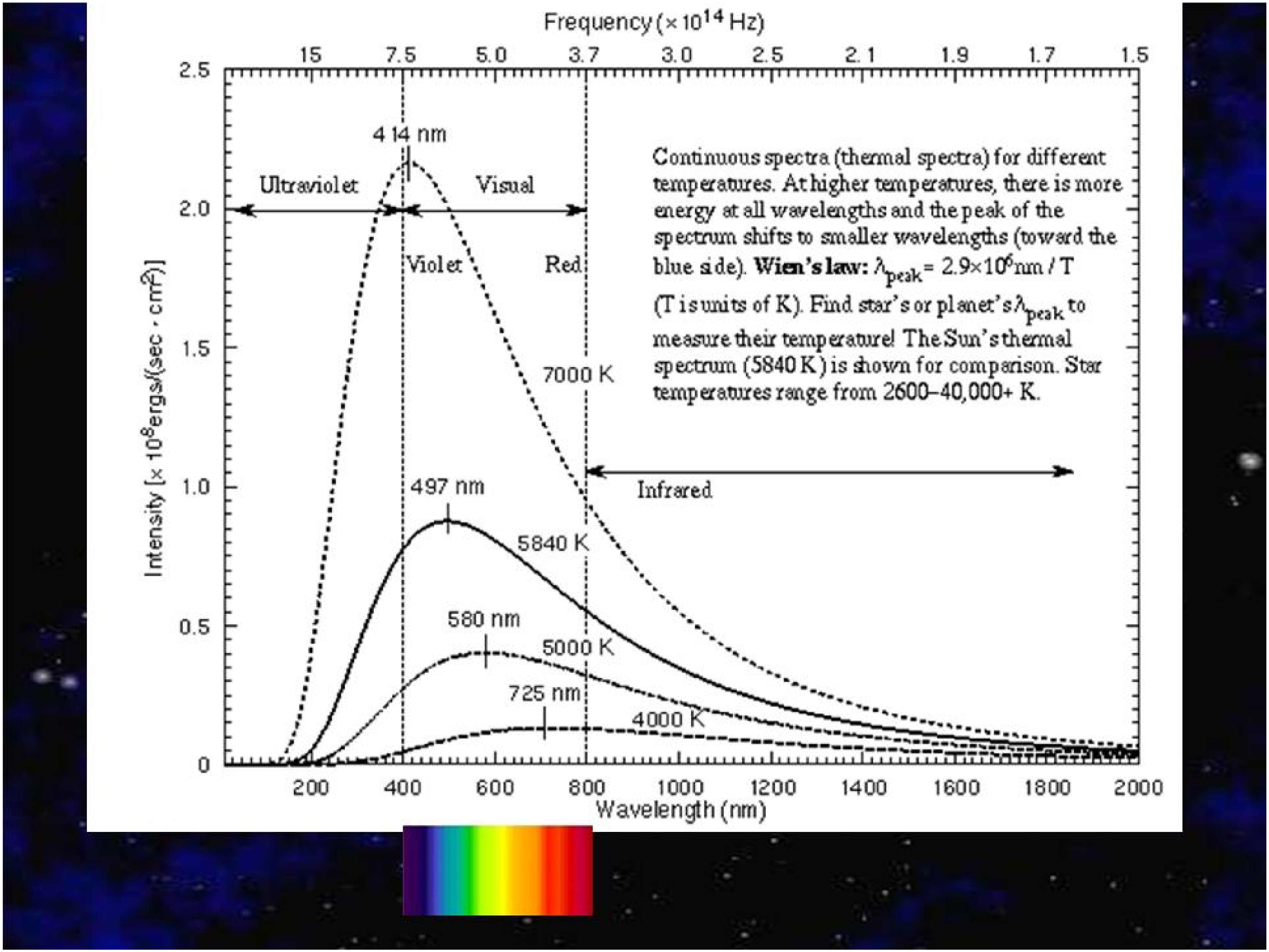
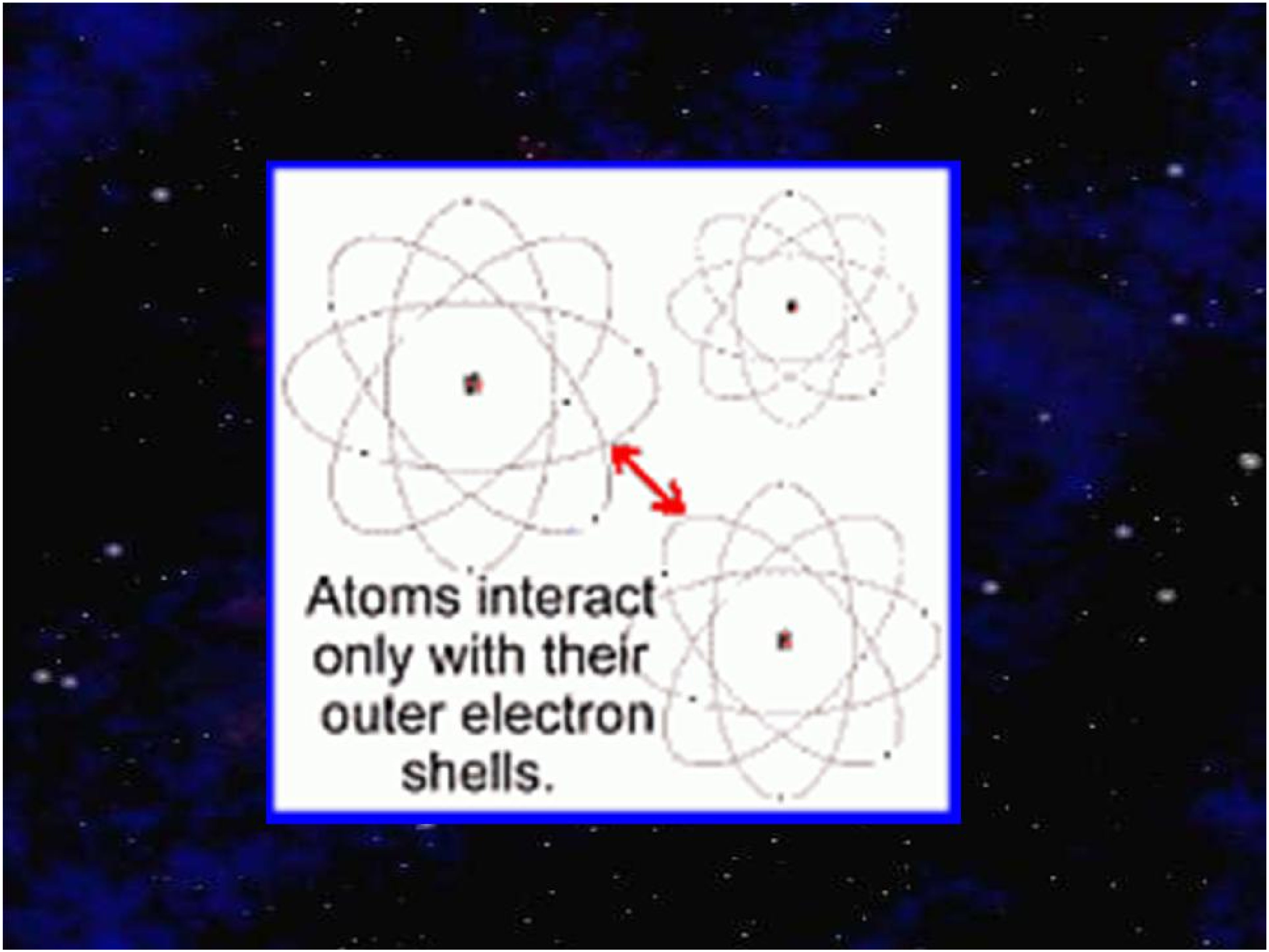
