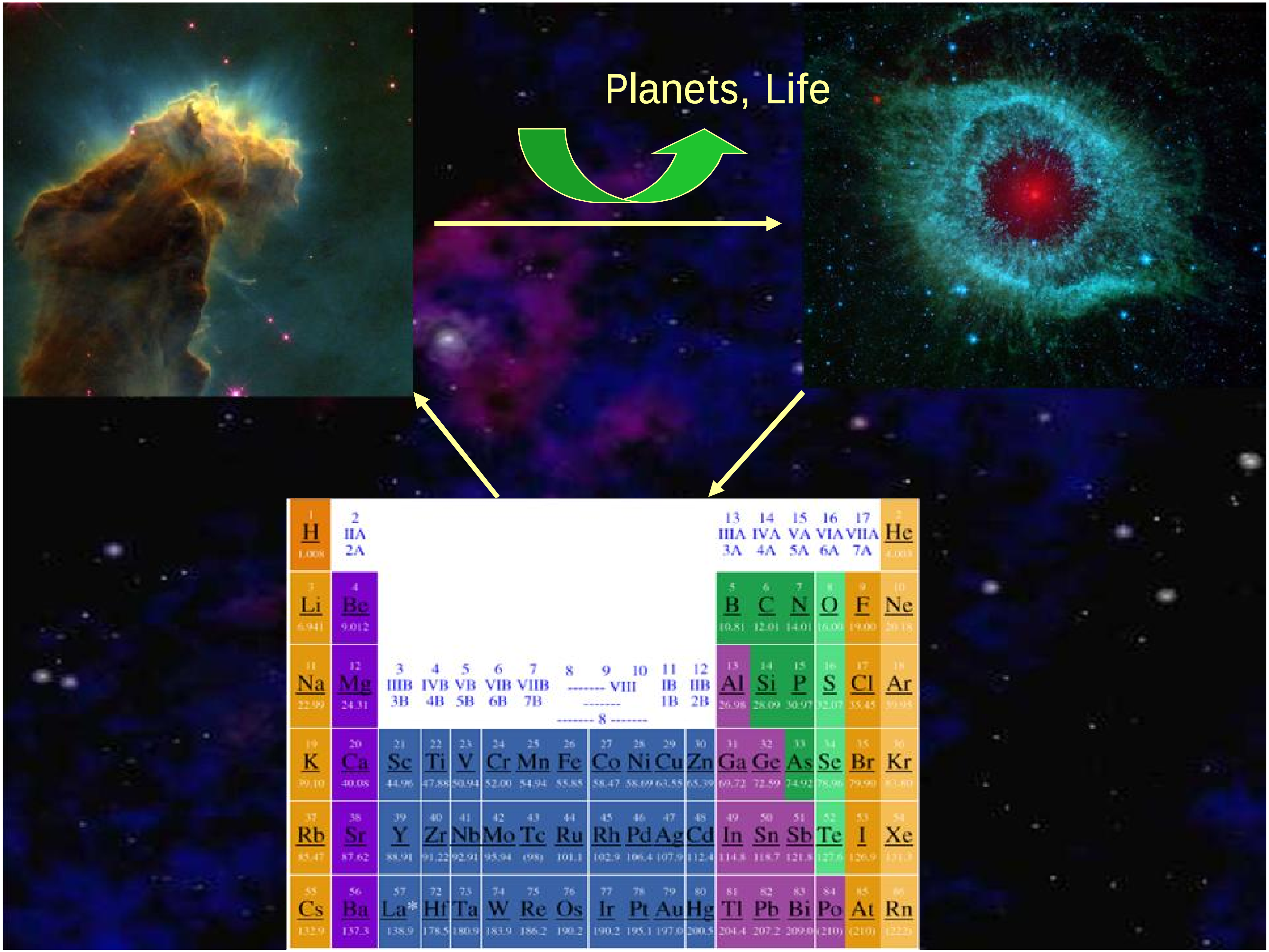
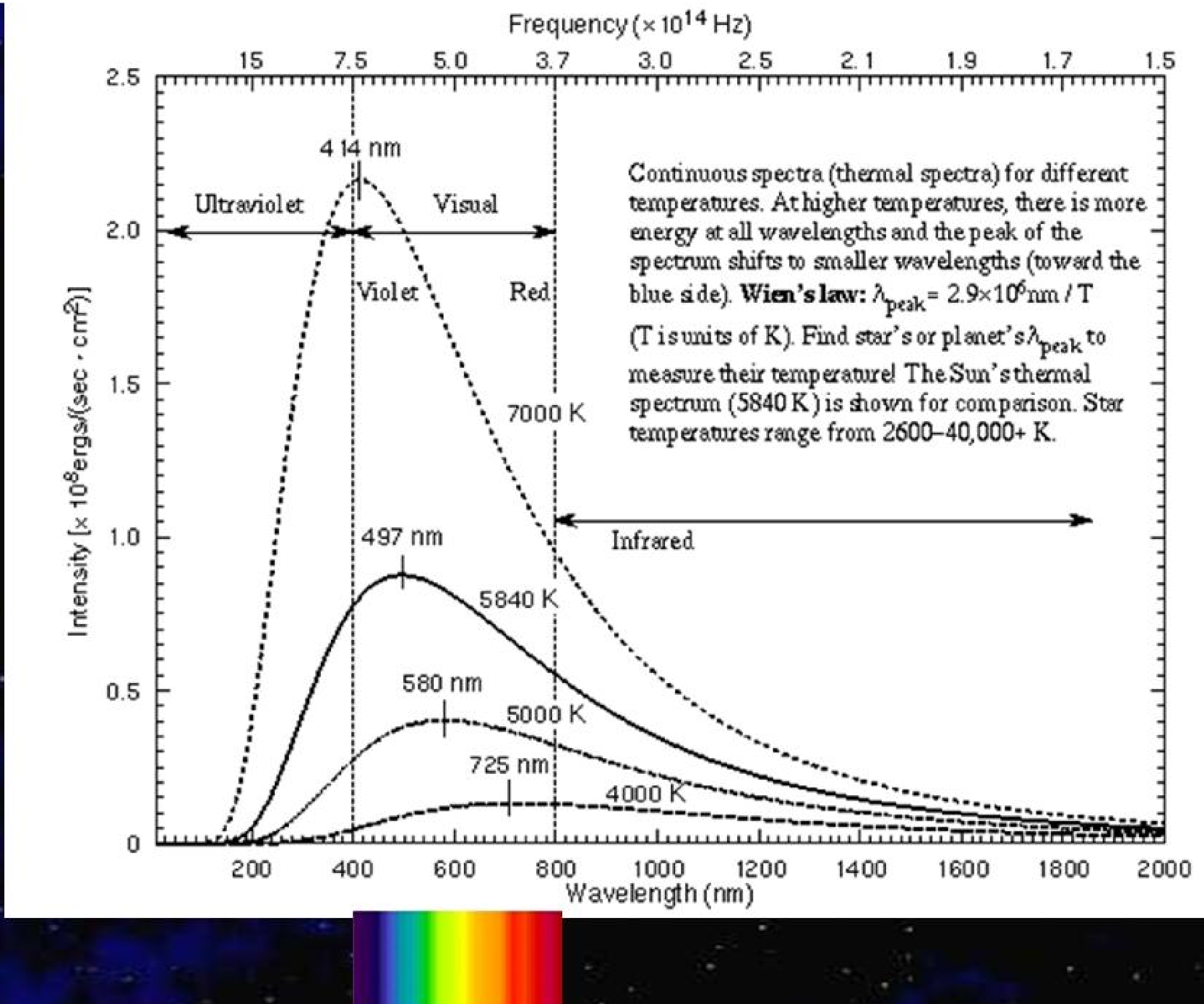
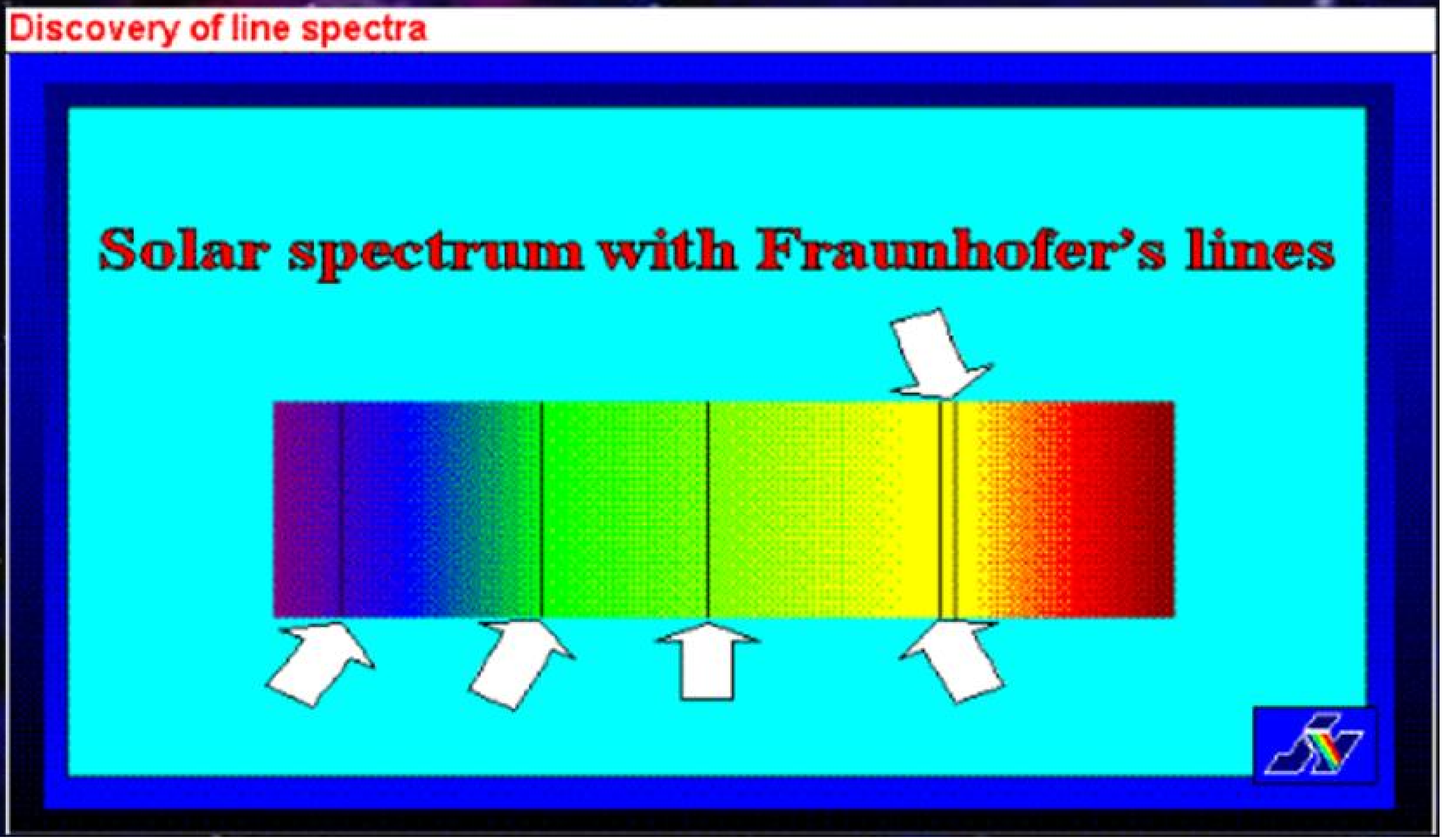
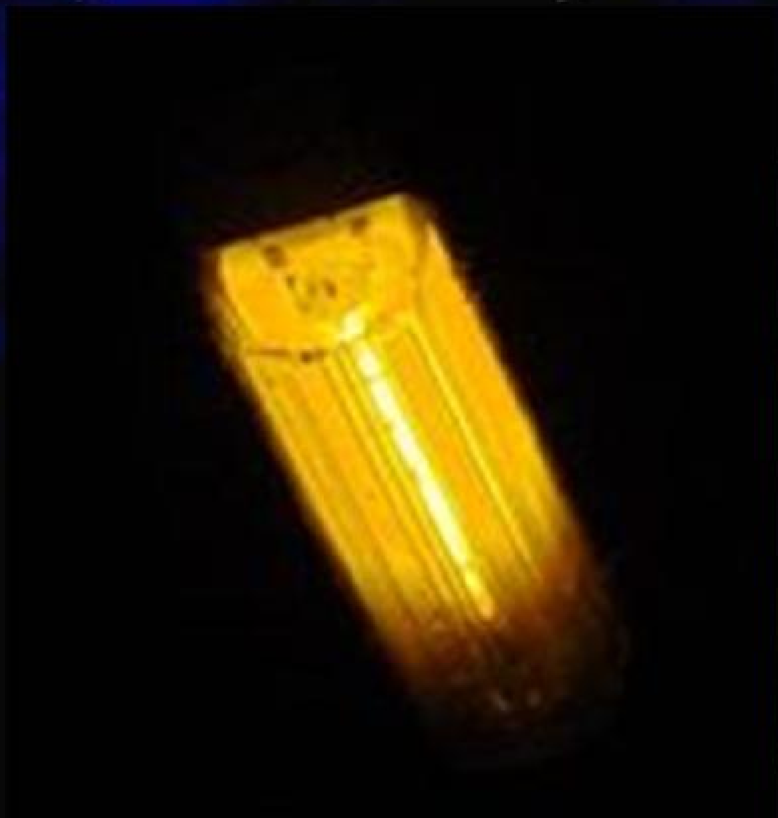

Planets, Life
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba La* Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn



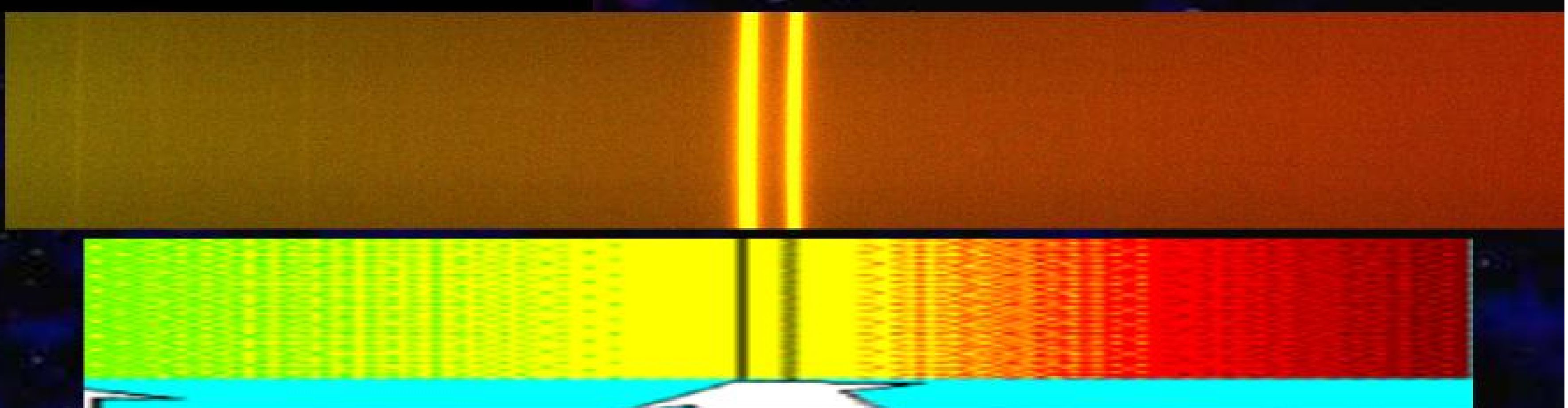
Frequency (× 10^14 Hz)
15 7.5 5.0 3.7 3.0 2.5 2.1 1.9 1.7 1.5
Intensity [× 10^8 ergs/(sec · cm^2)]
2.5 2.0 1.5 1.0 0.5 0
414 nm
Ultraviolet
Visual
Violet
Red
7000 K
497 nm
5840 K
580 nm
5000 K
725 nm
4000 K
Infrared
Continuous spectra (thermal spectra) for different temperatures. At higher temperatures, there is more energy at all wavelengths and the peak of the spectrum shifts to smaller wavelengths (toward the blue side). Wien's law: λpeak = 2.9×10^6 nm / T (T is units of K). Find star's or planet's λpeak to measure their temperature! The Sun's thermal spectrum (5840 K) is shown for comparison. Star temperatures range from 2600–40,000+ K.
200 400 600 800 1000 1200 1400 1600 1800 2000
Wavelength (nm)

Josef Fraunhofer, 1787-1826





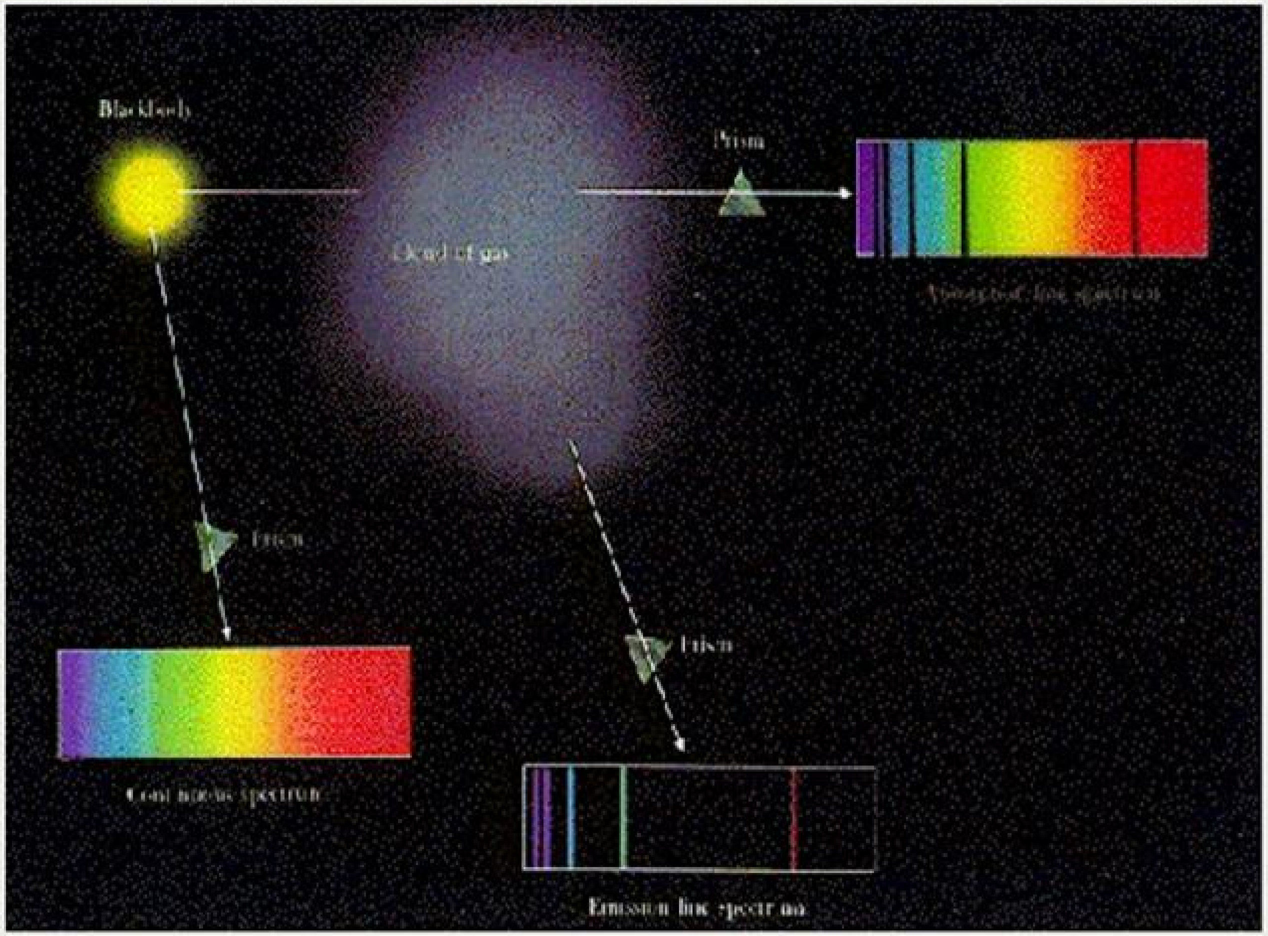
The Sodium Story



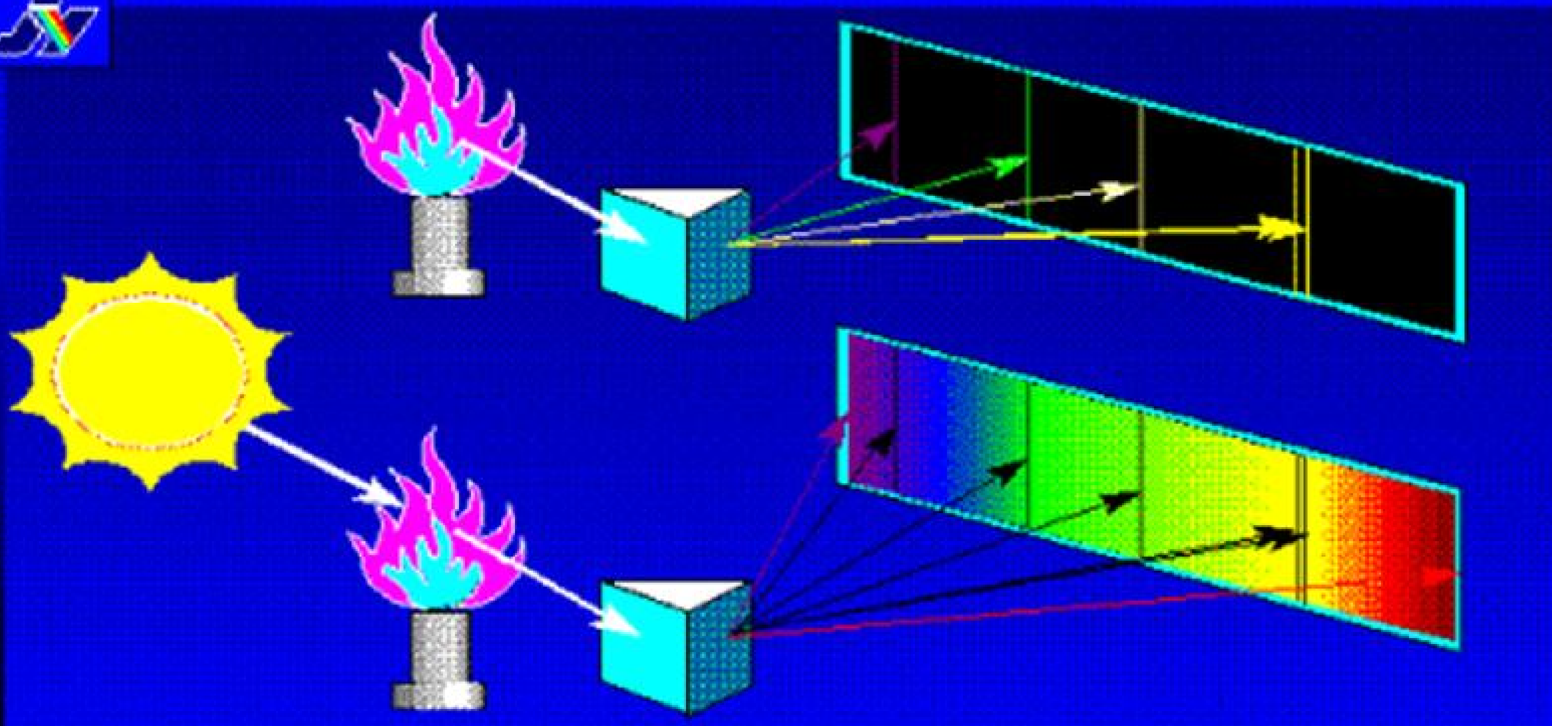
Bunsen

Kirchhoff

Kirchhoff's Laws

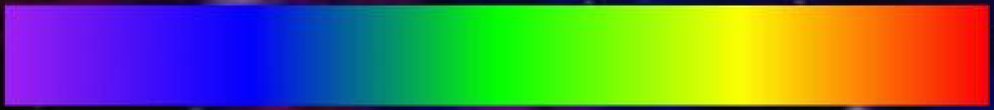


Spectrochemistry fundamentals

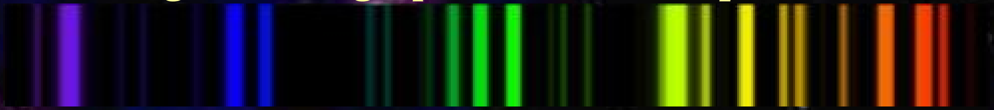


Kirchhof and Bunsen experiment diagram

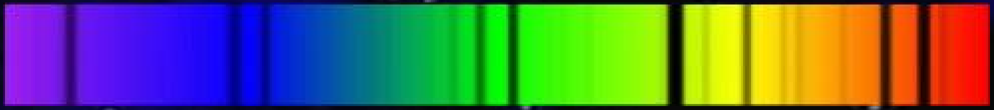
•from hot objects are *continuous*, like a rainbow



