
G5	+5.1
K0	+5.9
K5	+7.3
M0	+9.0
M5	+11.8
M8	+16.0



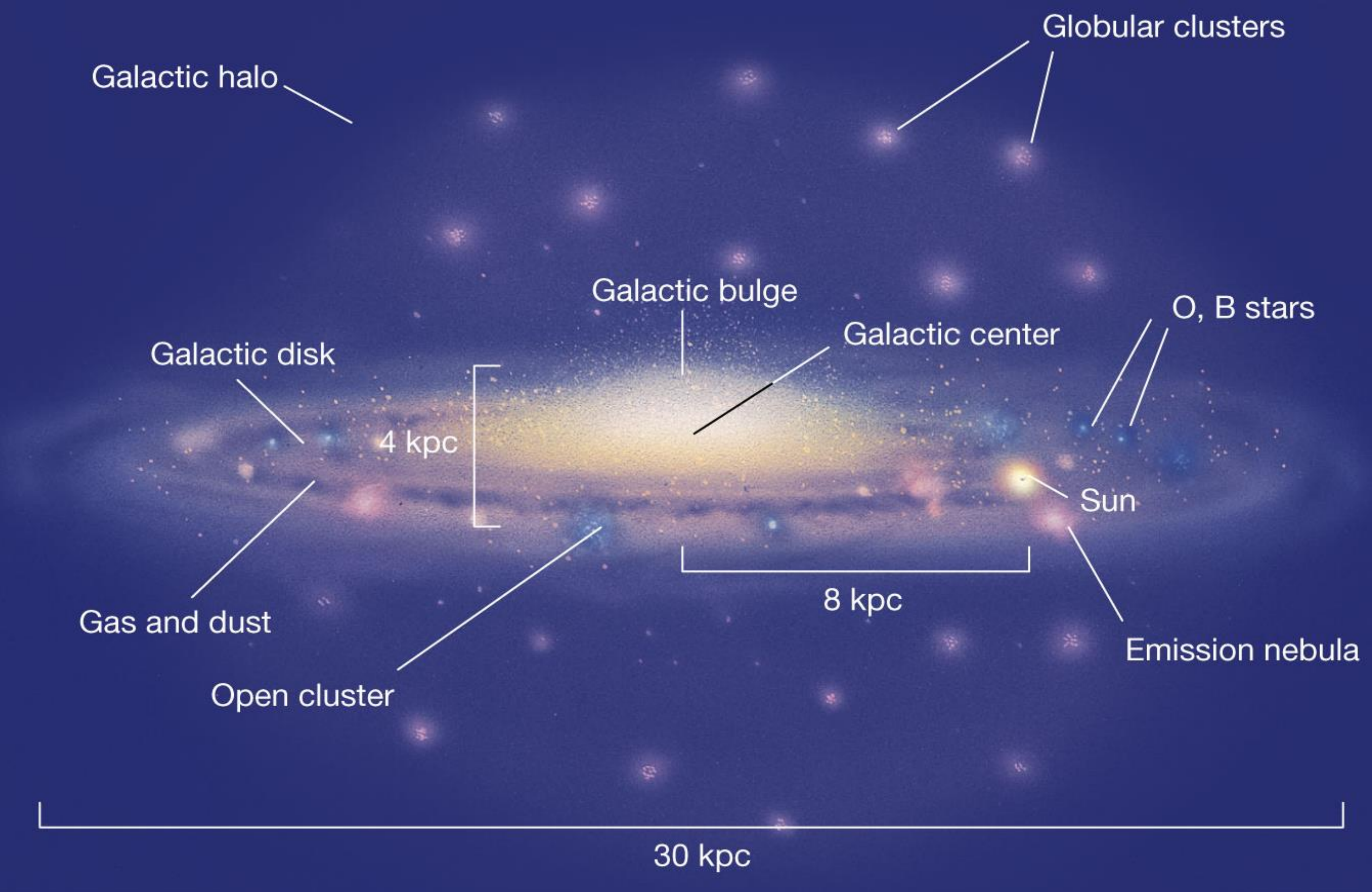
$$D = 10 \wedge [\,(m - M + 5)/5\,]$$

Pleiades (Seven Sisters)

- Open star cluster (~1000)
- Many young blue hot stars
- Distance ~ 410 light years



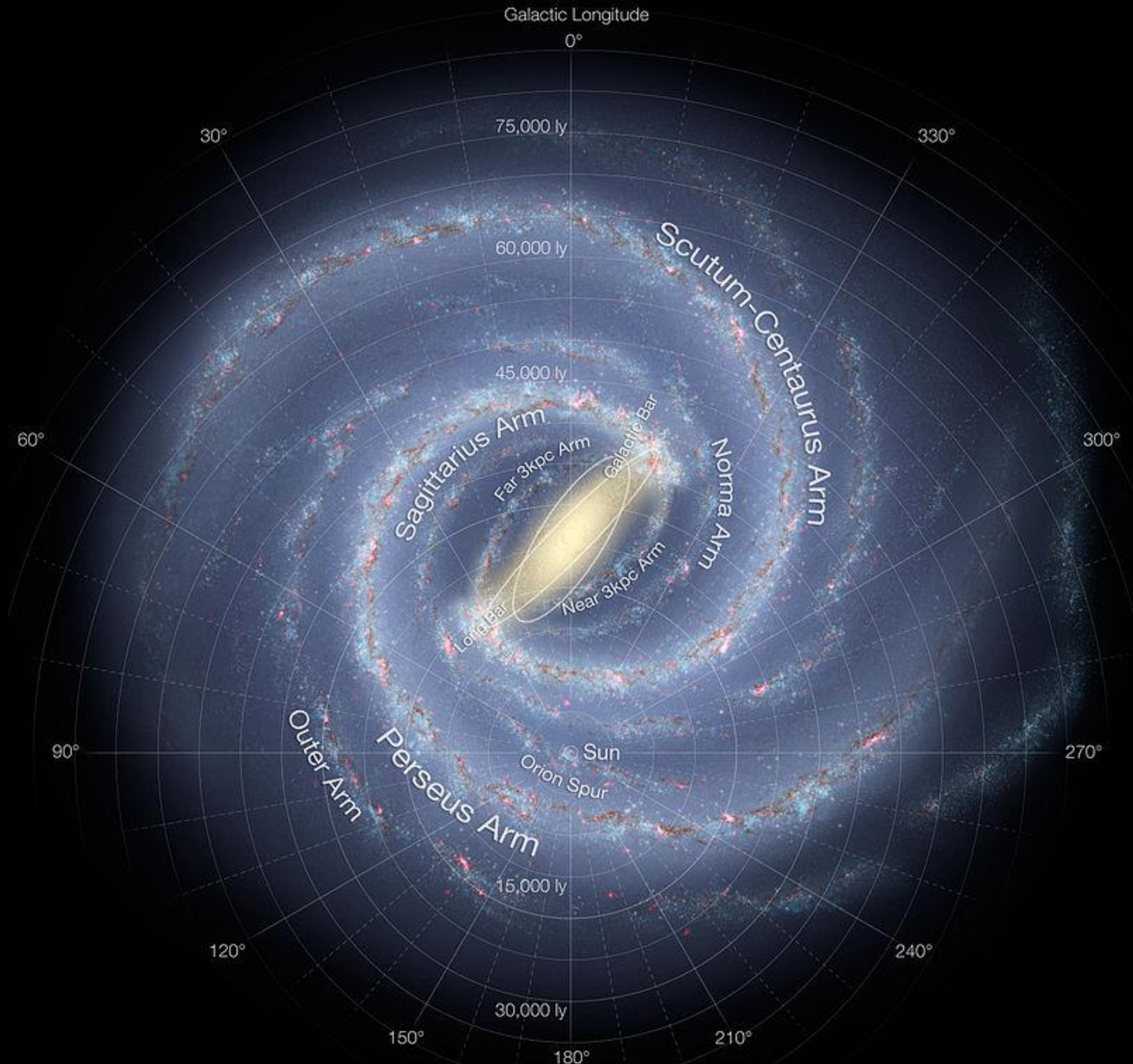
μUMa
αLyn
εBoo
100 Light Years
γLeo
α
αHya
γCrv
Ursa Major
η
βUMi
γ
δ
ε
μGem
βLib
β
ζ
γDra
180°
ηAur
Arcturus
γCen
Sun
Capella
270°
αCas
90°
Vega
Aldebaran
γOri
N Vel
Hyades Cluster
βCar
εSgr
τPup
γTrA
0°
βAnd
ηPeg
εLep
αAra
βPeg
φSgr
σSgr
γEri
αTel
αCet
Achernar
Galactic Centre
γHyi
αPav
βGru
αTuc
γGru
γPhe



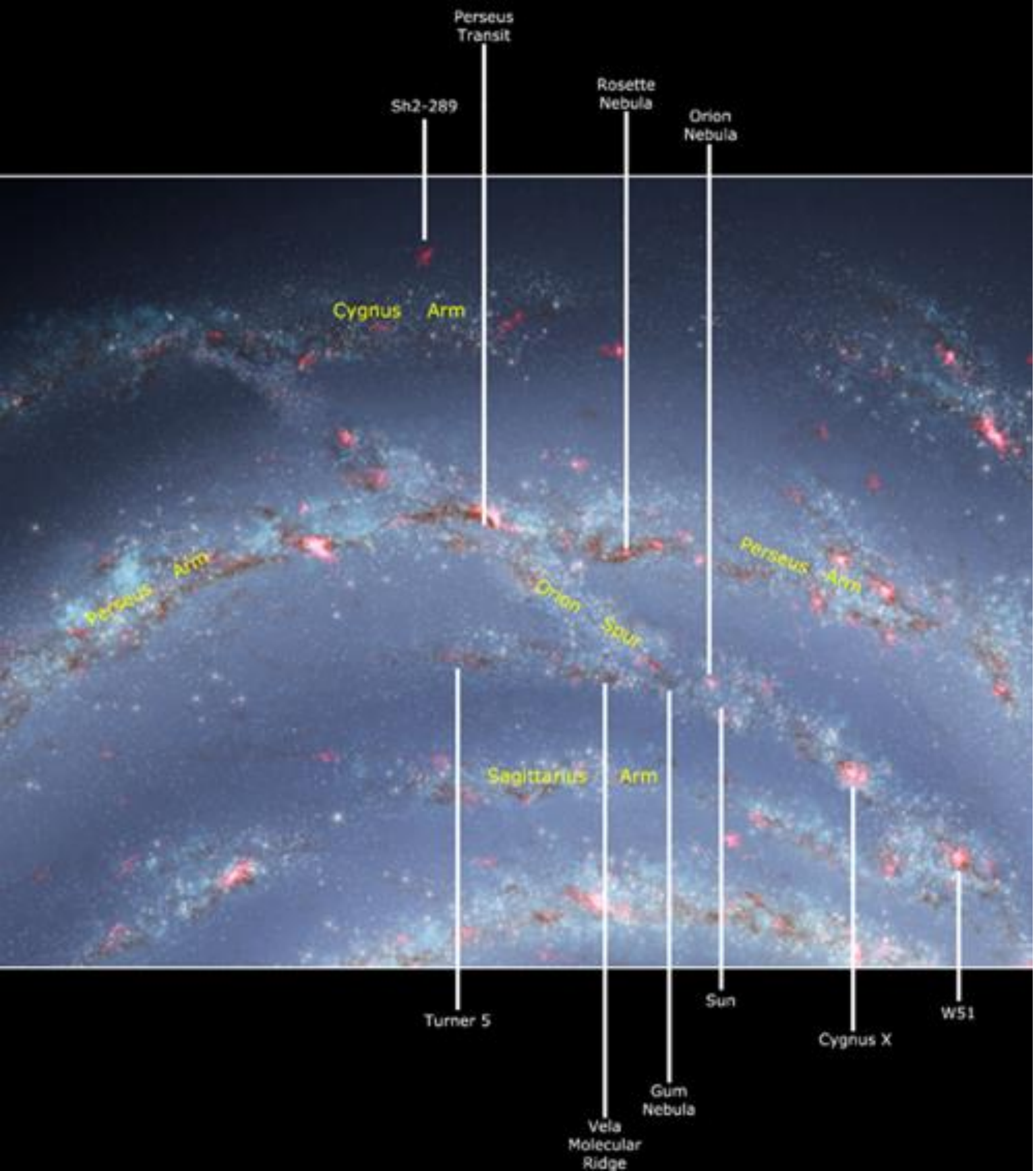
The Milky Way, Star Clusters

https://www.youtube.com/watch?v=tj_QPnO8vpQ&index=37&list=PL8dPuuaLjXtPAJr1ysd5yGIyiSFuh0mIL

https://www.youtube.com/watch?v=an4rgJ3O21A&list=PL8dPuuaLjXtPAJr1ysd5yGIyiSFuh0mIL&index=35



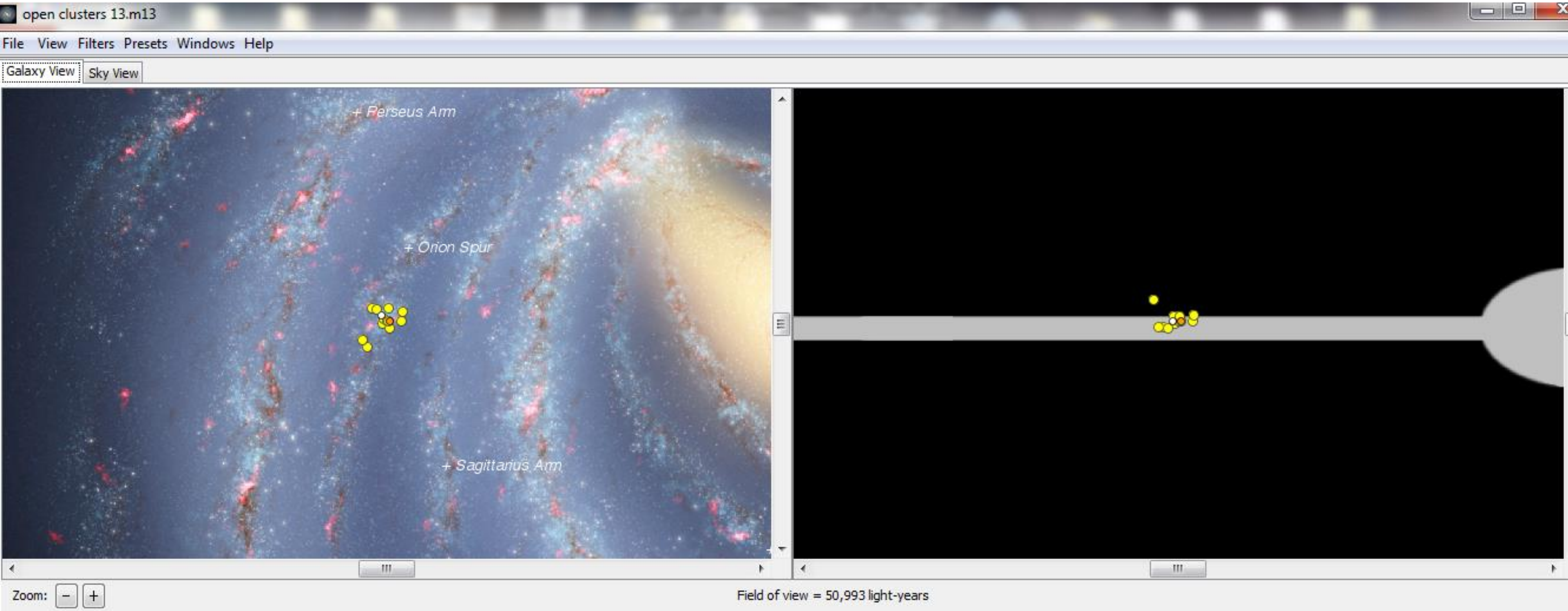
https://en.wikipedia.org/wiki/Density_wave_theory

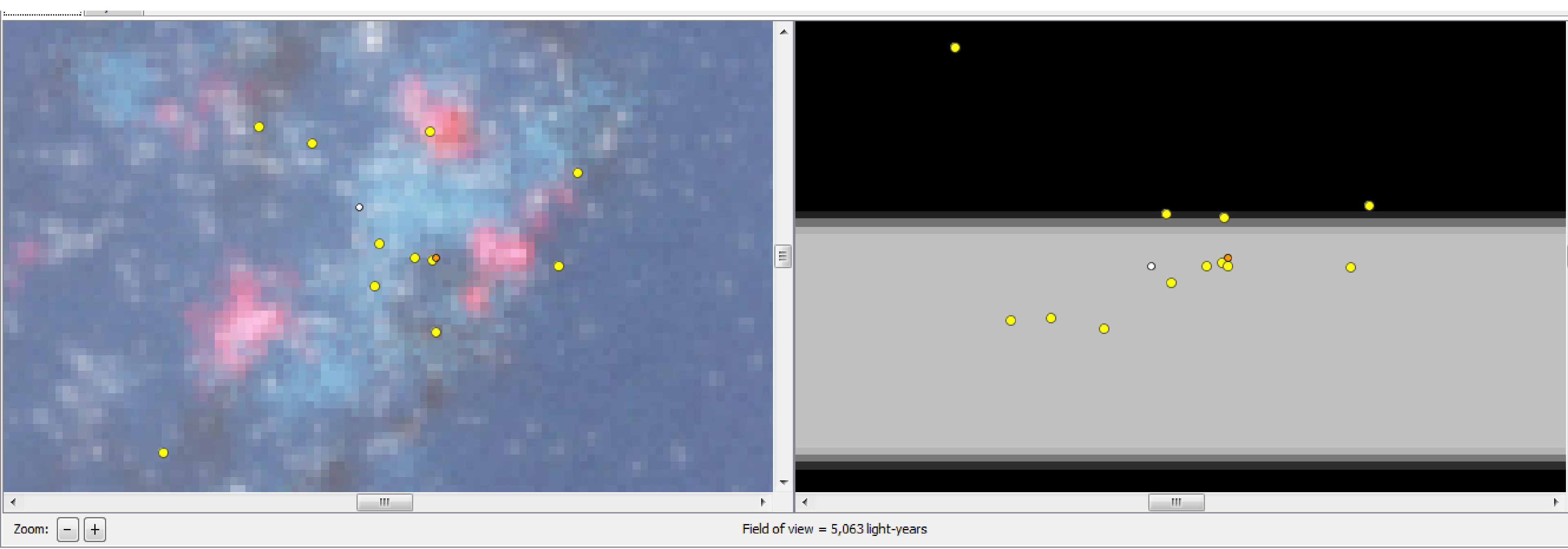


We are located in the "Orion Spur".

Also known as the
Local Spur,
Orion Arm,
Orion-Cygnus Arm.

*Gsizes

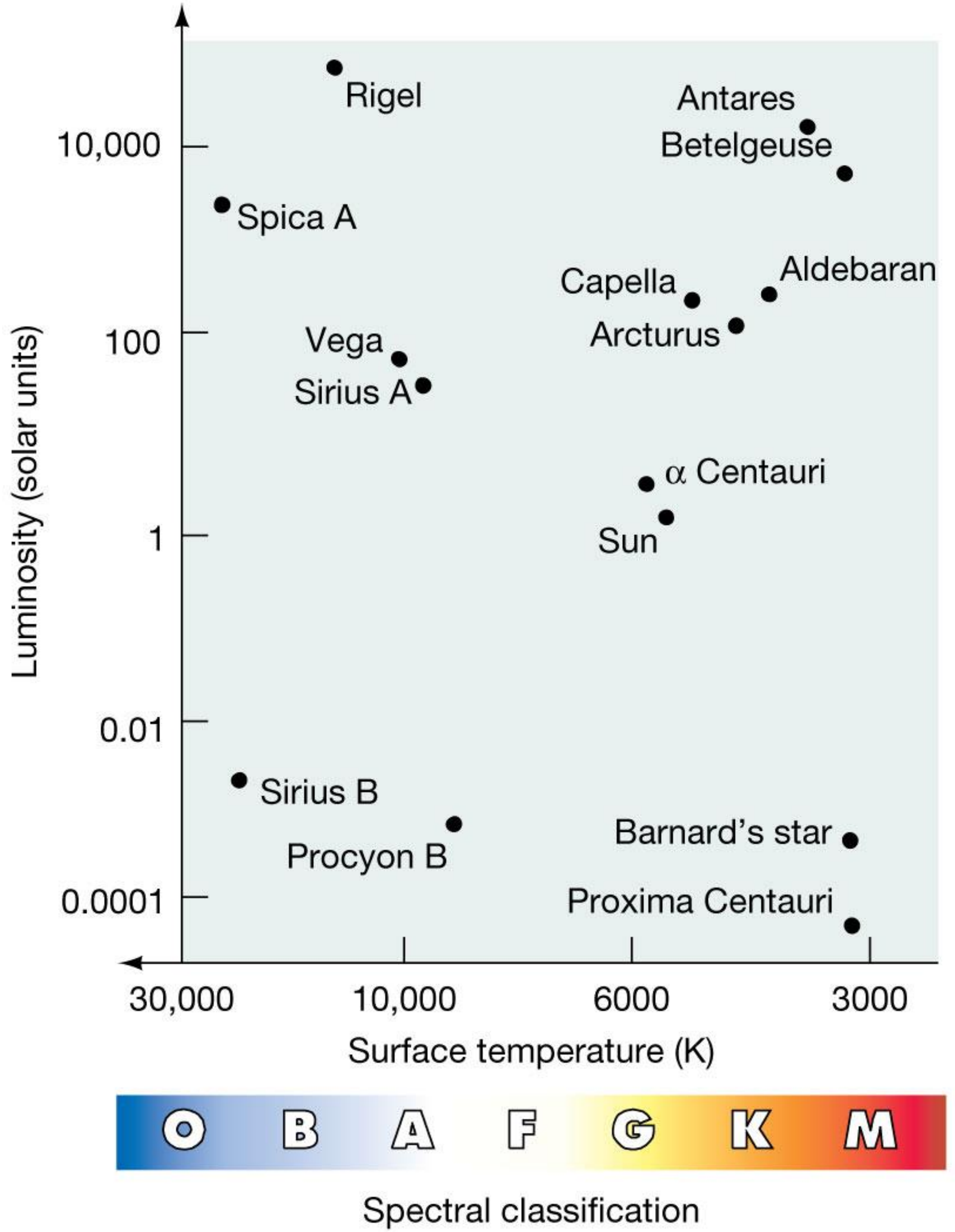

open clusters 13.m13
File View Filters Presets Windows Help
Galaxy View
Sky View
Perseus Arm
Orion Spur
Sagittarius Arm
Zoom:
Field of view = 50,993 light-years


Zoom:
Field of view = 5,063 light-years

Hertzsprung–Russell Diagram

The H–R diagram plots stellar luminosity against surface temperature.

This is an H–R diagram of a few prominent stars.