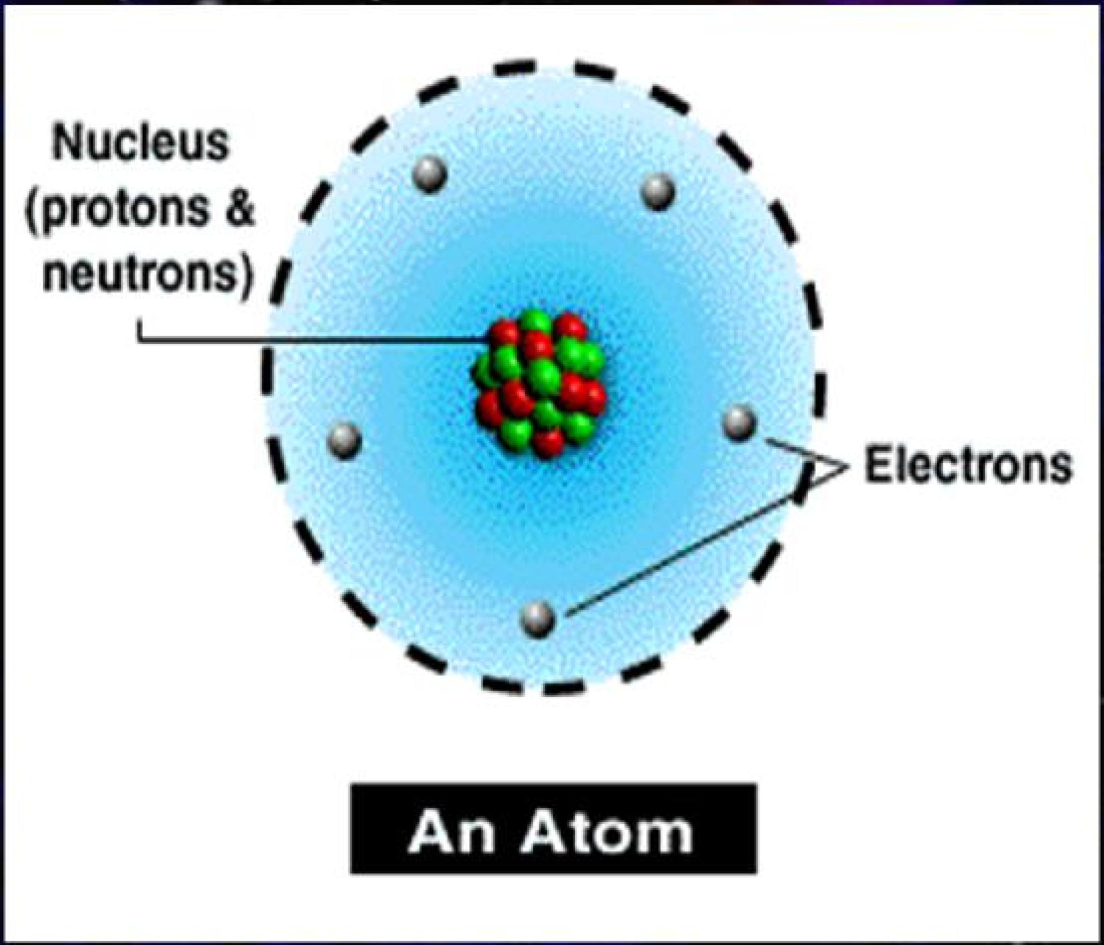