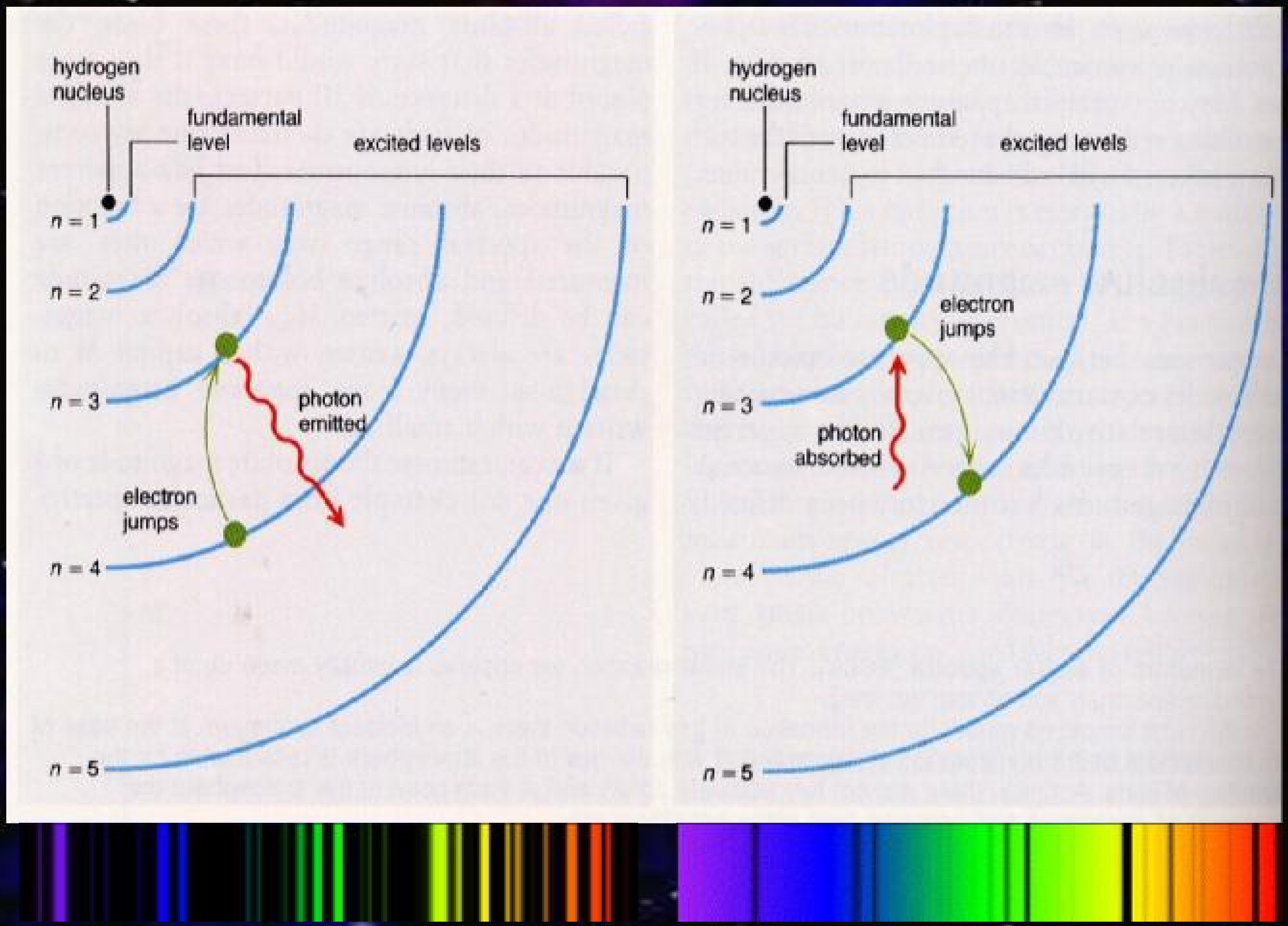
•atoms only emit light of specific colours, revealing their fingerprints as a *line spectrum*



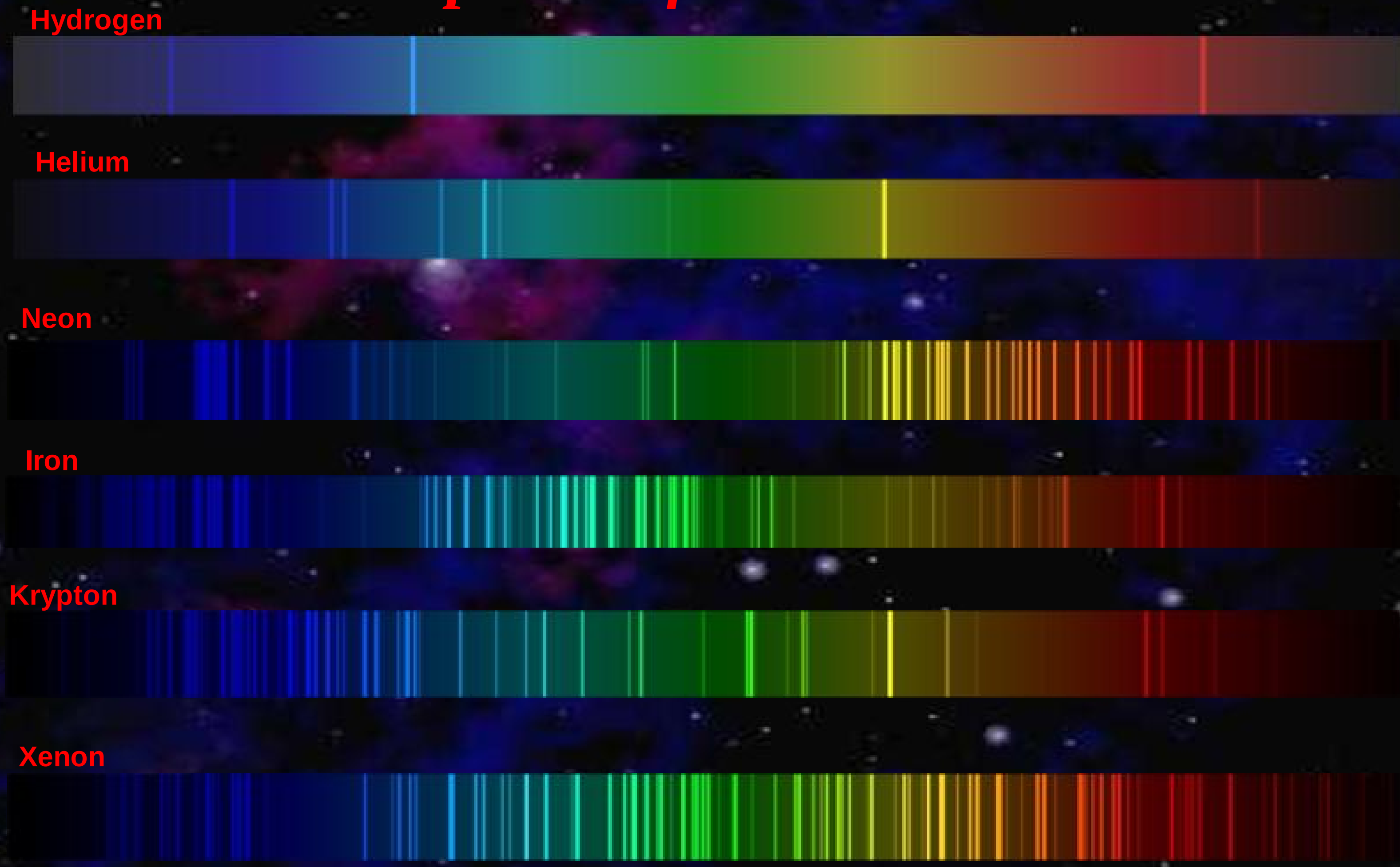
•atoms in front of a hot object absorb light at these colours, giving an *absorption spectrum*



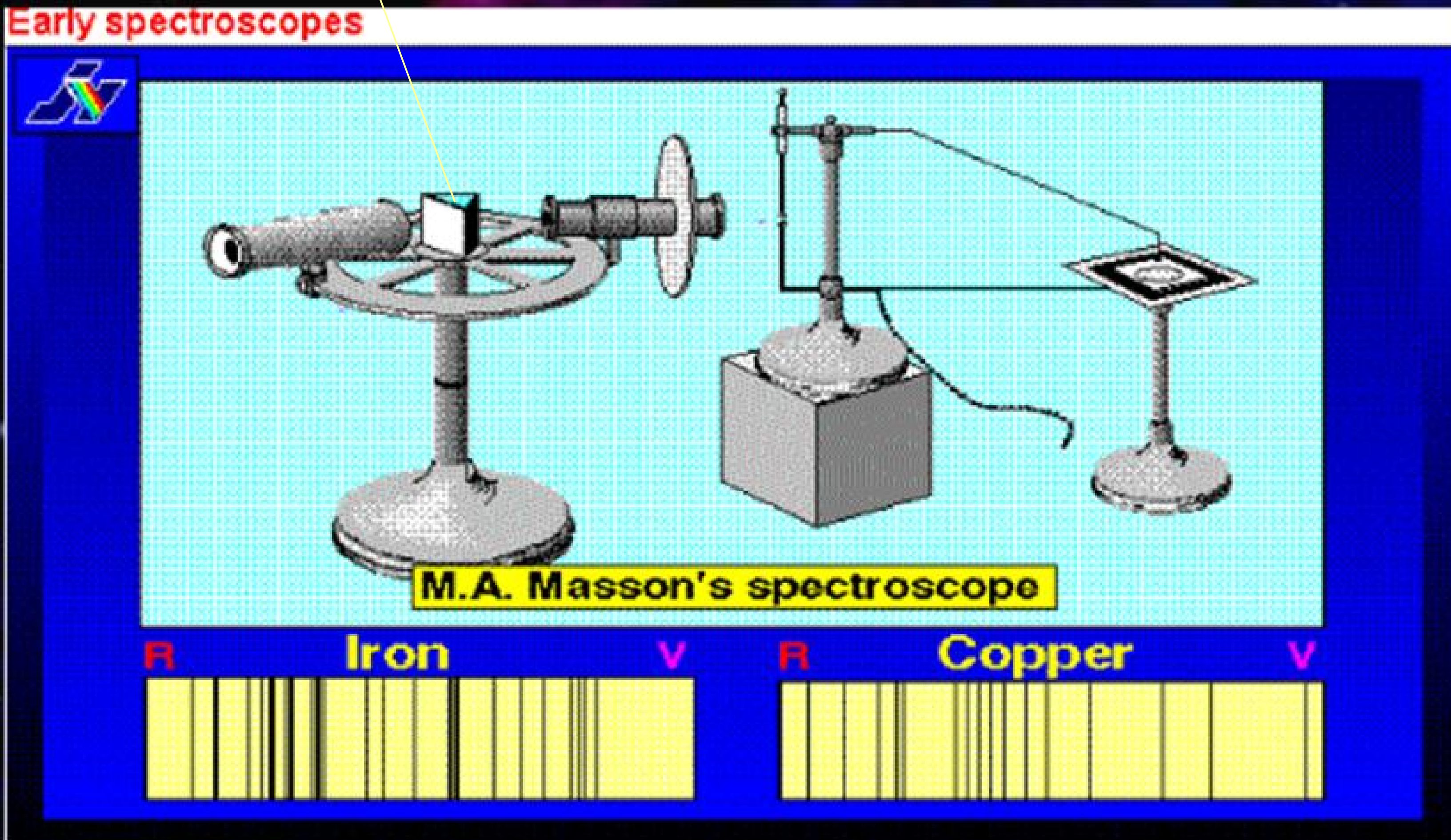
Generation of Emission or Absorption Line Spectrum