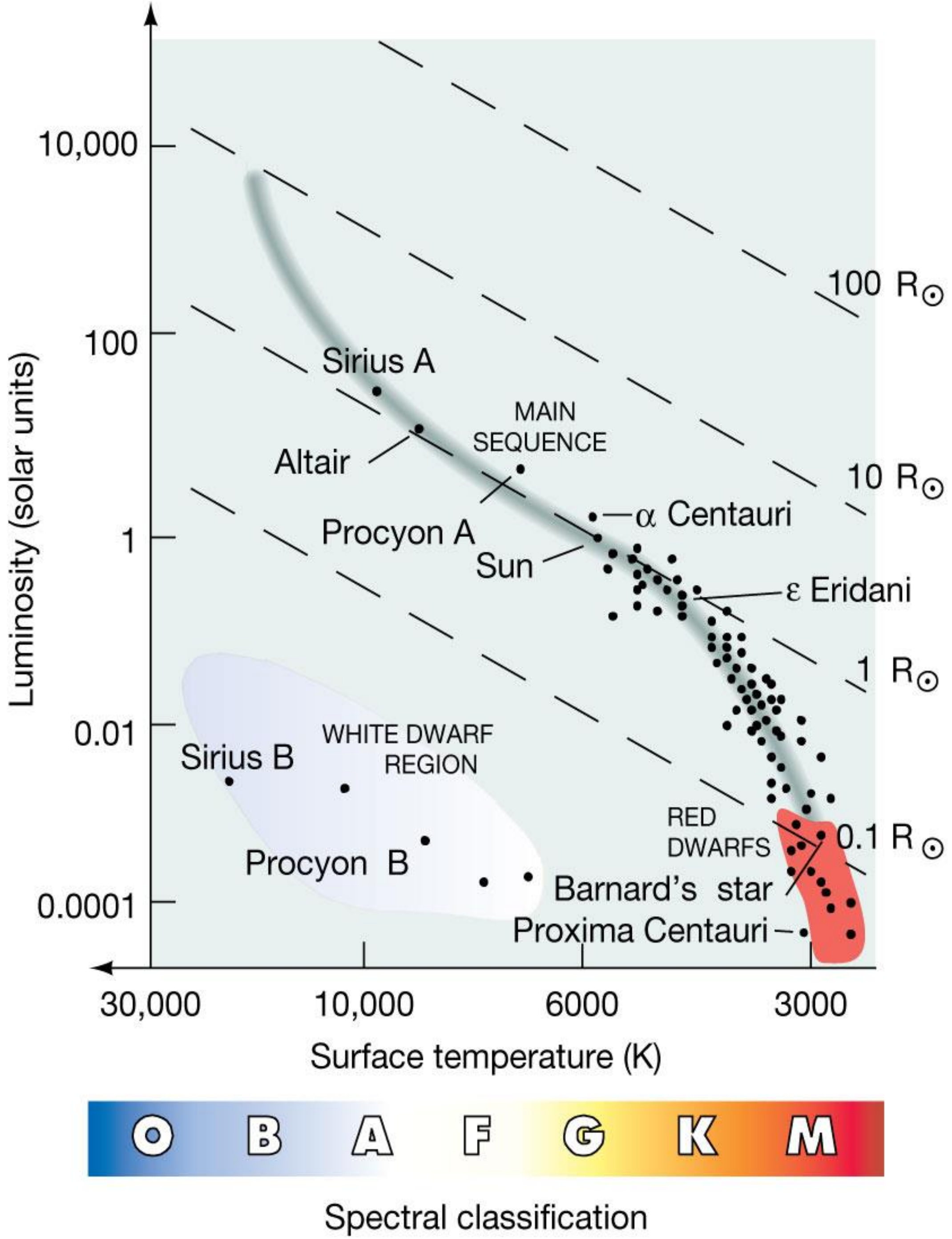
Hertzsprung–Russell Diagram

Once many stars are plotted on an H–R diagram, a pattern begins to form.

These are the 80 closest stars to us; note the dashed lines of constant radius.

The darkened curve is called the main sequence, as this is where most stars are. Red dwarfs most common.

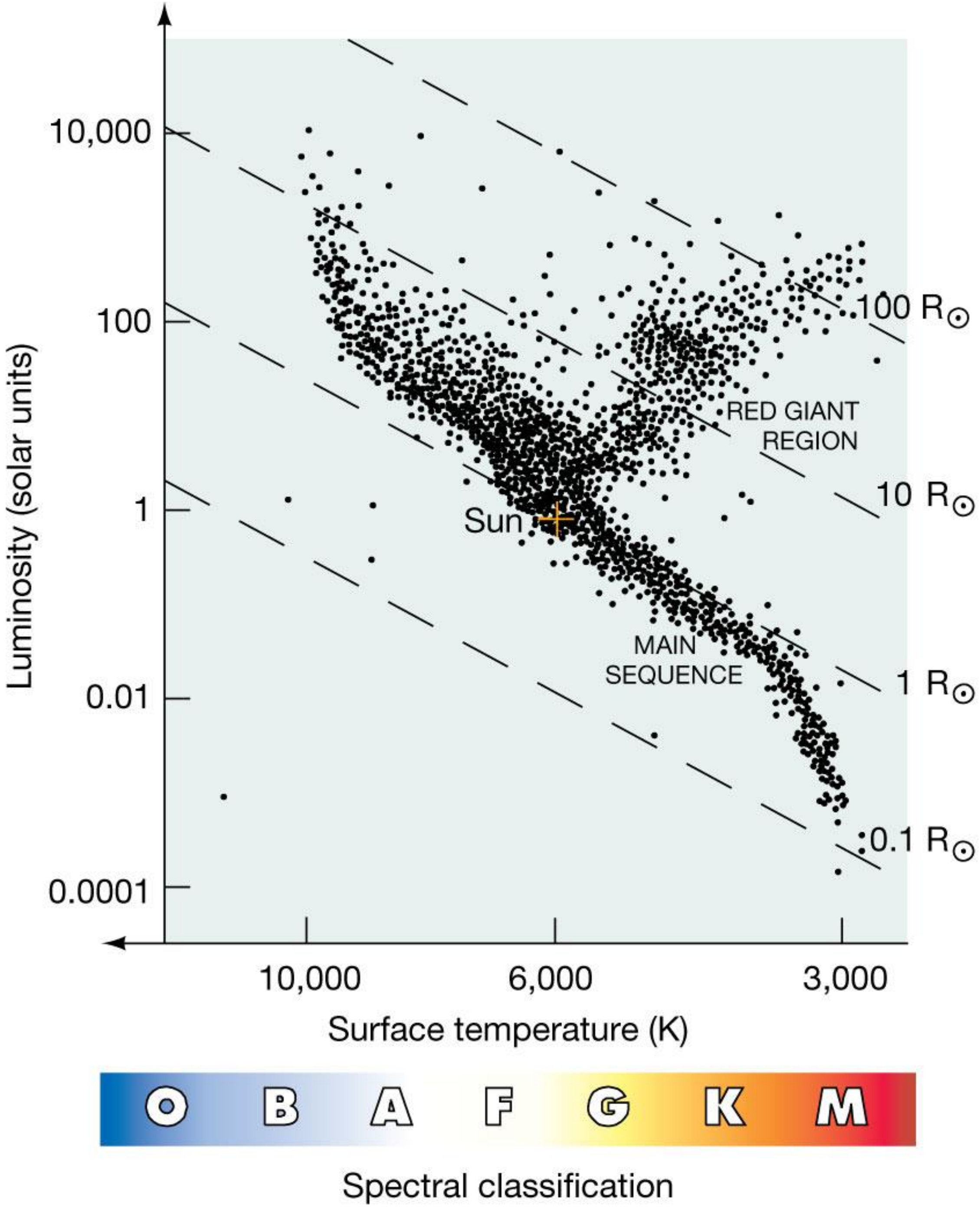
Also indicated is the white dwarf region; these stars are hot but not very luminous, as they are quite small.

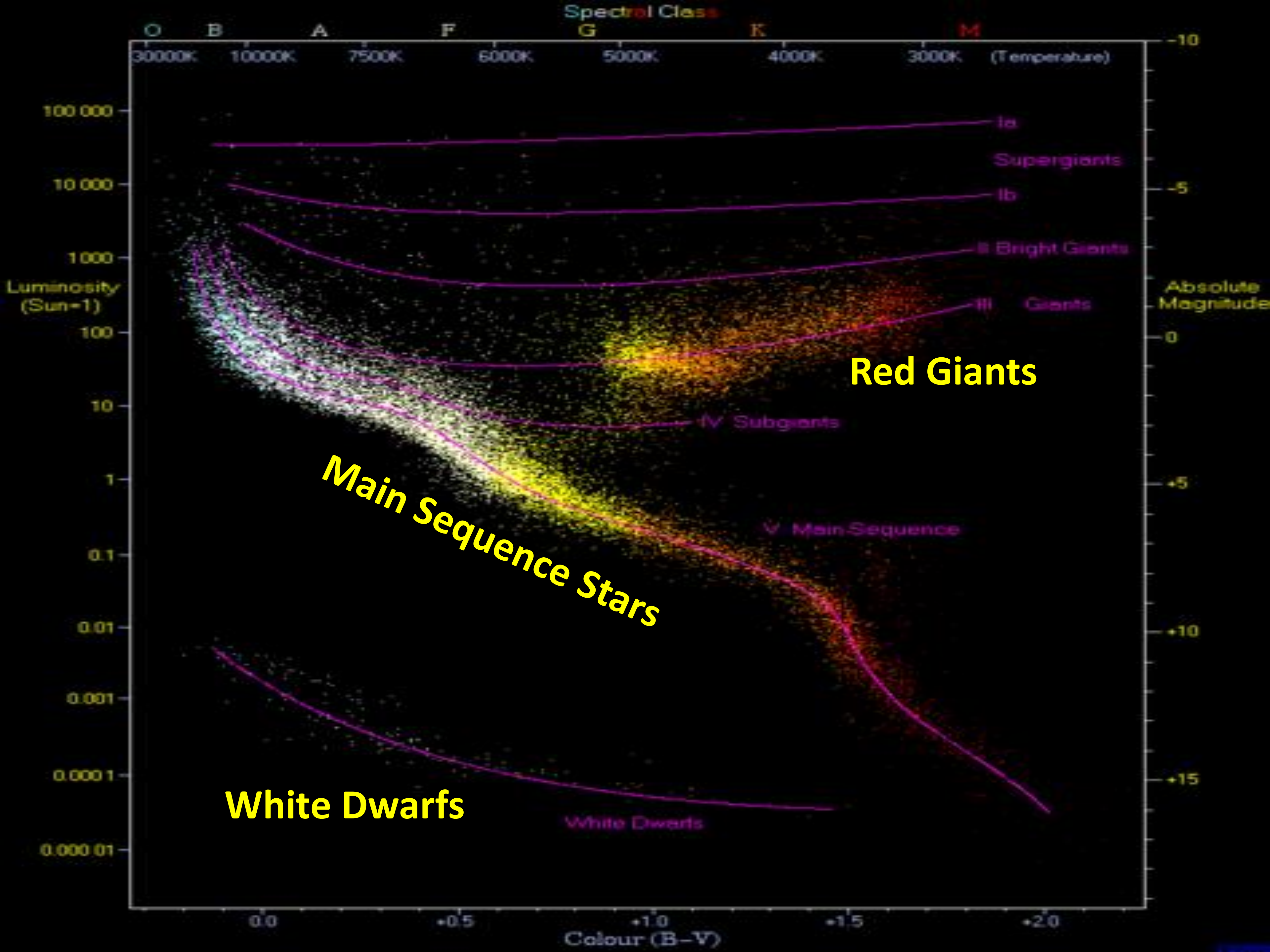


Hertzsprung–Russell Diagram

This is an H–R plot of about 20,000 stars. (Hipparcos satellite data.) The main sequence is clear, as is the red giant region.

About 90% of stars lie on the main sequence; 9% are red giants and 1% are white dwarfs.





Spectral Class
O
B
A
F
G
K
M
30000K
10000K
7500K
6000K
5000K
4000K
3000K
(Temperature)
100 000
10 000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.000 01
Luminosity (Sun=1)
Absolute Magnitude
-10
-5
0
+5
+10
+15
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
Red Giants
Main Sequence Stars
White Dwarfs
0.0
+0.5
+1.0
+1.5
+2.0
Colour (B-V)

Hertzsprung–Russell (H-R) Diagram

Plot of stars magnitude (V) vs color index (B-V)

M = absolute visible magnitude

B-V = apparent blue magnitude minus apparent visible magnitude

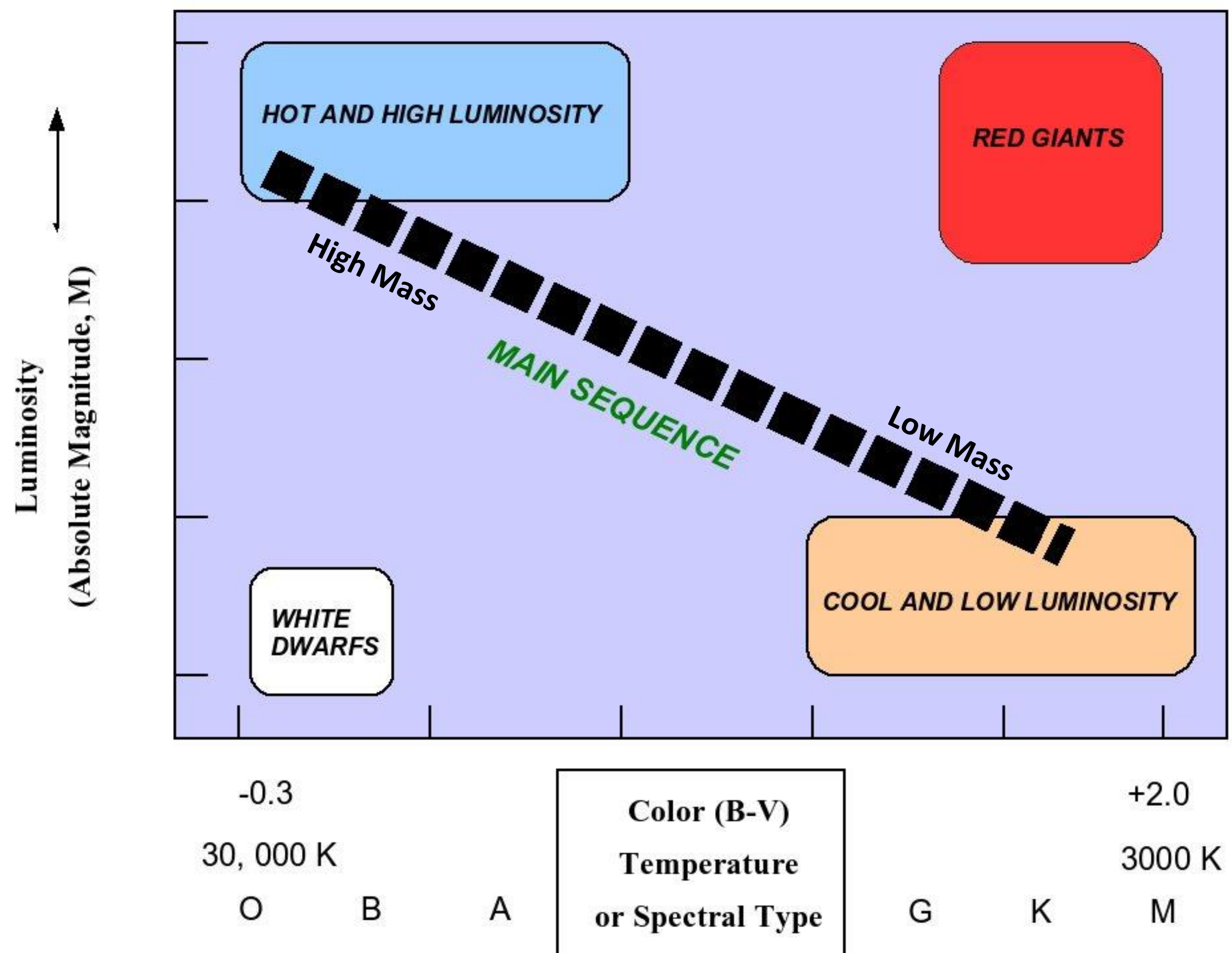
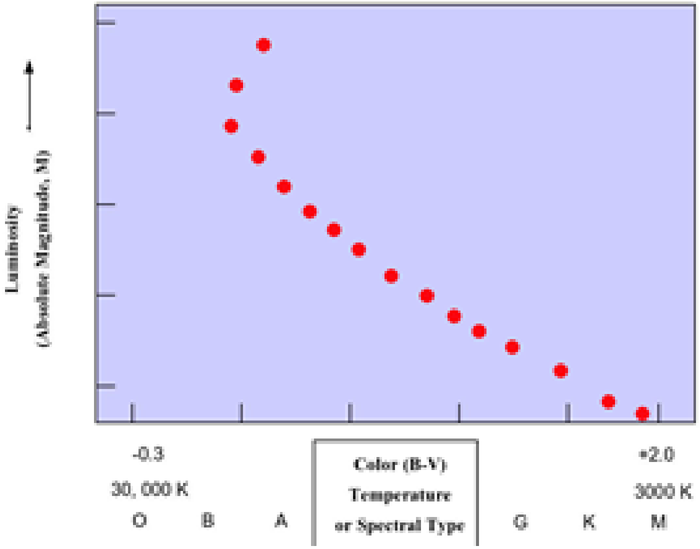
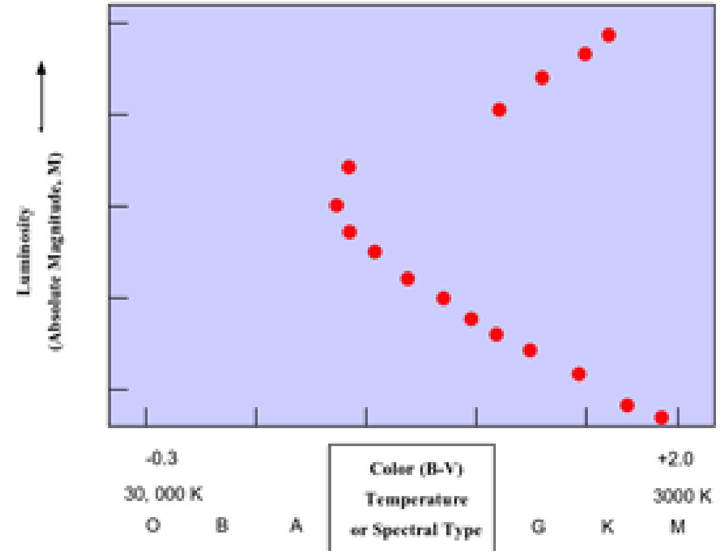


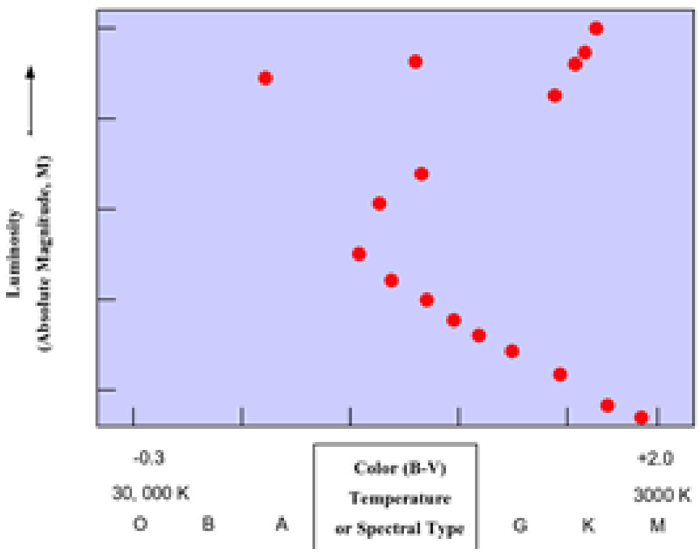
Figure 4: HOW THE HR DIAGRAM OF A CLUSTER CHANGES AS IT AGES