Frequency (× 10^14 Hz)
15
7.5
5.0
3.7
3.0
2.5
2.1
1.9
1.7
1.5
2.5
2.0
1.5
1.0
0.5
0
Intensity [× 10^8 ergs/(sec · cm^2)]
414 nm
Ultraviolet
Visual
Violet
Red
7000 K
Infrared
497 nm
5840 K
580 nm
5000 K
725 nm
4000 K
200
400
600
800
1000
1200
1400
1600
1800
2000
Wavelength (nm)
Continuous spectra (thermal 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.


Atoms interact
only with their
outer electron
shells.



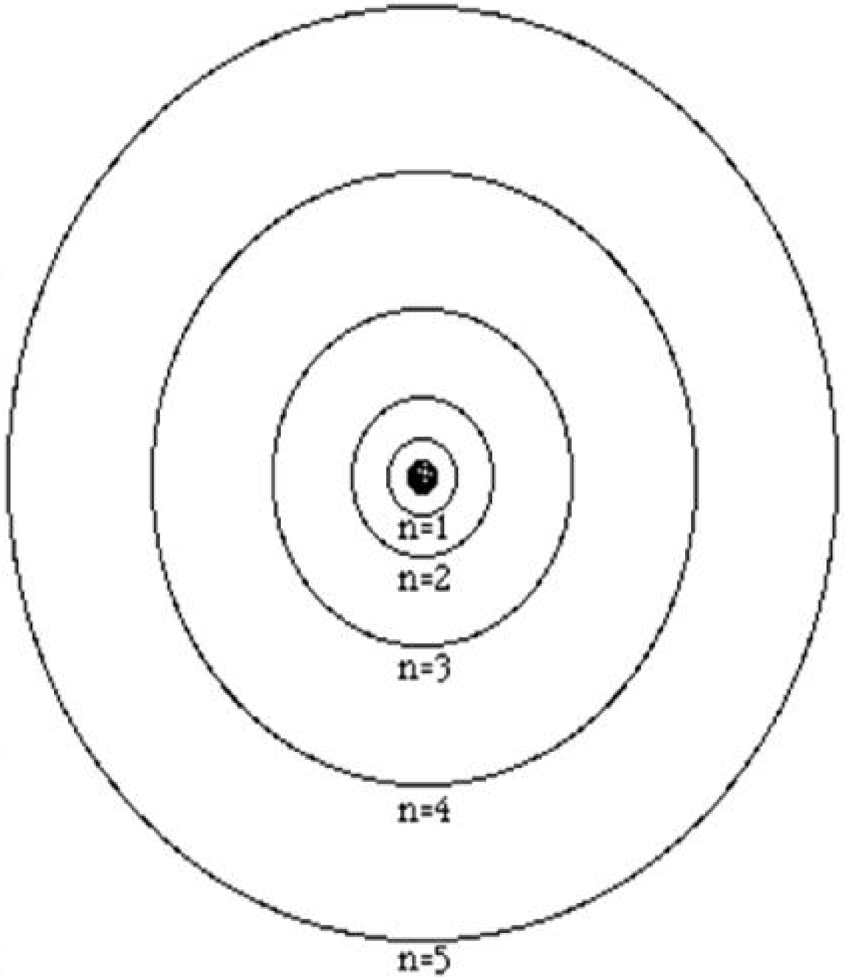
Protons: + charge
determines chemistry

Neutrons: no charge
adds stability
adds mass

Electrons: - charge
interacts with rest of
world interacts with
light

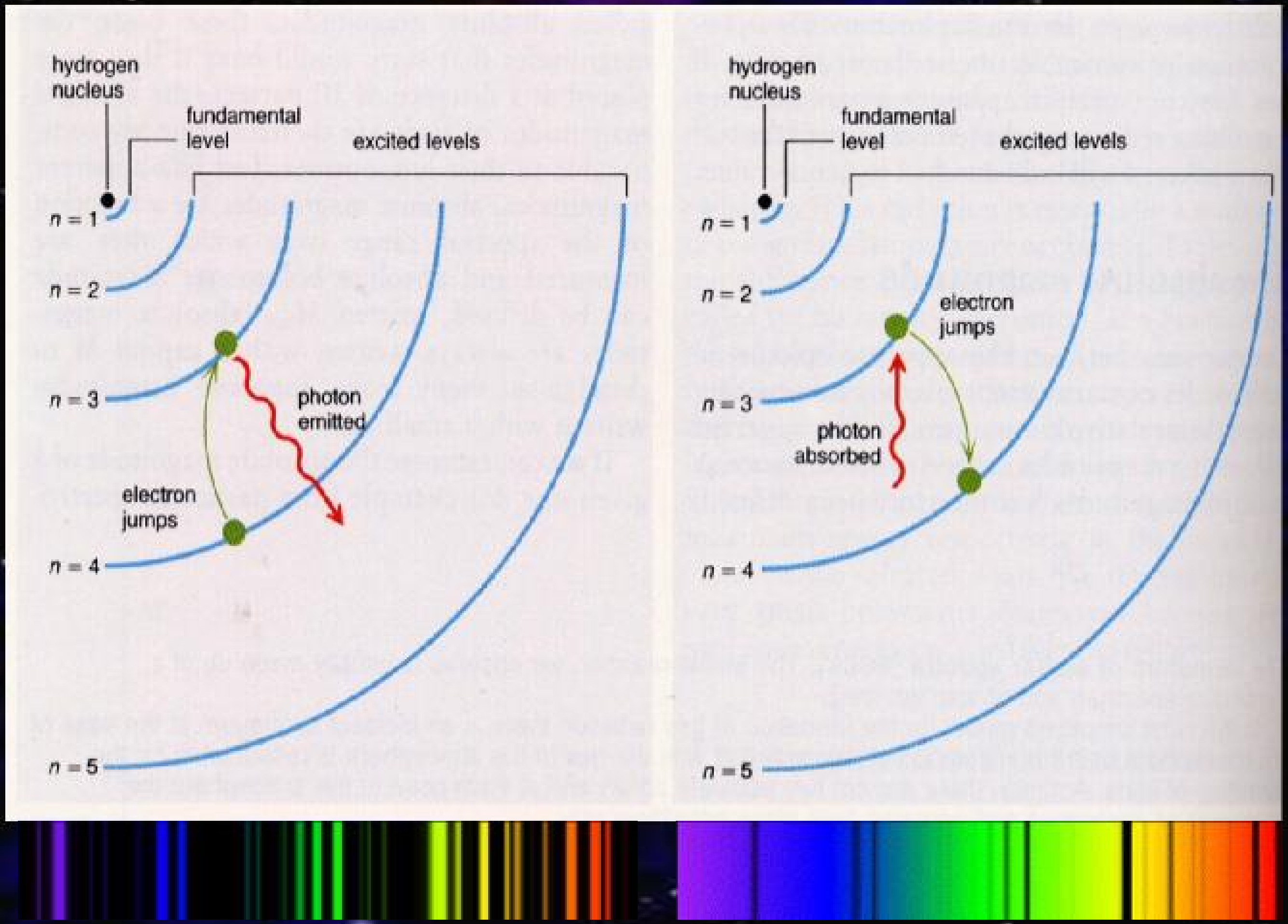
1 H 1.008	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 ------- VIII ------- ------- 8 -------	10	11 IB 1B	12 IIB 2B	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)