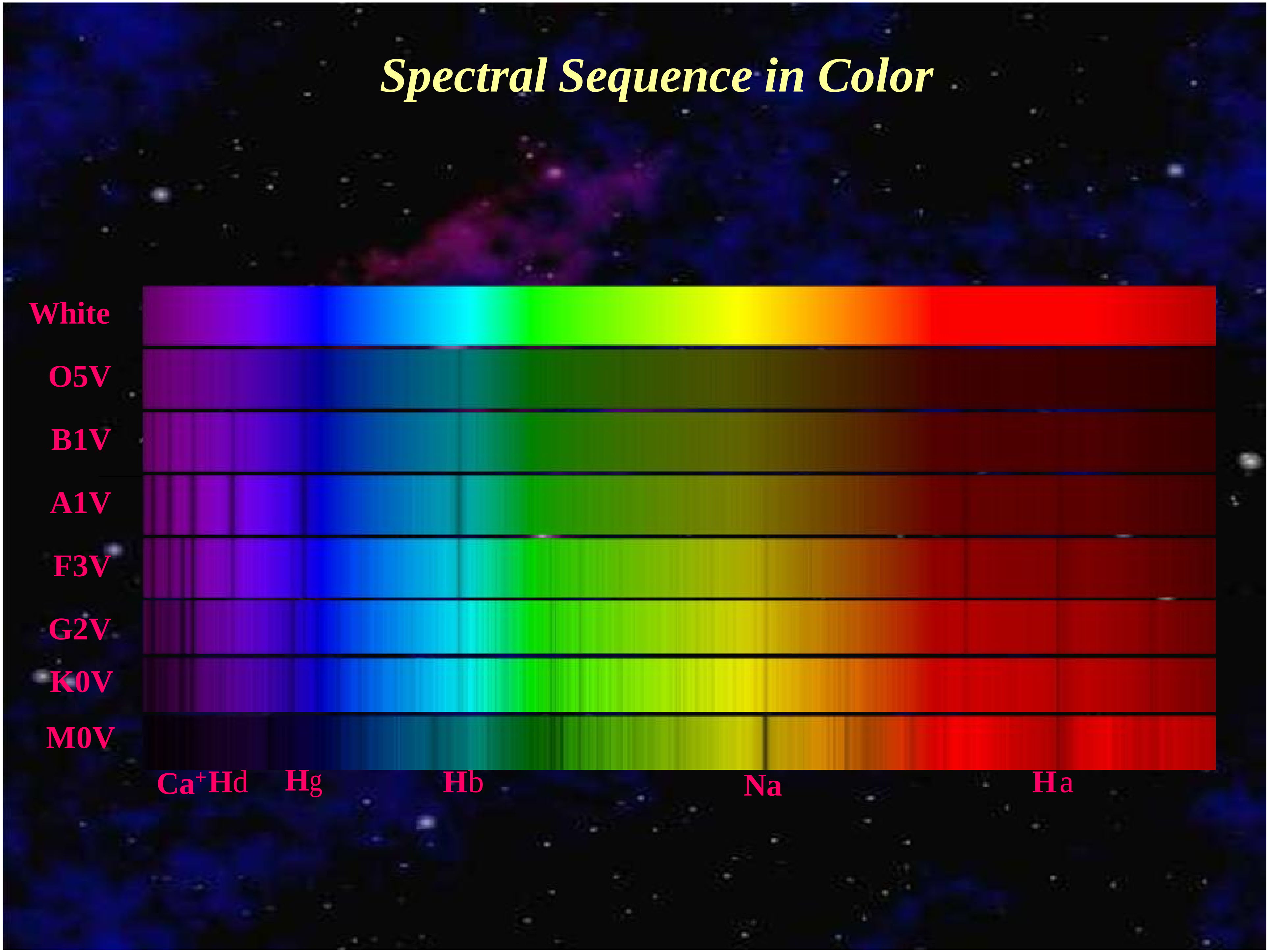


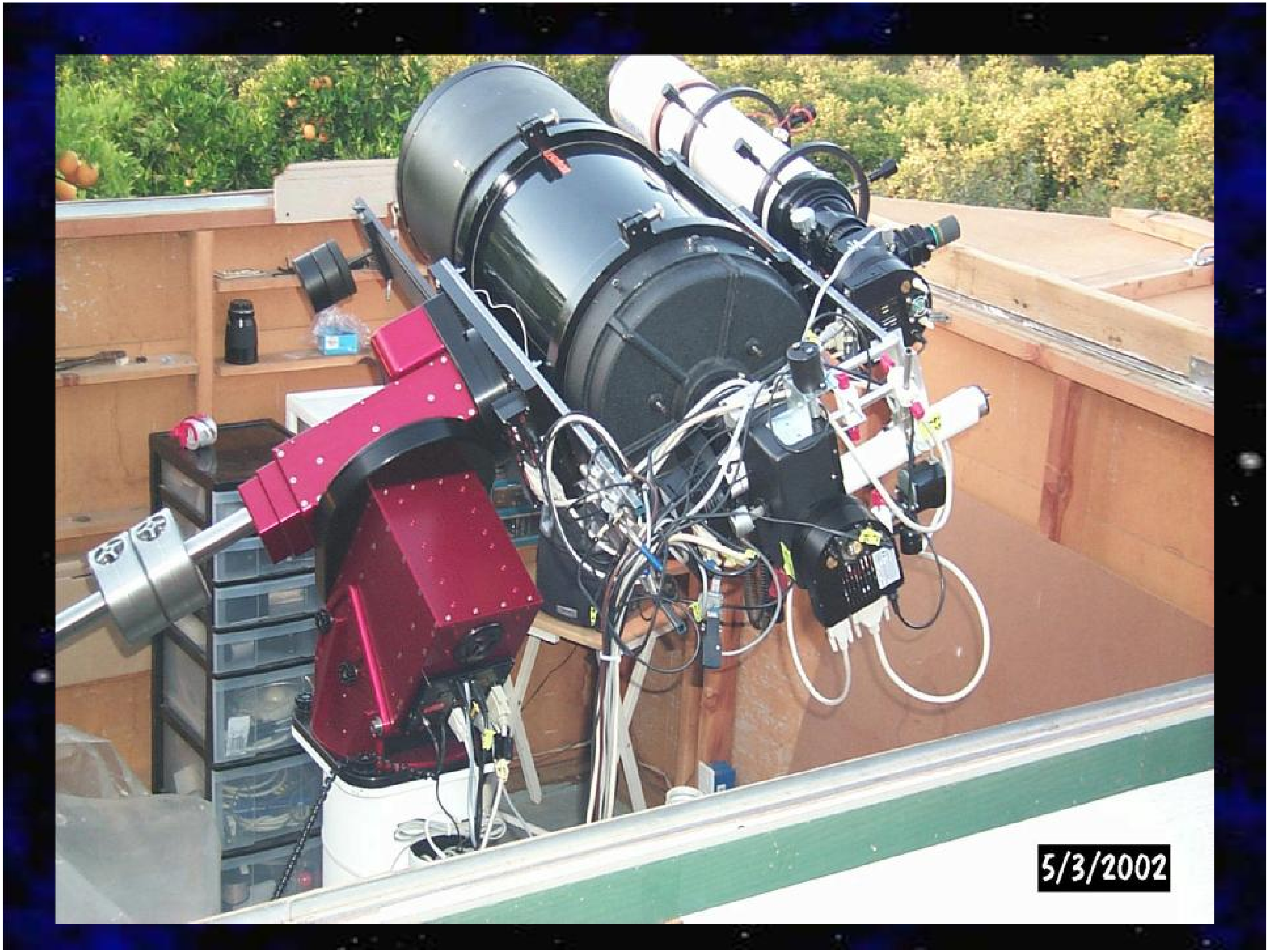
Visible Spectra of common Elements

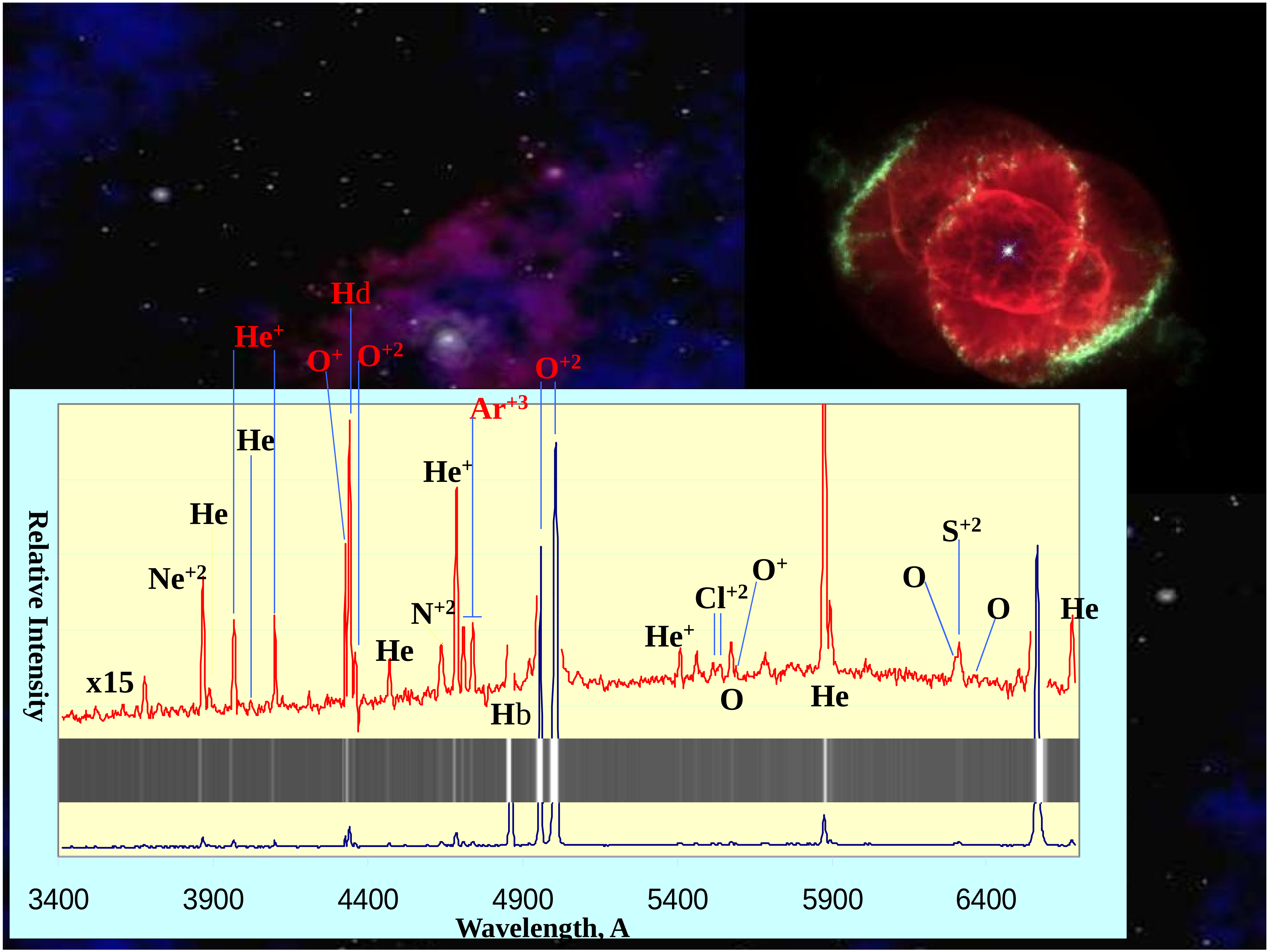


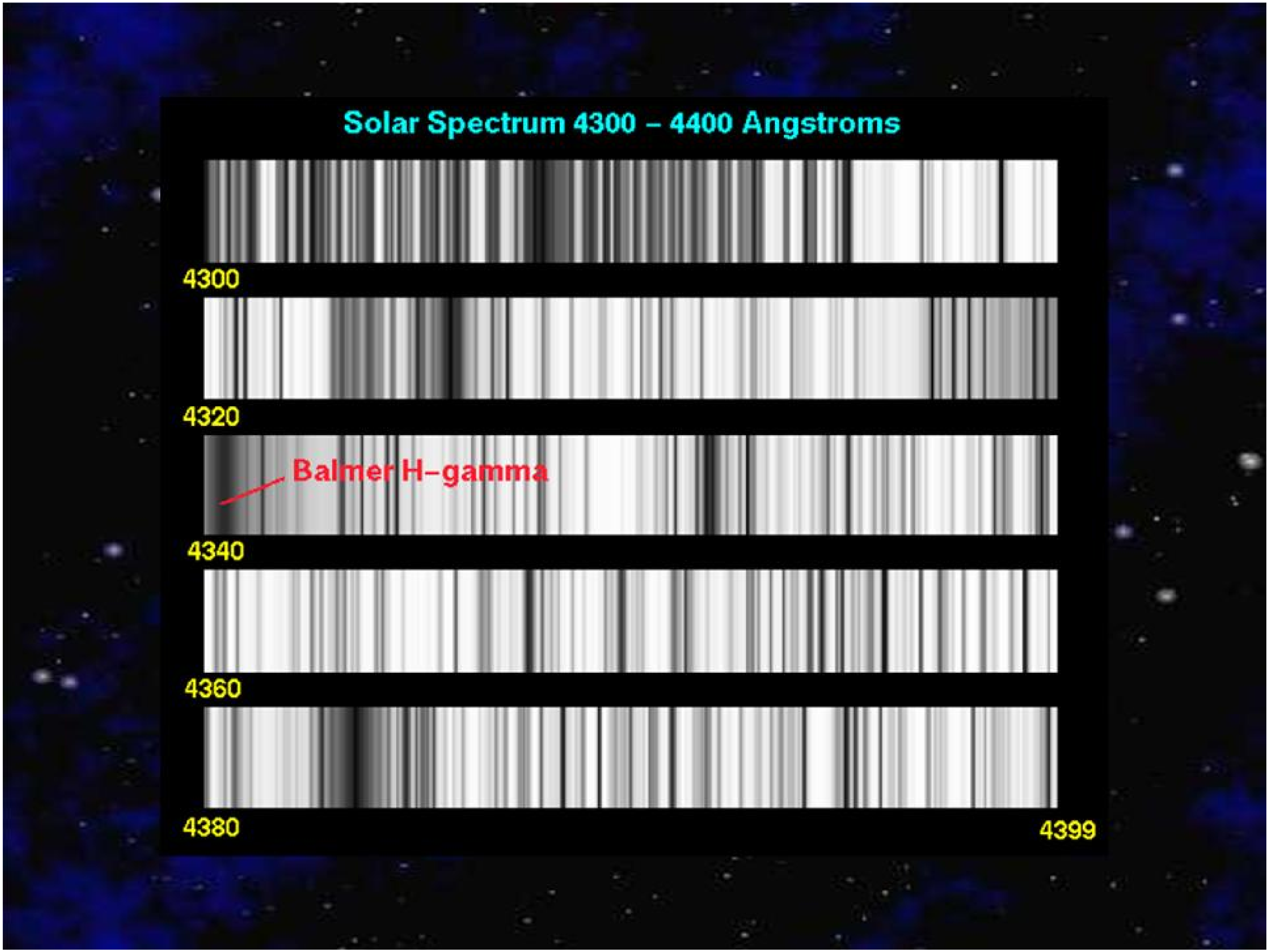
Prism or Diffraction Grating

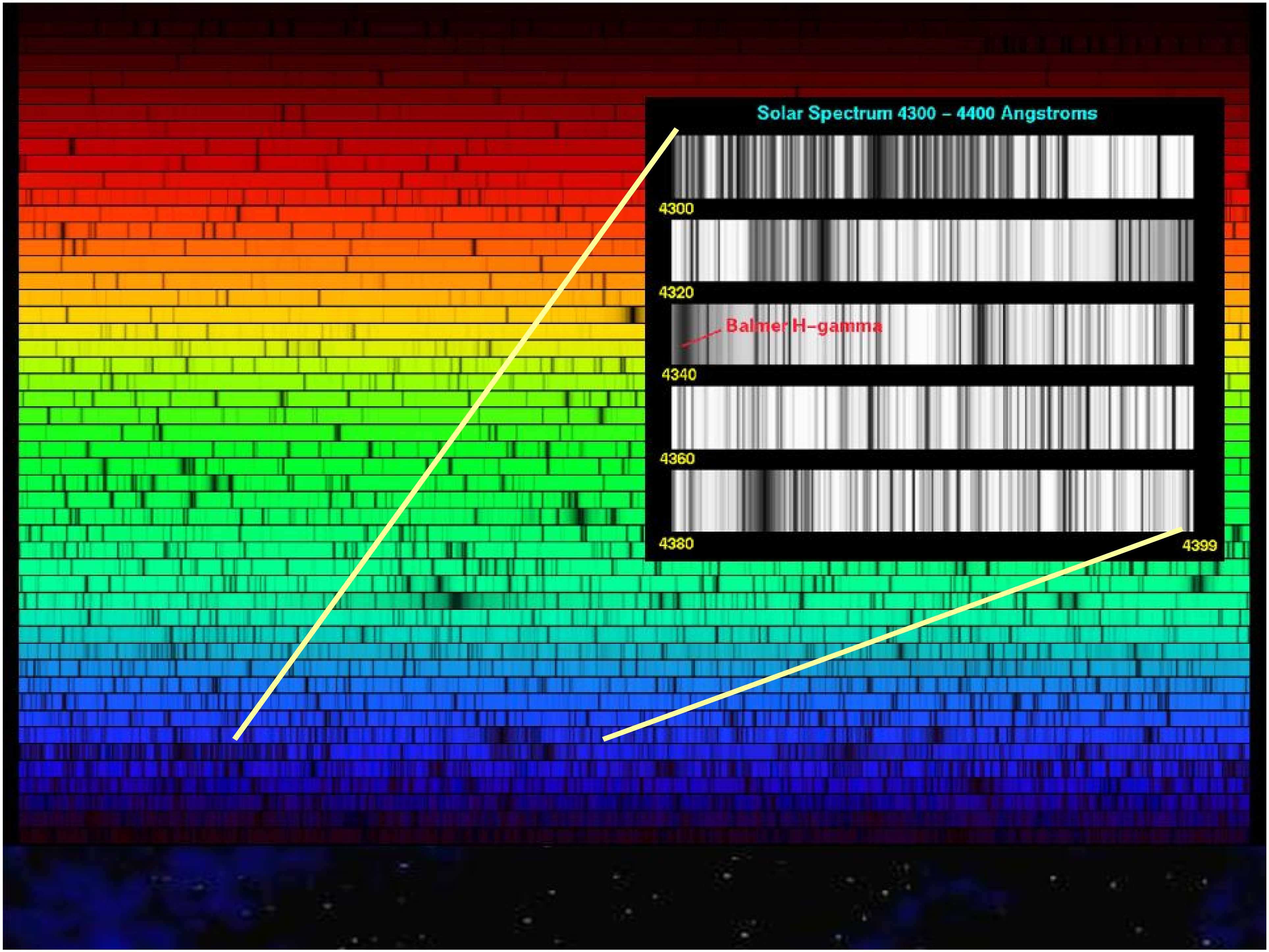



Spectral Sequence in Color
White
O5V
B1V
A1V
F3V
G2V
K0V
M0V
Ca+Hd
Hg
Hb
Na
Ha

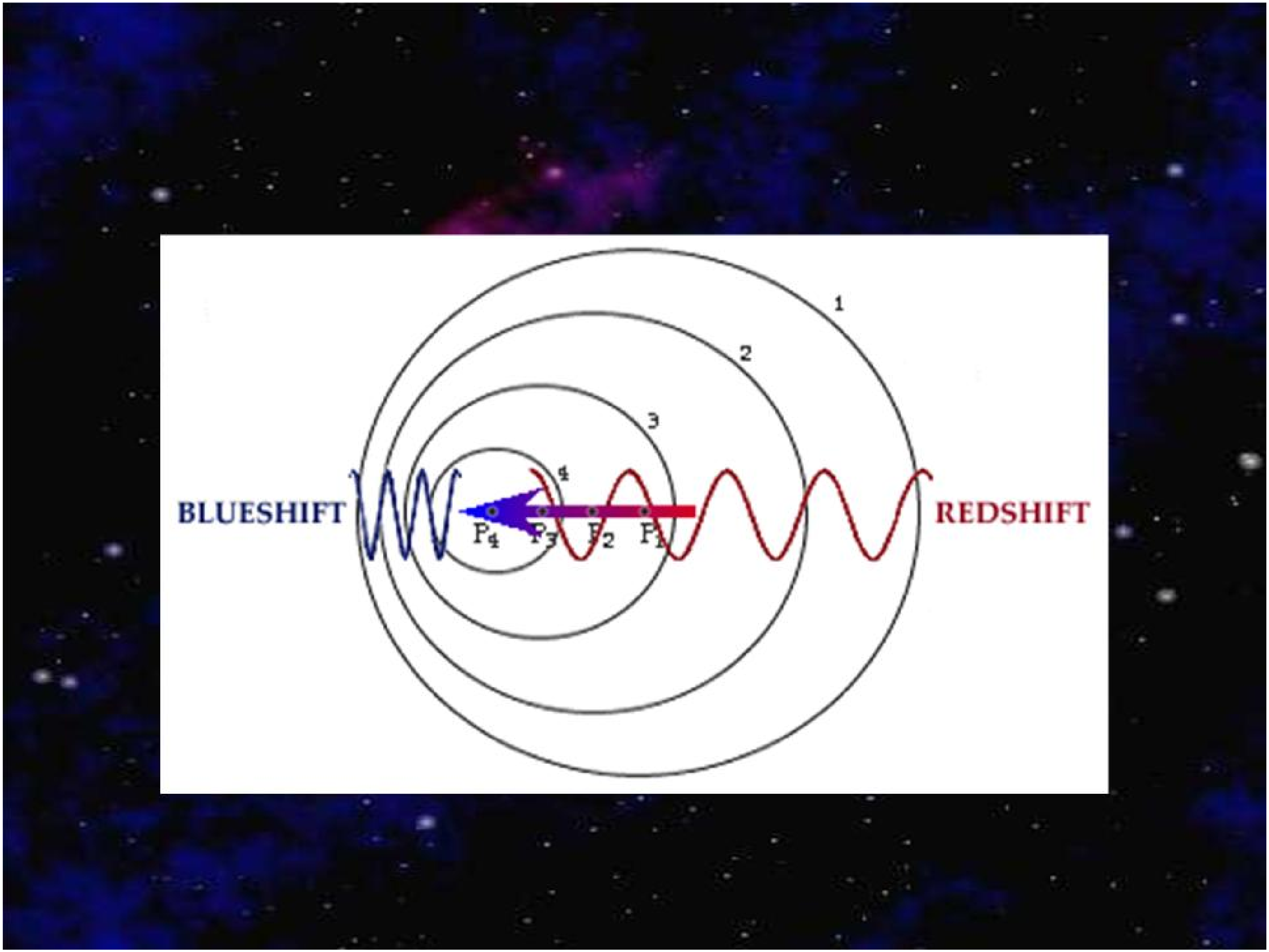

5/3/2002

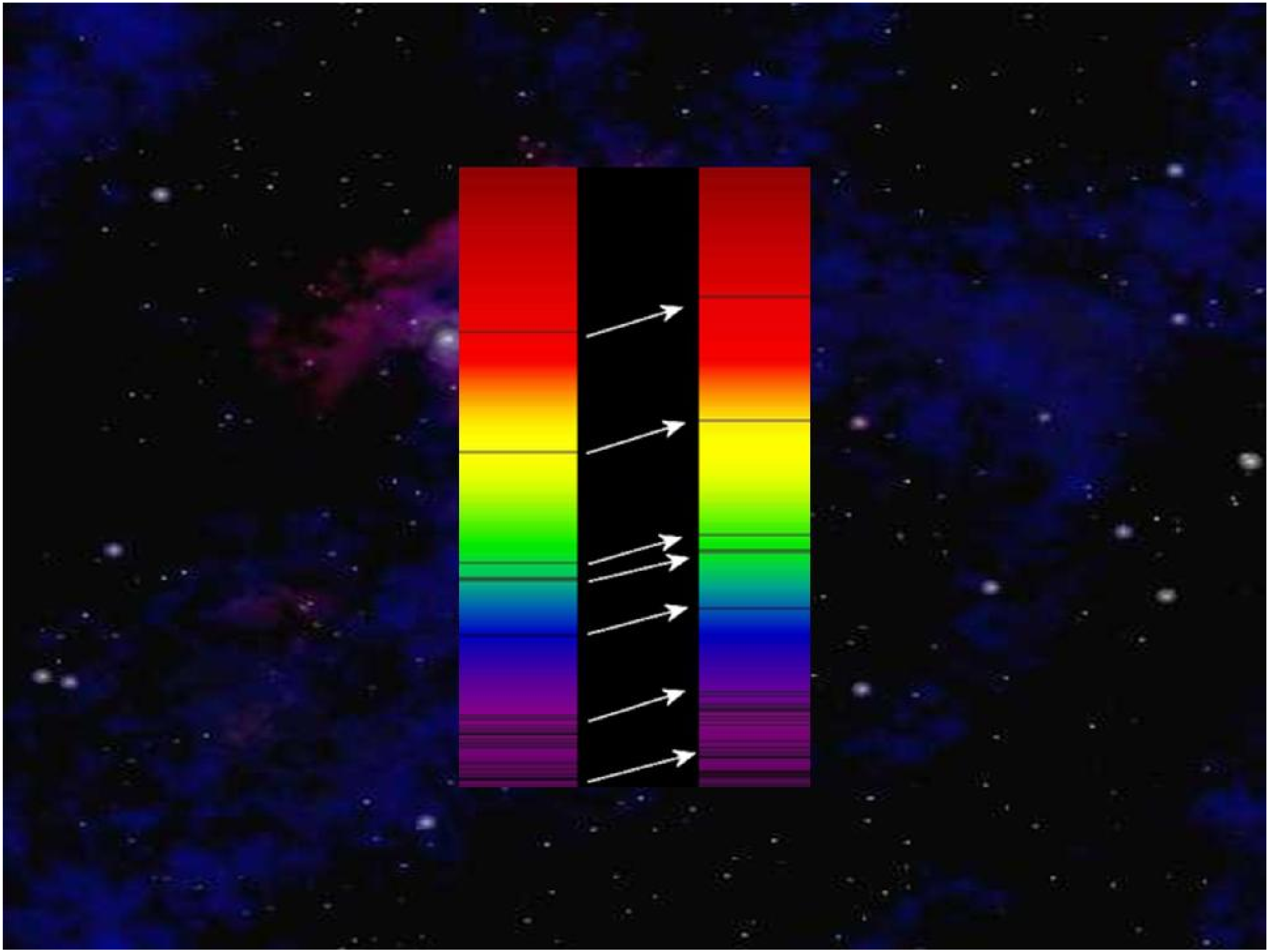

Hd
He+
O+
O+2
O+2
Ar+3
He
He+
He
Ne+2
N+2
He
x15
Hb
He+
Cl+2
O+
O
He
S+2
O
O
He
Relative Intensity
3400
3900
4400
4900
5400
5900
6400
Wavelength, A

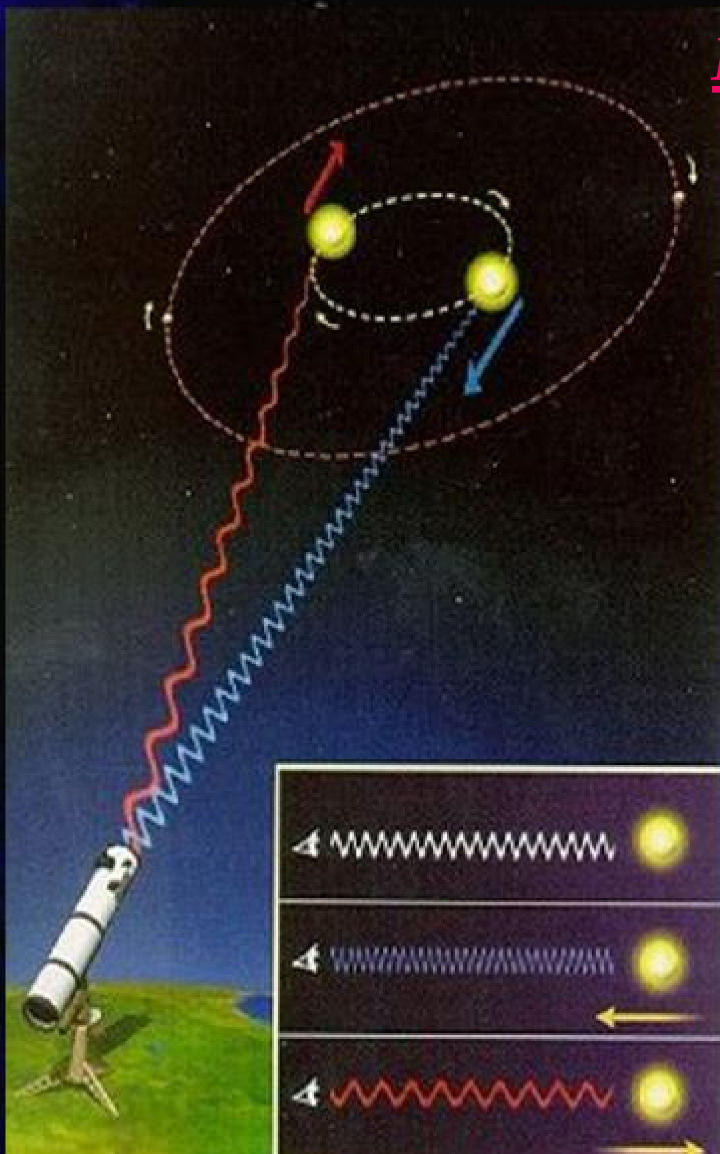

Solar Spectrum 4300 – 4400 Angstroms
4300
4320
Balmer H-gamma
4340
4360
4380
4399



Solar Spectrum 4300 – 4400 Angstroms
4300
4320
Balmer H-gamma
4340
4360
4380
4399


BLUESHIFT
REDSHIFT
1
2
3
4
P4
P3
P2
P1





Doppler Shift of Light: measuring the speed of objects

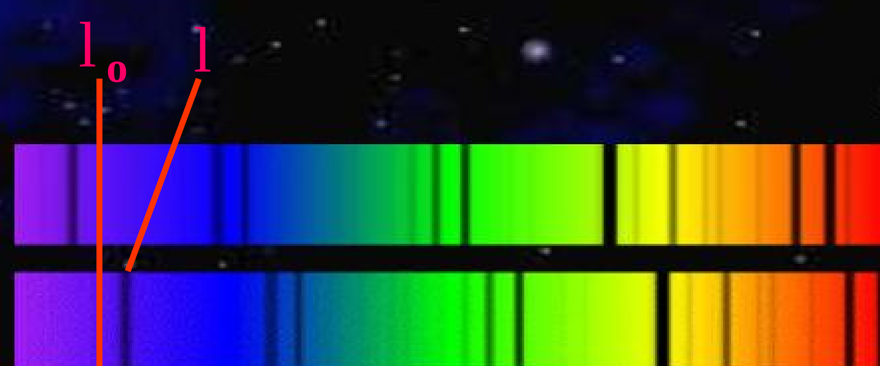
$$z = v/c = (l - l_o)/ l_o$$

v = velocity of object

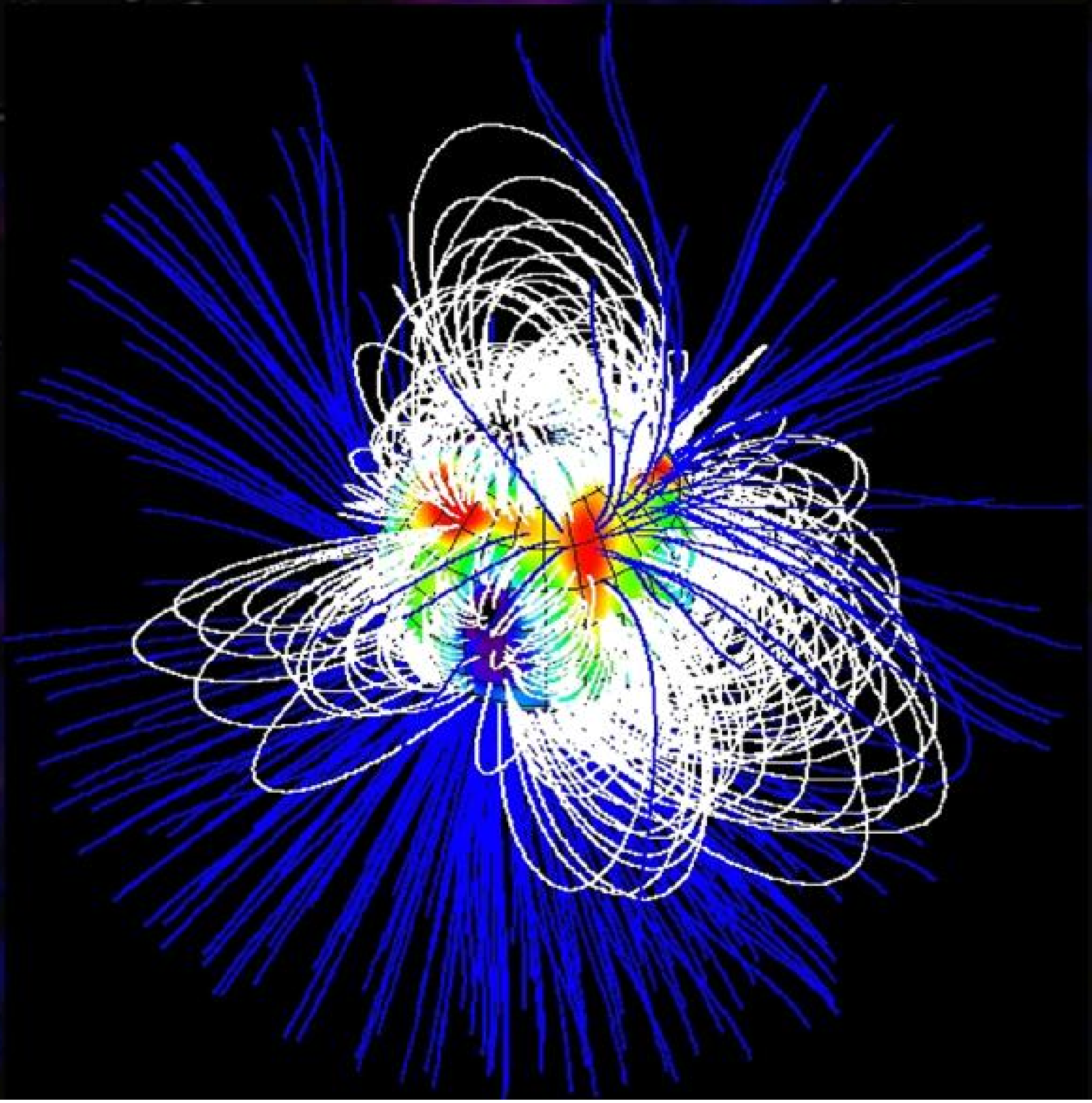
c = velocity of light (300,000 km/sec)

l_o = rest wavelength

l = measured wavelength



Magnetic Field Map of star FU Aurigae



In 1835, Auguste Comte, the French philosopher and founder of sociology, said of the stars:

"We shall never be able to study, by any method, their chemical composition or their mineralogical structure... Our positive knowledge of stars is necessarily limited to their geometric and mechanical phenomena".