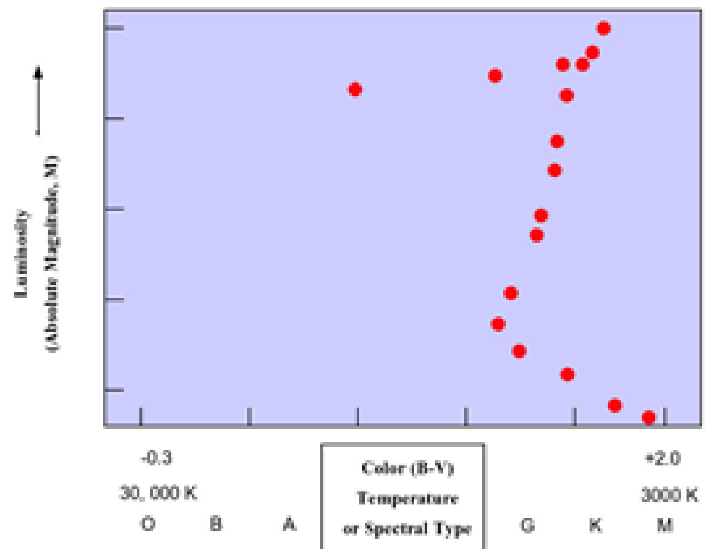
100 Million Years



800 million years



5 billion years



10 billion years

Main sequence fitting

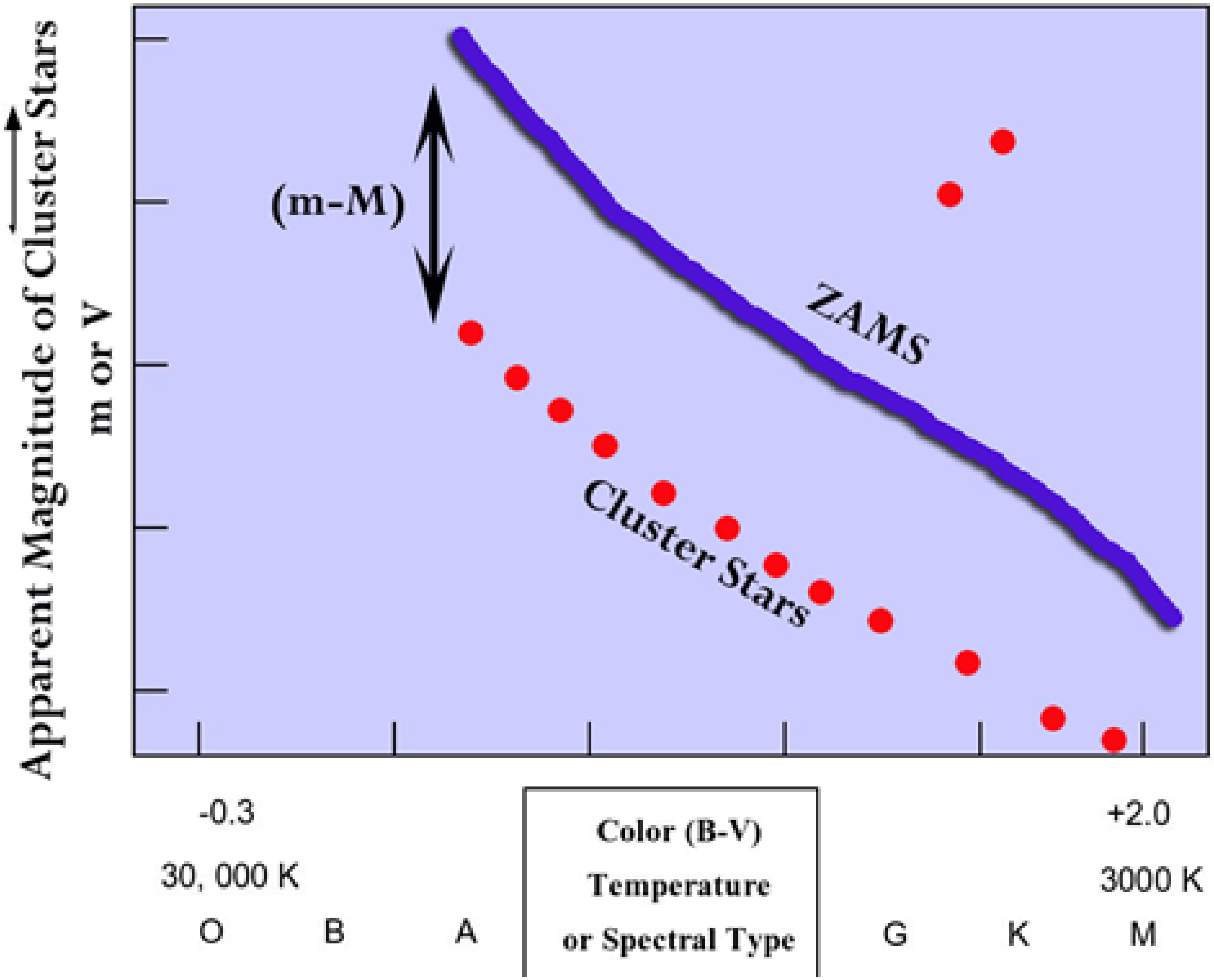
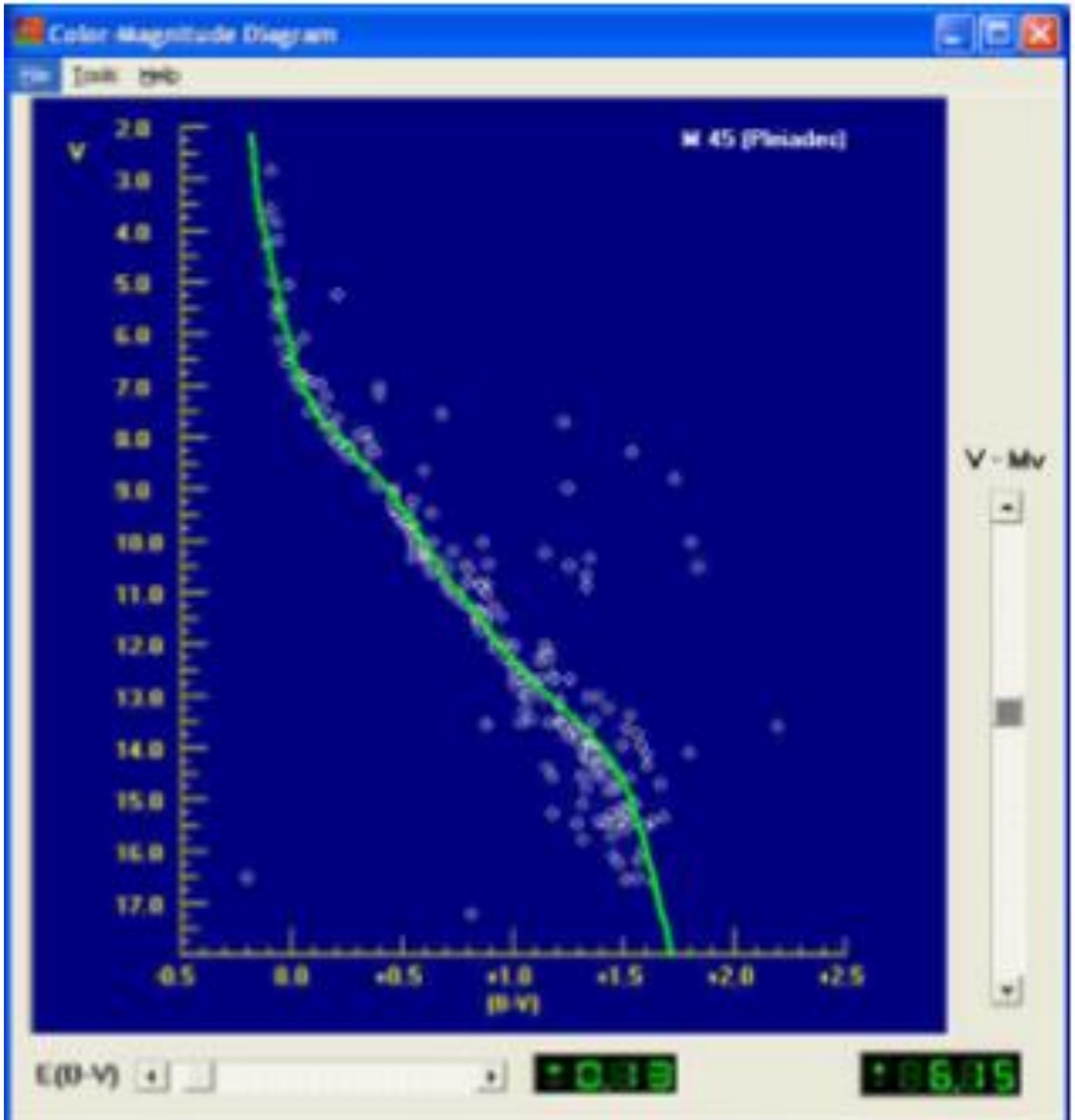


Figure 5: The *distance modulus*, m-M, of a cluster is the difference between the apparent magnitude of the main sequence stars and the absolute magnitude of the corresponding stars on the Zero-Age Main Sequence.

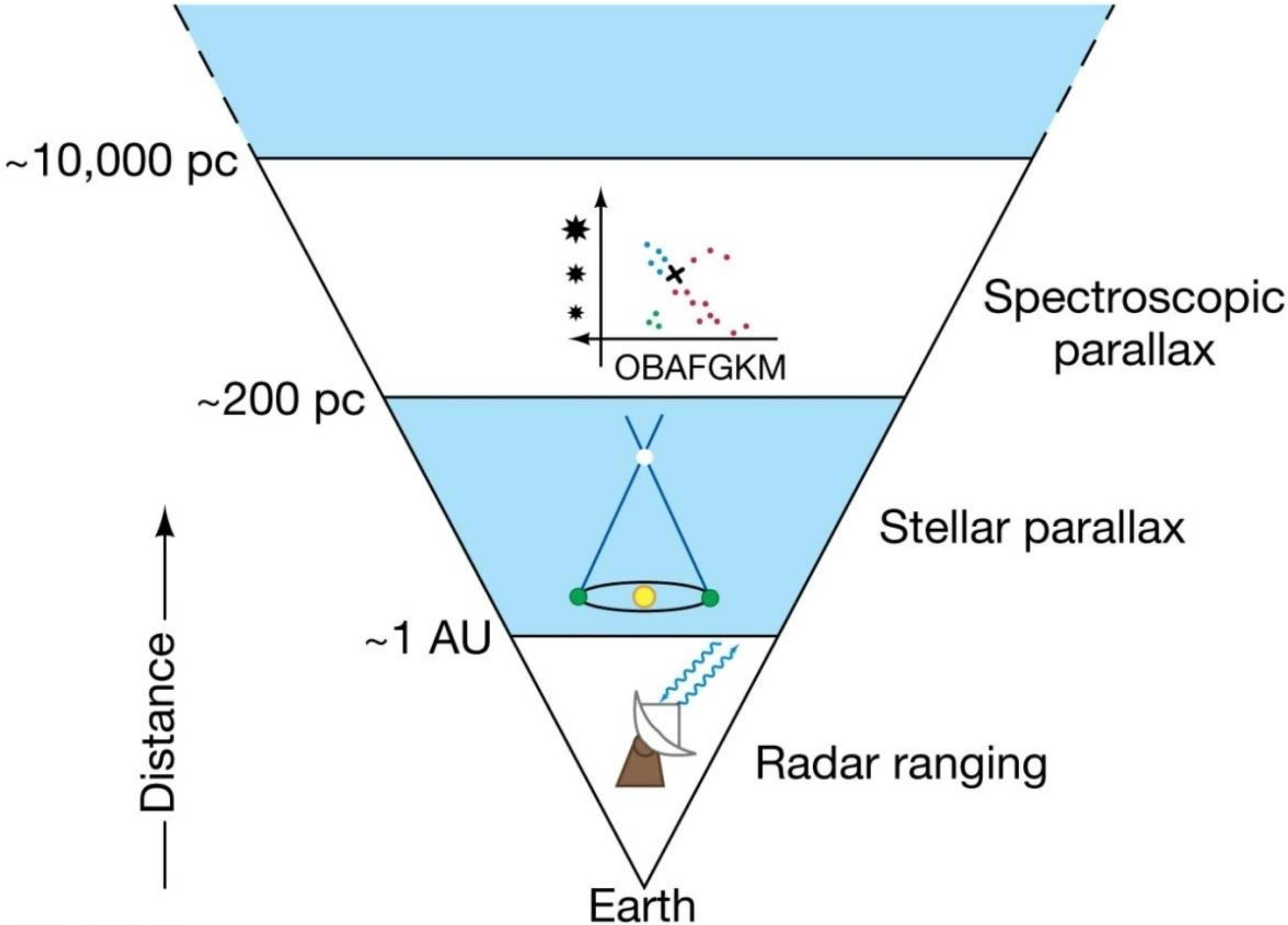
Example: M45 (Pleiades)



D = 10 ^ [(m – M + 5)/5]

Extending the Cosmic Distance Scale

Spectroscopic parallax can extend the cosmic distance scale to several thousand parsecs



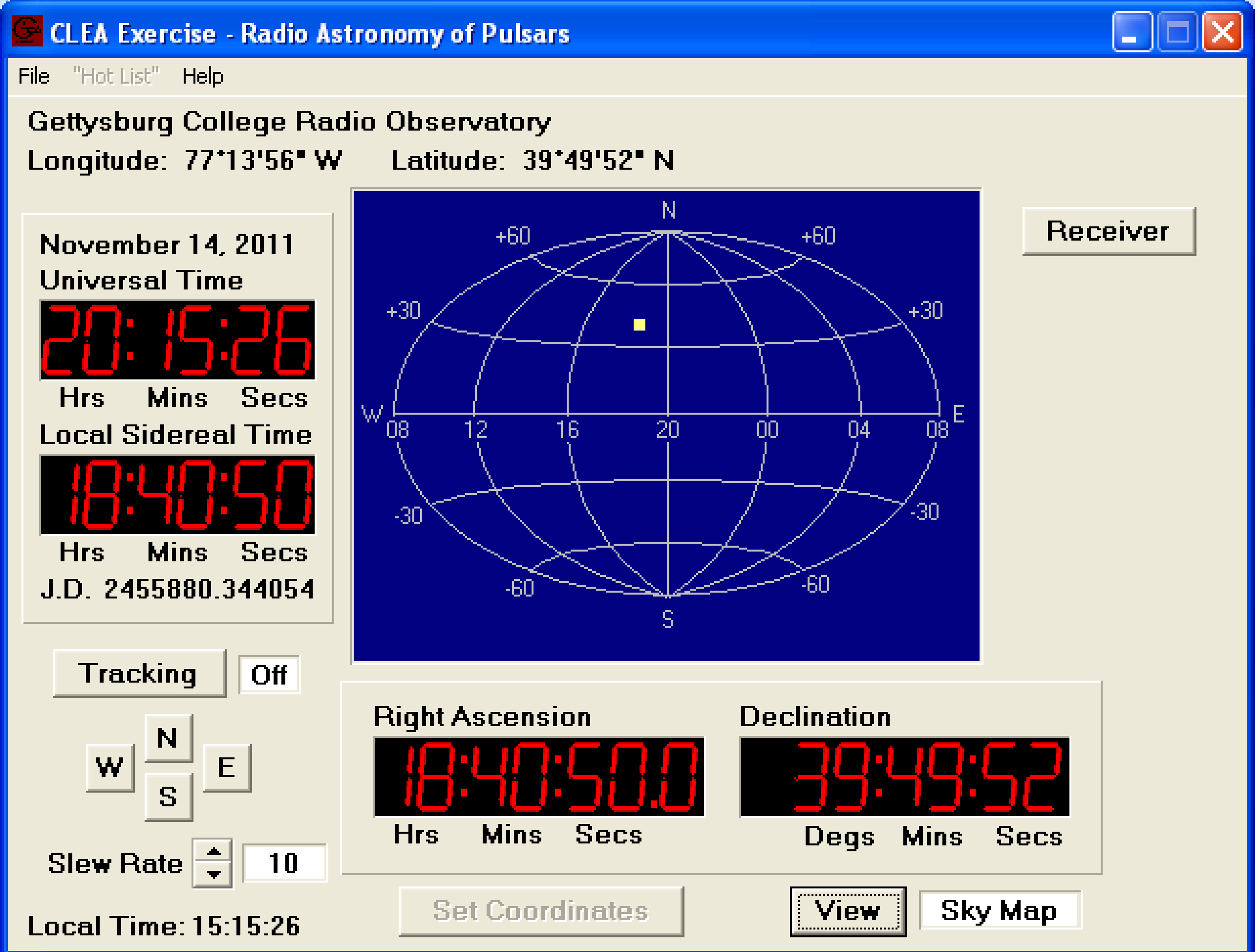
Pulsar Signals

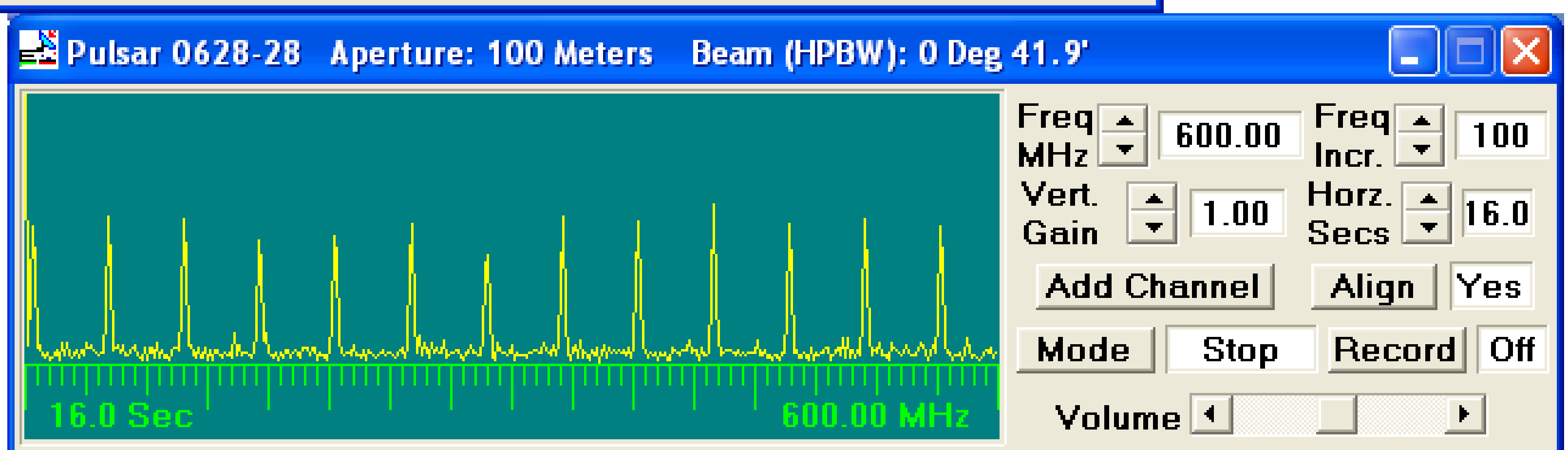
First pulsar detected by Jocelyn Bell in 1967 (“Little Green Men”).
More pulsar discoveries confirmed they were rapidly rotating neutron stars with strong magnetic fields.

Most emit in radio region of EM spectrum (some vis, X-ray, gamma).
Our radio observatory measures from 400 to 1400 MHz.

Higher frequencies travel faster through interstellar medium causing difference in timing between pulses.
This “interstellar dispersion” allows us to calculate distance to pulsar.

Figure 3: Typical Pulsar Signal



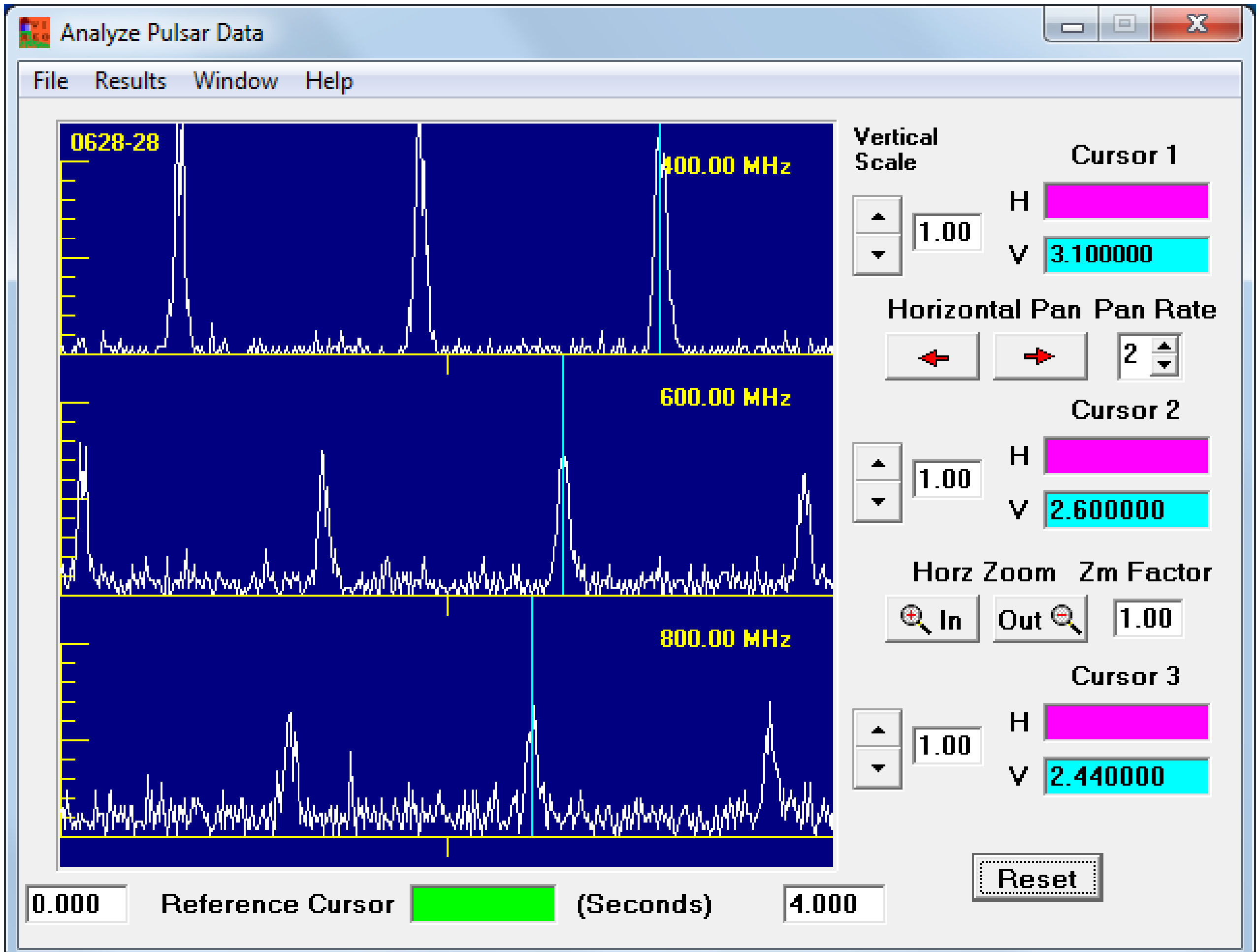


Screams of Rapidly Spinning Pulsars (2:33) Start at 0:55.

https://www.youtube.com/watch?v=SRDOCKOq5iQ&nohtml5=False

Dispersion in pulsar timing

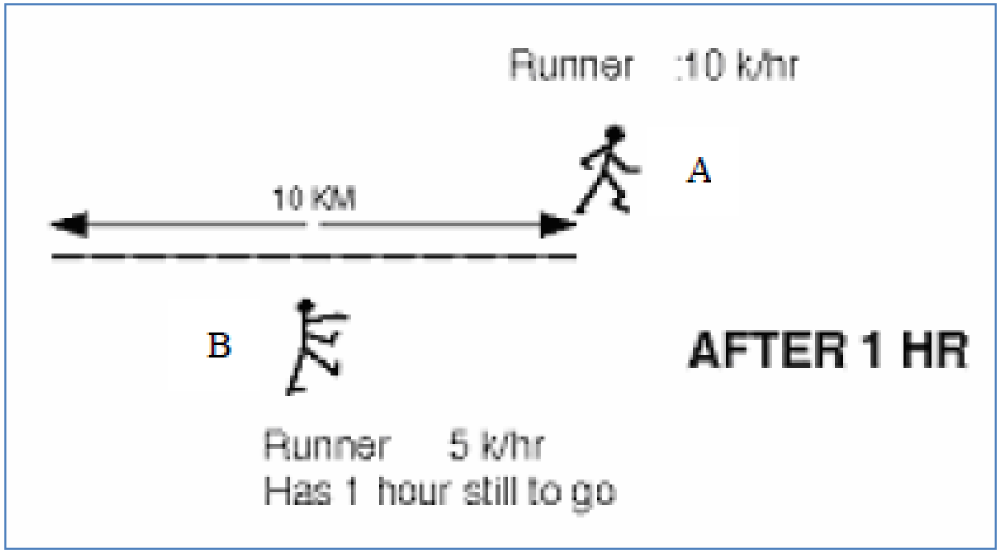
Pulsars are spinning neutron stars that emit pulses at very regular intervals ranging from milliseconds to seconds. Astronomers believe that the pulses are emitted simultaneously over a wide range of frequencies. However, as observed on Earth, the components of each pulse emitted at higher radio frequencies arrive before those emitted at lower frequencies. This dispersion occurs because of the ionized component of the interstellar medium, mainly the free electrons, which make the group velocity frequency dependent.



Measuring distance using dispersion

Pulsar emits radiation at many different frequencies.