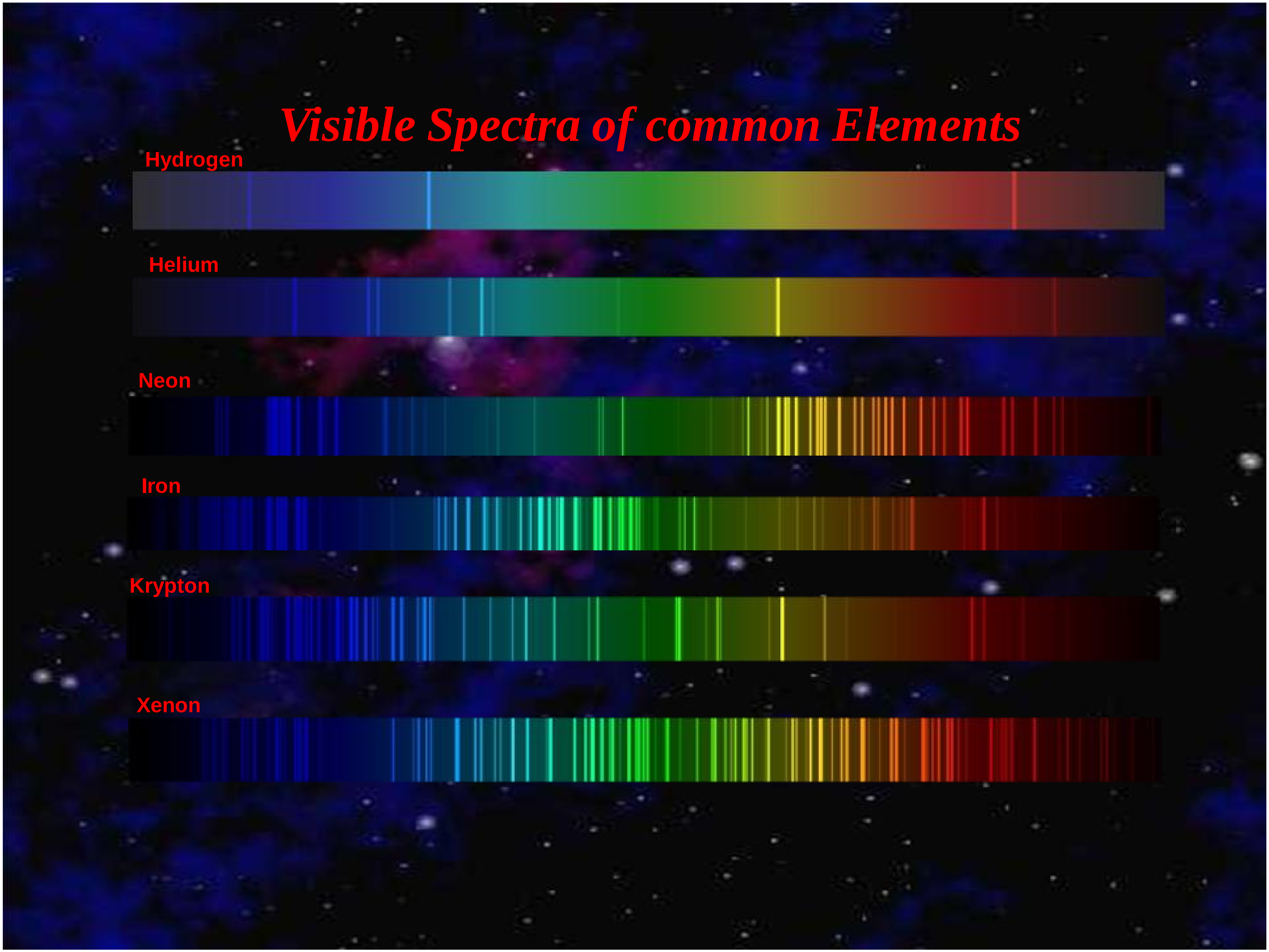
The Simplest: Hydrogen

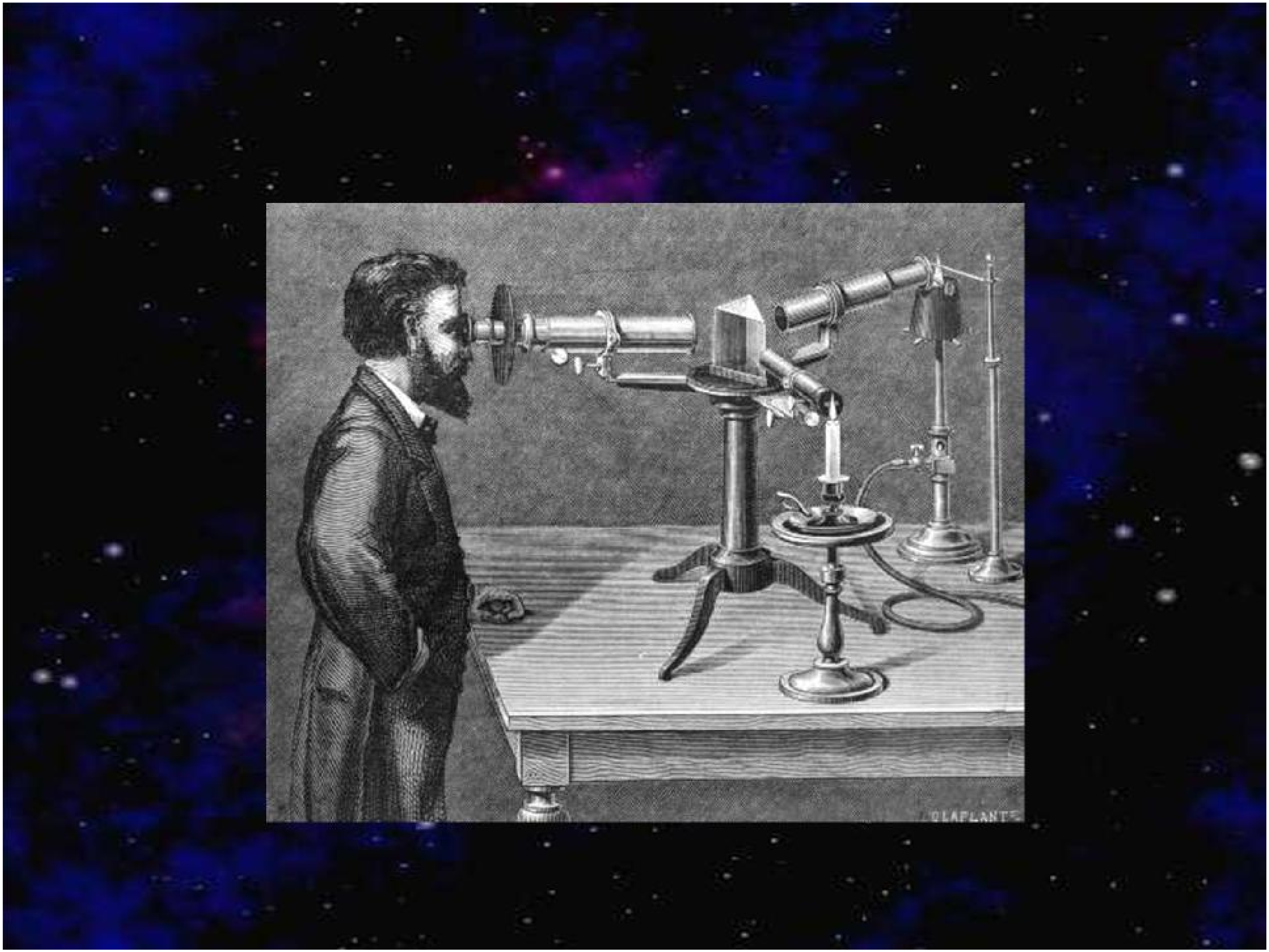


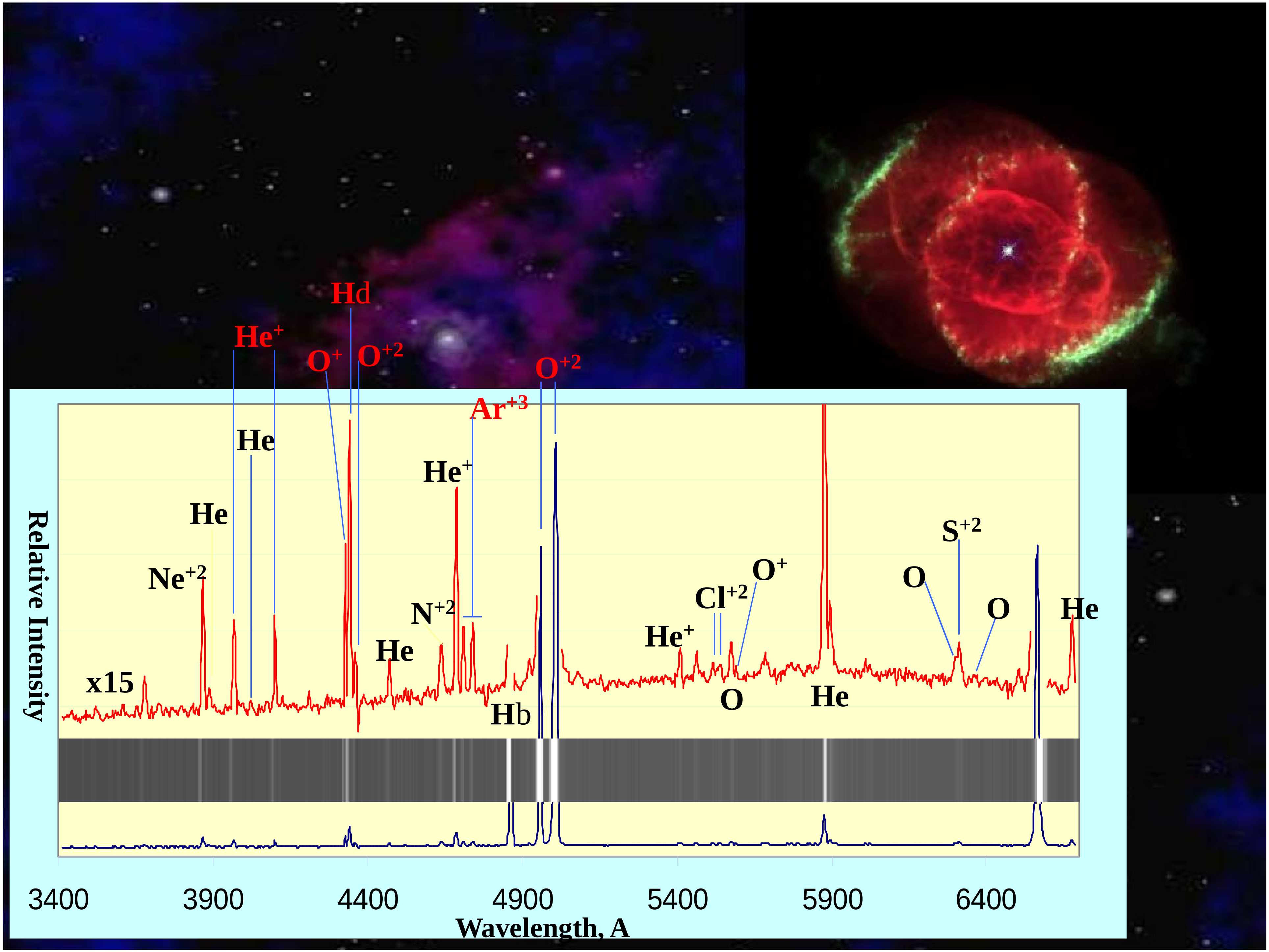