THE NATURE OF STARS

Stellar Properties:

MASS SIZE ENERGY TEMPERATURE

DISTANCE CHEMICAL-COMPOSITION

MOTION EVOLUTION

Stellar Properties:

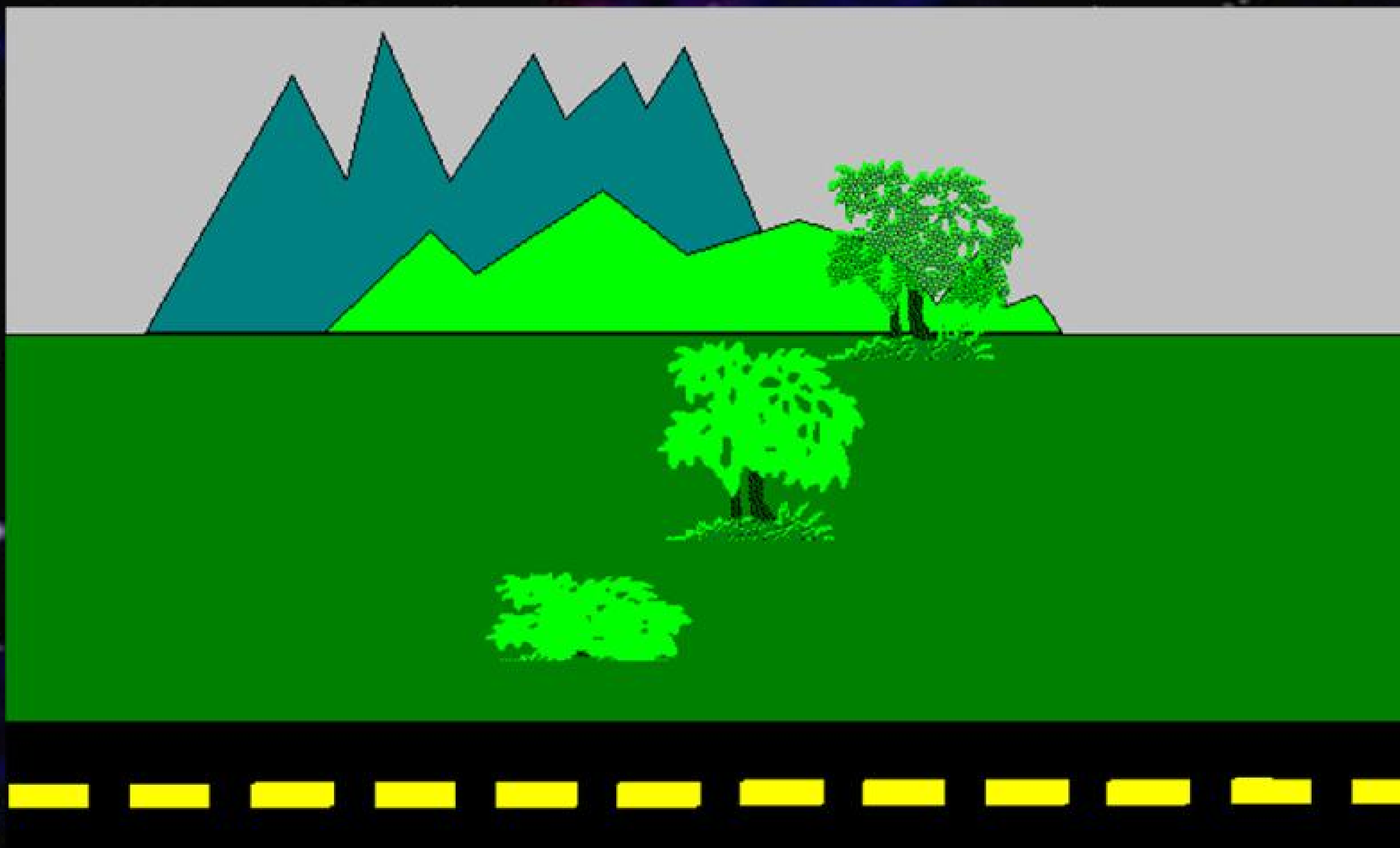
MASS SIZE ENERGY TEMPERATURE

DISTANCE CHEMICAL-COMPOSITION

MOTION EVOLUTION

Stellar Distances

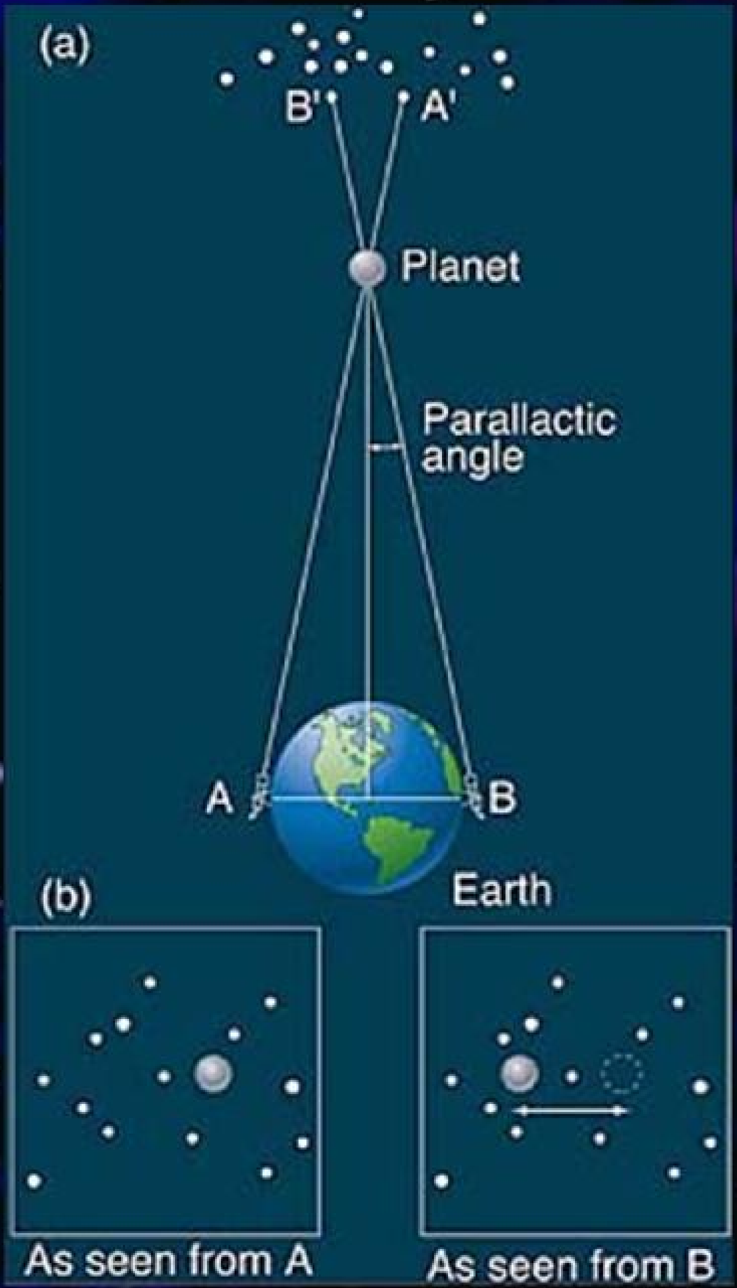
TRIGONOMETRIC PARALLAX



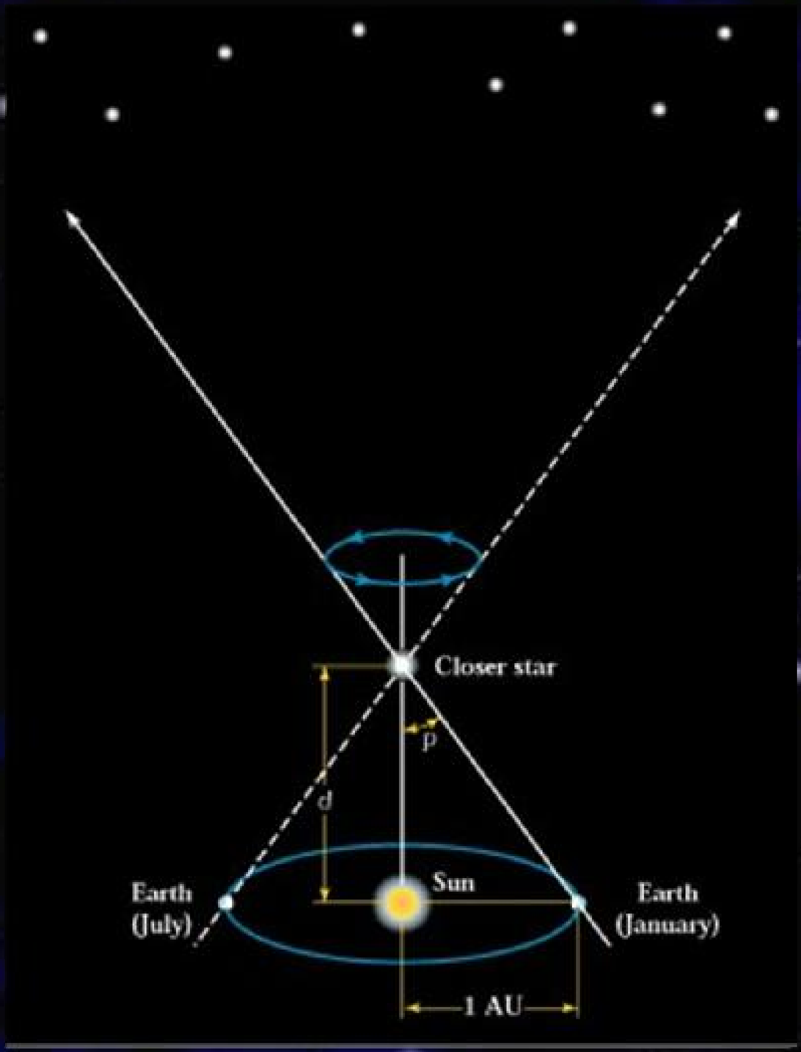
TRIGONOMETRIC PARALLAX

TRIGONOMETRIC PARALLAX

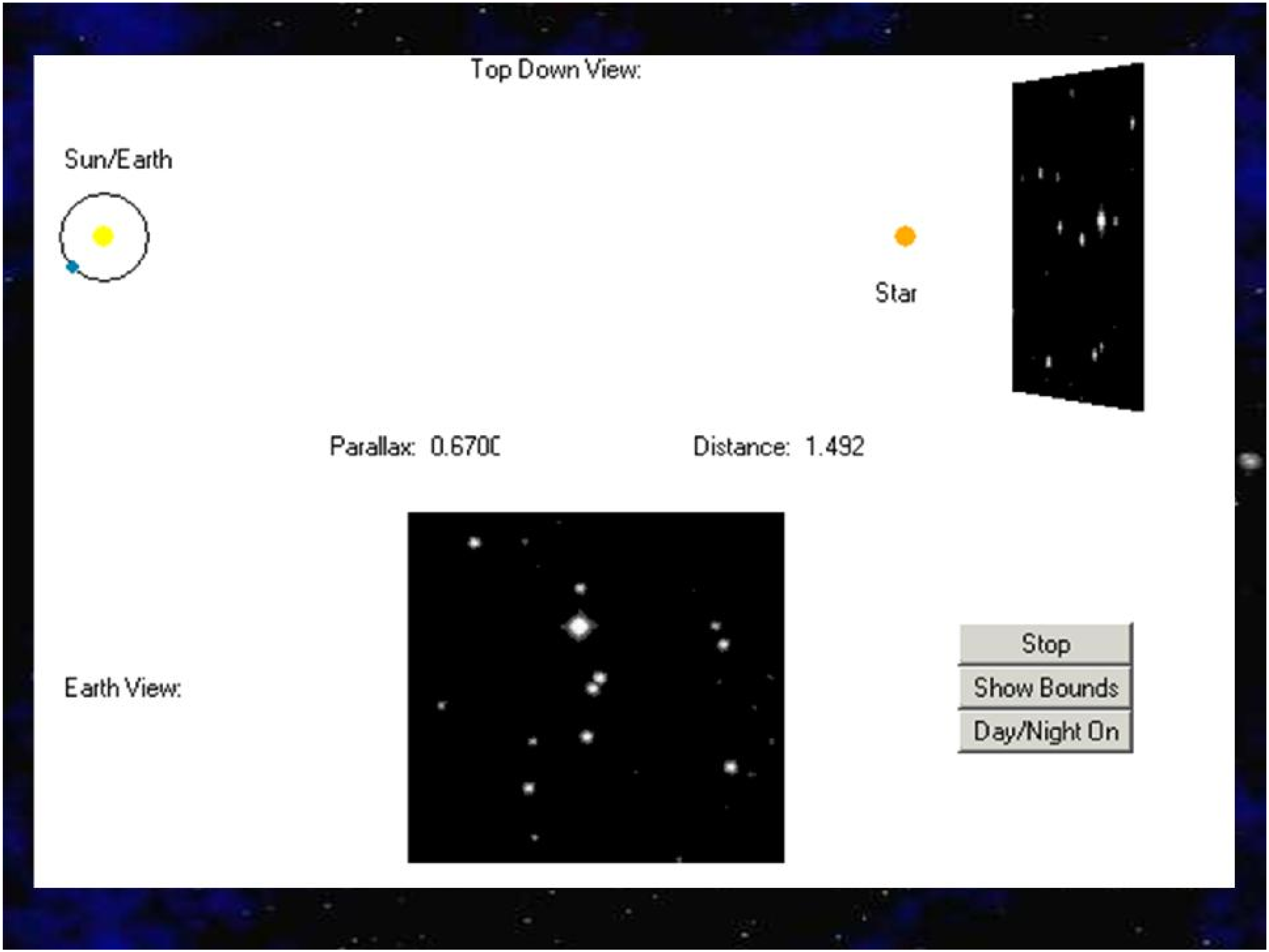
The apparent shift of a "nearby" object with respect to a distant background due to the observer's own motion.