Higher frequencies travel faster through interstellar medium.



$$T_A = L/ V_a$$

$$T_B = L/V_b$$

$$T_B - T_A = L/V_b - L/V_a$$

$$T_B - T_A = L(1/V_b - 1/V_a)$$

$$L = \frac{T_B - T_A}{\left(\frac{1}{V_b} - \frac{1}{V_a}\right)}$$

$$L = \frac{(2 - 1)}{(1/5 - 1/10)} = 10 \text{ km}$$

Dispersion formula for interstellar medium

Velocity of pulse depends on EM frequency and electron density.

$v = f^2 / (4150 * n_e)$

electron density

$n_e = 0.03$ electrons/cm^3

$v = f^2 / 124.5$

$1/v = 124.5 / f^2$

$$\boxed{D = \frac{T_2 - T_1}{124.5\left(\left(1/f_2\right)^2 - \left(1/f_1\right)^2\right)}}$$

T = arrival time (sec)

f = frequency (MHz)

D = distance (parsecs)

Example

$T_1 = 3.690$ sec
$T_2 = 4.355$ sec
$T_2 - T_1 = 0.665$ sec

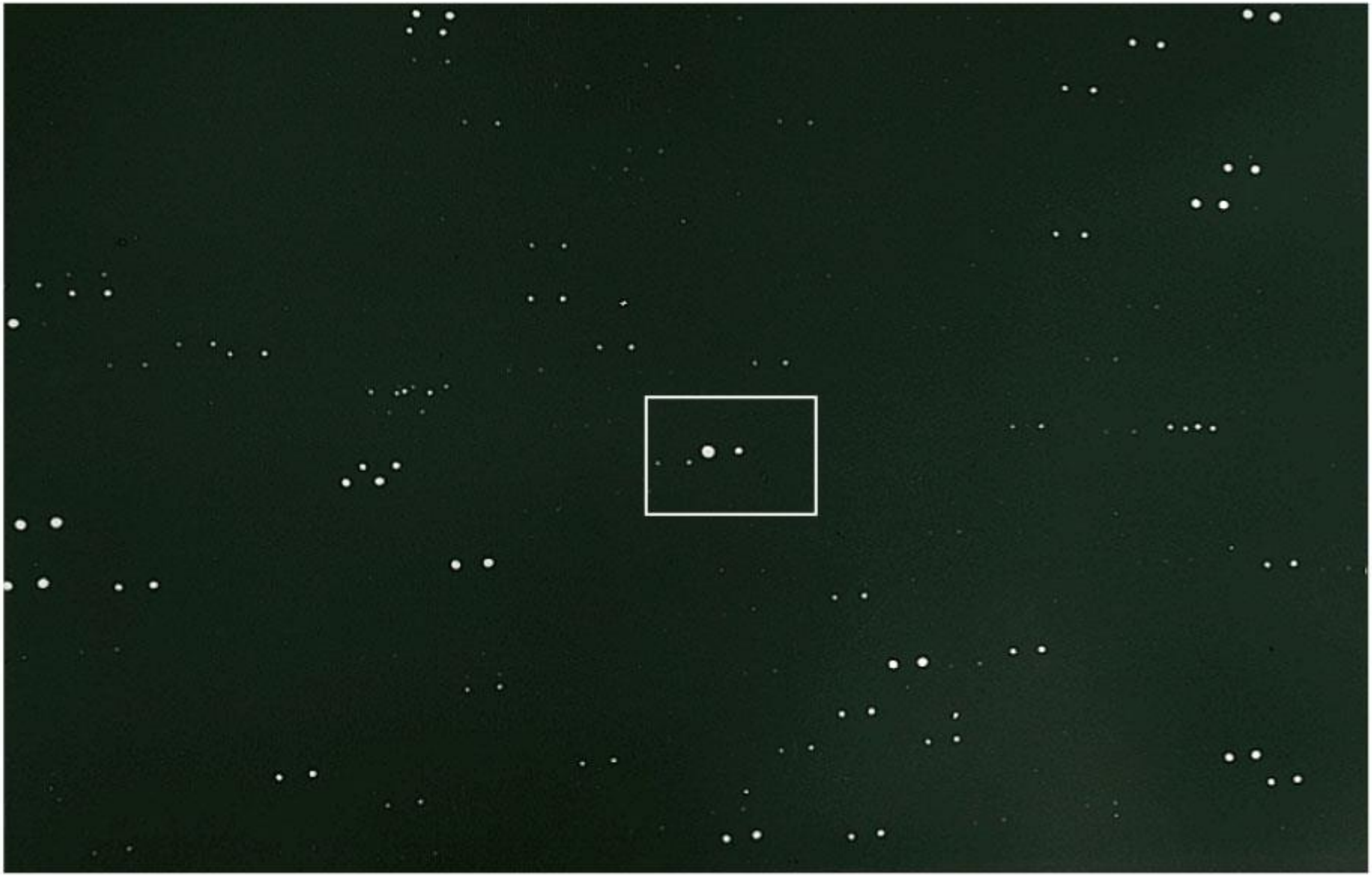
$f_1 = 800$ MHz
$f_2 = 400$ MHz

$$D = \frac{T_2 - T_1}{124.5\left((1/f_2)^2 - (1/f_1)^2\right)}$$

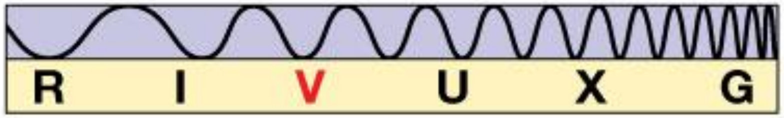
T = arrival time (sec)
f = frequency (MHz)
D = distance (parsecs)

$(1/f_2)^2 - (1/f_1)^2$
$= (1/400)^2 - (1/800)^2$
$= 4.687 \times 10^{-6}$

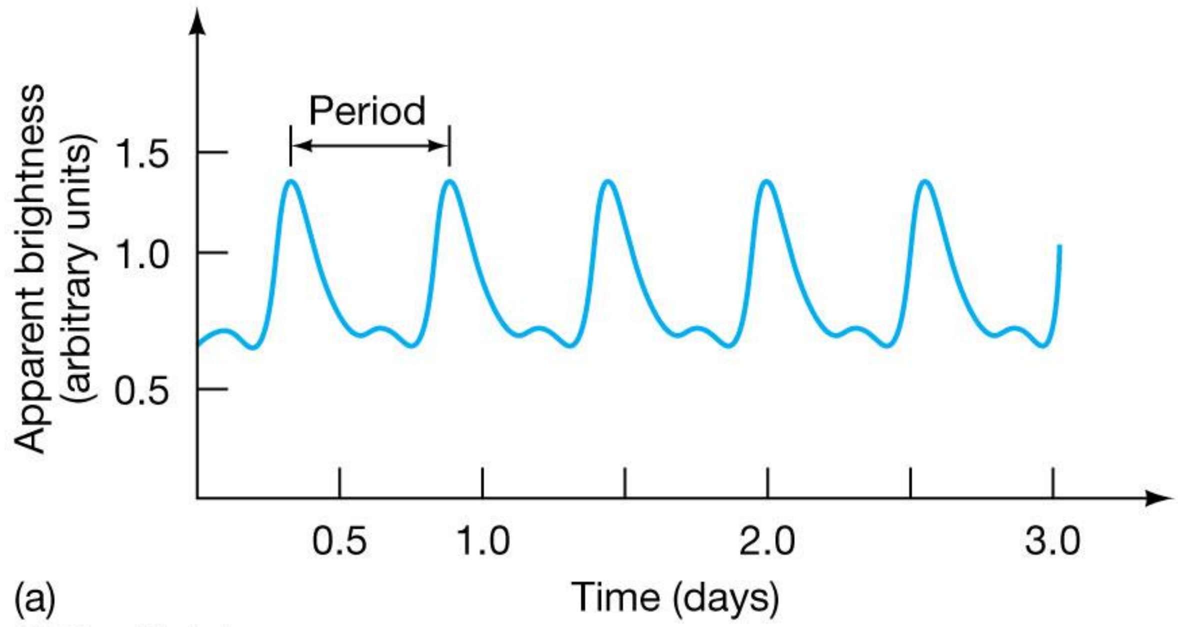
$$D = \frac{0.665}{124.5 * 4.687 \times 10^{-6}} = 1139 \text{ parsecs}$$



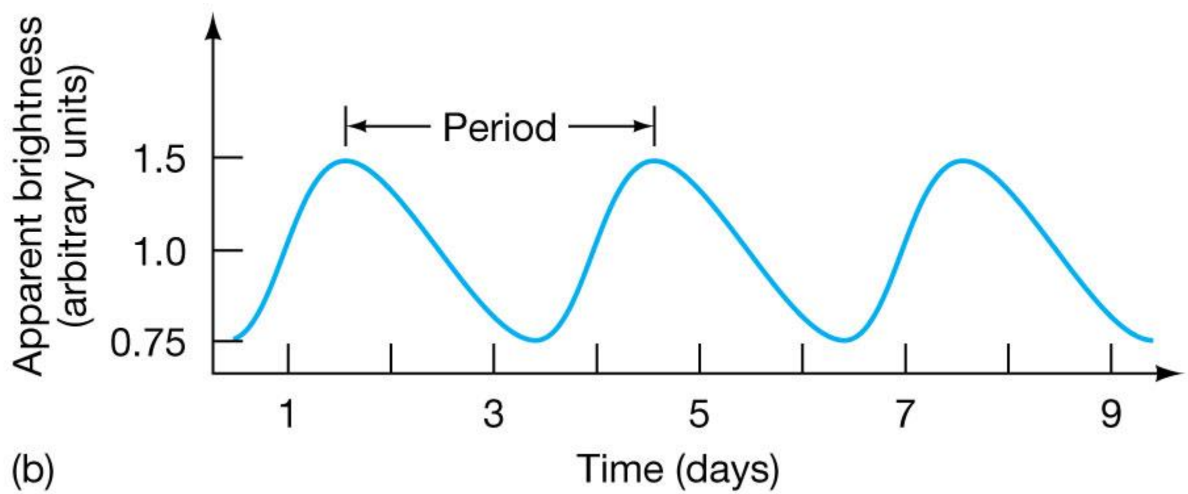
(c)



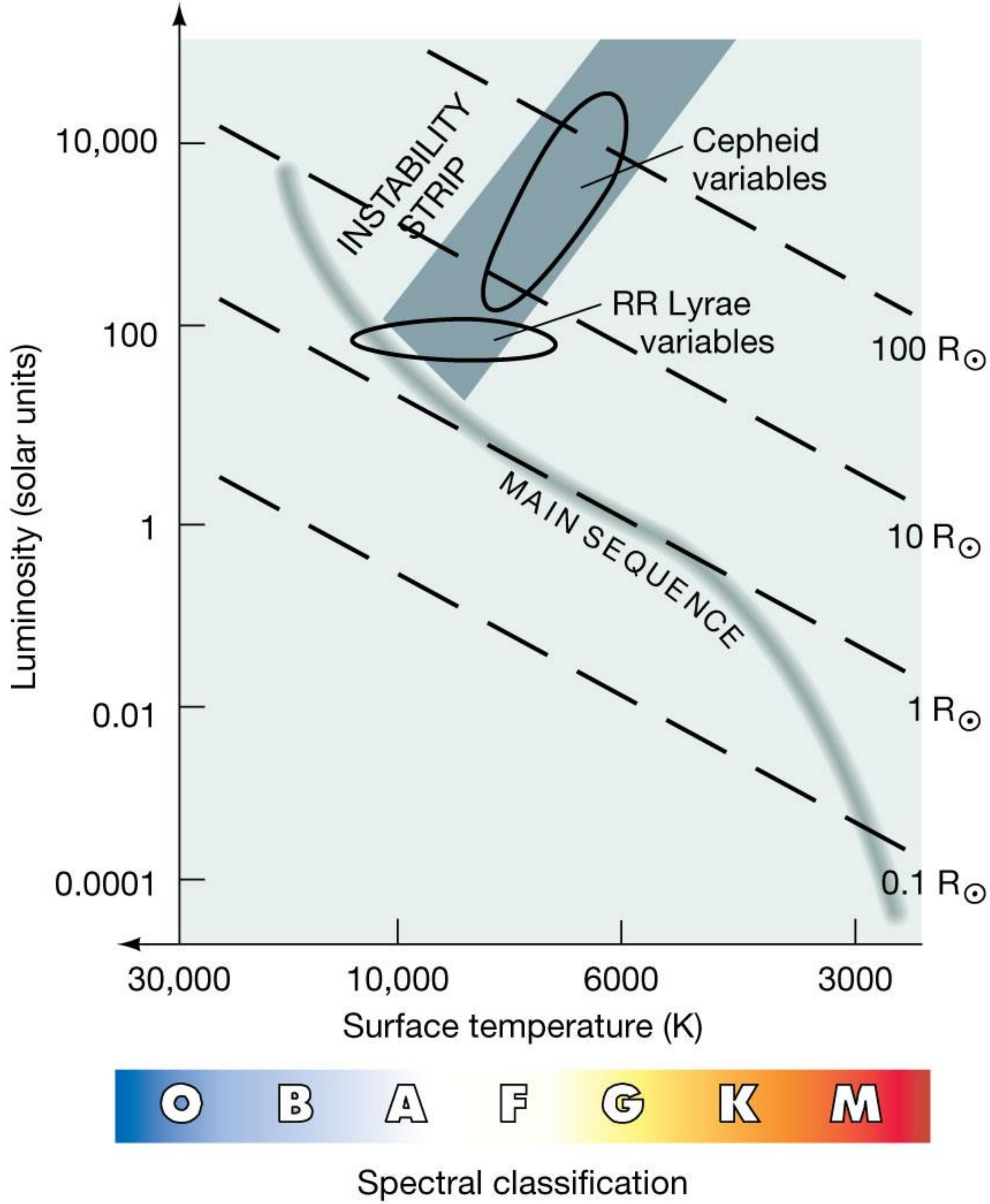
The upper plot is an RR Lyrae star. All such stars have essentially the same luminosity curve with periods from 0.5 to 1 day.



The lower plot is a Cepheid variable; Cepheid periods range from about 1 to 100 days.



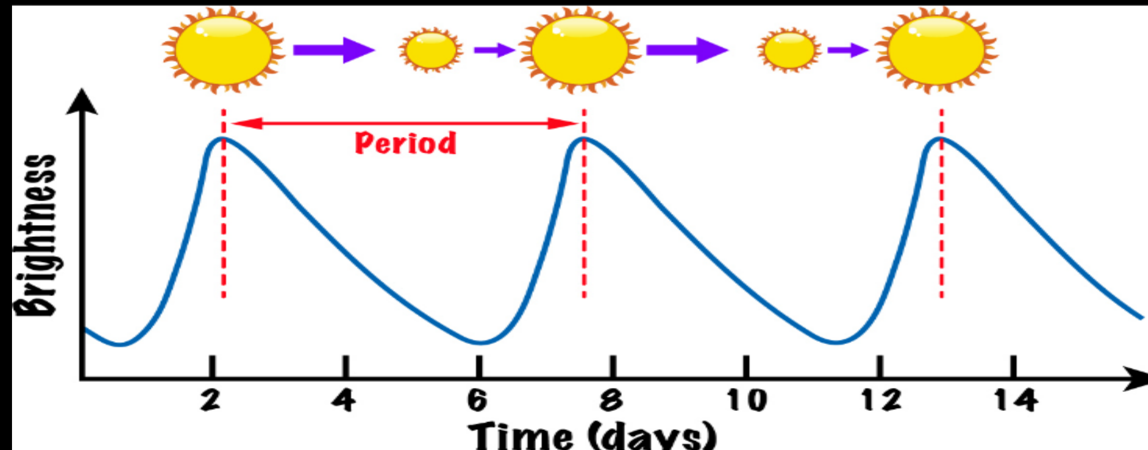
The variability of these stars comes from a dynamic balance between gravity and pressure—they have large oscillations around stability.