Orbit n	Distance from Nucleus
1	0.529 Å
2	2.116 Å
3	4.761 Å
4	8.464 Å
5	13.225 Å

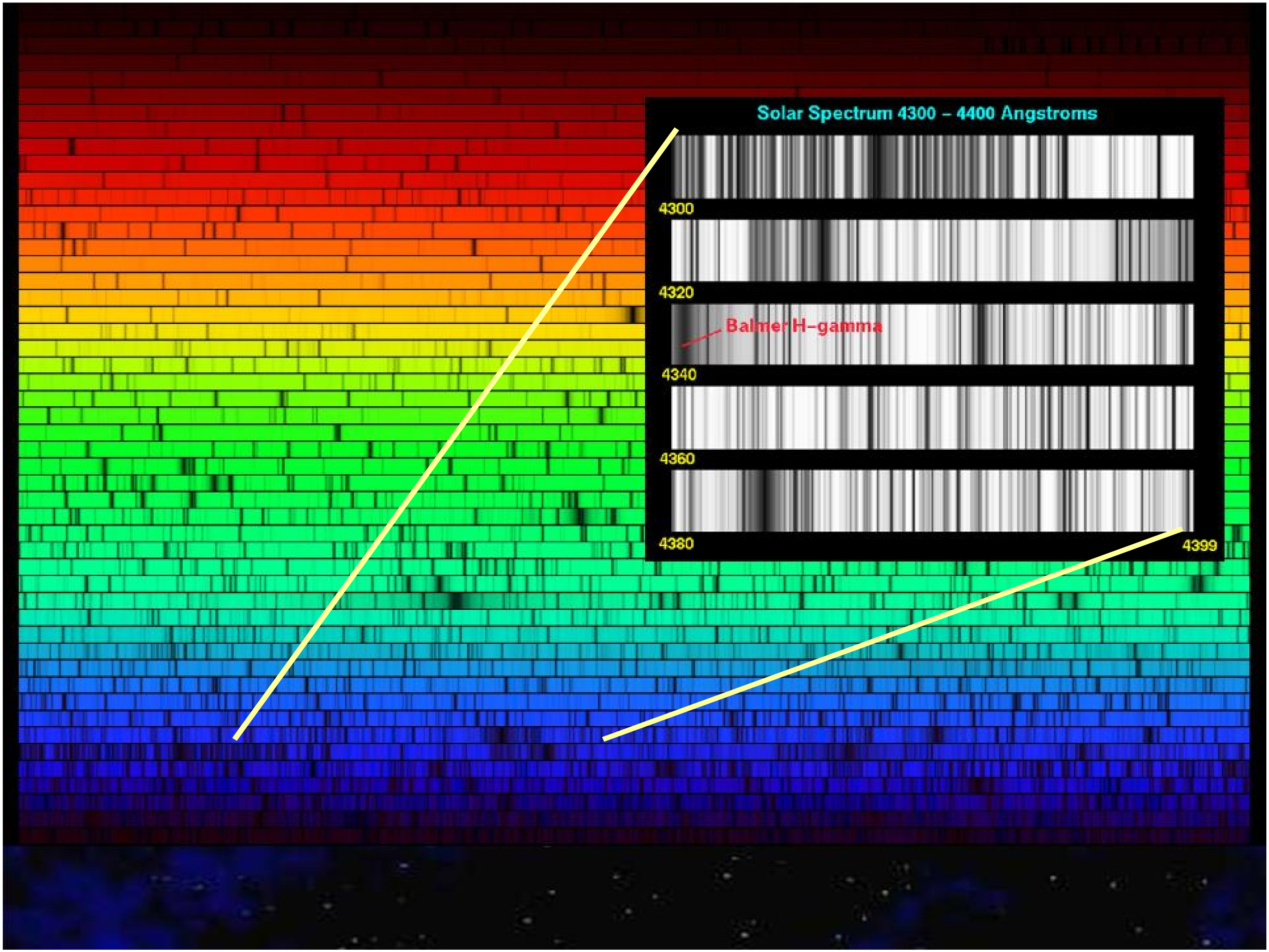
Generation of Emission or Absorption Line Spectrum