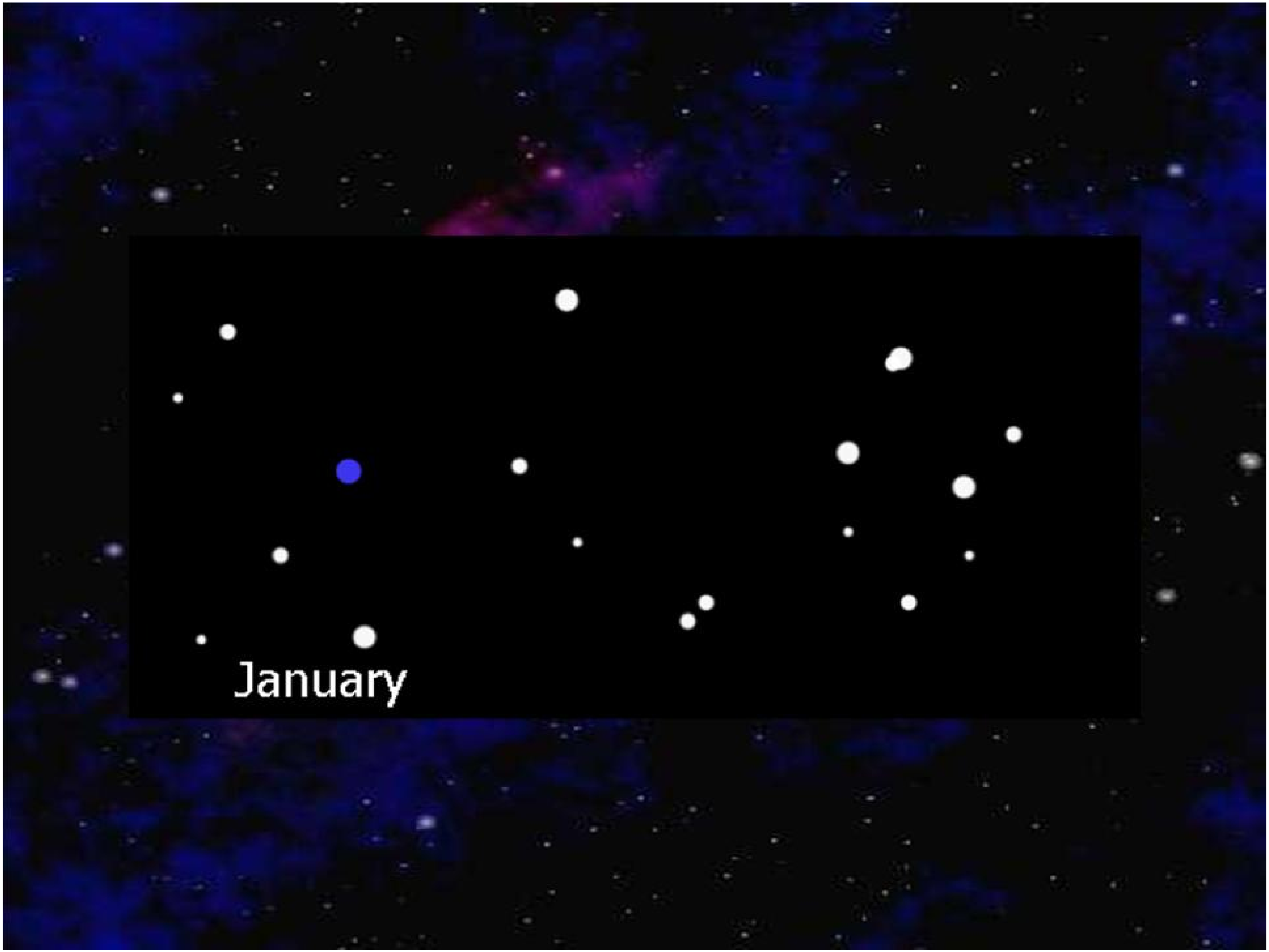
$$d \propto \frac{1}{p}$$

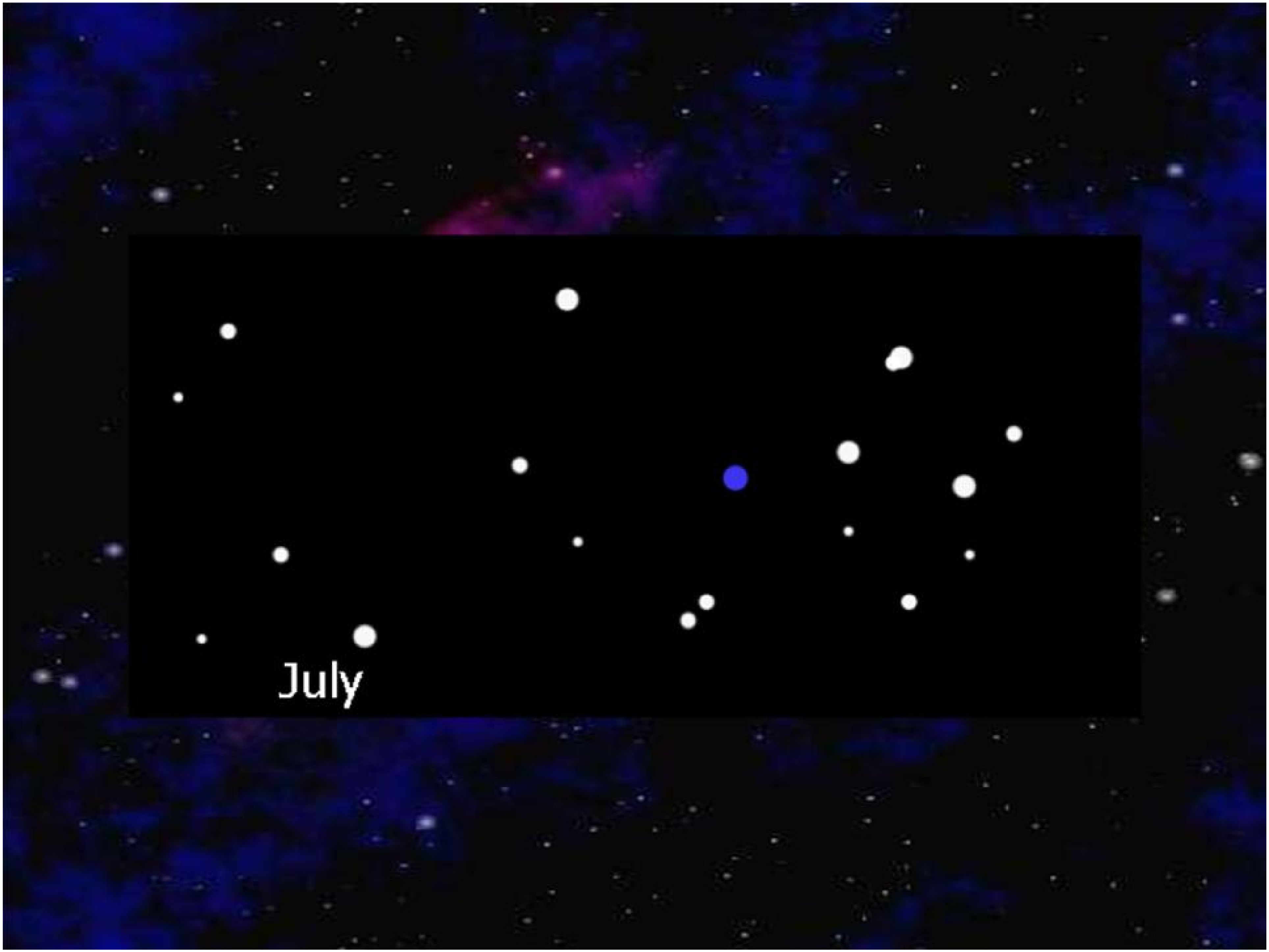


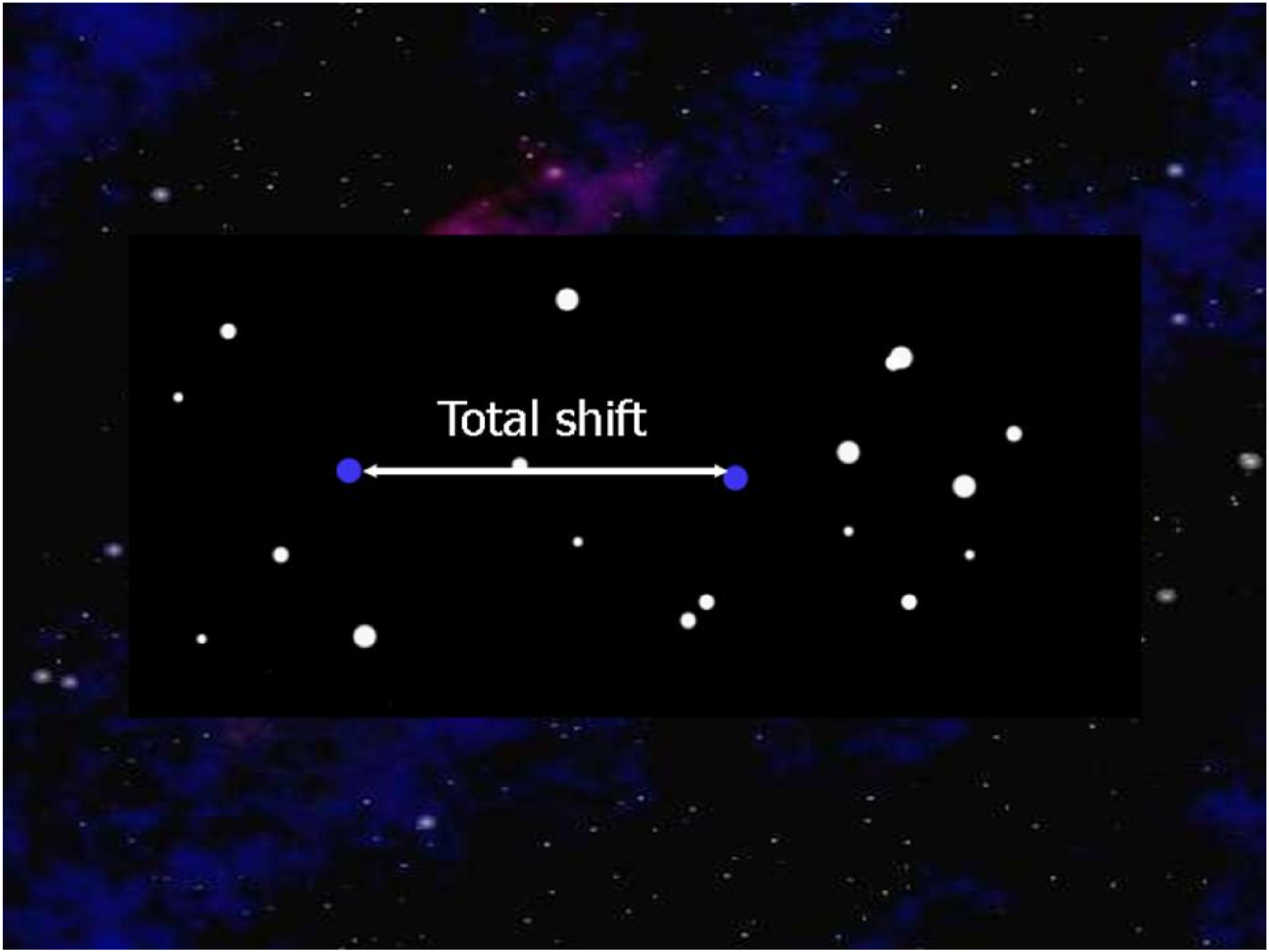
$$d \propto \frac{1}{p}$$

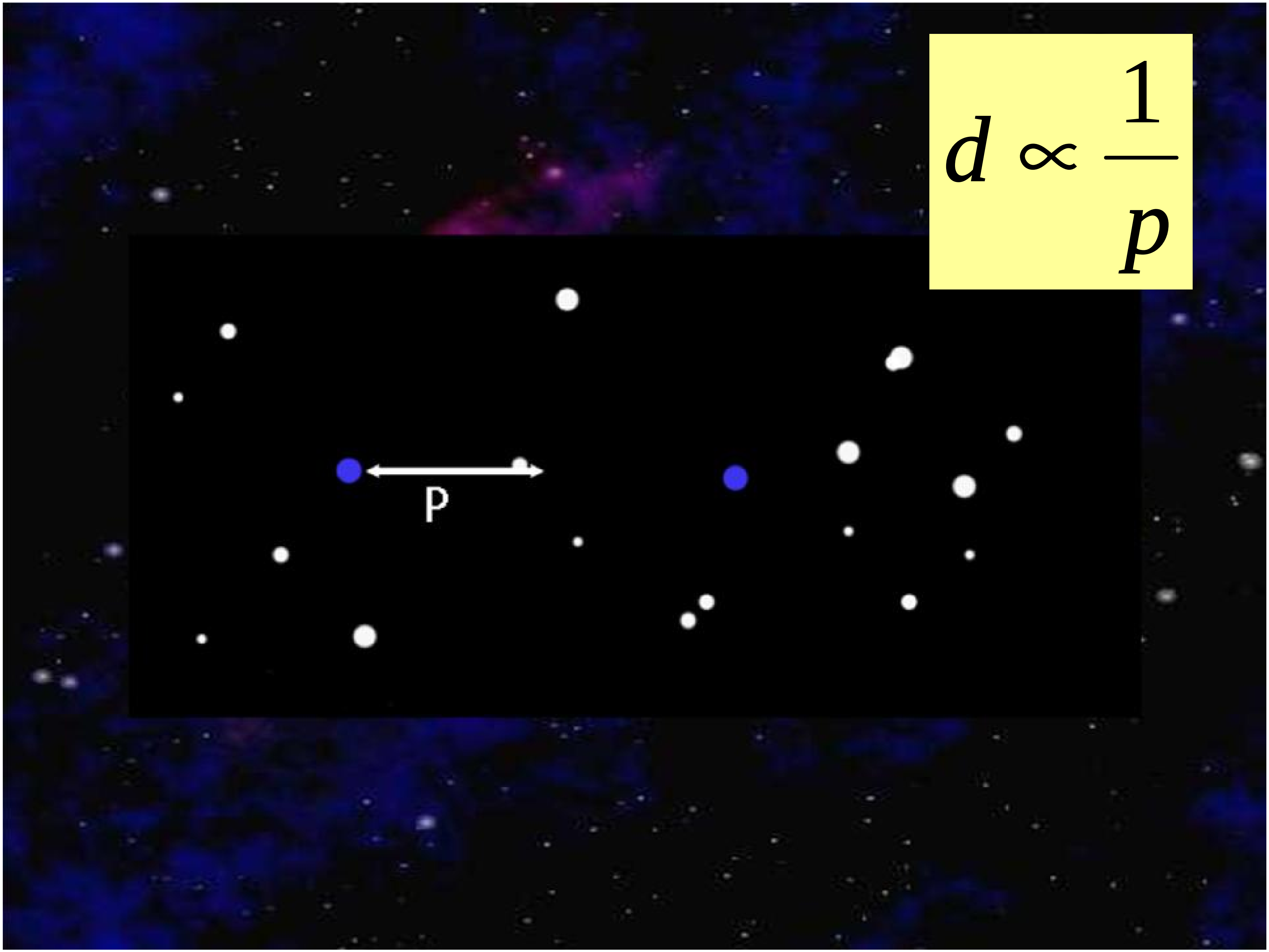


Top Down View:
Sun/Earth
Star
Parallax: 0.670C
Distance: 1.492
Earth View:
Stop
Show Bounds
Day/Night On


January


July


Total shift



$$d \propto \frac{1}{p}$$

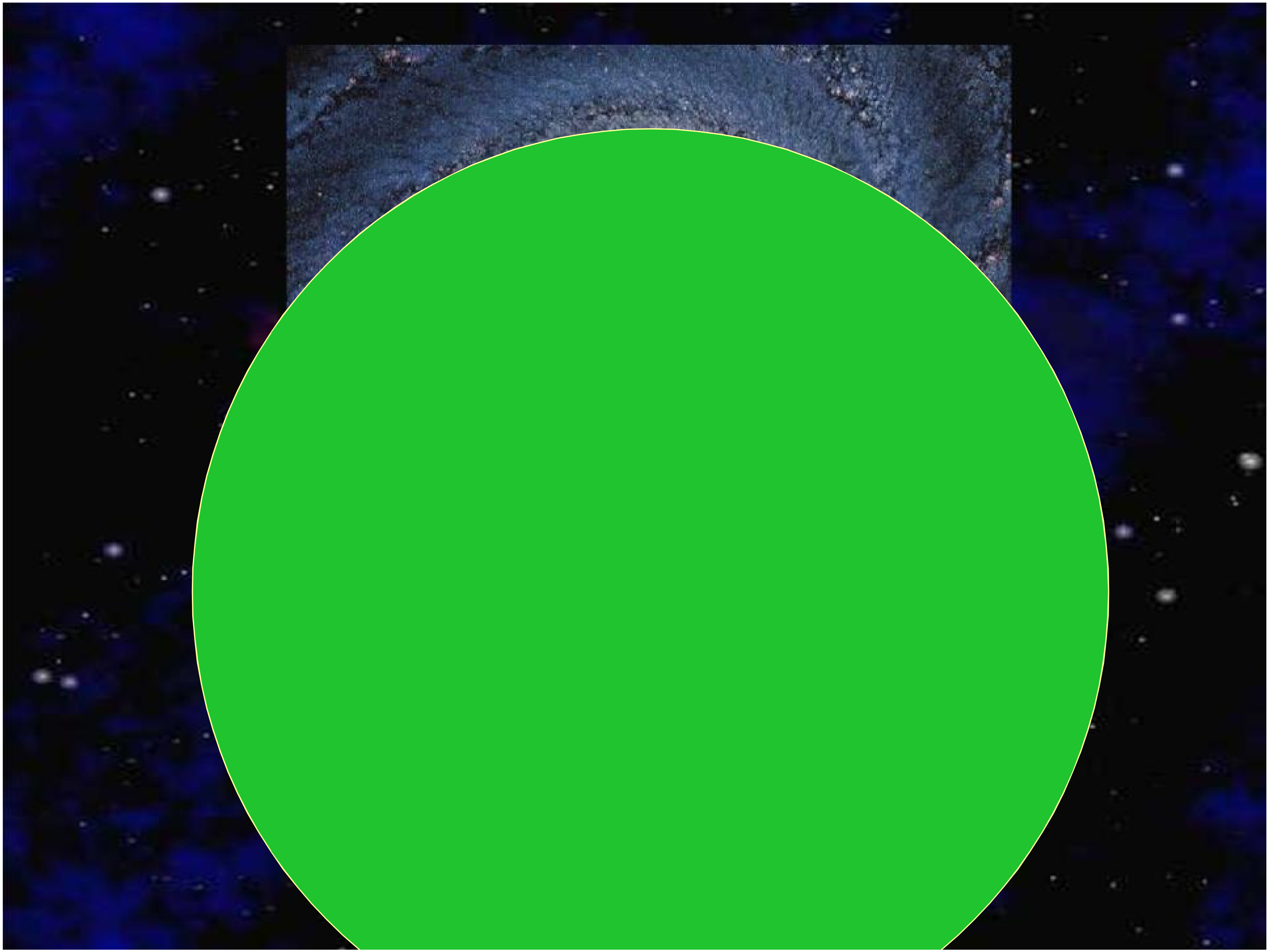
What are the limitations of Trigonometric Parallax?

Only works for the nearest stars

How can we improve upon this method?

Earth based telescopes at best, 0.01” = 100 parsecs = ~326 ly

Hipparcos, 1989, parallax to 0.001” = 1000 parsecs = 3260 ly



Is there another way to measure distances to stars?

(apparent brightness)

–

(true energy given off)

∝

(distance)

APPARENT MAGNITUDE (m)

How bright an object *appears* to an observer on Earth

THE MAGNITUDE SCALE

Hipparchus (2nd Century B.C.)

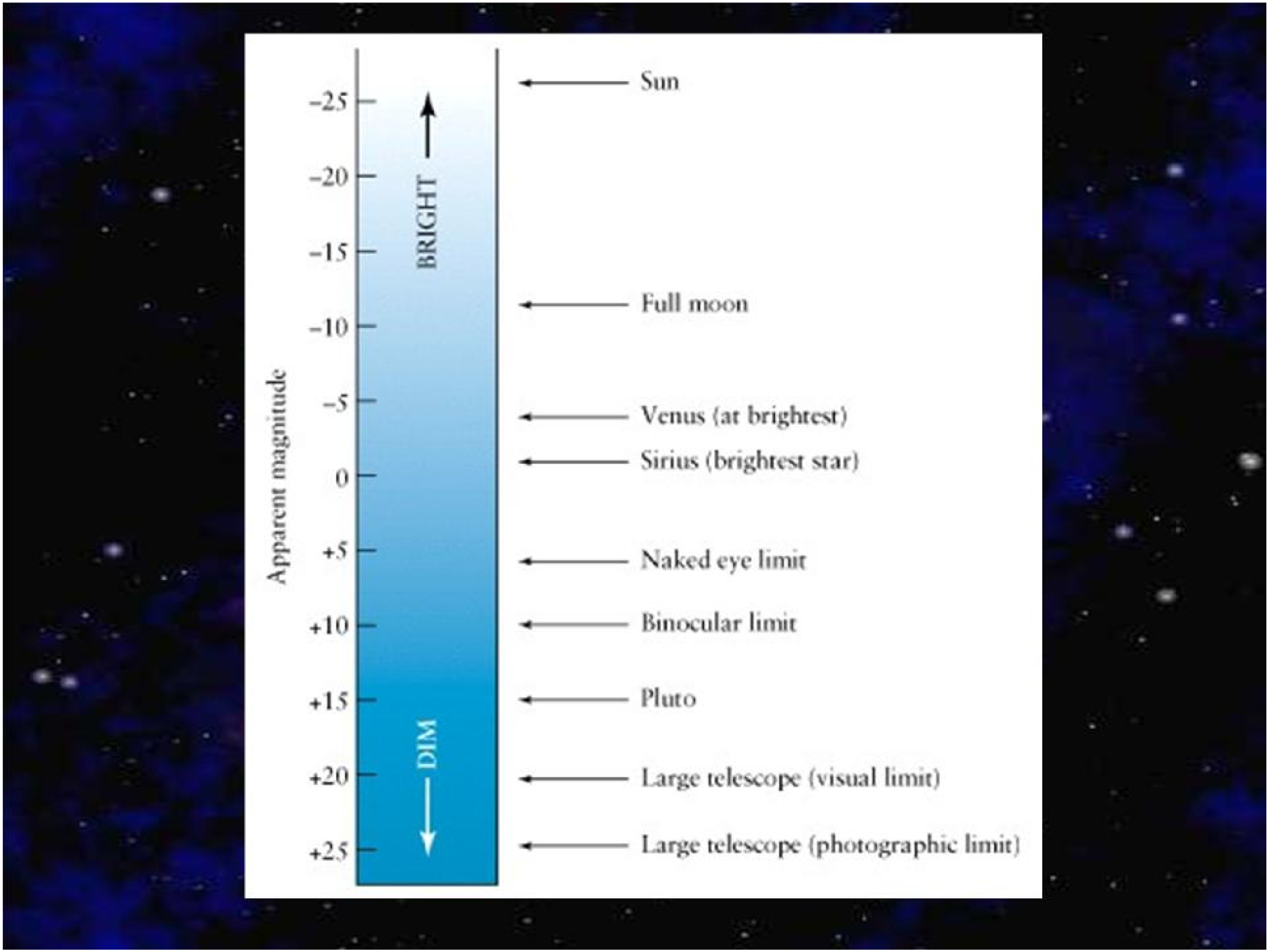
Brightest stars ð 1st magnitude

Faintest stars ð 6th magnitude

Modern astronomers kept old system but adapted it to a modern scale

A difference of 5 magnitudes is a difference of 100 times in brightness

$$\sqrt[5]{100} = 2.512$$


Apparent magnitude
-25
-20
-15
-10
-5
0
+5
+10
+15
+20
+25
BRIGHT
DIM
Sun
Full moon
Venus (at brightest)
Sirius (brightest star)
Naked eye limit
Binocular limit
Pluto
Large telescope (visual limit)
Large telescope (photographic limit)

ABSOLUTE MAGNITUDE (M)

The apparent magnitude of a star at a distance of 33 light years.

Related to the amount of energy the star is emitting

(apparent brightness)-(true energy) μ (distance)

$$m - M = 5\log d - 5$$

$$m - M = 5\log d - 5$$

m= -26.5

M=4.83

d=93,000,000 miles

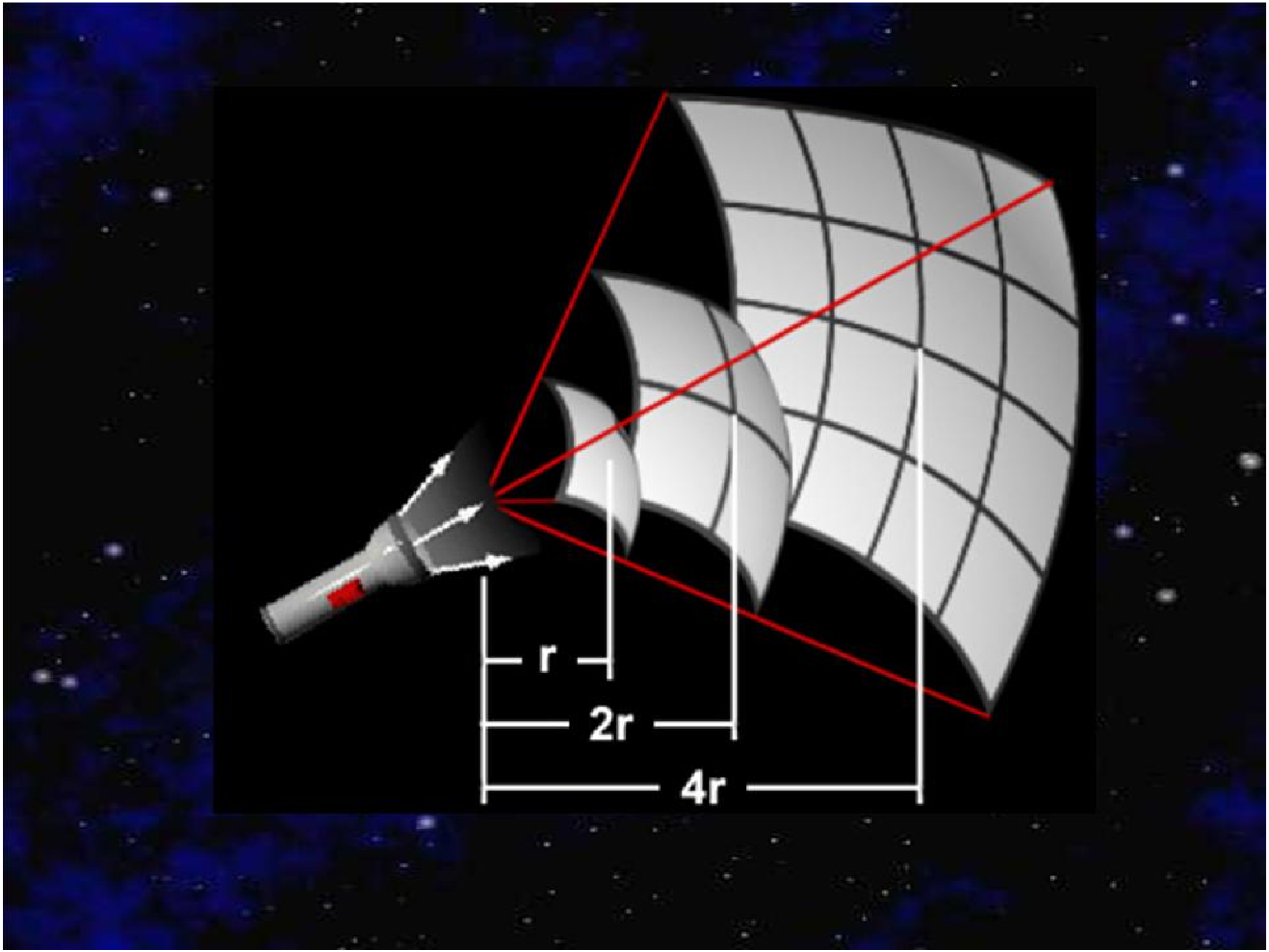
Luminosity vs. brightness

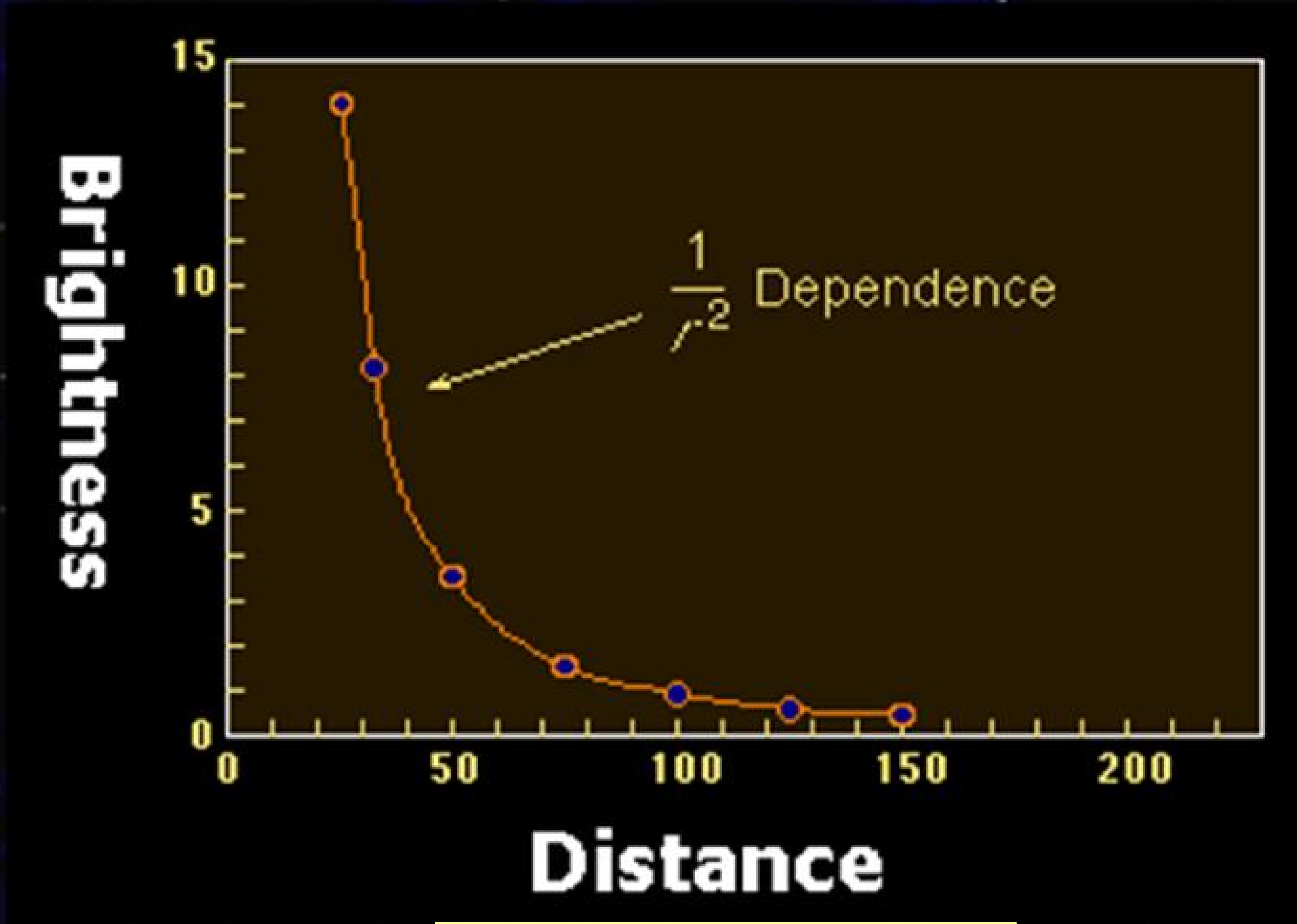
LUMINOSITY:

The amount of energy radiated by a star each second.