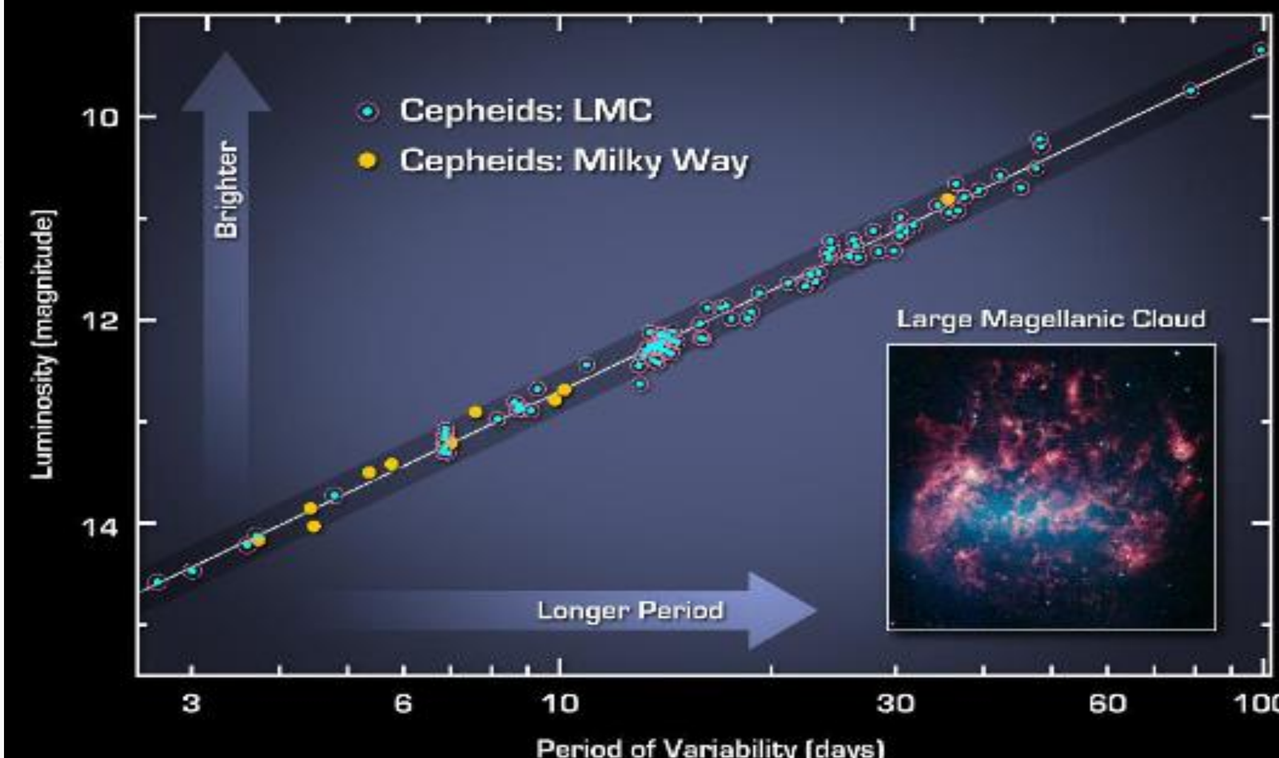


Cepheid Variable Stars

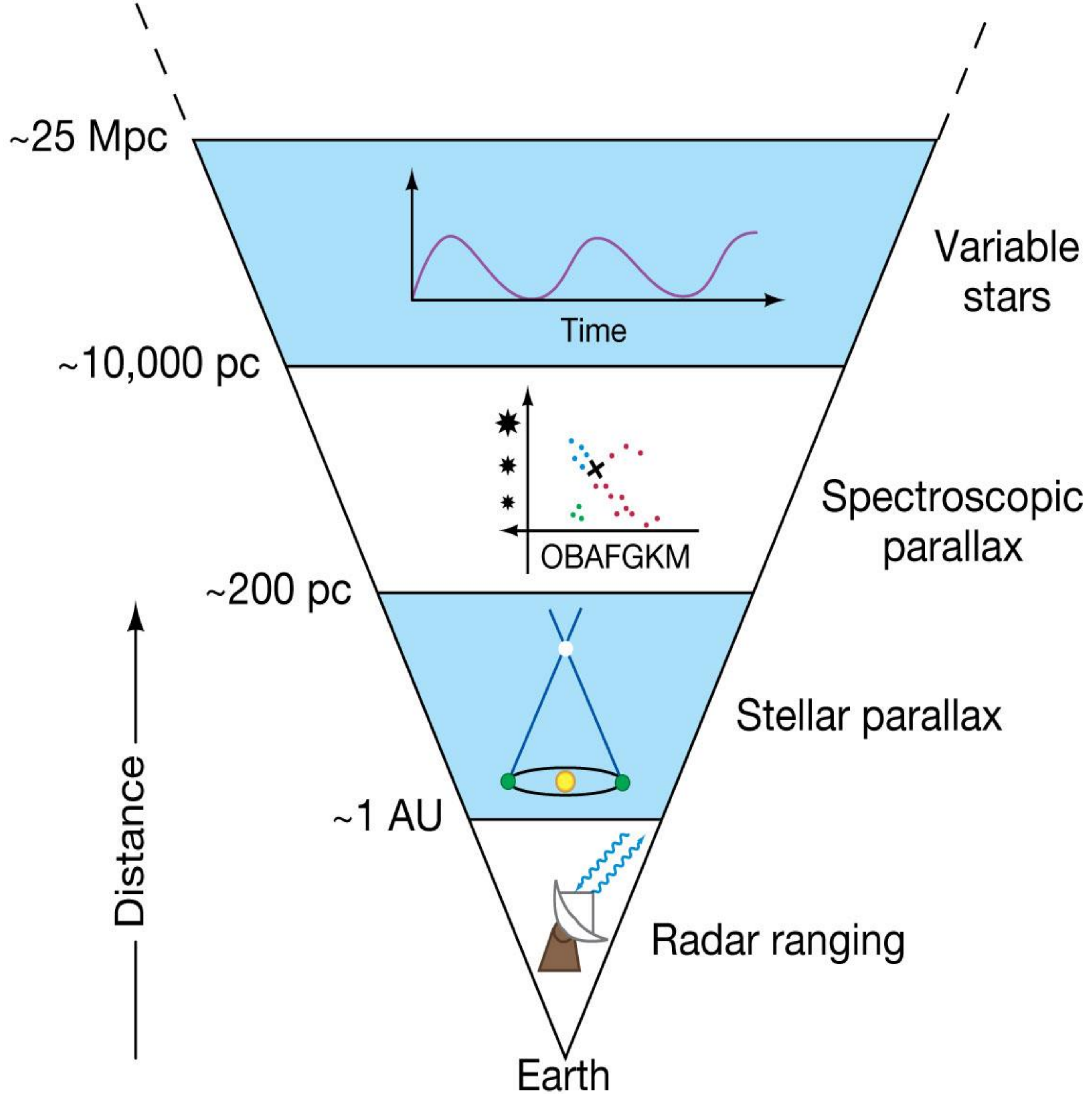
Henrietta Swan Leavitt

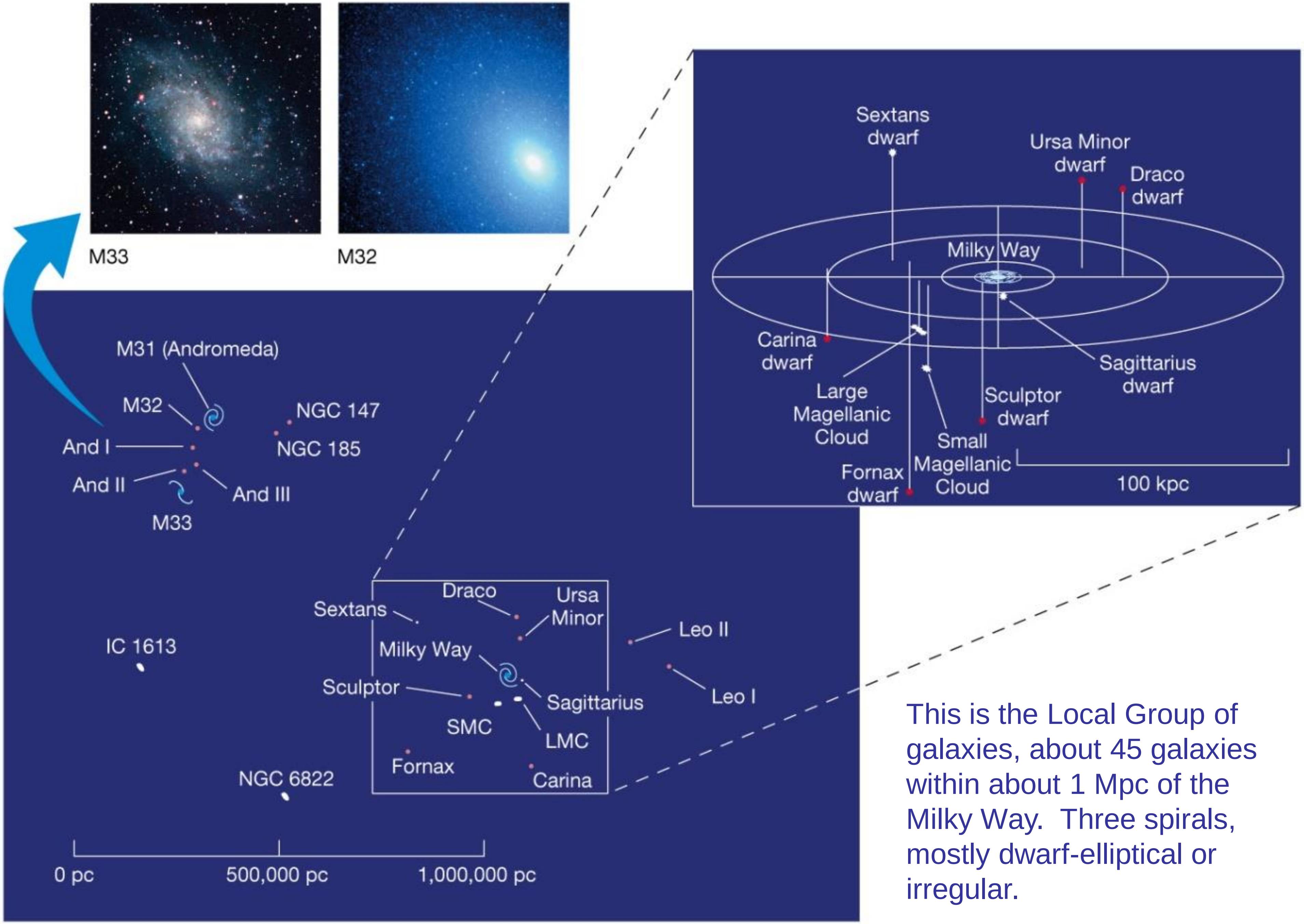
Born	July 4, 1868 Lancaster, Massachusetts, U.S.
Died	December 12, 1921 (aged 53) Cambridge, Massachusetts, U.S.
Residence	Cambridge, Massachusetts
Citizenship	United States
Nationality	American
Fields	Astronomy
Institutions	Harvard University
Alma mater	Radcliffe College, Oberlin College
Known for	Leavitt's Law: the period –luminosity relationship of Cepheid stars





We have now expanded our cosmic distance ladder one more step:

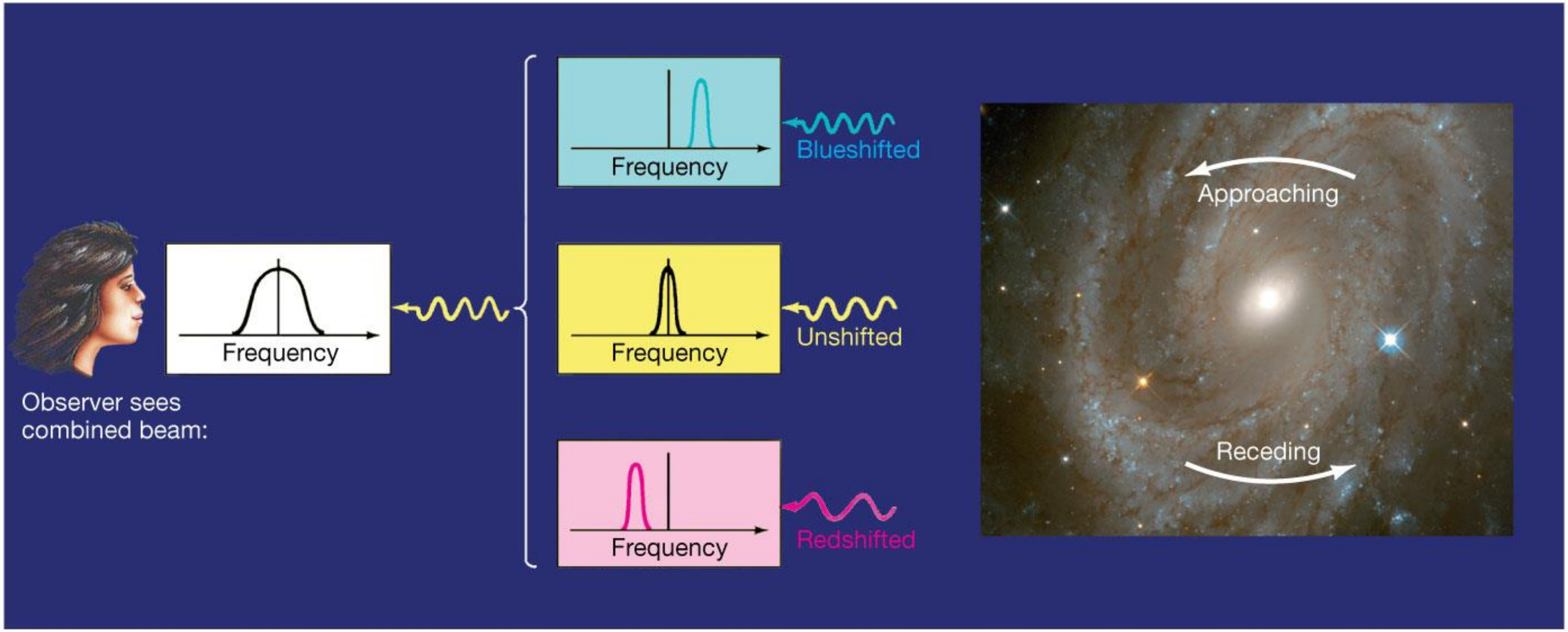


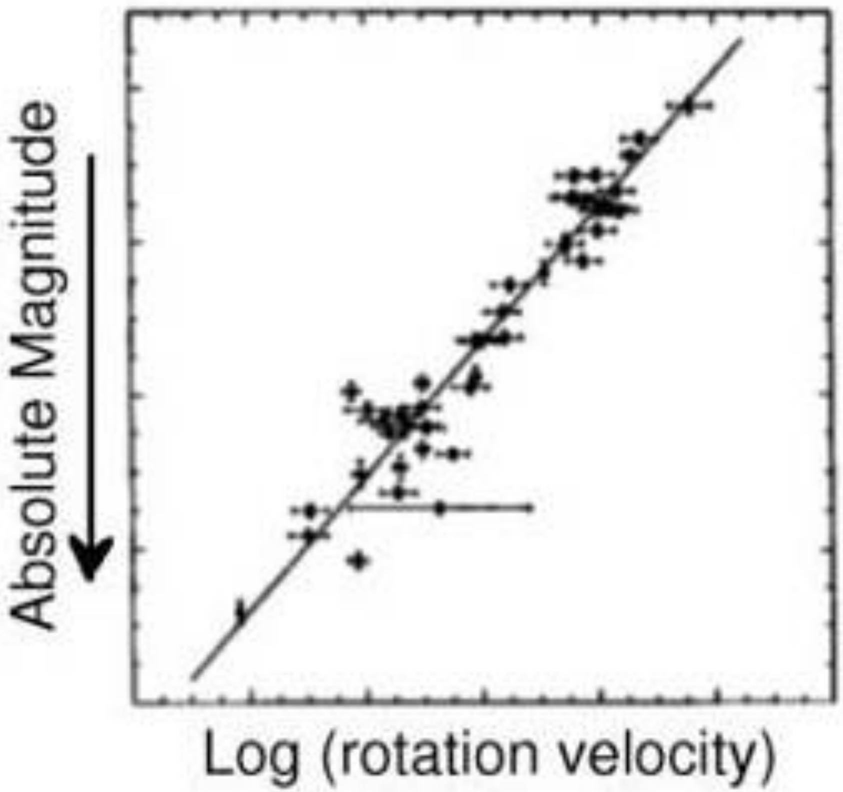


This is the Local Group of galaxies, about 45 galaxies within about 1 Mpc of the Milky Way. Three spirals, mostly dwarf-elliptical or irregular.

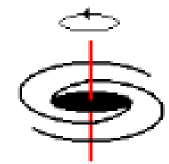
However, some galaxies have no Cepheids, and most are farther away than 25 Mpc. New distance measures are needed.

• Tully-Fisher relation correlates a galaxy's rotation speed (which can be measured using the Doppler effect) to its luminosity. Very tight correlation. Using 21-cm and IR to avoid dust. 200 Mpc.

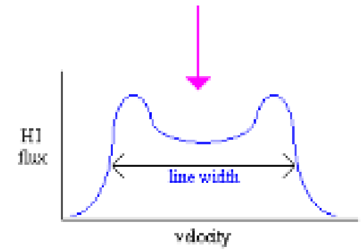




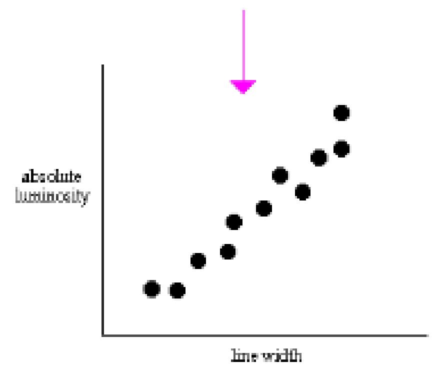
Tully–Fisher relation



spiral galaxies rotate, and the rotation speed is proportional to the mass of the galaxy



measurements of neutral hydrogen (HI) display a ''double–horned'' profile, where the width of the line indicates the mass

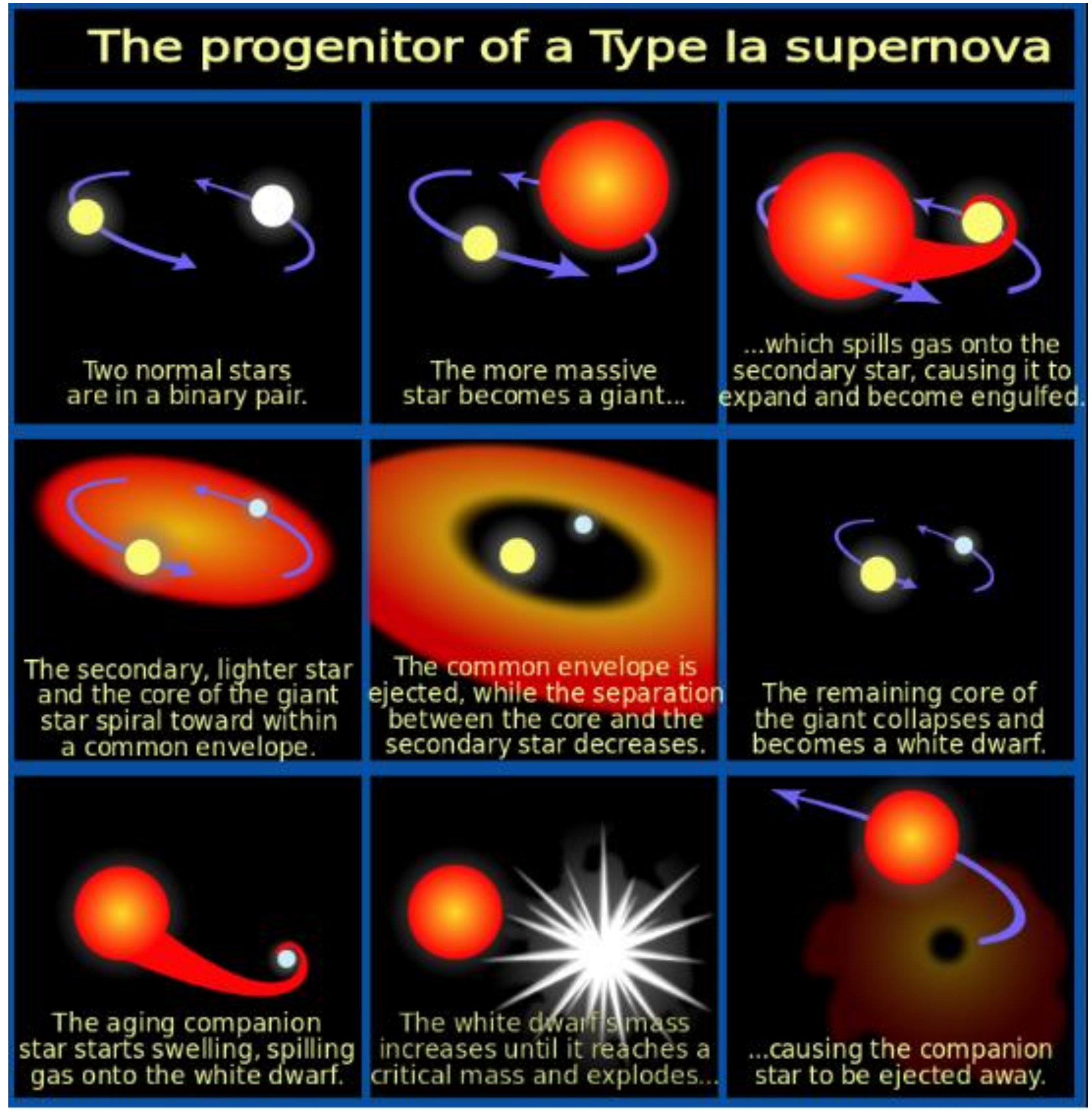


a plot of line width versus absolute luminosity of a galaxy is called the Tully–Fisher relation. When calibrated using galaxies with Cepheid distances, the TF relation is used to determine Hubble's constant.

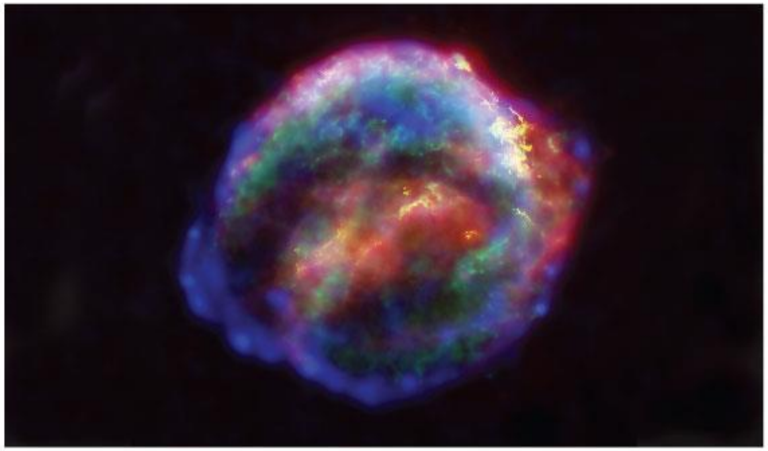
A type Ia supernova (type one-a) is a type of supernova that occurs in binary systems (two stars orbiting one another) in which one of the stars is a white dwarf. The other star can be anything from a giant star to an even smaller white dwarf.

Physically, carbon–oxygen white dwarfs with a low rate of rotation are limited to below 1.44 solar masses.
Beyond this, they re-ignite and in some cases trigger a supernova explosion.

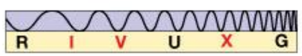
This type Ia category of supernovae produces consistent peak luminosity because of the uniform mass of white dwarfs that explode via the accretion mechanism. The stability of this value allows these explosions to be used as standard candles to measure the distance to their host galaxies because the visual magnitude of the supernovae depends primarily on the distance.

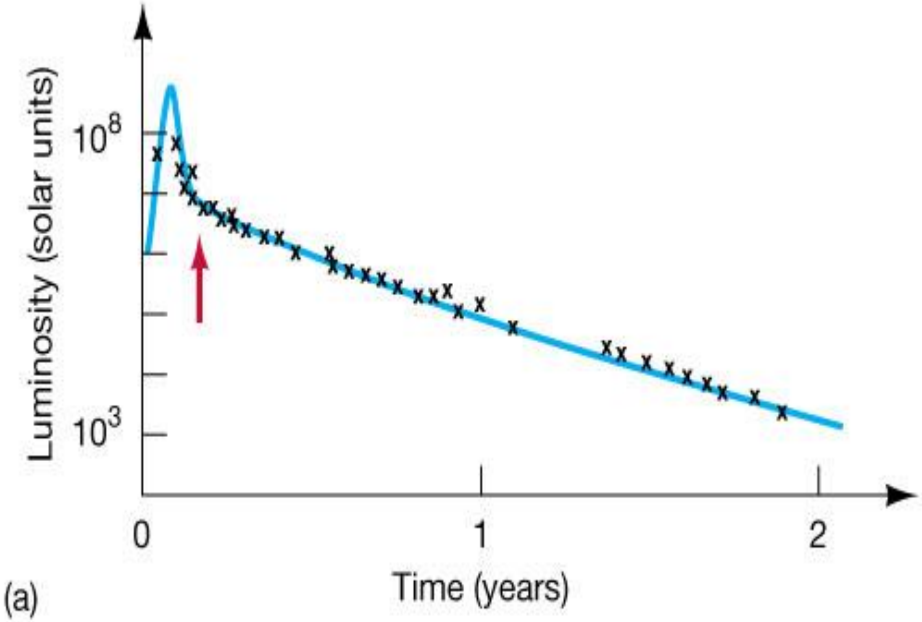


This theory of formation of new elements in supernova explosions produces a light curve that agrees quite well with observed curves:

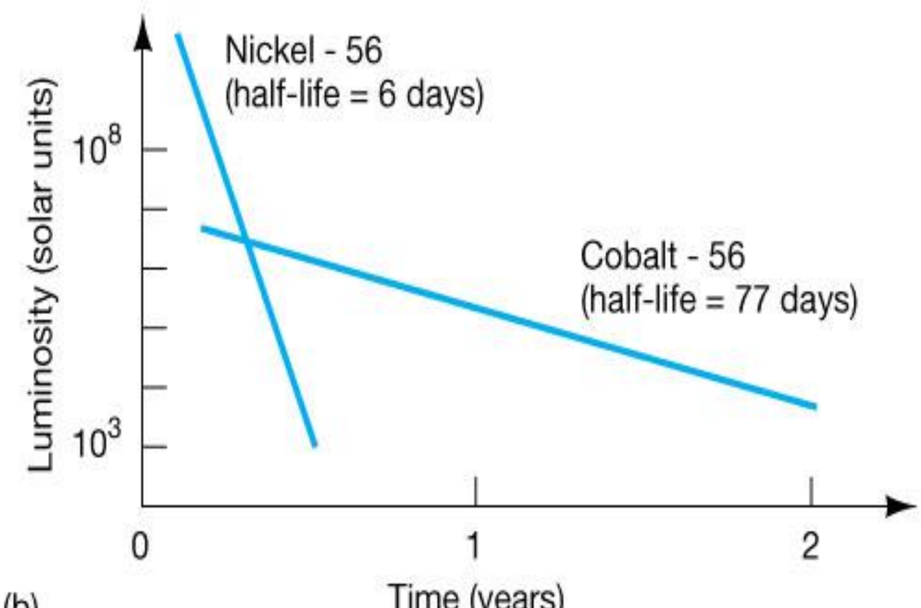


(c)





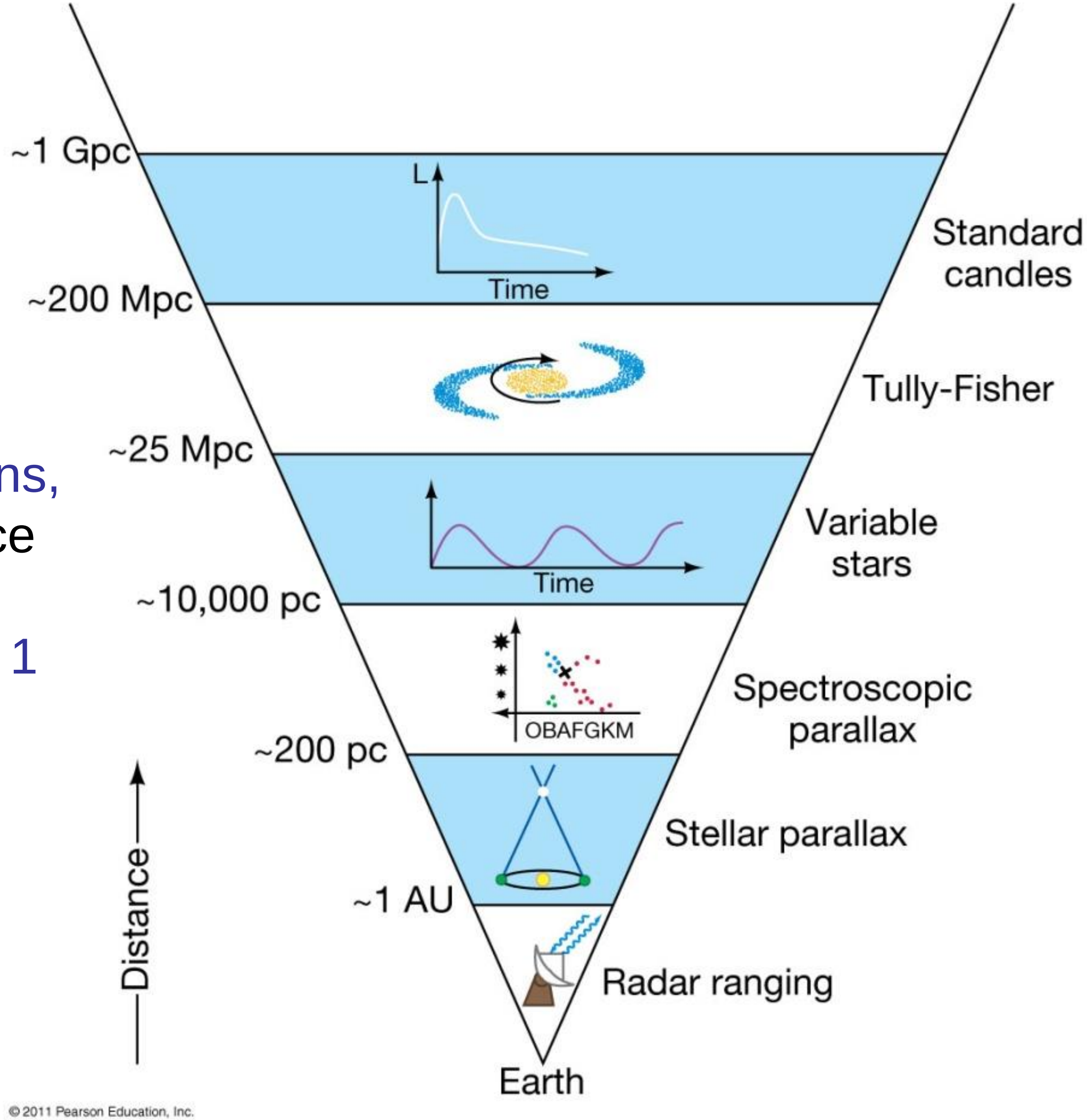
(a)



(b)

Type I supernovae all have about the same luminosity, as the process by which they happen doesn't allow for much variation. They can be used as "standard candles"—objects whose absolute magnitude is known, and which can therefore be used to determine distance using their apparent magnitude.