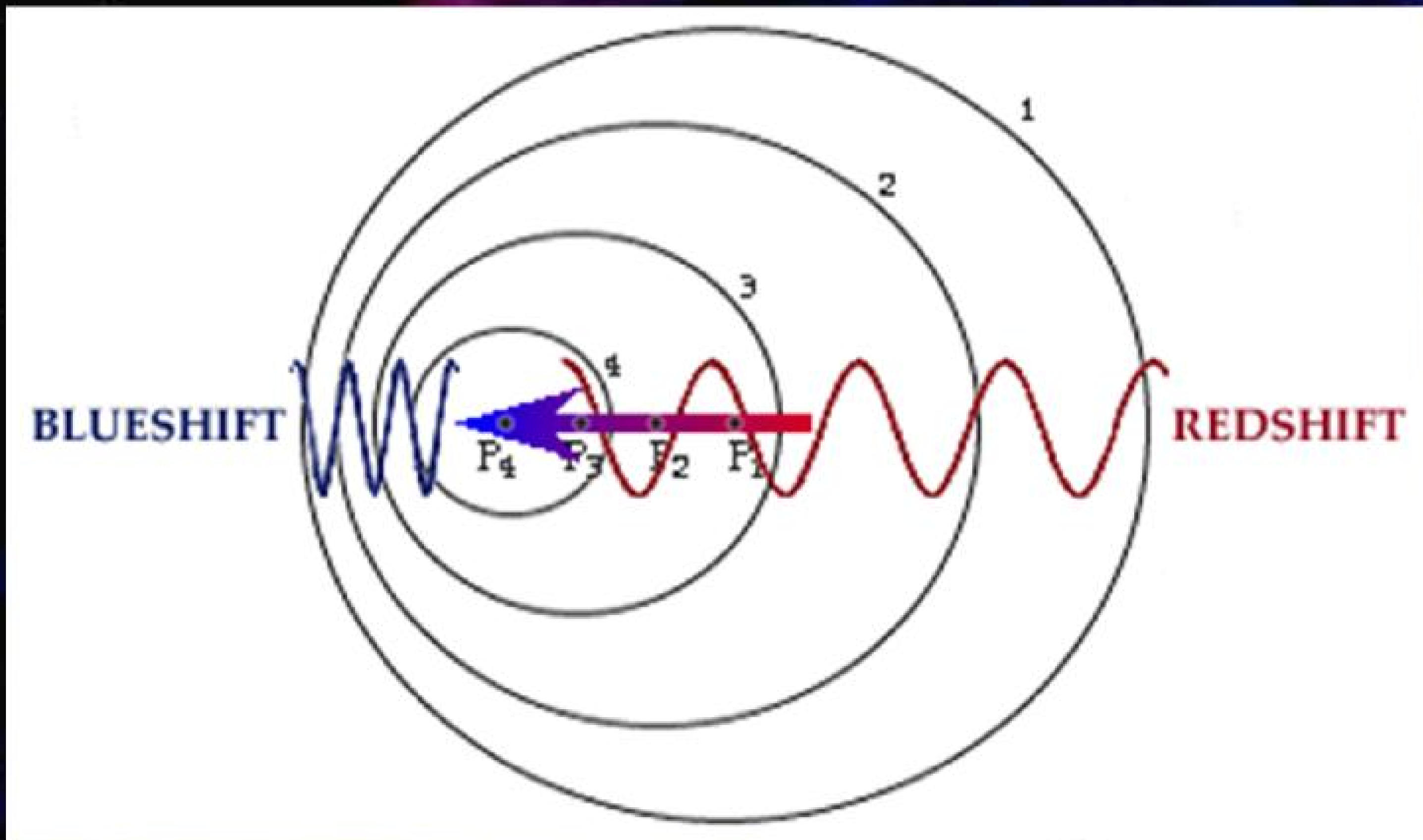


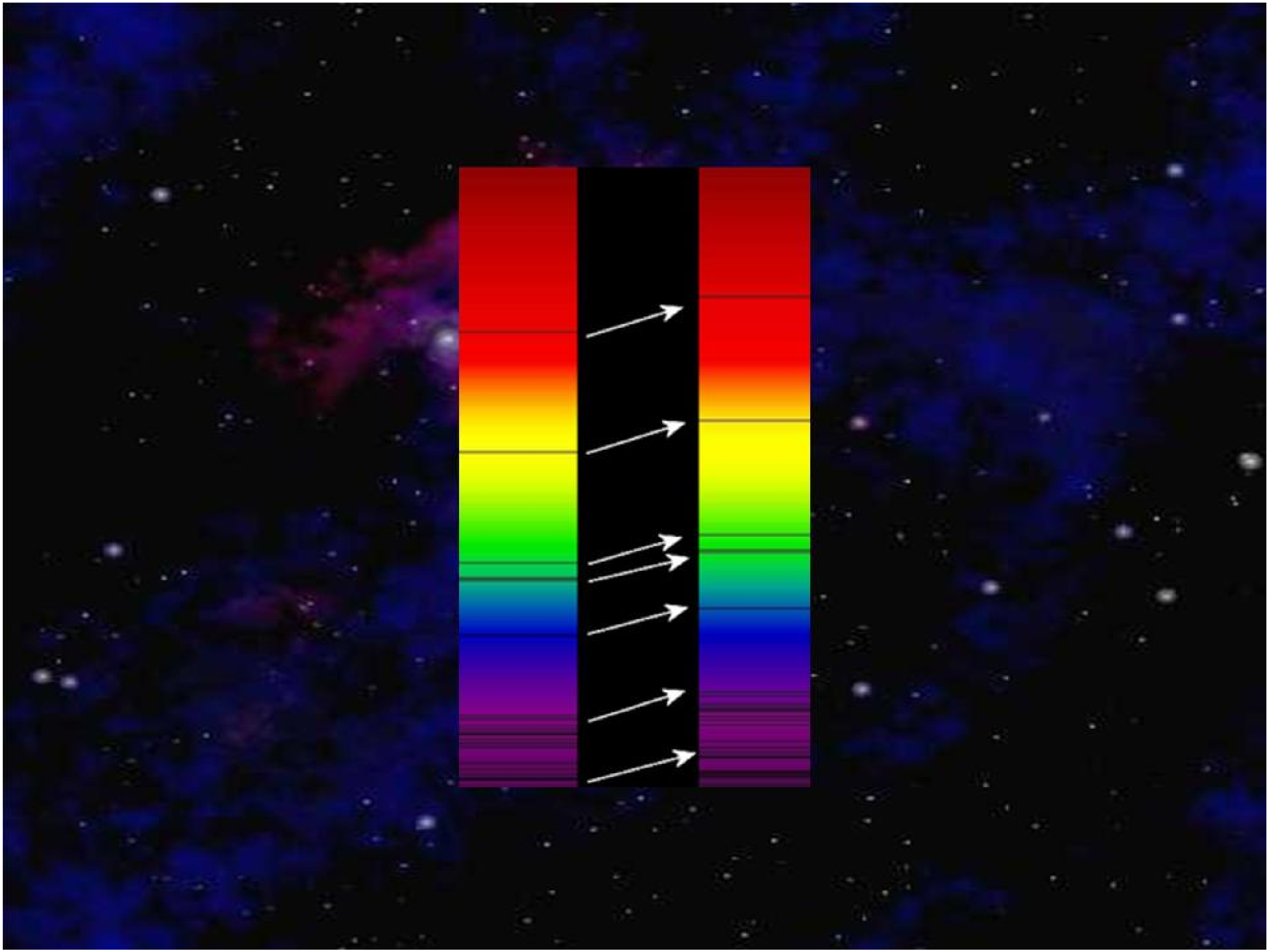

Visible Spectra of common Elements
Hydrogen
Helium
Neon
Iron
Krypton
Xenon




Hd
He+
O+
O+2
O+2
Ar+3
He
He+
He
Ne+2
He
N+2
x15
Hb
He+
Cl+2
O+
O
S+2
O
O
He
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


BLUESHIFT
REDSHIFT
1
2
3
4



Why do astronomers use telescopes?