BRIGHTNESS:

The amount of energy radiated by a star that is *received by an observer* at a distance.


r
2r
4r



$$b = \frac{L}{\left(4pd^{2}\right)}$$

Luminosity of the Sun

$L_{¤} = 3.9\text{x}10^{26}$ watts

390,000,000,000,000,000,000,000,000 watts!

The most luminous stars $L=10^{6}\ L_{¤}$

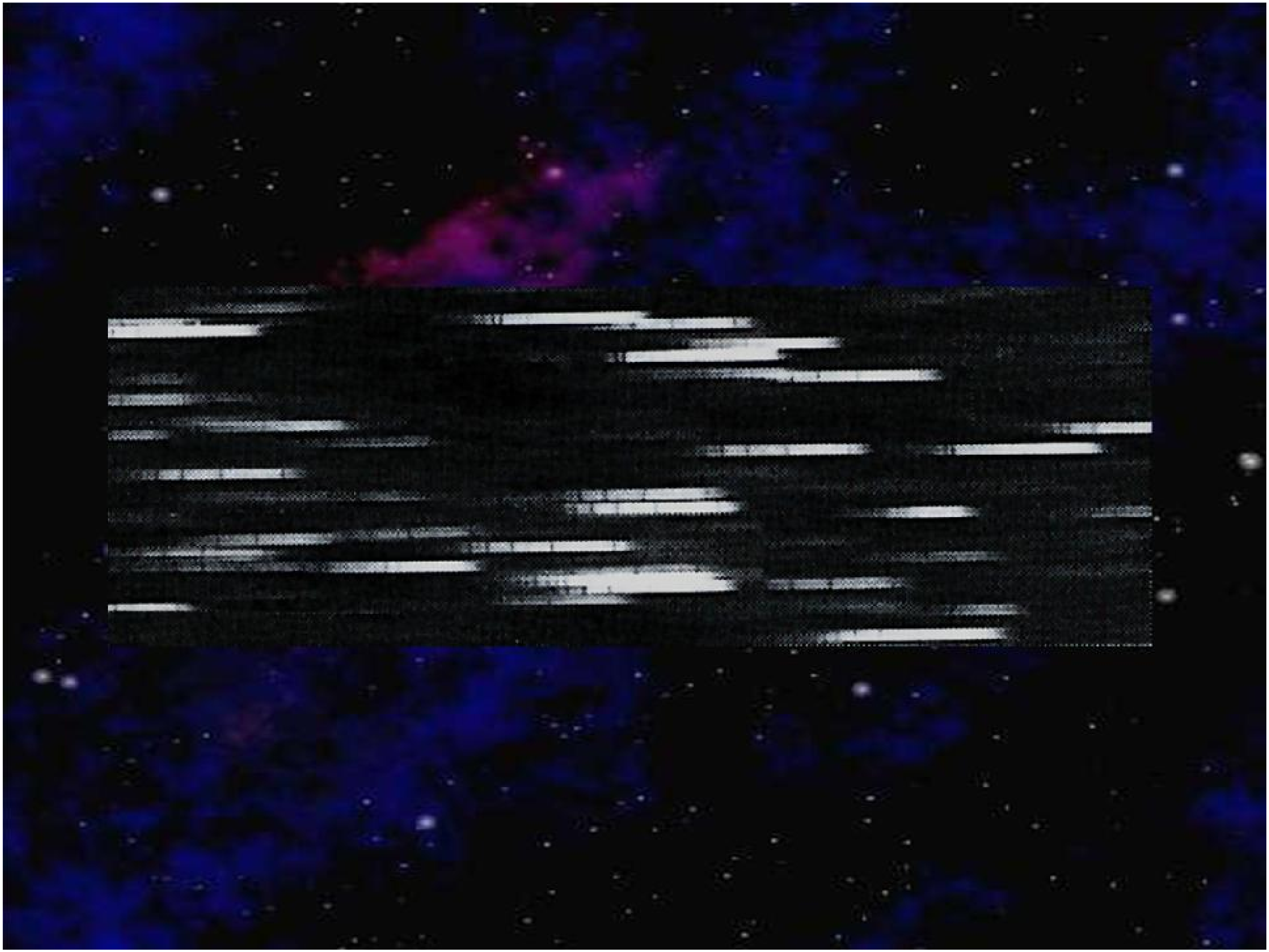
The least luminous stars $L = 0.0001\ L_{¤}$

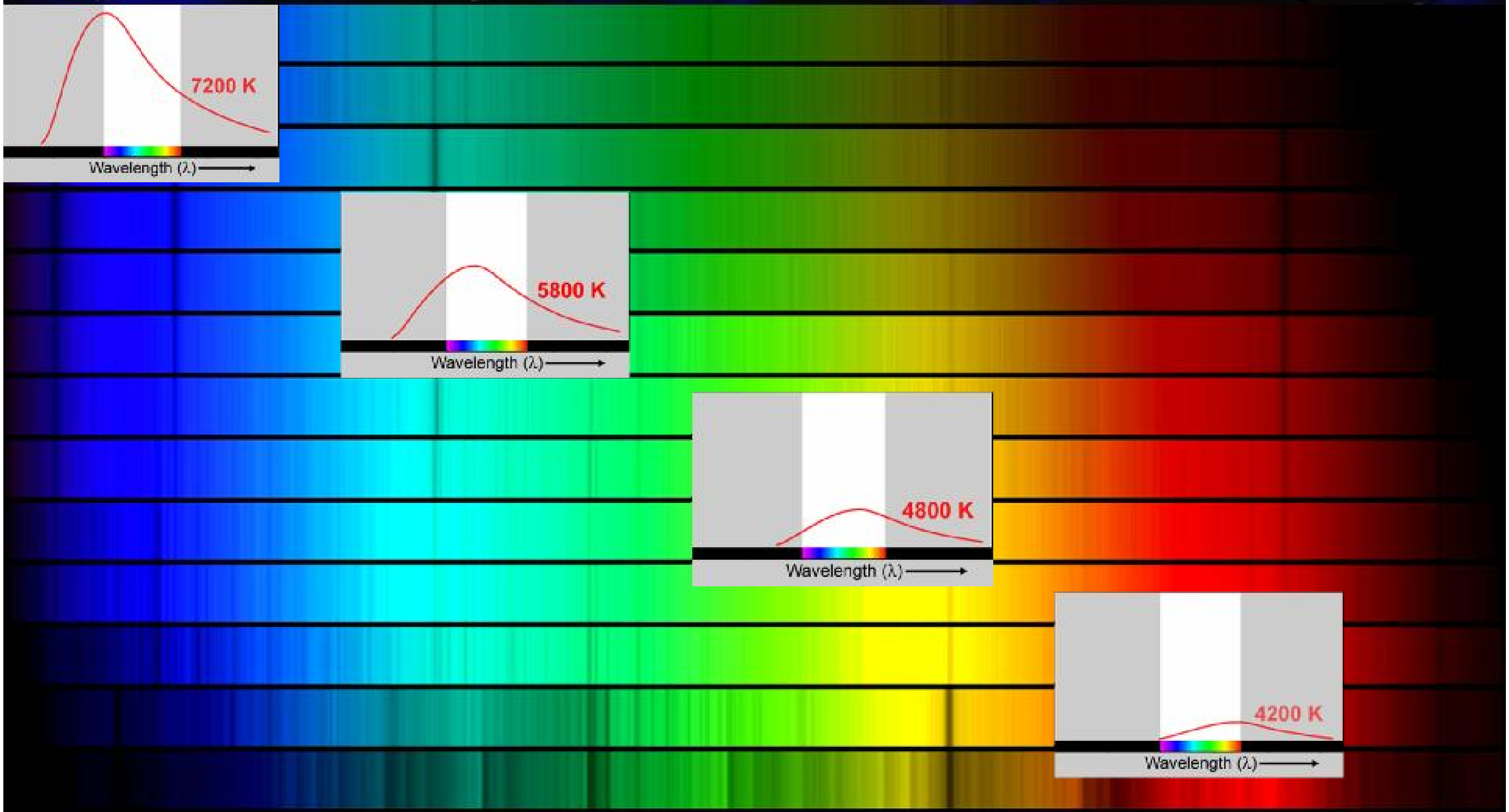
If Absolute Magnitude is related to the amount of energy a star is emitting...

Then

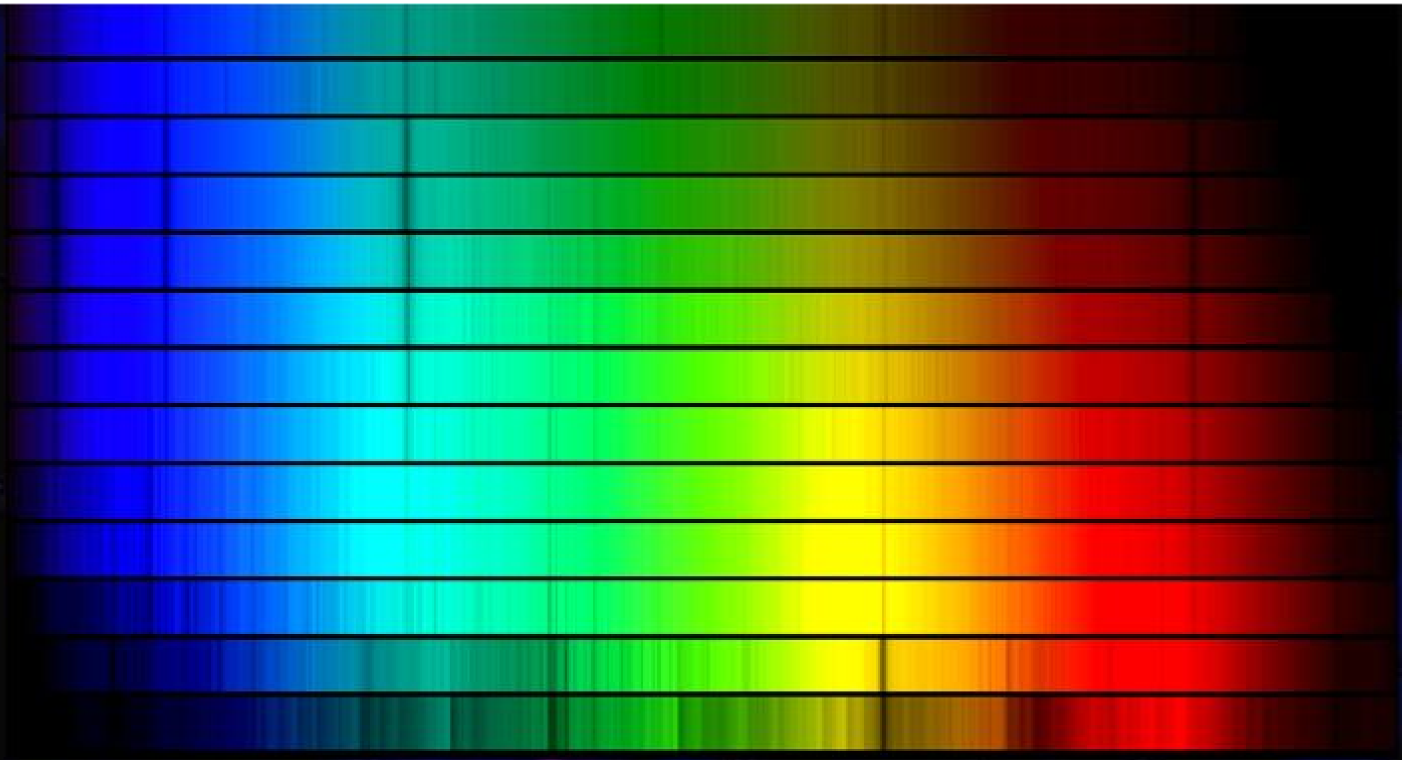
Absolute Magnitude μ Luminosity

But how do we determine a star’s luminosity??





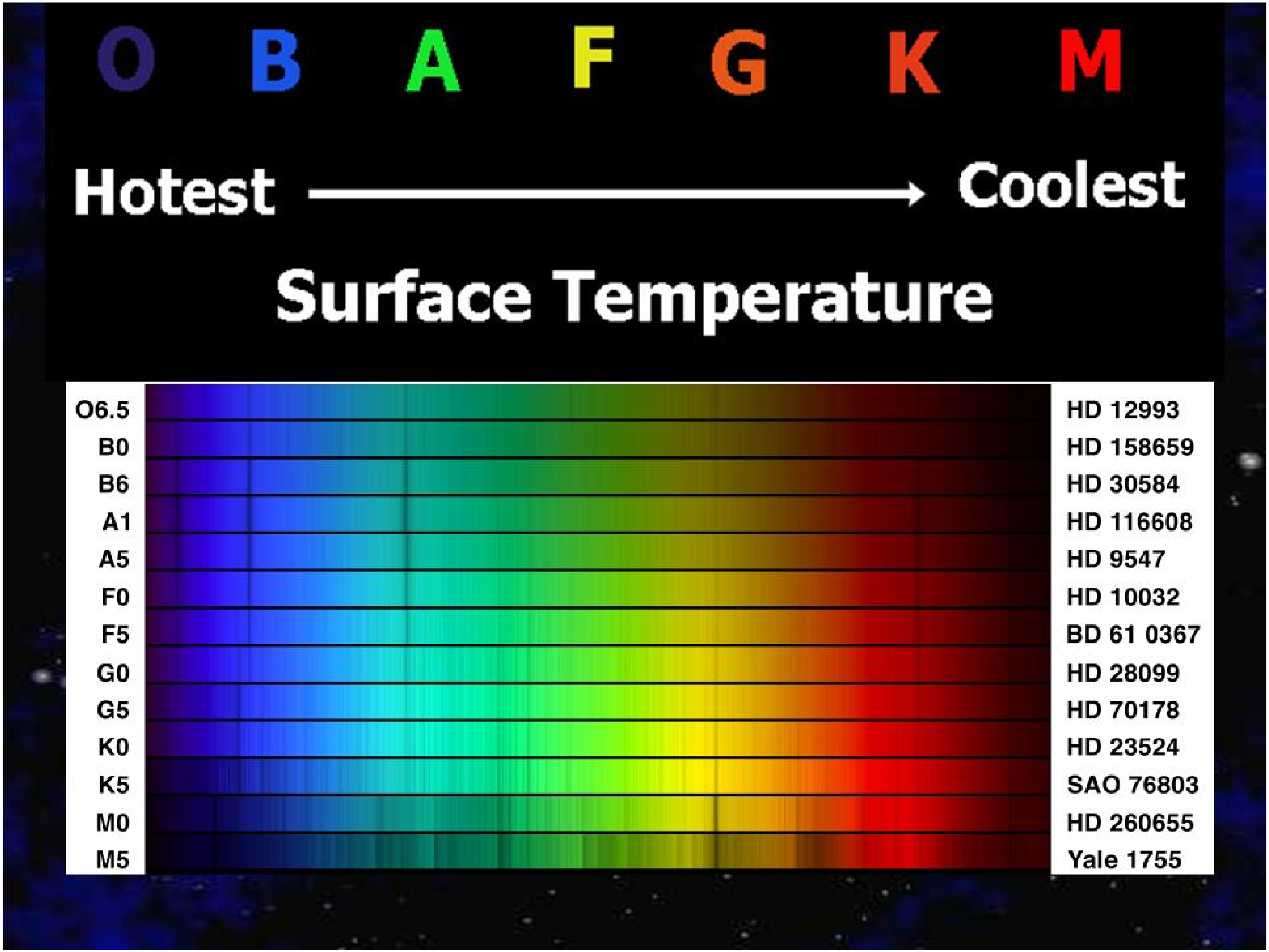
Every star's spectrum has characteristics that allow it to be categorized.



Originally categories were based upon the complexities of the spectrum...

A, B, C, D, E, ... Q

Ultimately found to be similar chemical compositions, different temperatures!


O B A F G K M
Hotest
Coolest
Surface Temperature
O6.5
B0
B6
A1
A5
F0
F5
G0
G5
K0
K5
M0
M5
HD 12993
HD 158659
HD 30584
HD 116608
HD 9547
HD 10032
BD 61 0367
HD 28099
HD 70178
HD 23524
SAO 76803
HD 260655
Yale 1755

O B A F G K M

Oh, Be A Fine Girl, Kiss Me!

Oh Brother, Astronomers Frequently Give Killer Midterms.

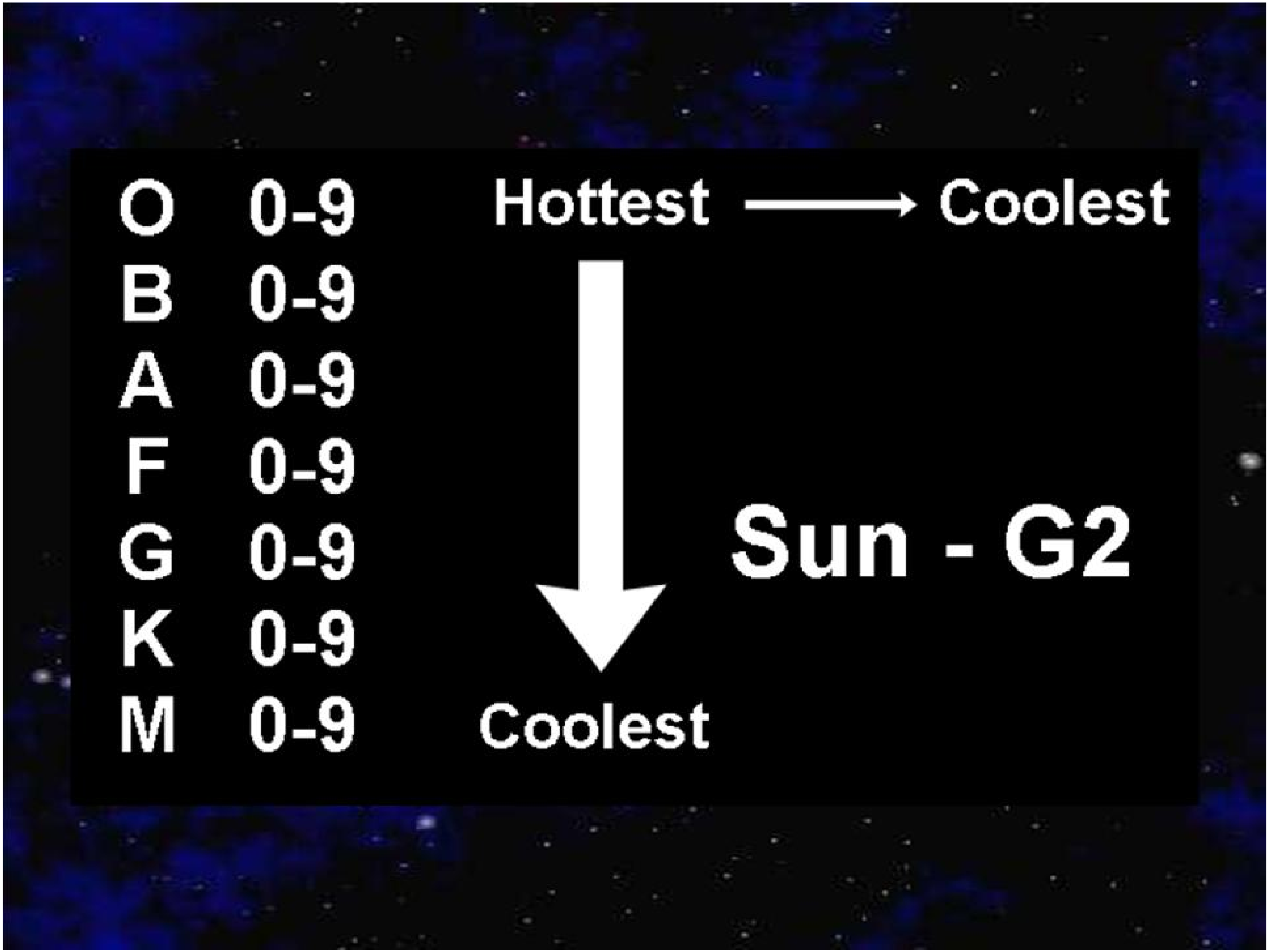
Oh Brother, Another F's Gonna Kill Me.

Oh Boy, A Fuzzy Gremlin Kissed Me

Orion Battles Across Far Galaxies Killing Martians

Only Big And Fat Guys Kiss Me

Oh Boy, A Furry Green Kiwi-Monster


O 0-9
B 0-9
A 0-9
F 0-9
G 0-9
K 0-9
M 0-9
Hottest
Coolest
Coolest
Sun - G2

$$L \propto T^4$$

SPECTRAL TYPE ð TEMPERATURE

TEMPERATURE ð LUMINOSITY

LUMINOSITY ð ABSOLUTE MAGNITUDE

THEREFORE...