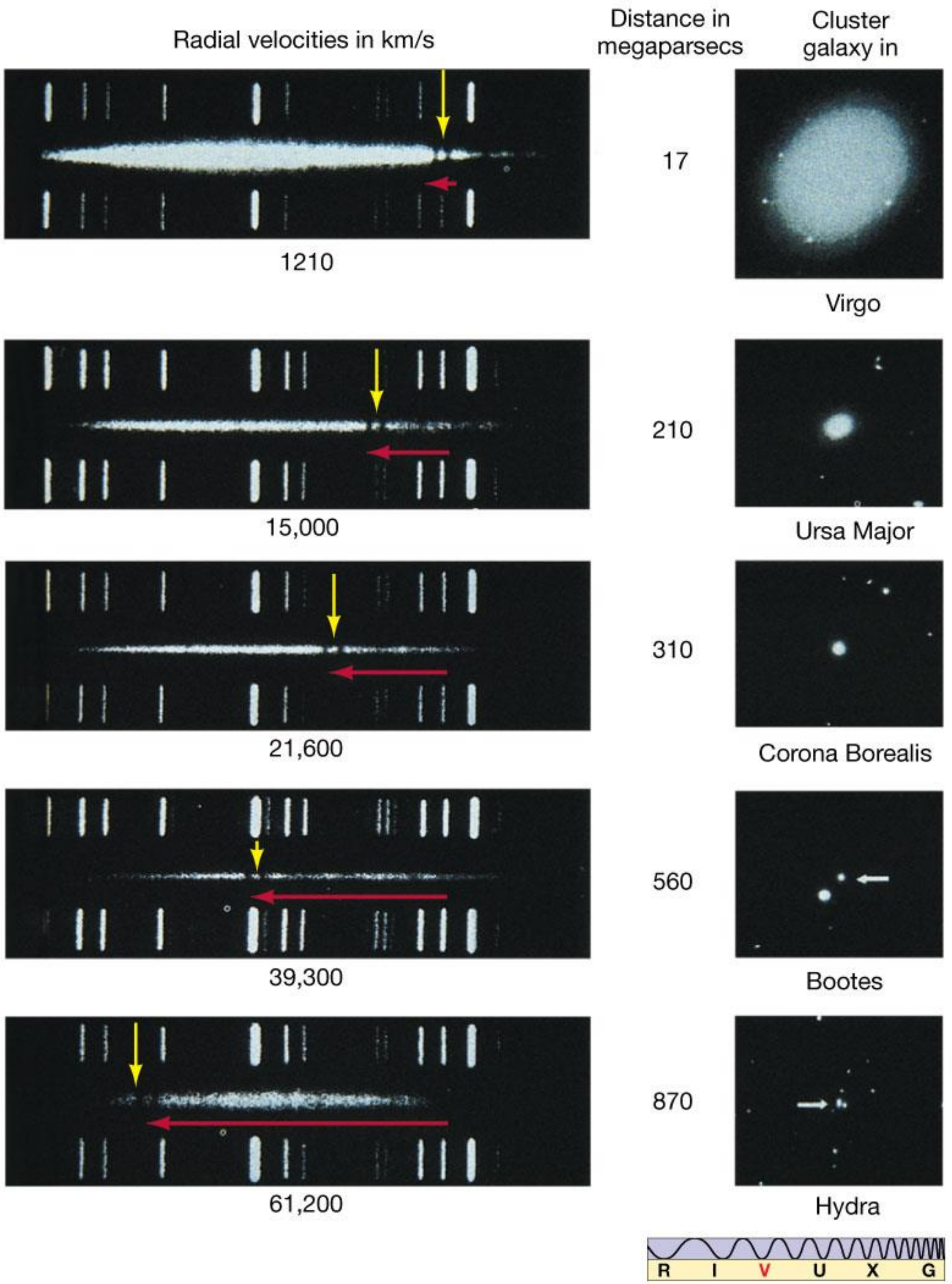
With these additions, the cosmic distance ladder has been extended to about 1 Gpc



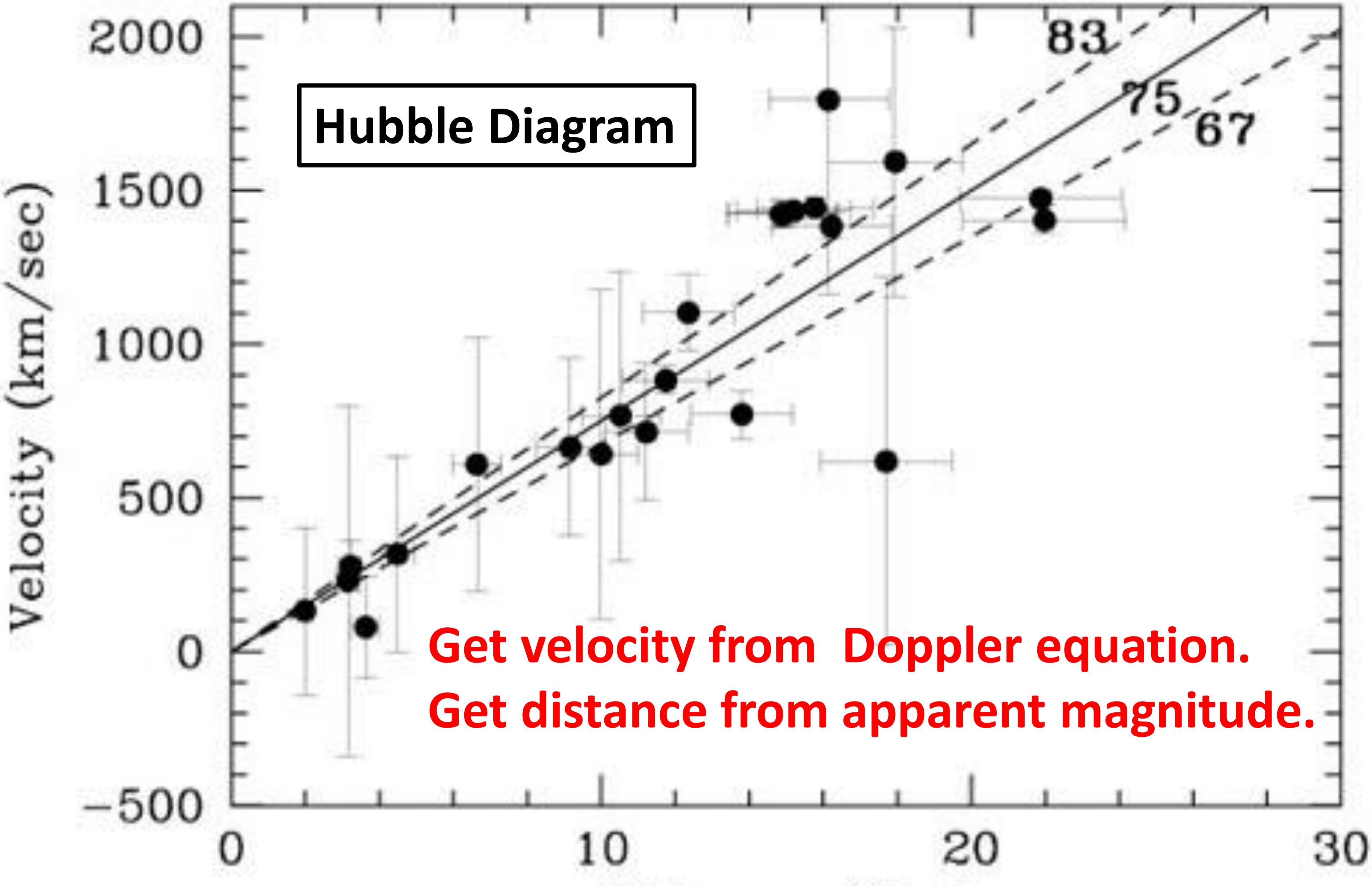
Hubble Ultra Deep Field

Hubble's Law

Universal recession: all galaxies (with a couple of nearby exceptions) seem to be moving away from us, with the redshift of their motion correlated with their distance.



Hubble Parameter (H) = 67 to 83 km/sec/Mpc



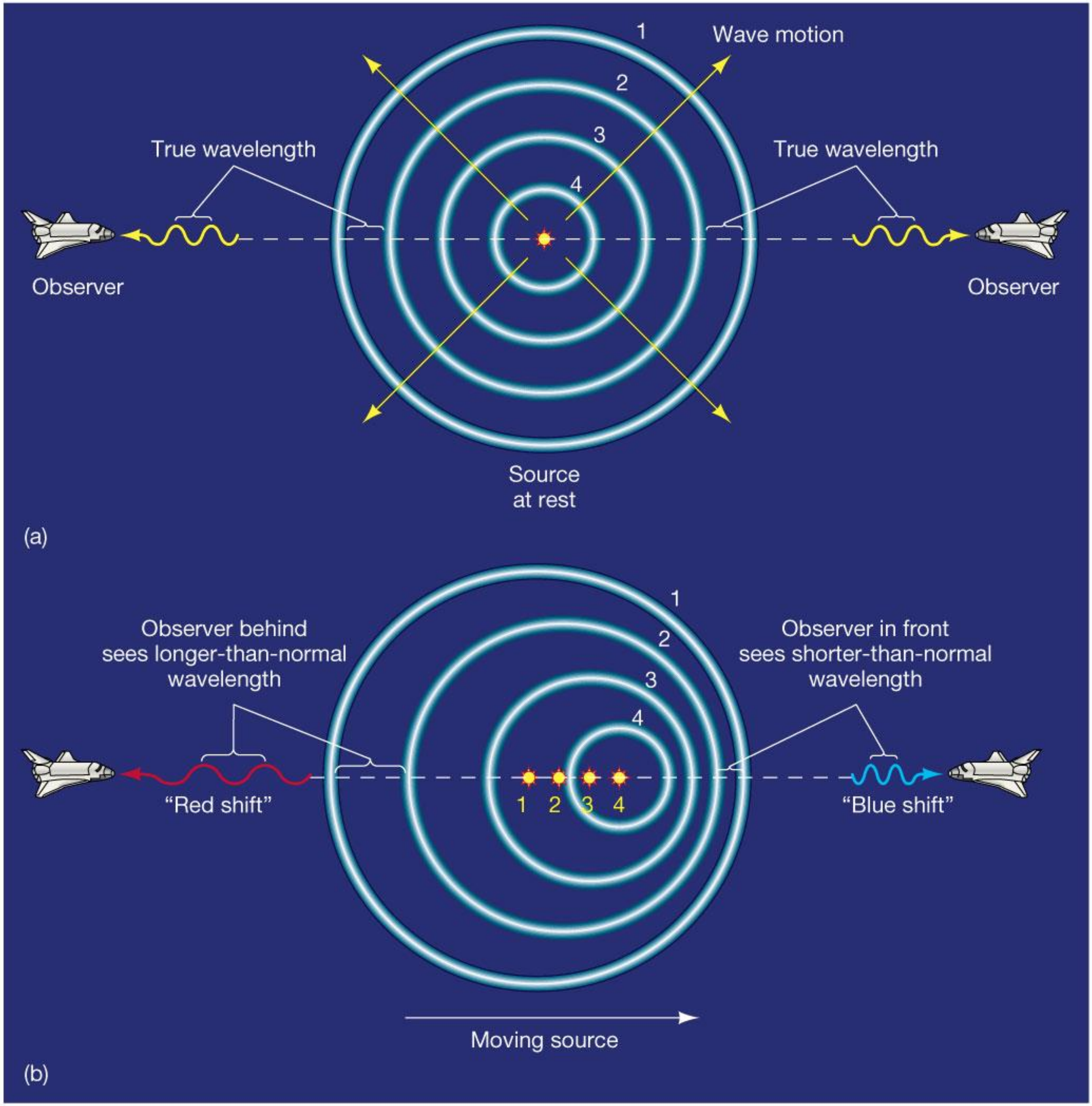
Get velocity from Doppler equation.

Get distance from apparent magnitude.

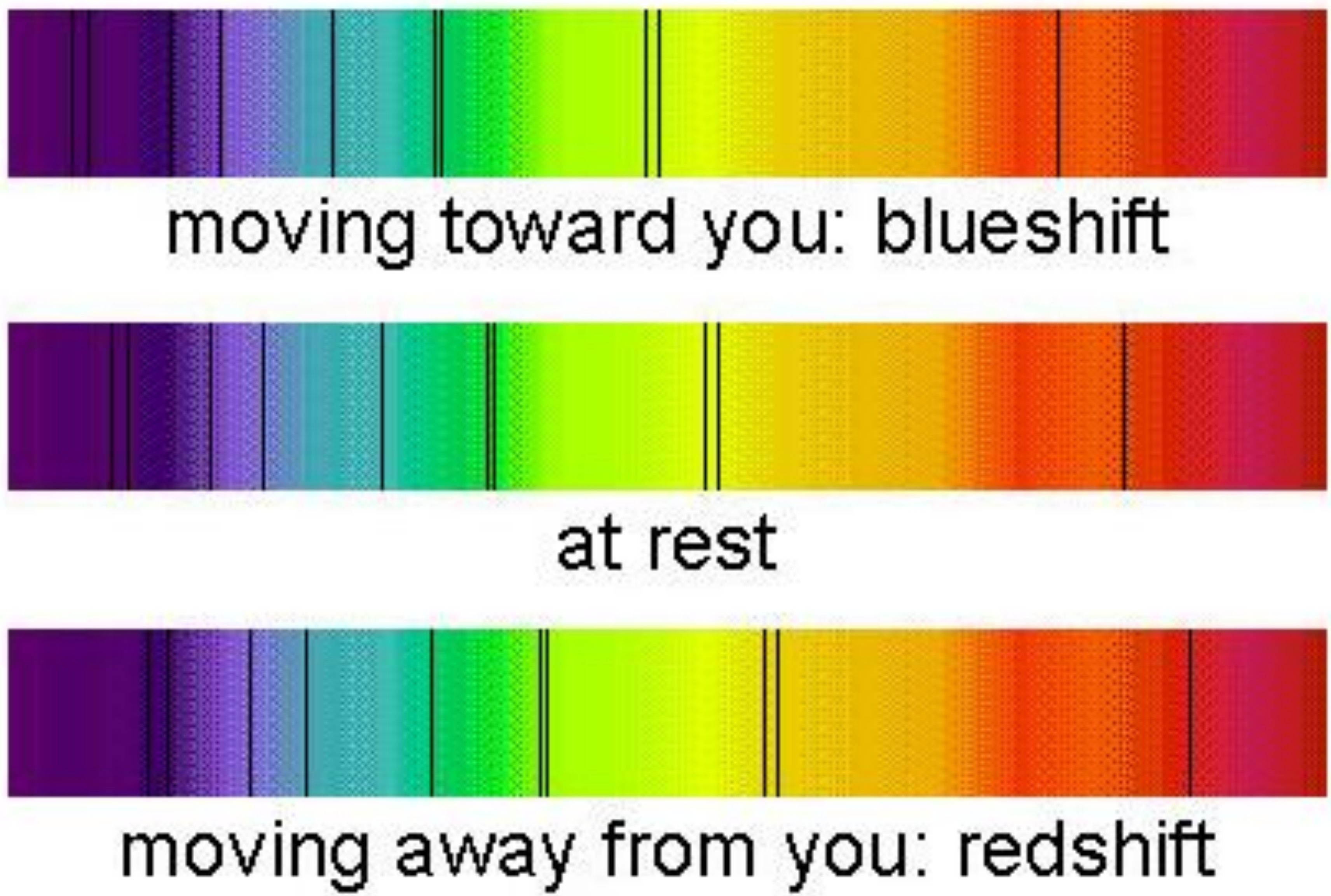
(megaparsec = 10^6 parsecs)

The Doppler Effect

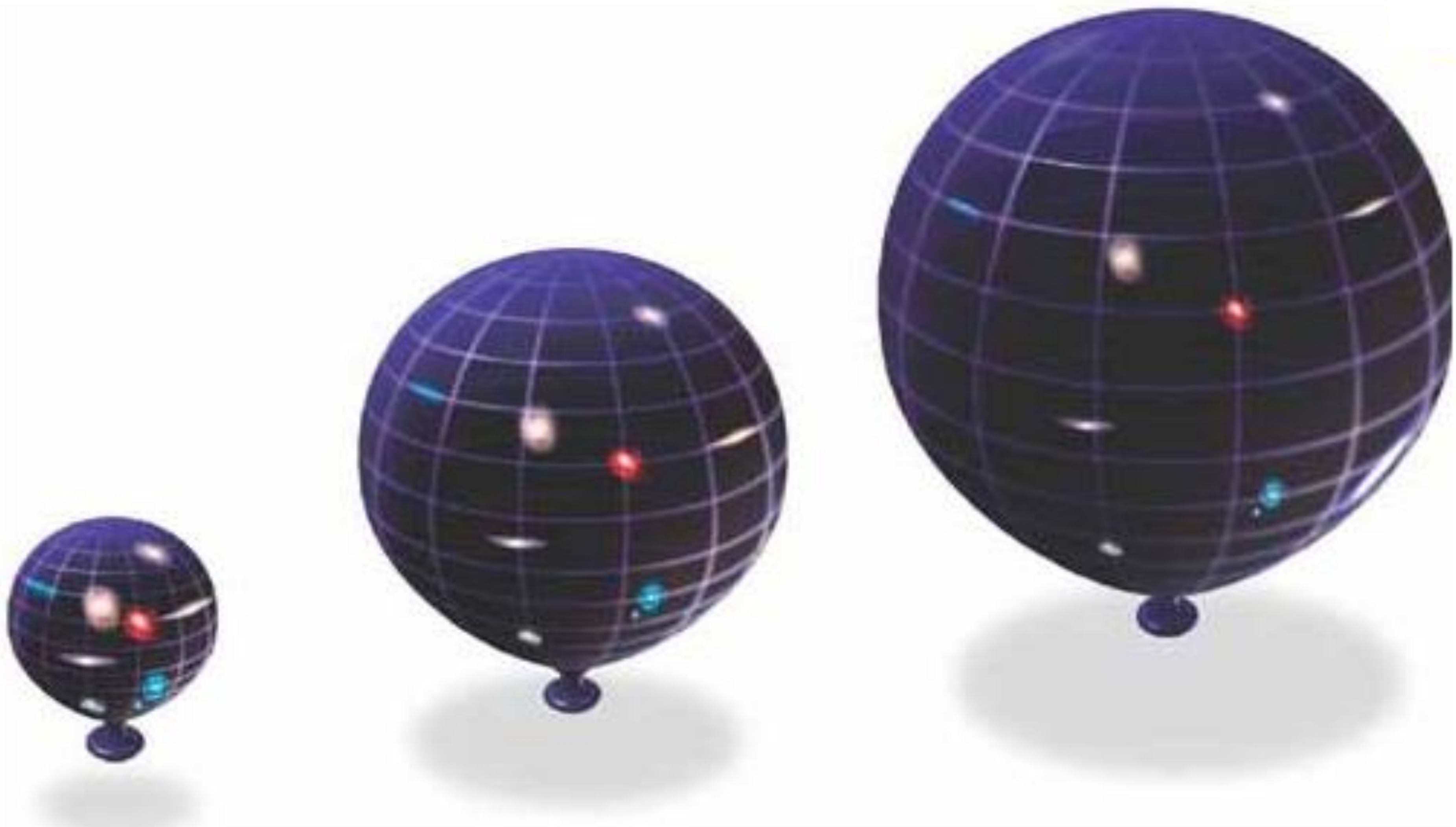
Depends only on the relative motion of source and observer