SPECTRAL TYPE ð ABSOLUTE MAGNITUDE

Ejnar Hertzsprung

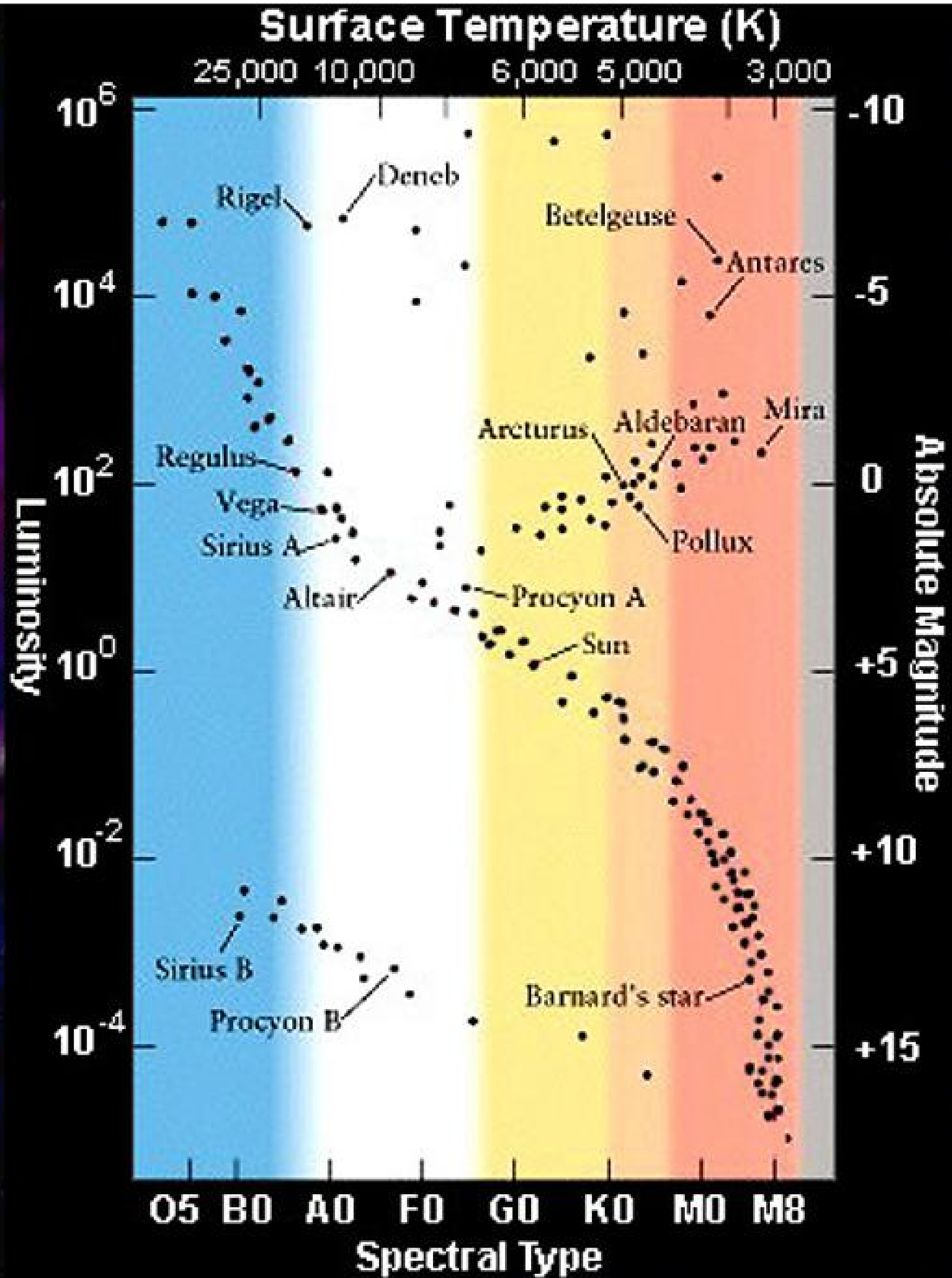
Henry Norris Russell

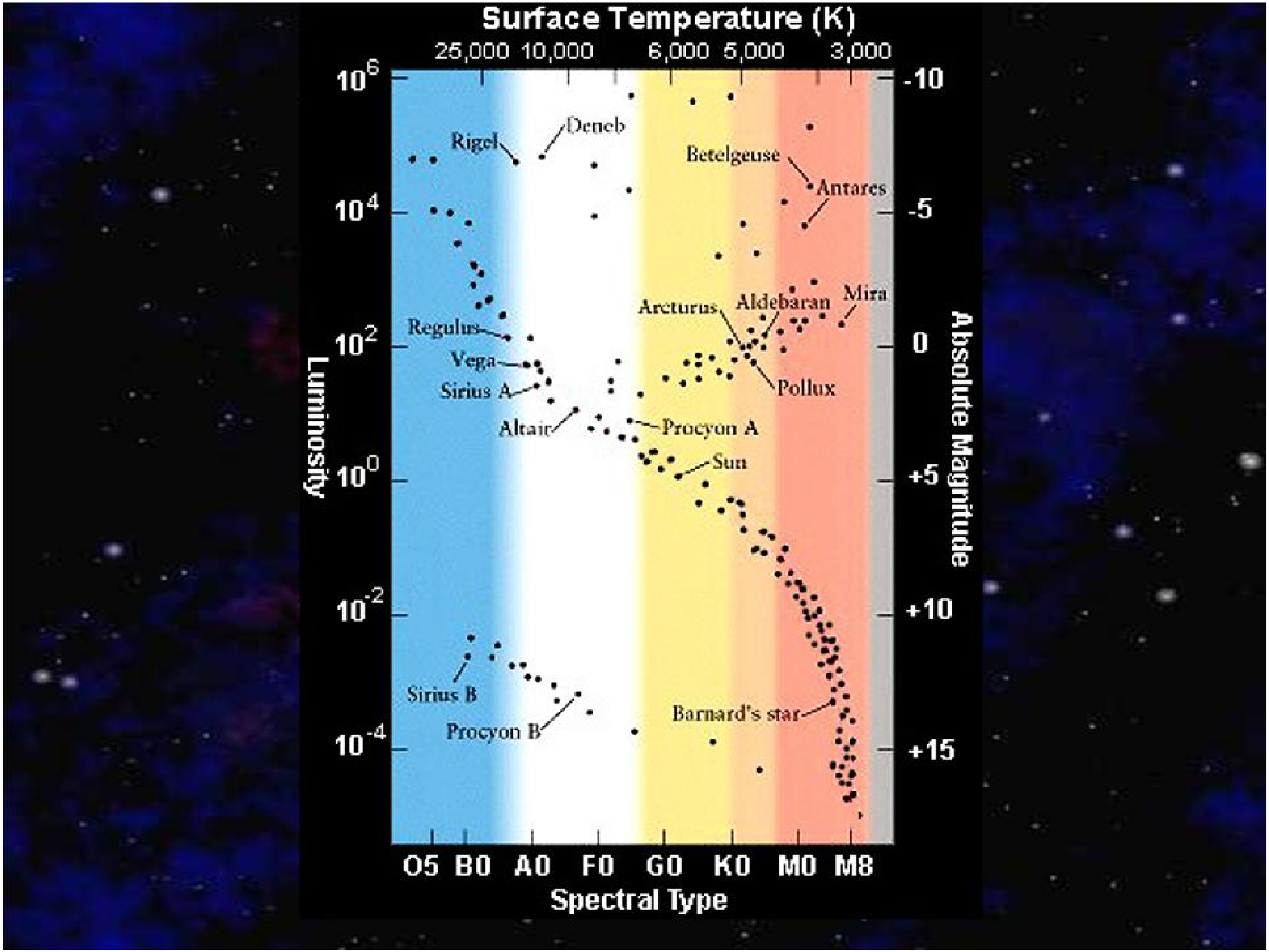
Hertzsprung & Russell

$$m - M = 5\log d - 5$$

- Took stars of known distances (parallax)
- Measured their apparent magnitude
- Calculated the star's absolute magnitude
- Discovered a relationship...

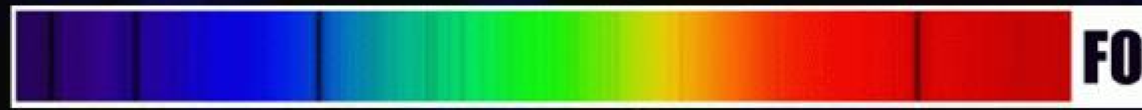
The Hertzsprung – Russell Diagram

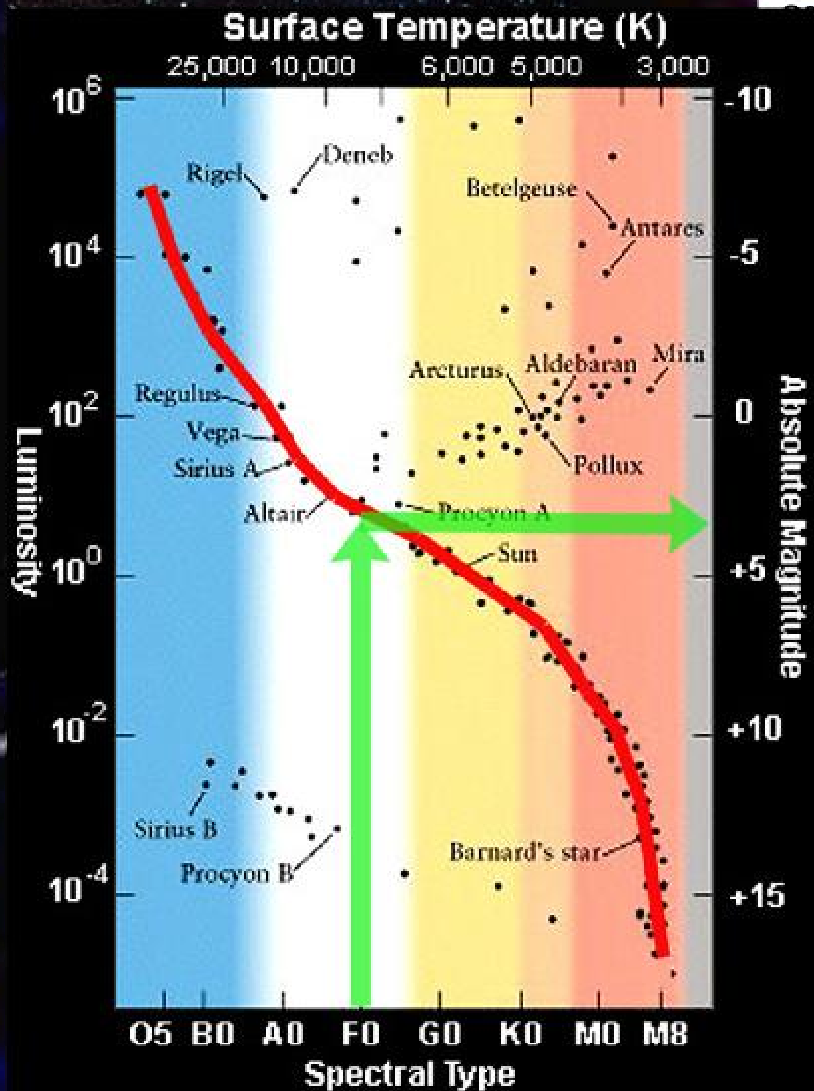


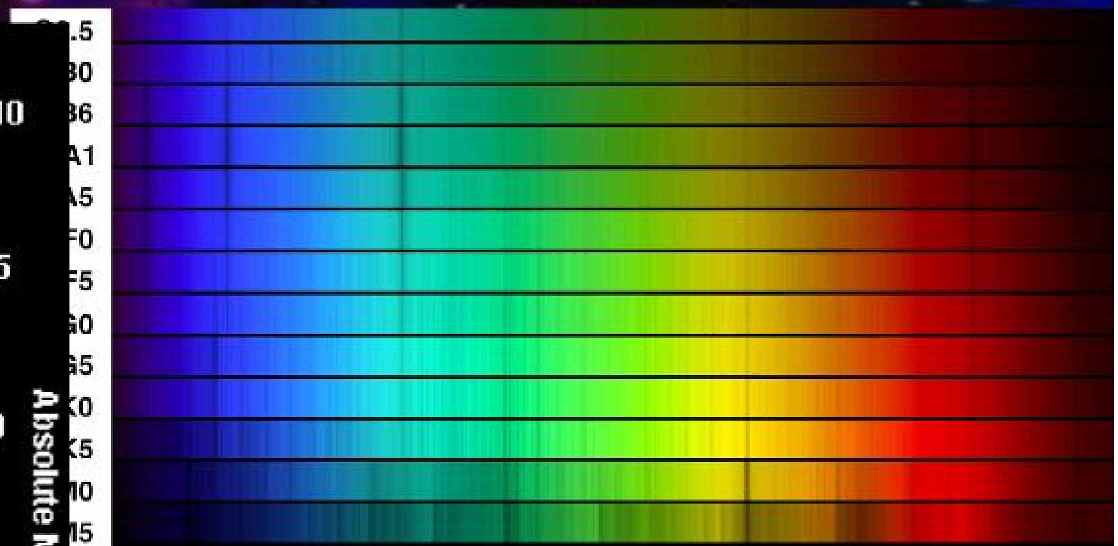


Surface Temperature (K)
25,000 10,000 6,000 5,000 3,000
Luminosity
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
Absolute Magnitude
-10
-5
0
+5
+10
+15
Deneb
Rigel
Betelgeuse
Antares
Mira
Arcturus
Aldebaran
Regulus
Vega
Sirius A
Pollux
Altair
Procyon A
Sun
Sirius B
Procyon B
Barnard's star
O5 B0 A0 F0 G0 K0 M0 M8
Spectral Type

So finally...to determine distances to stars too far away for trigonometric parallax...