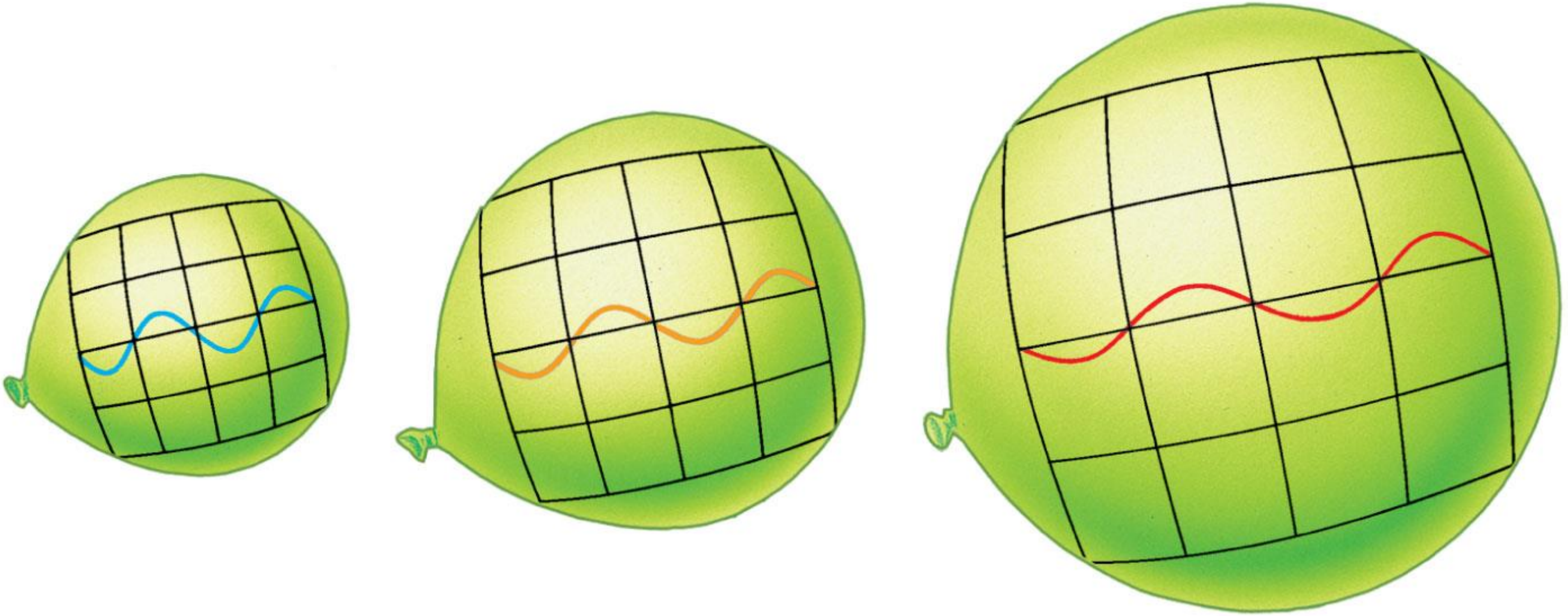
Doppler Effect on Spectra

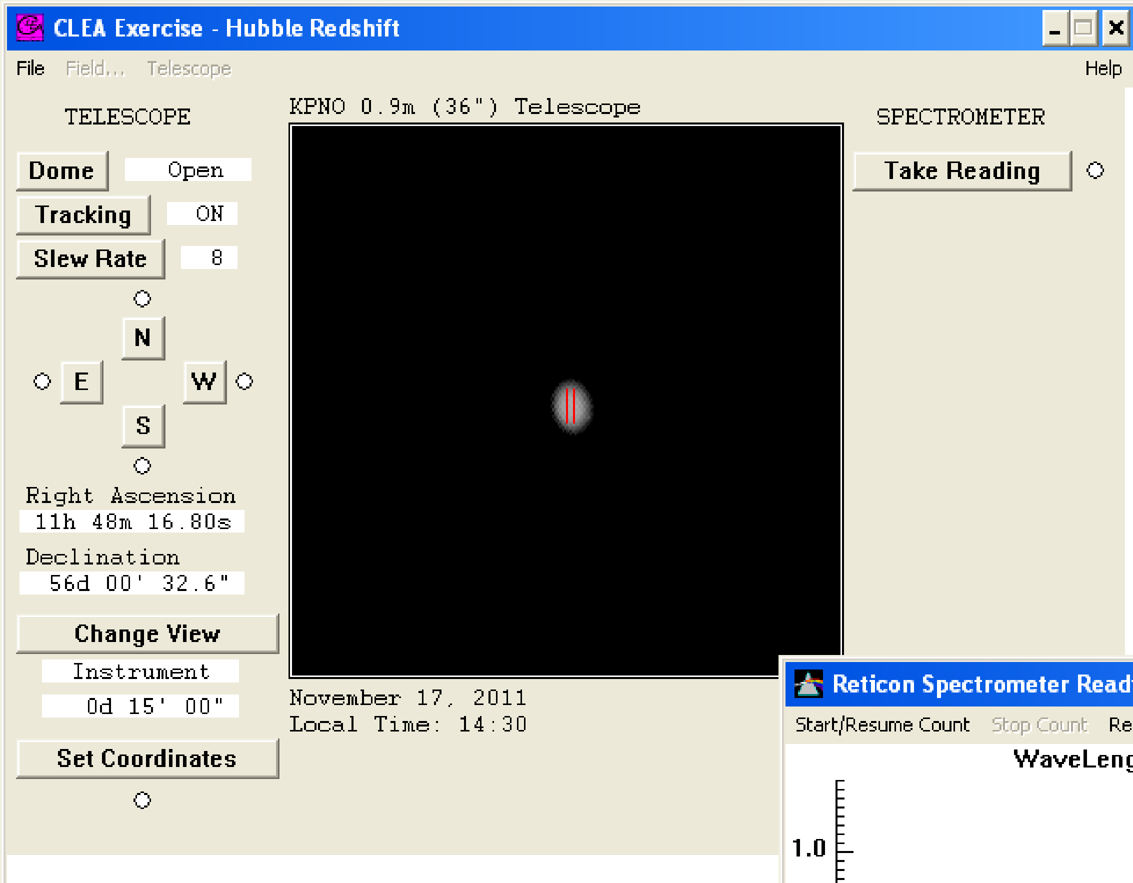


Expanding Universe



The same analogy can be used to explain the cosmological redshift



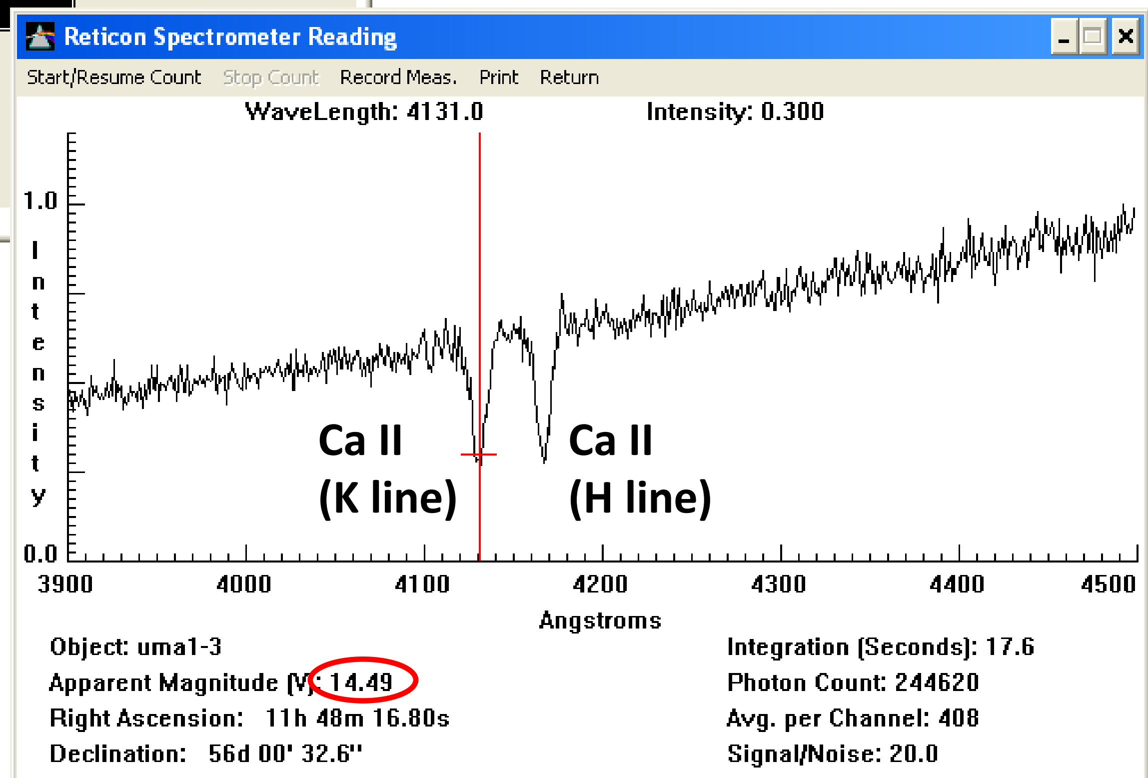


P. 9, Step 11.
File / Data / Save Spectrum

VIREO / Tools / Spectrum Measuring

File / Data / Load Saved Spectrum

Record App. Mag. on P. 14.



Velocity from redshift.

$$v_H = c * \frac{\Delta\lambda_H}{\lambda_H}$$

$$\Delta\lambda_H = \lambda_{H\ measured} - \lambda_H$$

Wavelength of H Line:

$\lambda_H = 3968.47$ Å

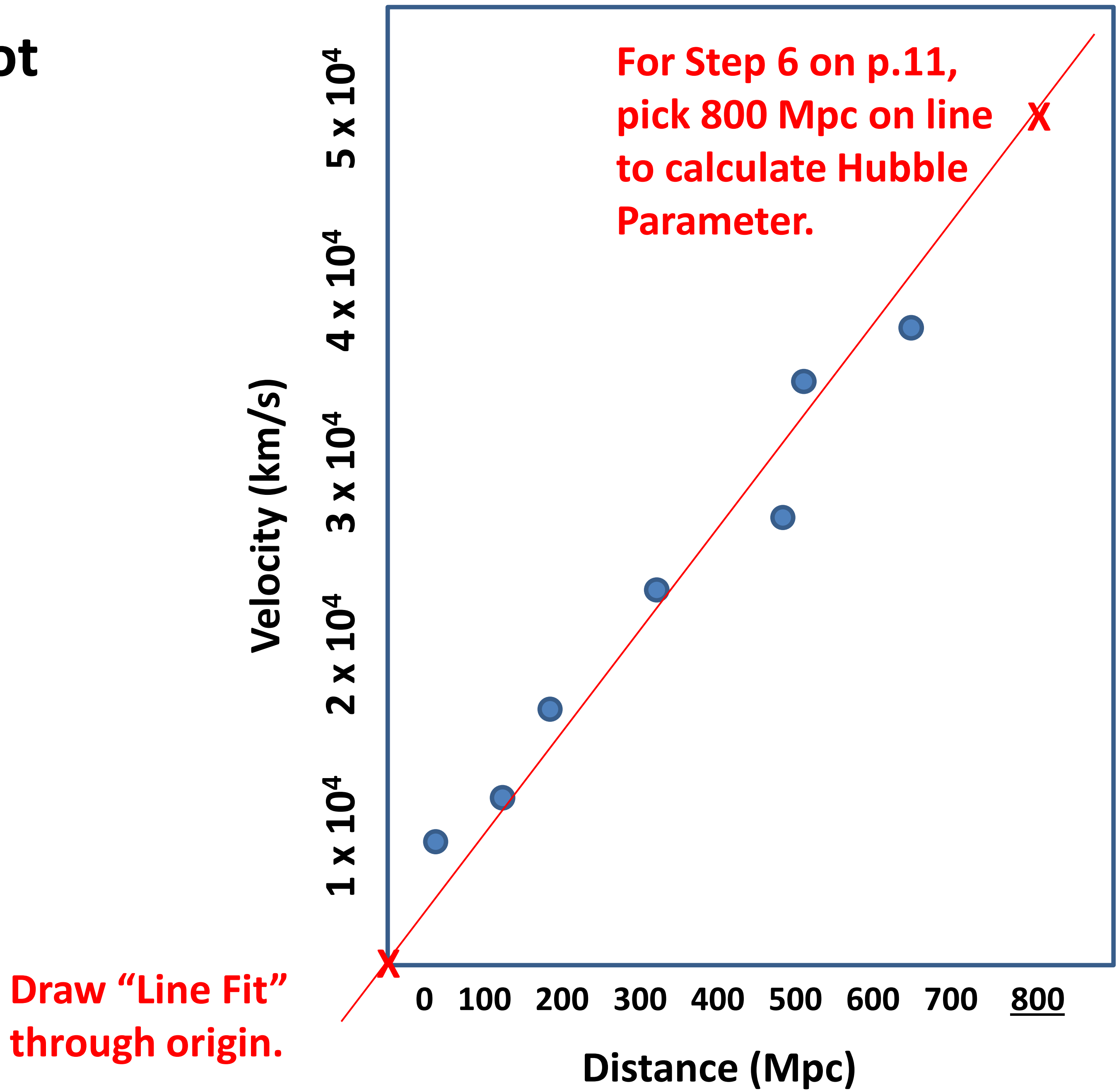
λ_{Hm} = 4088 Å

$\Delta\lambda_H$ = 4088 - 3968.47 Å
= 120 Å

v_H = $(3 \times 10^5$ km/s)(120/3968)
= 9×10^3 km/s

(at D = 123 Mpc)

Hubble Plot


For Step 6 on p.11, pick 800 Mpc on line to calculate Hubble Parameter.
X
Velocity (km/s)
5 x 10⁴
4 x 10⁴
3 x 10⁴
2 x 10⁴
1 x 10⁴
X
Draw "Line Fit" through origin.
0 100 200 300 400 500 600 700 800
Distance (Mpc)

Hubble's Law

$H = (5.2 \times 10^4 \text{ km/s}) \ / \ (800 \text{ Mpc})$

$= 65 \text{ km/s/Mpc}$

$= (65 \text{ km/s/Mpc})(\text{Mpc}/10^6 \text{pc})(\text{pc}/3.26 \text{ ly})(\text{ly}/9.46 \times 10^{12} \text{ km})$

$= 2.11 \times 10^{-18} \text{ /s}$

So $T = 1/H = 4.74 \times 10^{17}$ sec

$T = 1.5 \times 10^{10}$ yr $= 15$ Byr

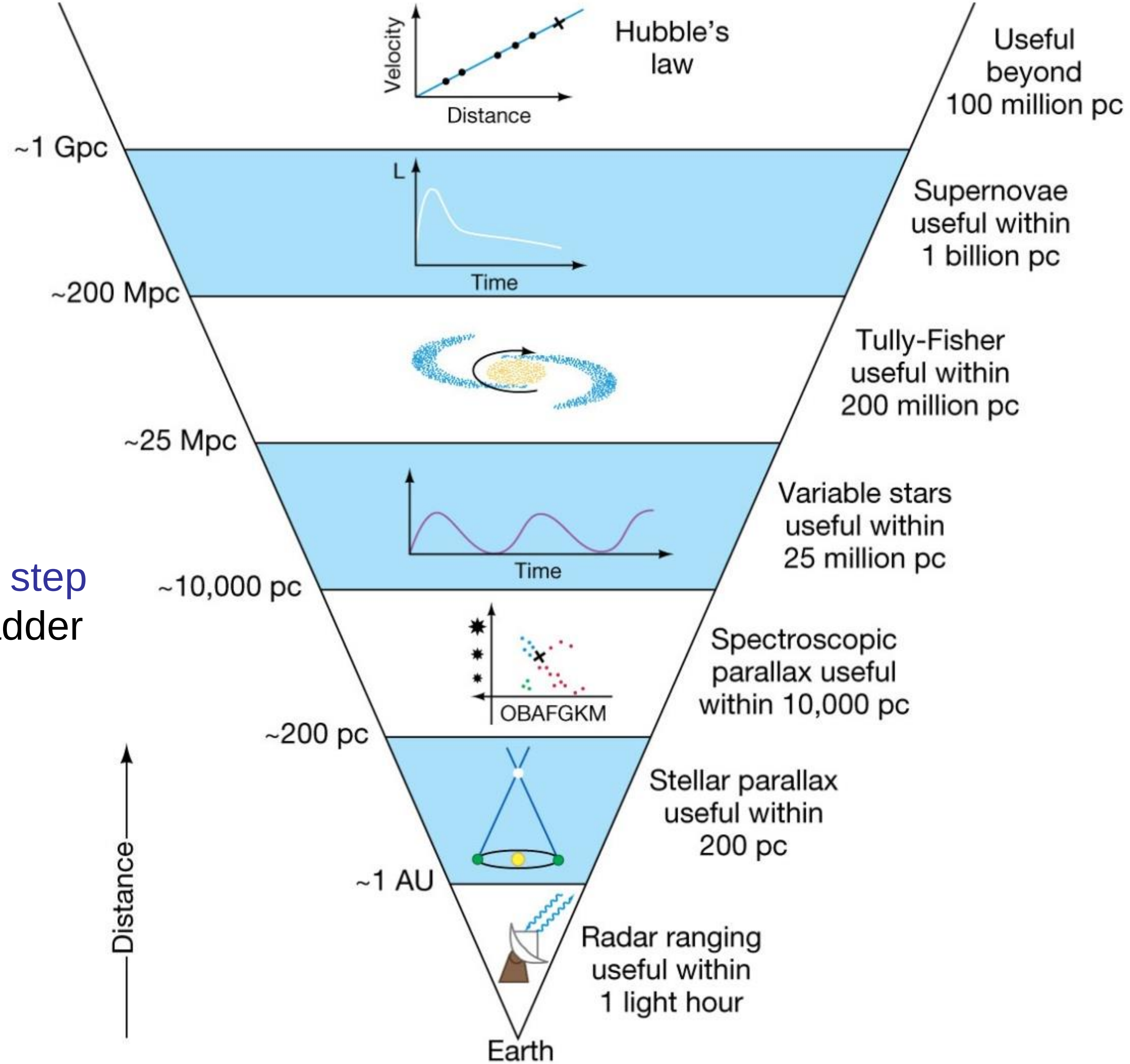
Note: Estimates for Hubble's Constant (H_0) varies from 67 to 77 km/s/Mpc, depending on data sets and methods.

Data from the WMAP probe collecting data on the cosmic microwave background radiation gives the age of the universe at 13.75 ± 0.11 billion years.

13.75 billion years ± 110 million years

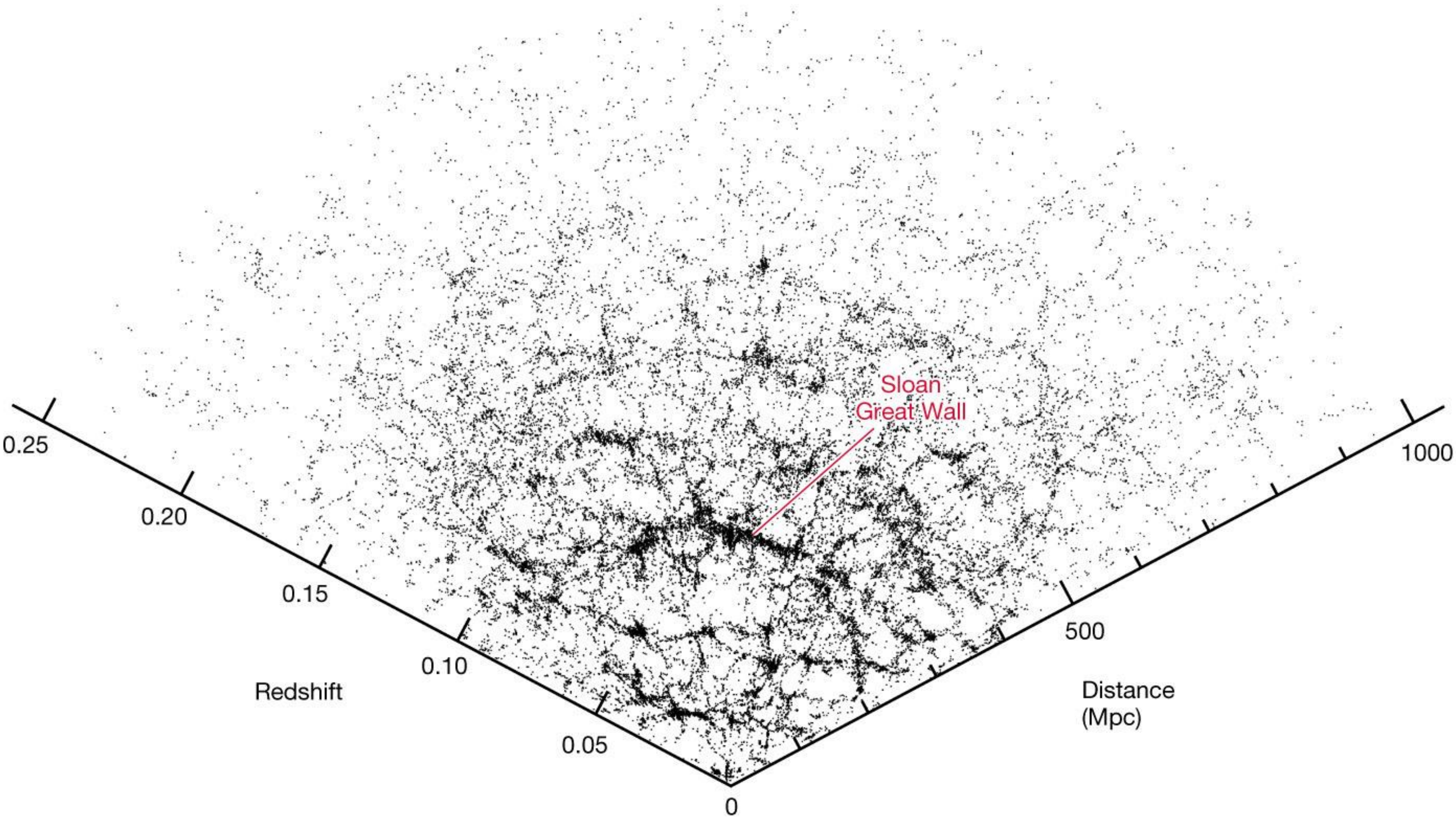
(uncertainty of 0.8%)

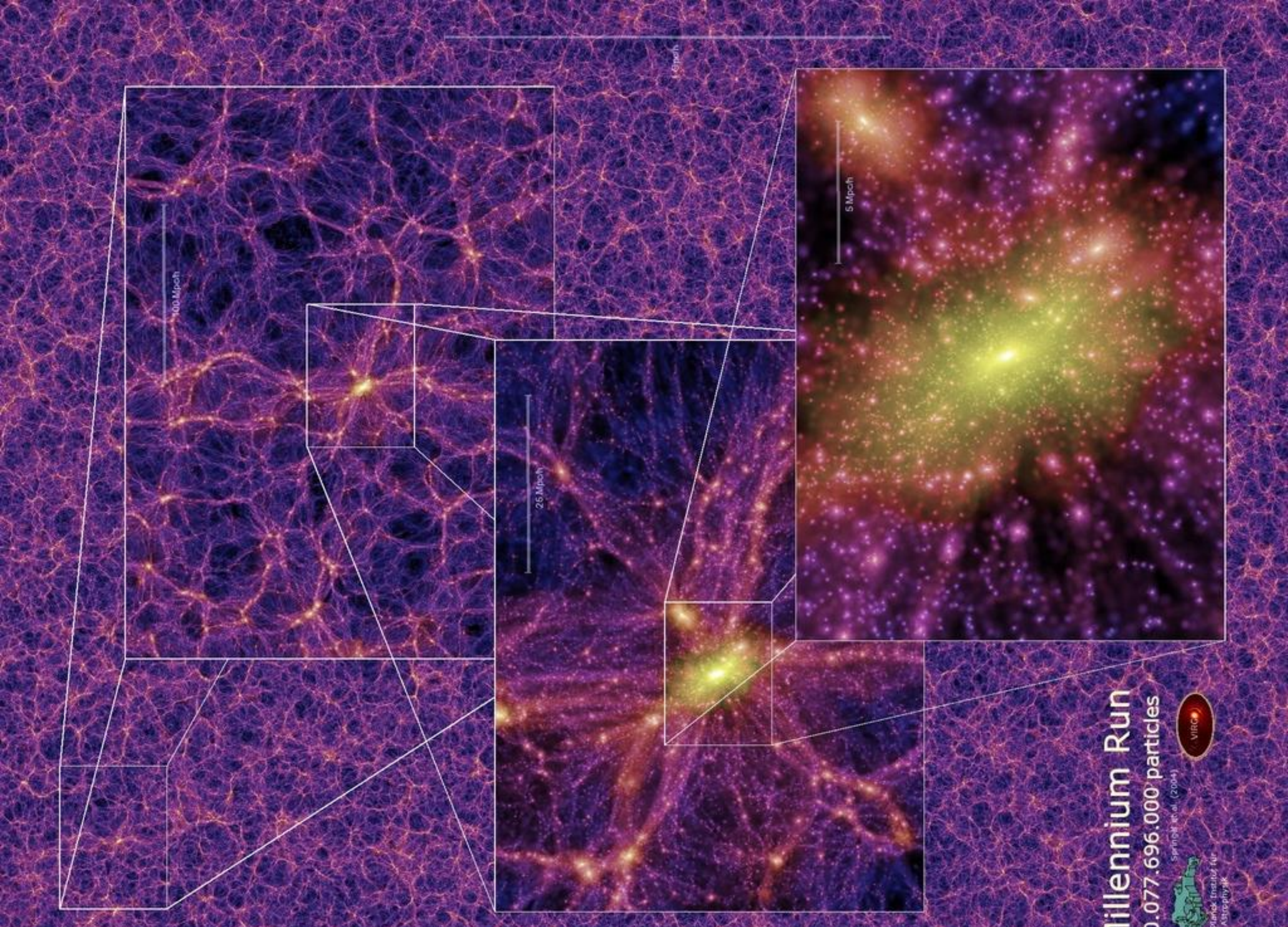
This puts the final step on our distance ladder



The Universe on the Largest Scales

This galaxy map shows the largest structure known in the Universe, the Sloan Great Wall. No structure larger than 300 Mpc is seen.