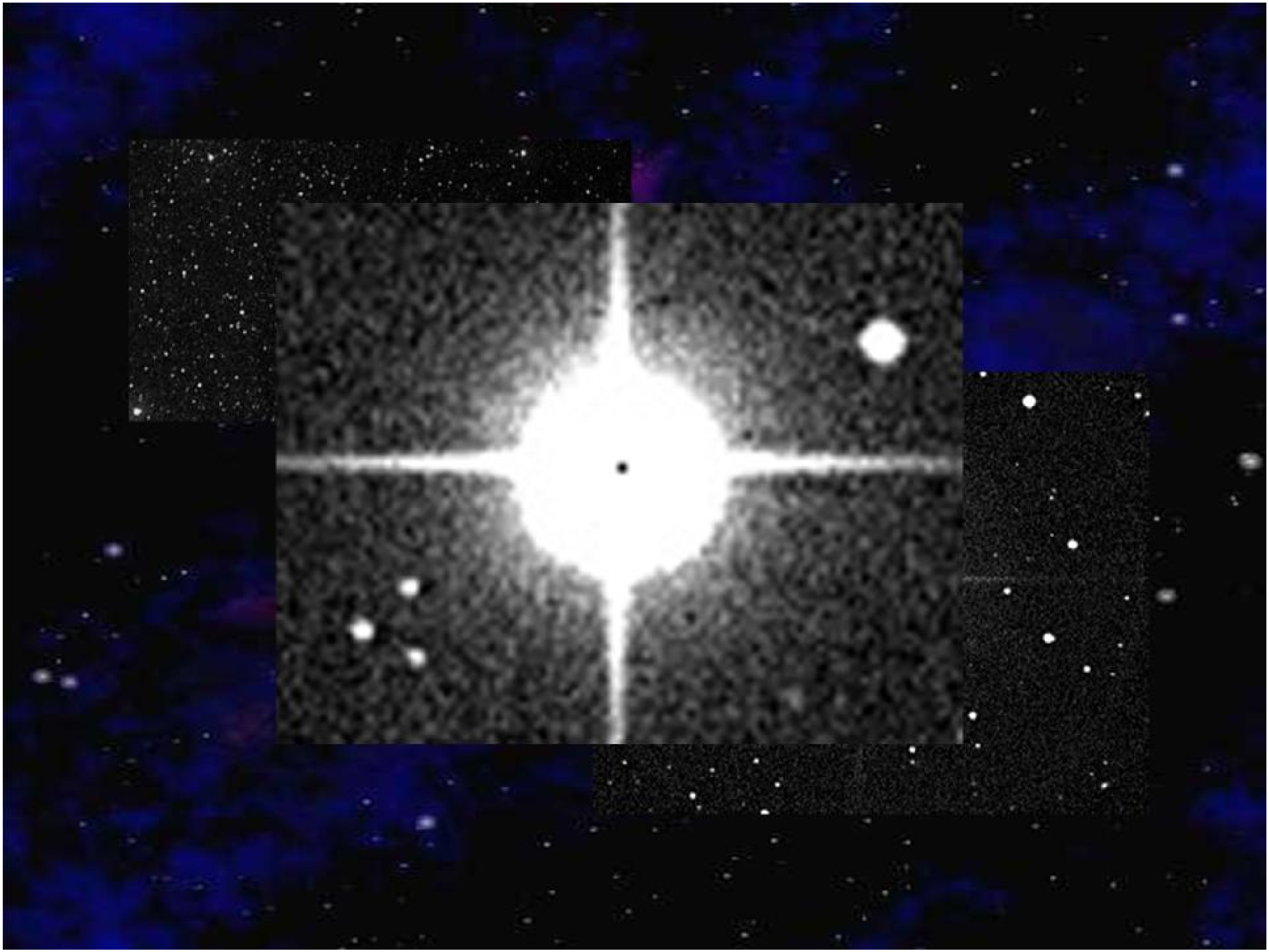


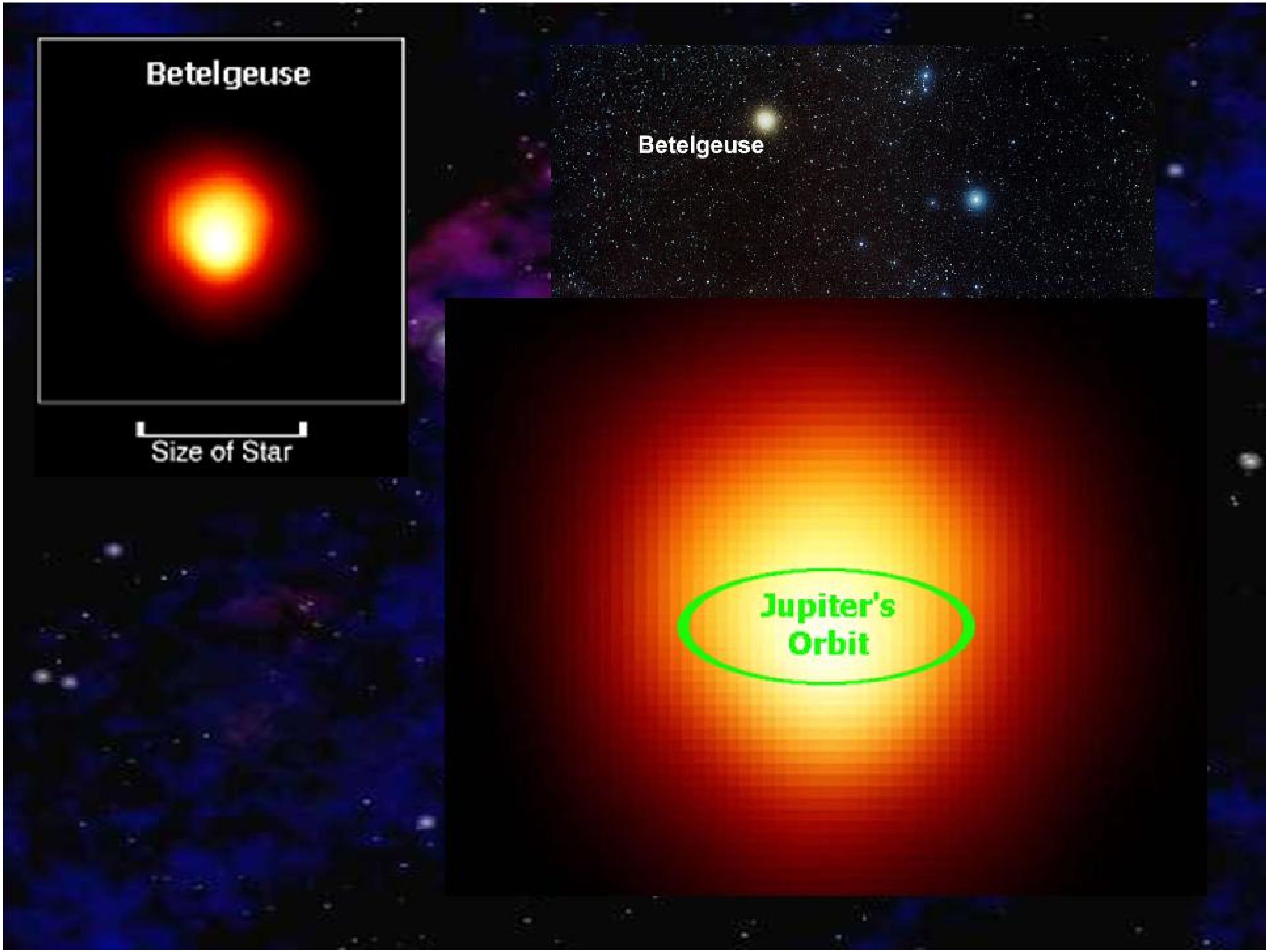




$$m - M = 5\log d - 5$$

Spectroscopic Parallax




Betelgeuse
Size of Star
Betelgeuse
Jupiter's
Orbit

Temperature – Radius – Luminosity Relationship

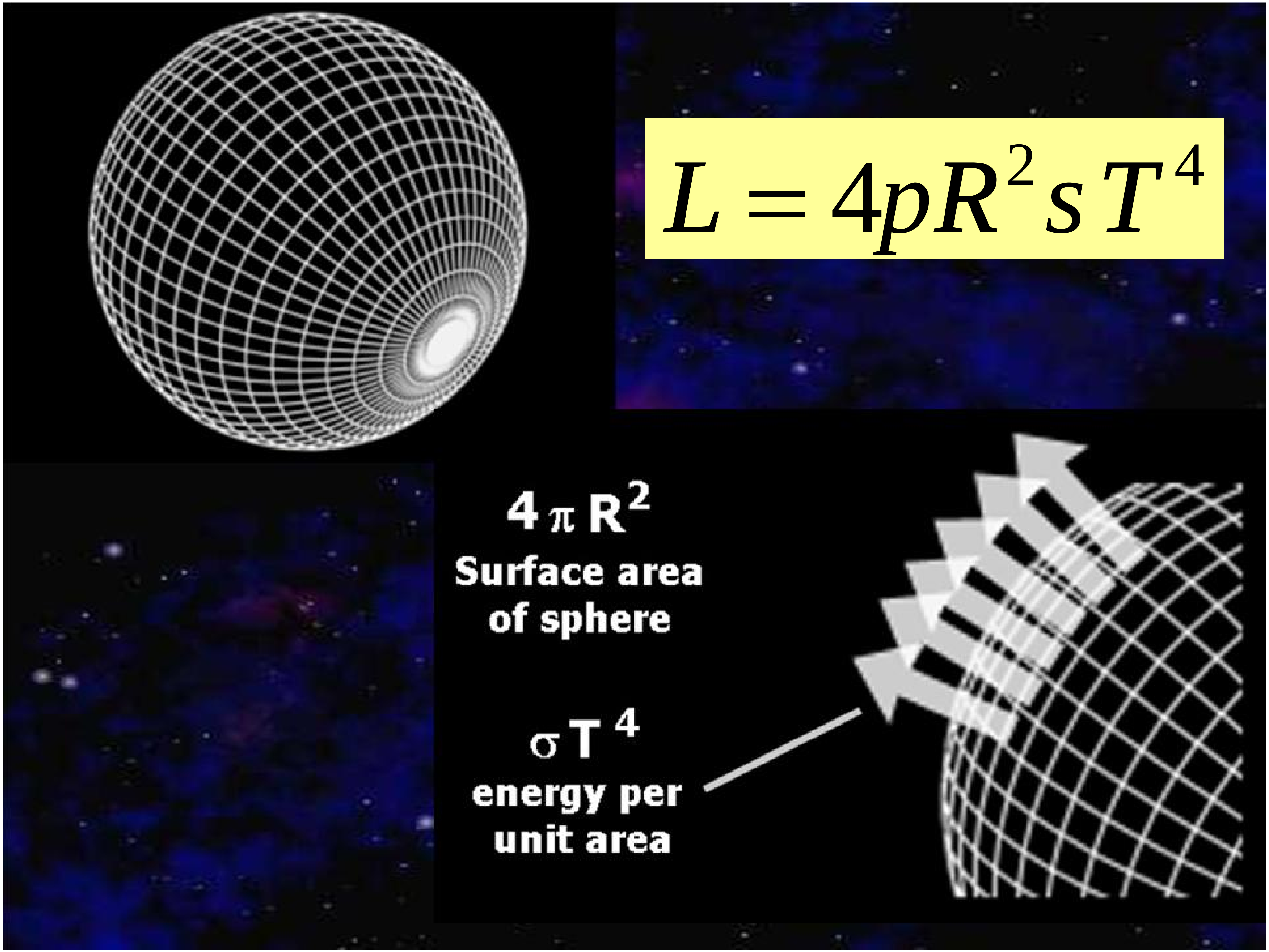
$$L = 4pR^2 sT^4$$

L = luminosity of the star

R = radius of the star

T = surface temperature of the star

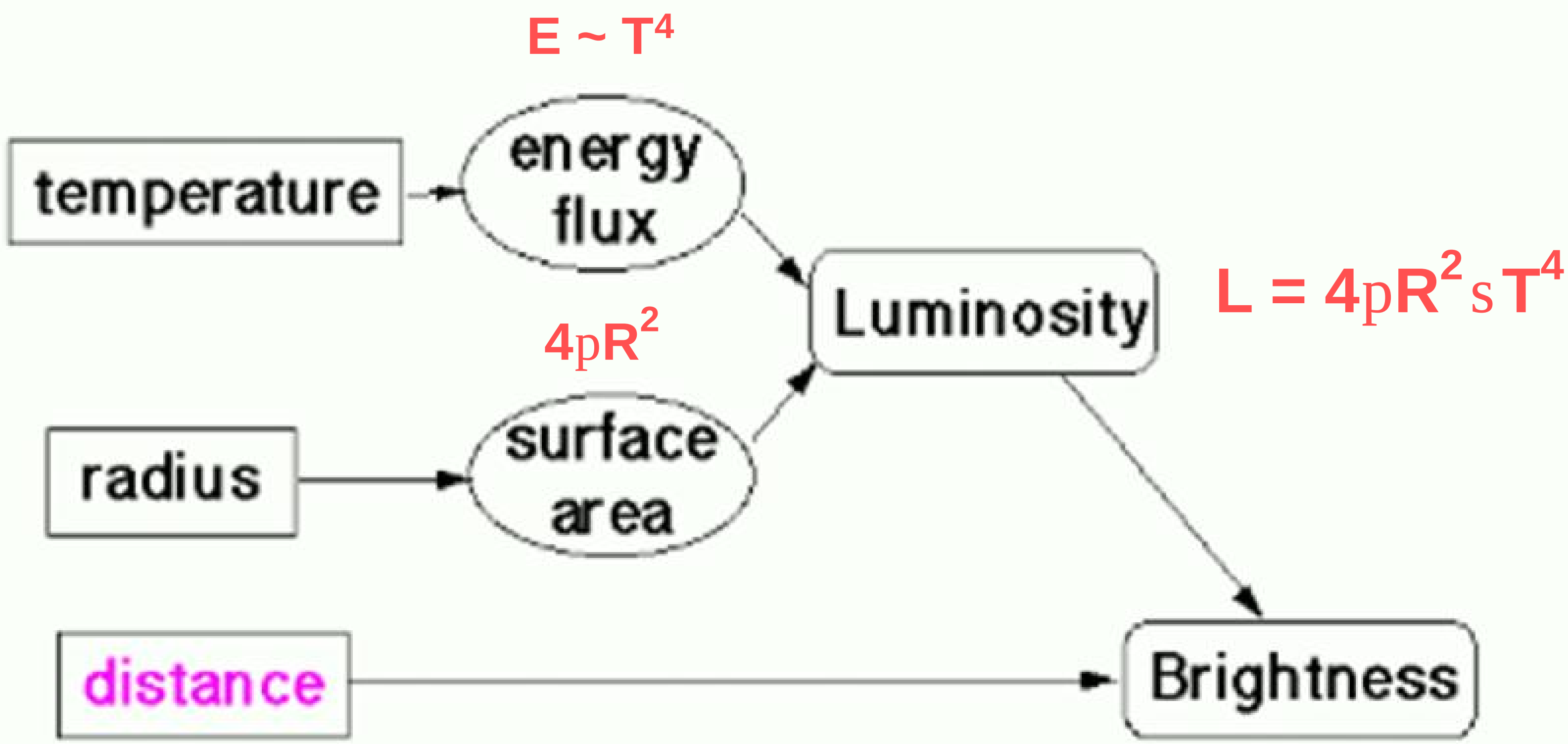
π,σ = constants

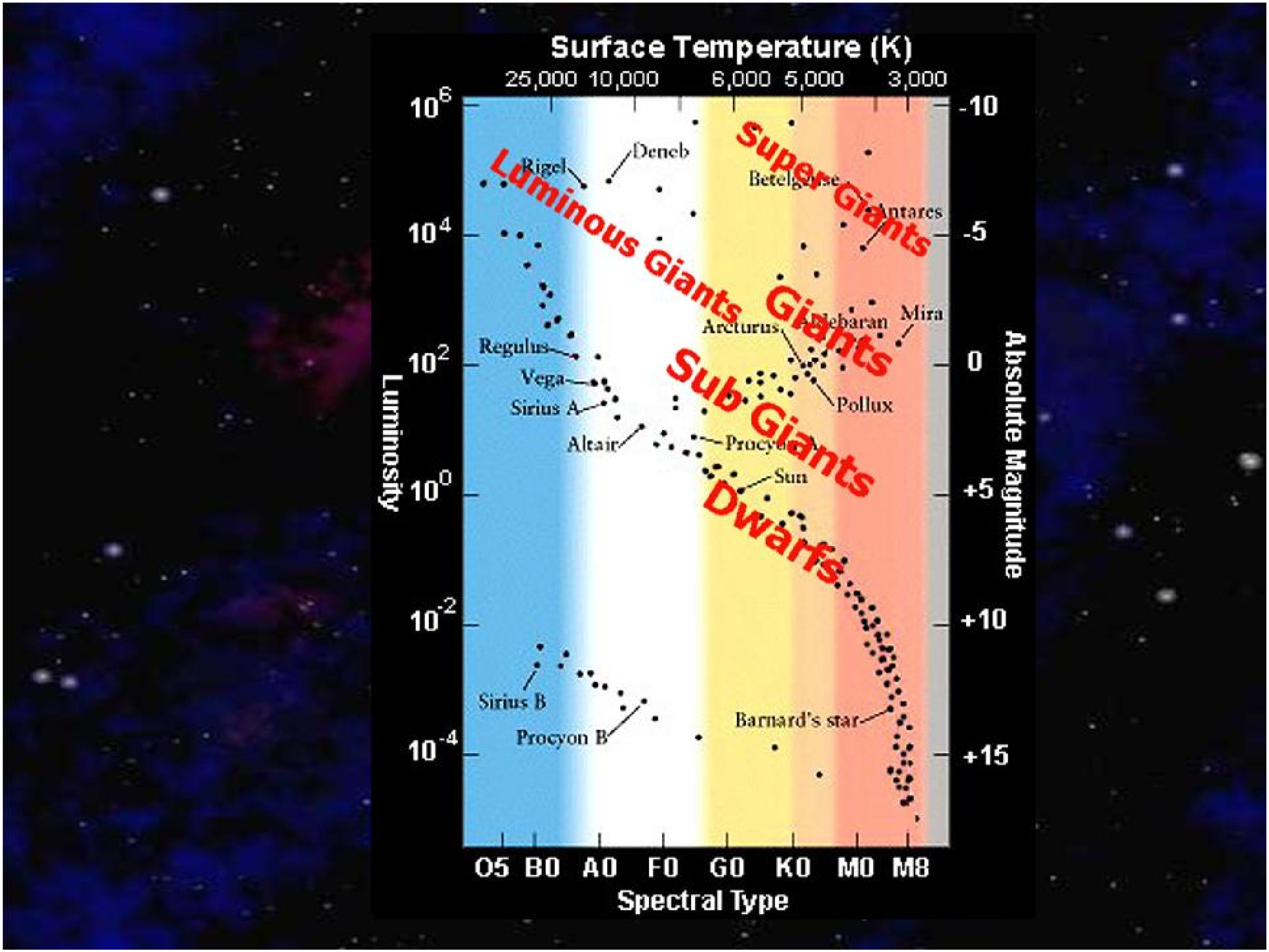

$L = 4pR^2sT^4$
$4\pi R^2$
Surface area of sphere
σT^4
energy per unit area

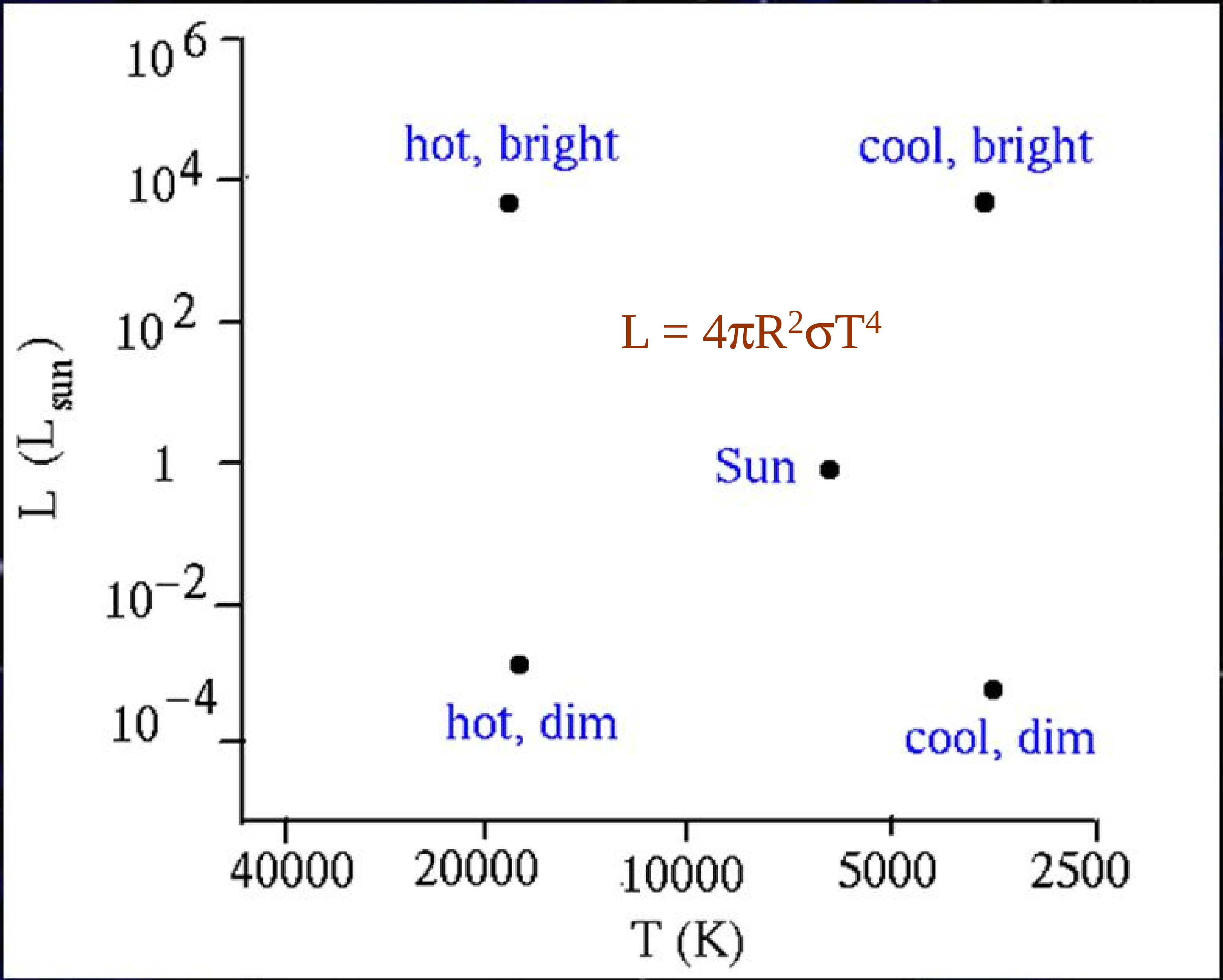
$$R = \sqrt{\frac{L}{4p s T^4}}$$

$$R \propto \frac{L}{T}$$

Luminosity and Brightness




Surface Temperature (K)
25,000 10,000 6,000 5,000 3,000
Luminosity
Absolute Magnitude
Spectral Type
O5 B0 A0 F0 G0 K0 M0 M8
Super Giants
Luminous Giants
Giants
Sub Giants
Dwarfs
Deneb
Rigel
Betelgeuse
Antares
Mira
Arcturus
Aldebaran
Regulus
Vega
Sirius A
Pollux
Altair
Procyon A
Sun
Sirius B
Procyon B
Barnard's star



hot, bright
cool, bright
L = 4πR²σT⁴
Sun
hot, dim
cool, dim
L (L_sun)
10^6
10^4
10^2
1
10^-2
10^-4
40000
20000
10000
5000
2500
T (K)

Luminosity Classes

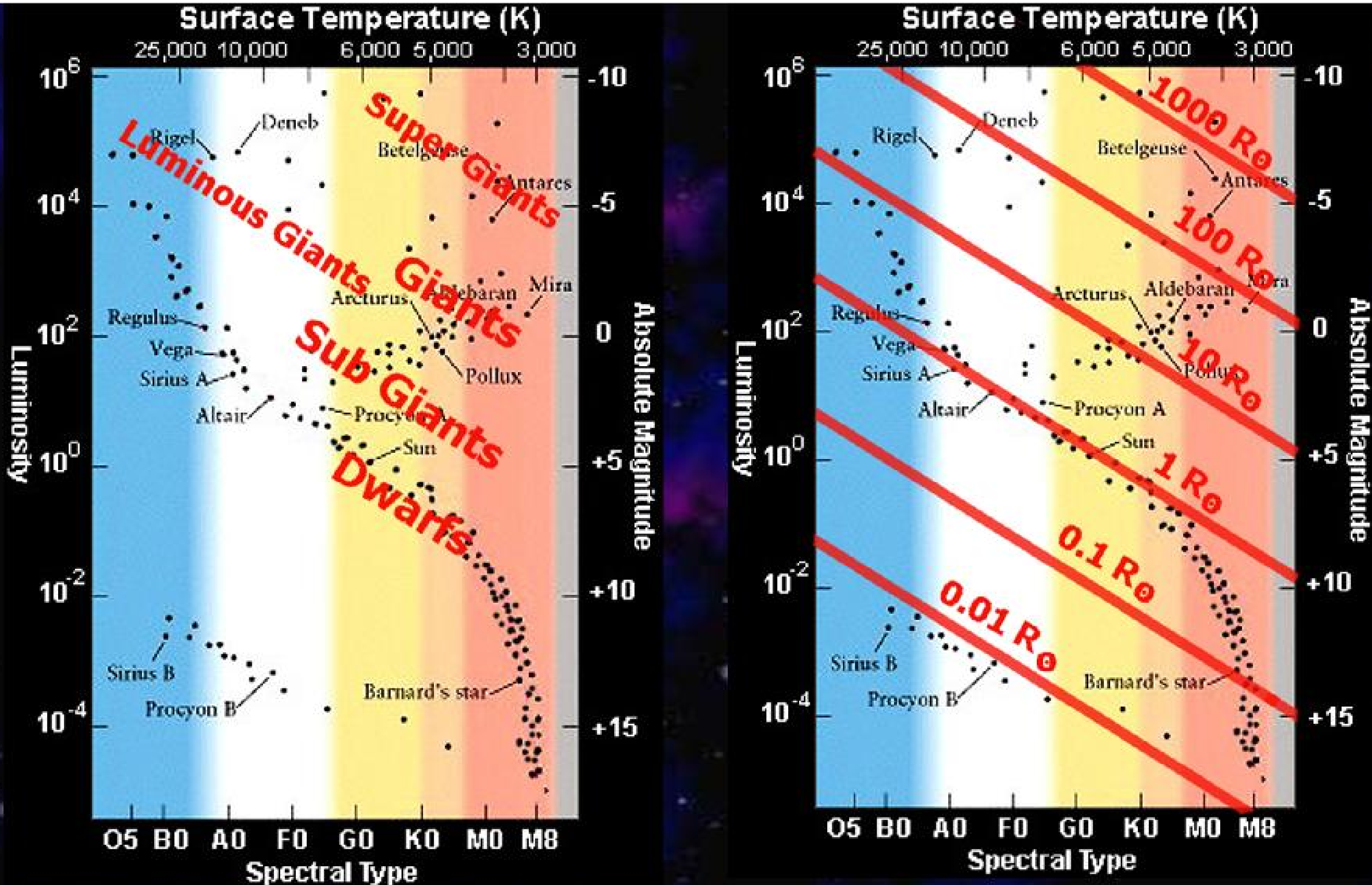
I	Super Giants
II	Luminous Giants
III	Giants
IV	Sub Giants
V	Dwarfs

The Sun is a Dwarf…

So finally, stars can be classified...

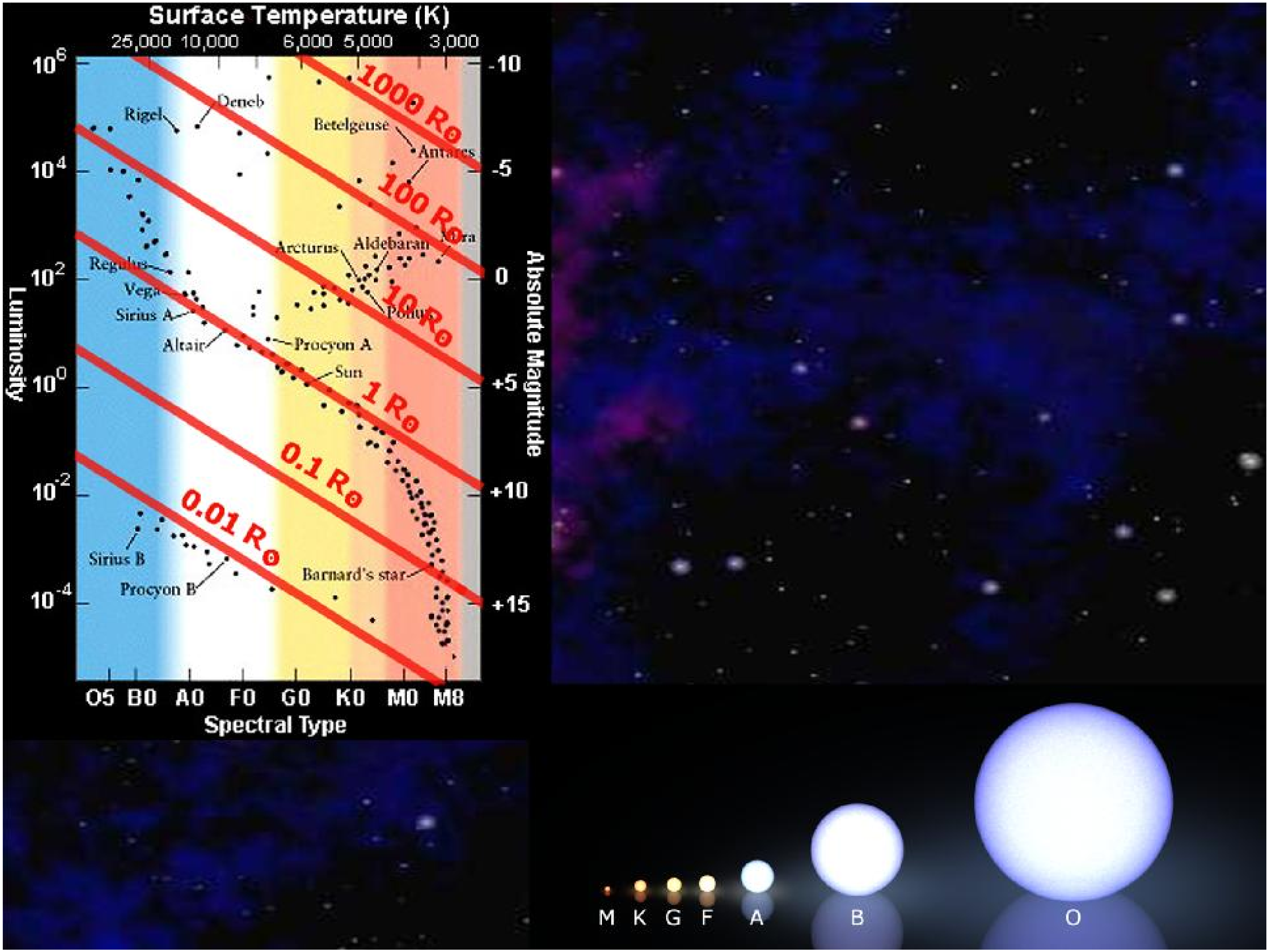
By spectral type (OBAFGKM)

Luminosity class (I,II,III,IV,V)

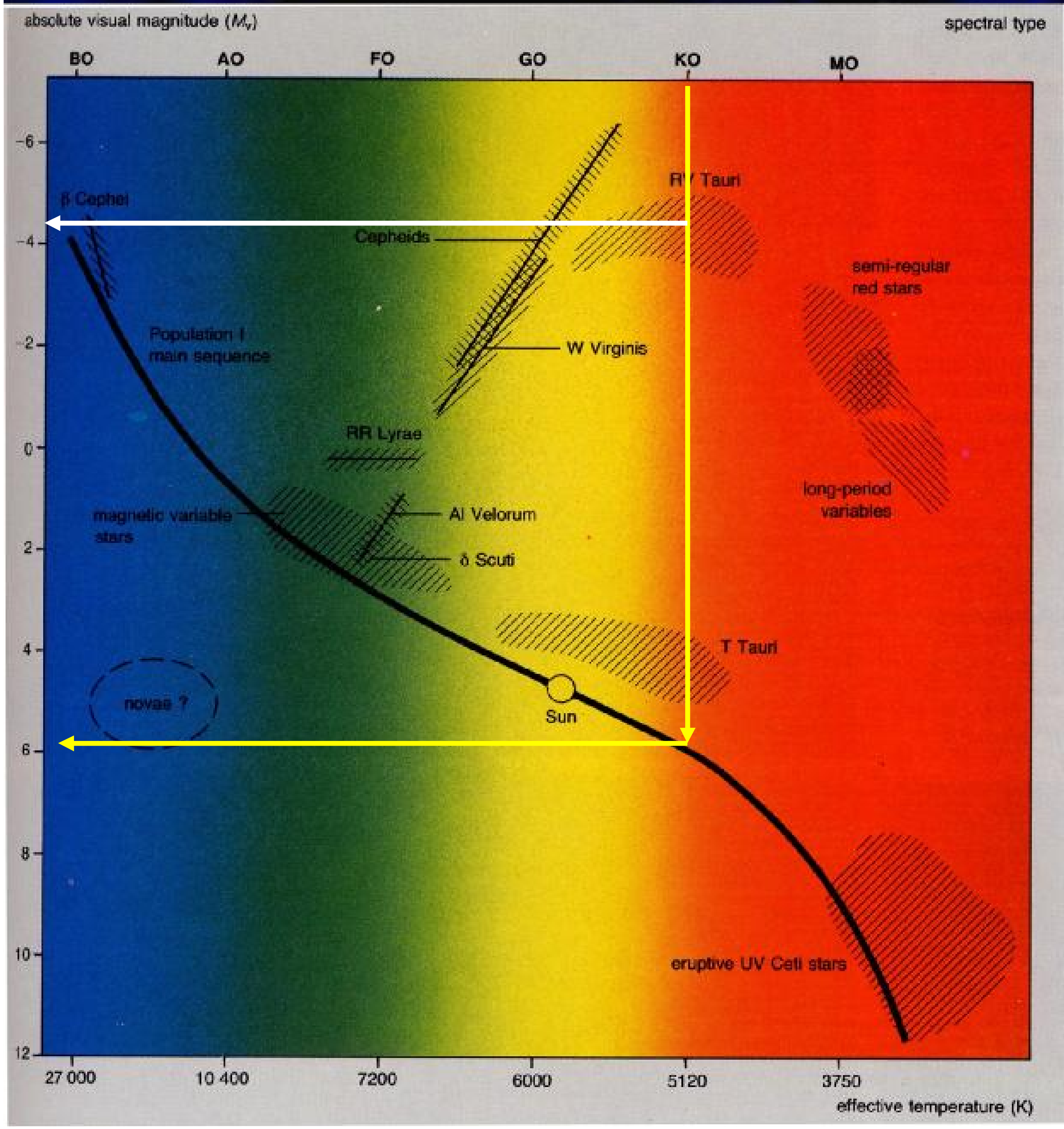


Betelgeuse: M1 I

Sun: G2 V


Surface Temperature (K)
25,000 10,000 6,000 5,000 3,000
Luminosity
10^6
10^4
10^2
10^0
10^-2
10^-4
Absolute Magnitude
-10
-5
0
+5
+10
+15
1000 R⊙
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
Rigel
Deneb
Betelgeuse
Antares
Mira
Aldebaran
Arcturus
Pollux
Regulus
Vega
Sirius A
Altair
Procyon A
Sun
Sirius B
Procyon B
Barnard's star
O5 B0 A0 F0 G0 K0 M0 M8
Spectral Type
M K G F A B O

The Art of Spectroscopic Parallax



1) Measure spectral type
2) Measure m_v
3) Determine luminosity class
4) Place on HR diagram
5) Read Mv

Example: Record spectrum of star and find it is K0 V type

Read off Mv

Determine visual mag, m_v

$$m - M = 5 \log d - 5$$

100 fold error in d