Note: Each point is a galaxy cluster

USS Nimitz UFO incident 2004

https://en.wikipedia.org/wiki/USS_Nimitz_UFO_incident
https://en.wikipedia.org/wiki/Advanced_Aviation_Threat_Identification_Program
https://www.msn.com/en-us/video/wonder/moment-ufo-spotted-by-us-navy-jet/vi-BBH16H2?ocid=spartandhp

Fighters were approx. 100 mi from coast of San Diego when they were directed to intercept the UFO[1]

- 100 mi from San Diego County coast
- 100 mi from San Diego coast

USS *Nimitz* and USS *Princeton*


IT WAS
ALIENS!
HD
HISTORY.COM

Neil deGrasse Tyson said, "The universe brims with mysteries. Just because you don't know what it is you're looking at doesn't mean it's intelligent aliens visiting from another planet."

https://www.cnn.com/2017/12/20/us/neil-degrasse-tyson-ufos-new-day-cnntv/index.html

Harley D. Rutledge (January 10, 1926 - June 5, 2006) was a U.S. physics professor, and ufologist.

In 1966, Harley Rutledge completed his Ph.D. in solid state physics at the University of Missouri. He subsequently took the position of Professor and Chairman of the Physics Department at Southeast Missouri State University. He was Department Chairman from 1964 to 1982 and retired from teaching in 1992.

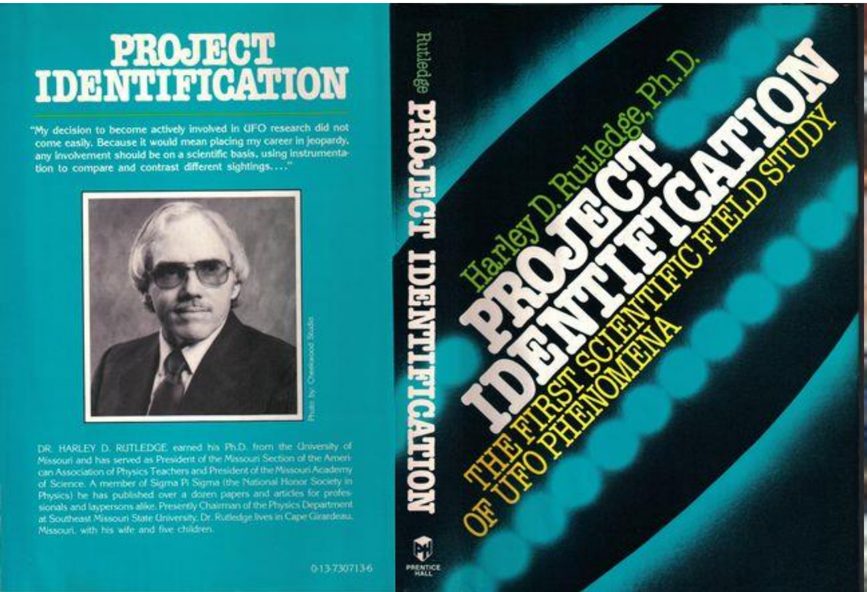
UFO Research - Challenged to explain sightings of unidentified lights and luminous phenomena in the sky around Piedmont, Missouri, Dr. Harley Rutledge decided to subject these reports to scientific analysis. He put together a team of observers with college training in the physical sciences, including a large array of equipment: RF spectrum analyzers, Questar telescopes, low-high frequency audio detectors, electromagnetic frequency analyzer, cameras, and a galvanometer to measure variations in the Earth's gravitational field.

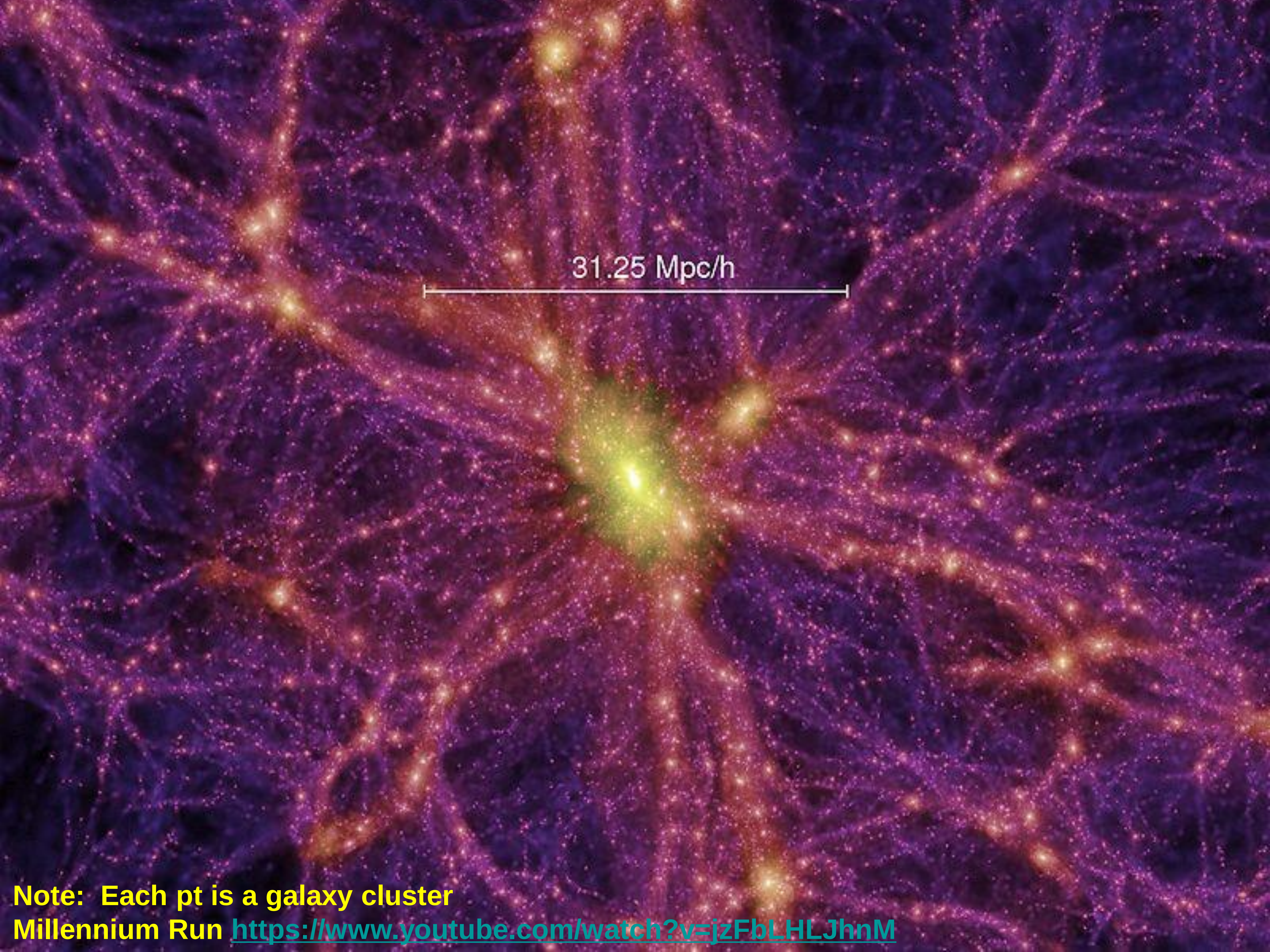
The resulting Project Identification commenced in April 1973, logging several hundred hours of observation time. This was the first UFO scientific field study, able to monitor the phenomena in real-time, enabling Rutledge to calculate the objects' actual velocity, course, position, distance, and size.

Observation of the unclouded night sky often revealed "pseudostars" - stationary lights camouflaged by familiar constellations. Some objects appeared to mimic the appearance of known aircraft; others violated the laws of physics. The most startling discovery was that on at least 32 recorded occasions, the movement of the lights synchronized with actions of the observers. They appeared to respond to a light being switched on and off, and to verbal or radio messages. The final results of this project were documented in the 1981 book, Project Identification: The first Scientific Study of UFO Phenomena.

Books - Project Identification: The first Scientific Study of UFO Phenomena. Prentice-Hall 1981 ISBN 0-13-730713-6 by Harley D. Rutledge, Ph.D.

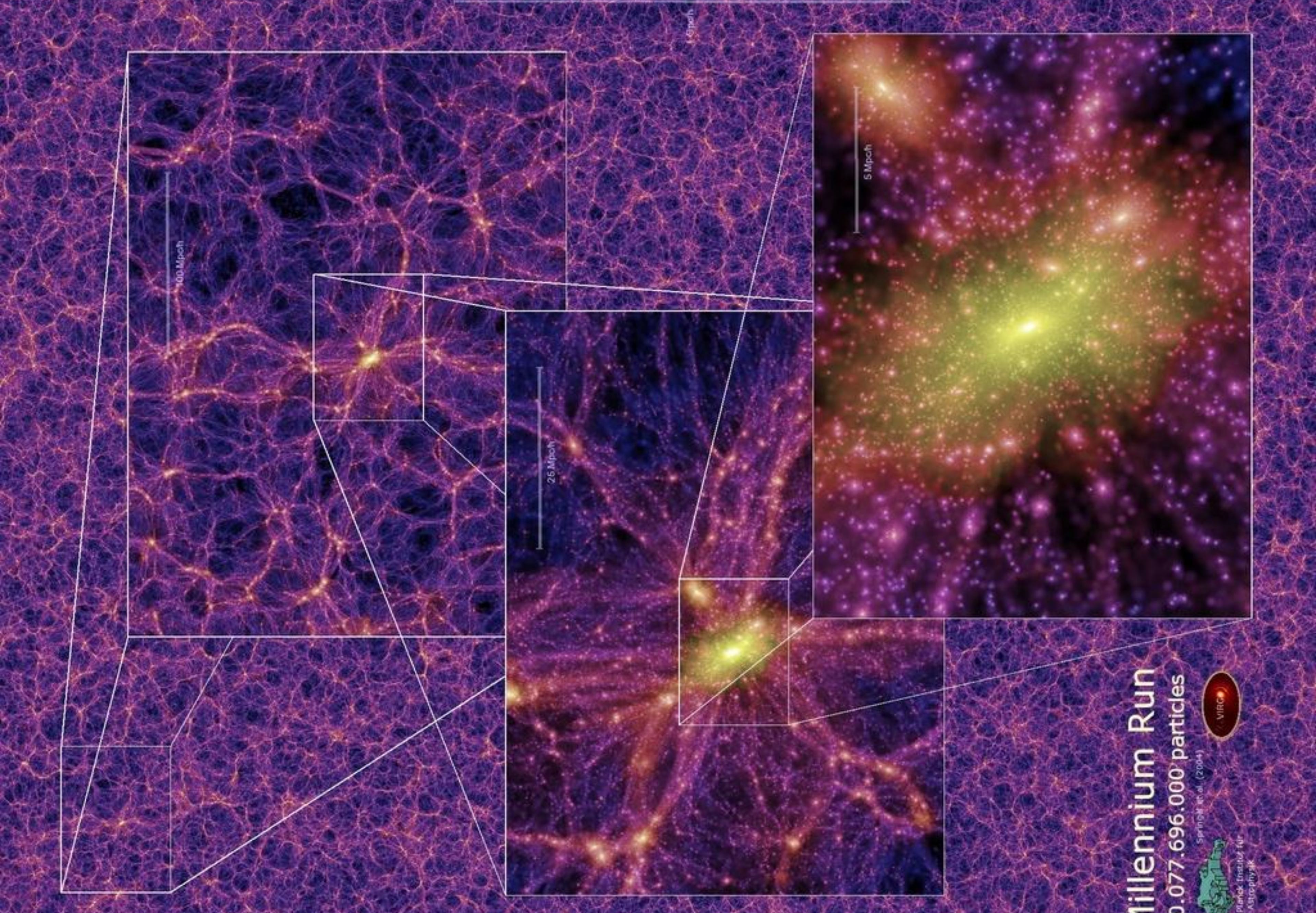
Research Papers - Project Identification: Thirteen Years and One-Hundred and Sixty Sightings Later, Harley D. Rutledge, Ph.D. (presented at the 1986 MUFON symposium). https://en.wikipedia.org/wiki/Harley_Rutledge



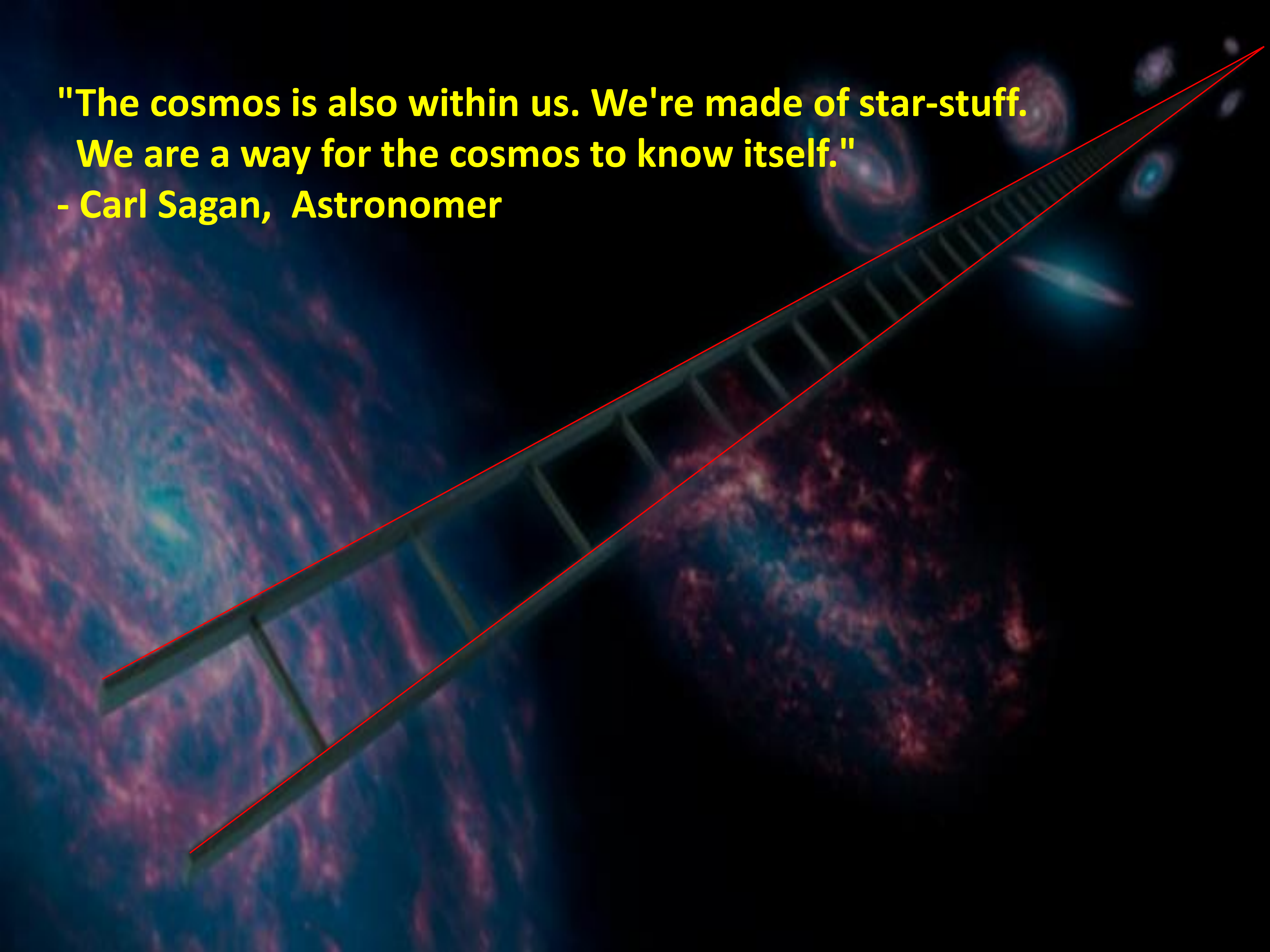


Note: Each pt is a galaxy cluster
Millennium Run https://www.youtube.com/watch?v=jzFbLHLJhnM

Existential crisis https://www.facebook.com/JukinVideo/videos/1340165472738386/?hc_ref=NEWSFEED

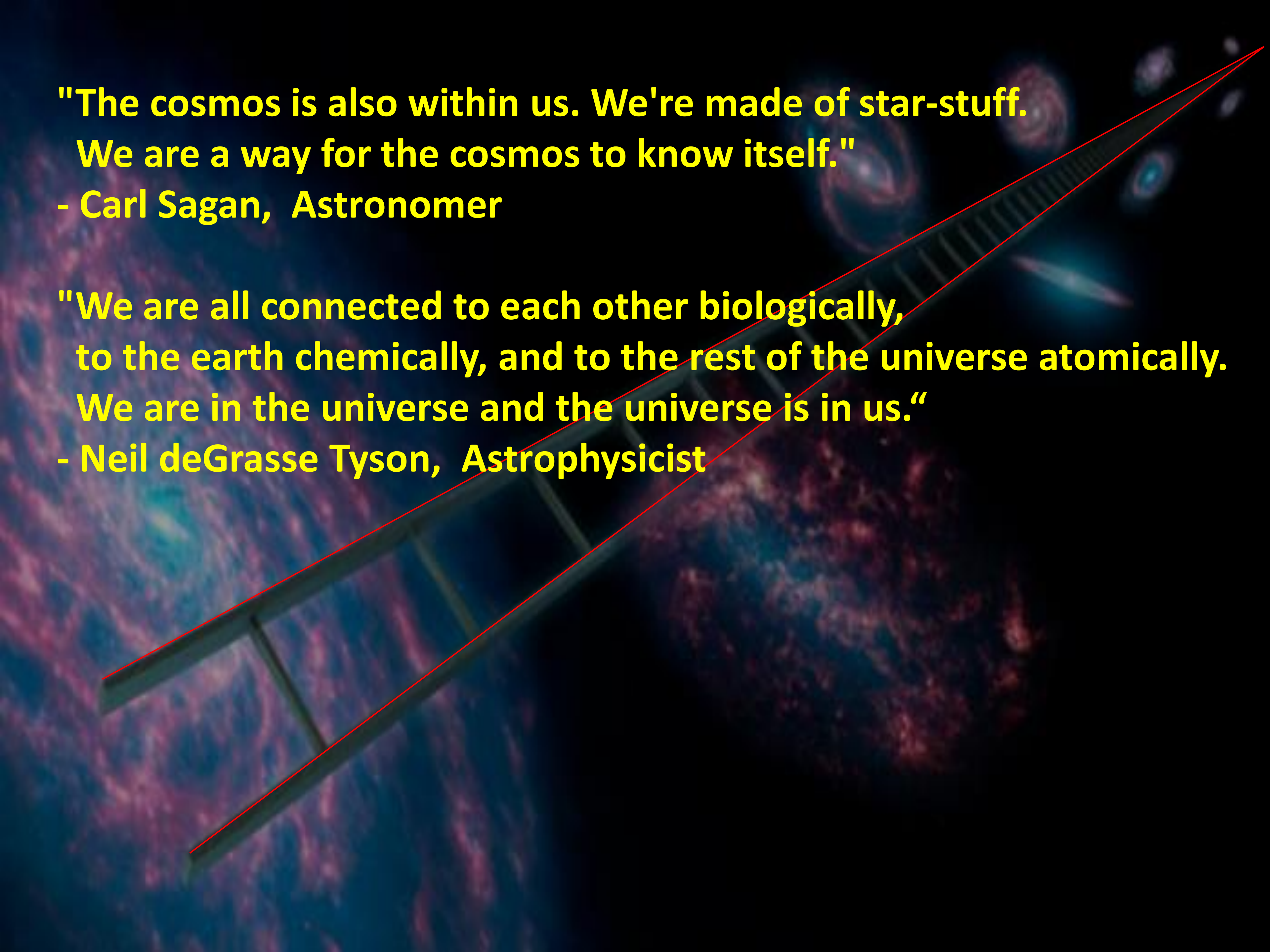


Note: Each point is a galaxy cluster


"The cosmos is also within us. We're made of star-stuff.
We are a way for the cosmos to know itself."
- Carl Sagan, Astronomer

"The cosmos is also within us. We're made of star-stuff.
We are a way for the cosmos to know itself."
- Carl Sagan, Astronomer

"We are all connected to each other biologically,
to the earth chemically, and to the rest of the universe atomically.
We are in the universe and the universe is in us."
- Neil deGrasse Tyson, Astrophysicist



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We are a way for the cosmos to know itself."
- Carl Sagan, Astronomer

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to the earth chemically, and to the rest of the universe atomically.
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"We are the universe experiencing itself through us."
- Mark Fraser, Astronomy Instructor

The Astounding Fact About The Universe
Neil deGrasse Tyson (3.5 min)
https://www.youtube.com/watch?v=0azoN7t3UhM

Question or comments?

Contact Mark Fraser at
ippon@earthlink.net

(Also see my Climate talk at nmsr.org)