1. Light Gathering Power

Gathering more light makes faint objects appear brighter.

Objects that are normally too distant and faint to be seen with the eye can be seen with a telescope.

Modest sized telescope (MLO 40inch):

Area of telescope opening = πr^2

Area = π (50 cm)^2 = 7,800 cm^2

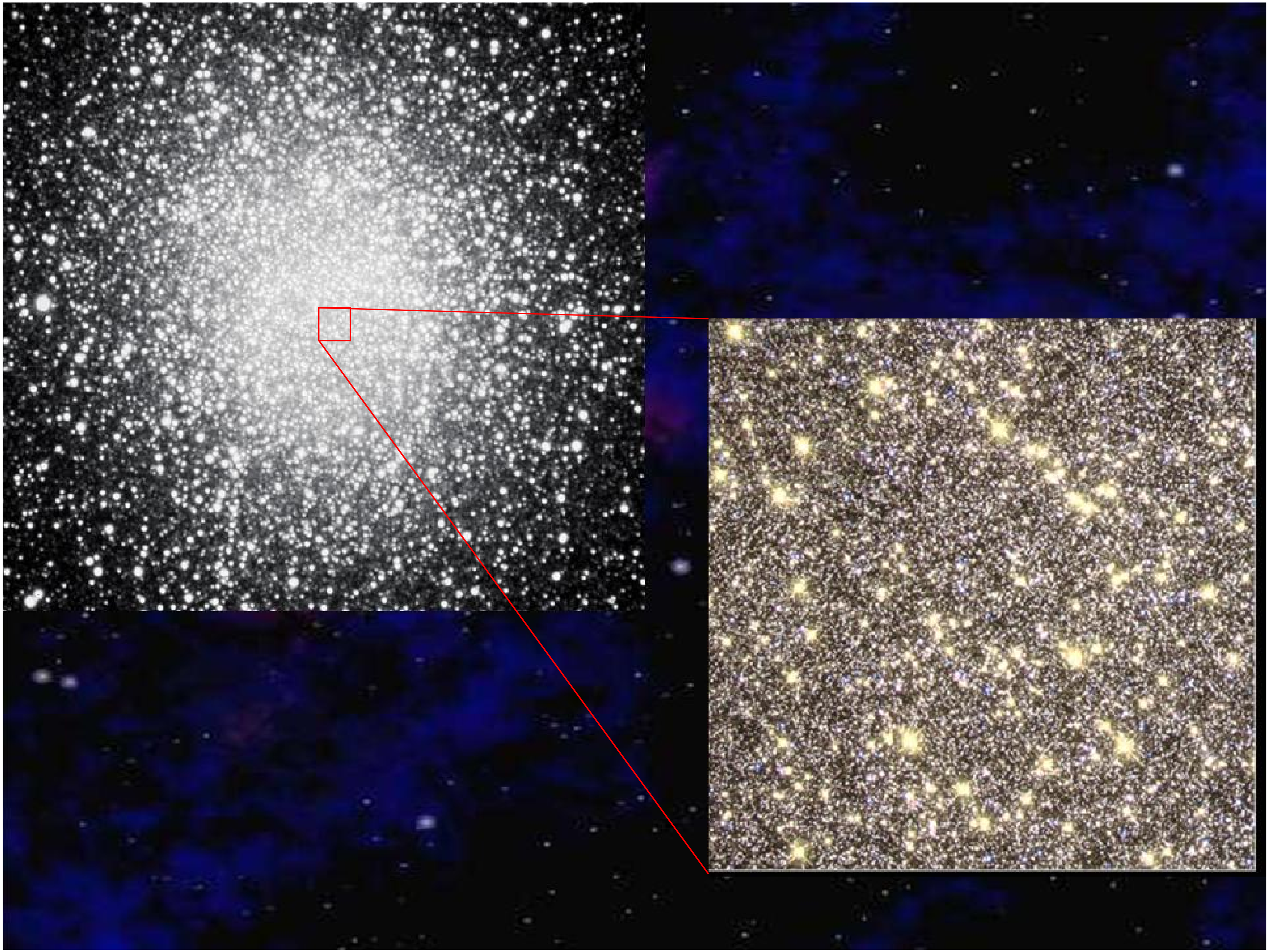
RATIO = 7,800/0.07 = 111,000

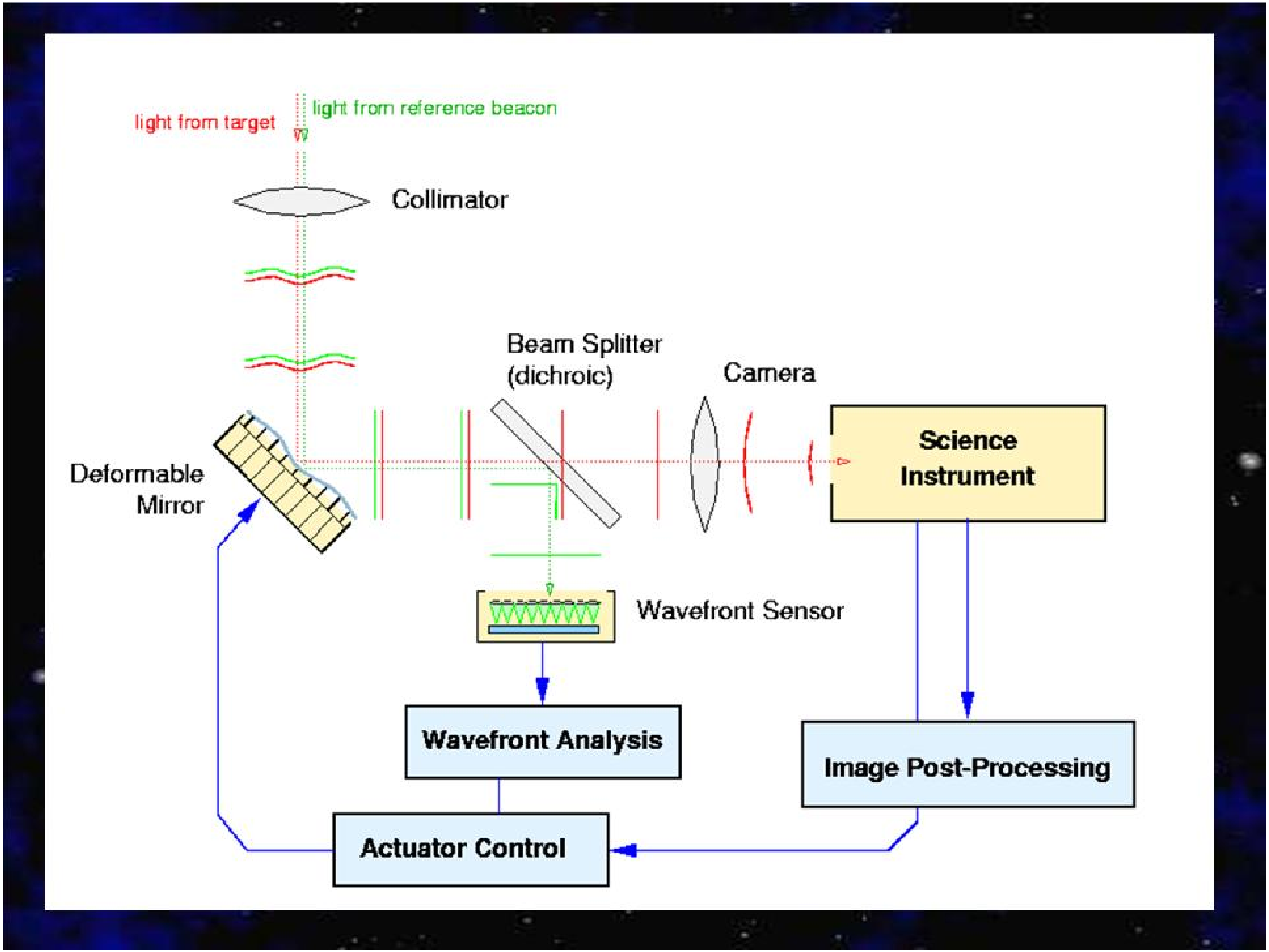
2. Increased Resolution

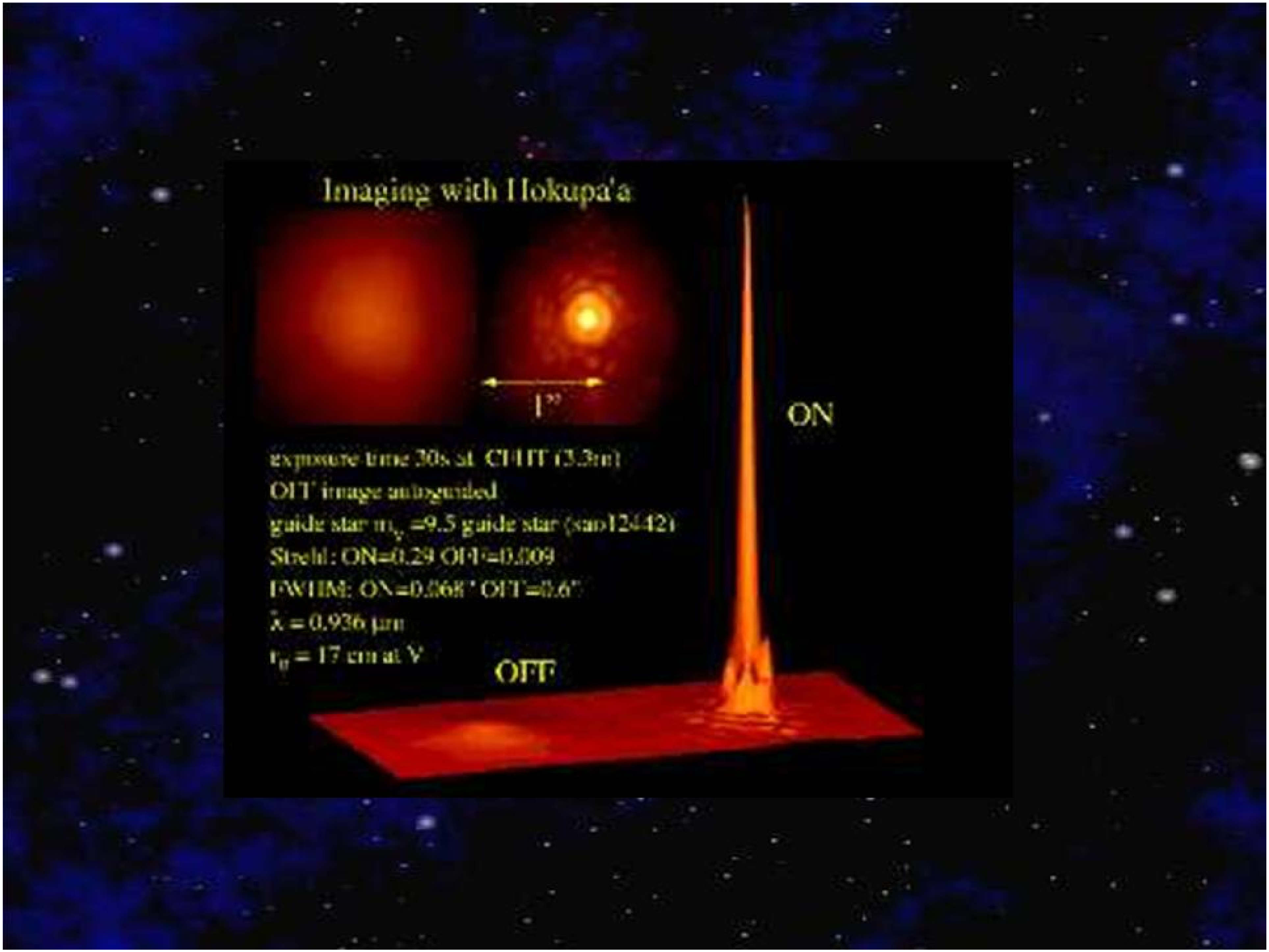
Resolution:

The ability to see fine details in small objects.

Where is the ULTIMATE place to put a telescope?




light from target
light from reference beacon
Collimator
Beam Splitter
(dichroic)
Camera
Deformable
Mirror
Science
Instrument
Wavefront Sensor
Wavefront Analysis
Image Post-Processing
Actuator Control



Imaging with Hokupa'a
1"
ON
exposure time 30s at CFHT (3.3m)
OFF image autoguided
guide star m_v =9.5 guide star (sao12442)
Strehl : ON=0.29 OFF=0.009
FWHM: ON=0.068" OFF=0.6"
λ = 0.936 μm
r_0 = 17 cm at V
OFF

THE NATURE OF STARS

Stellar Properties:

MASS SIZE ENERGY TEMPERATURE

DISTANCE CHEMICAL-COMPOSITION

MOTION EVOLUTION

Stellar Properties:

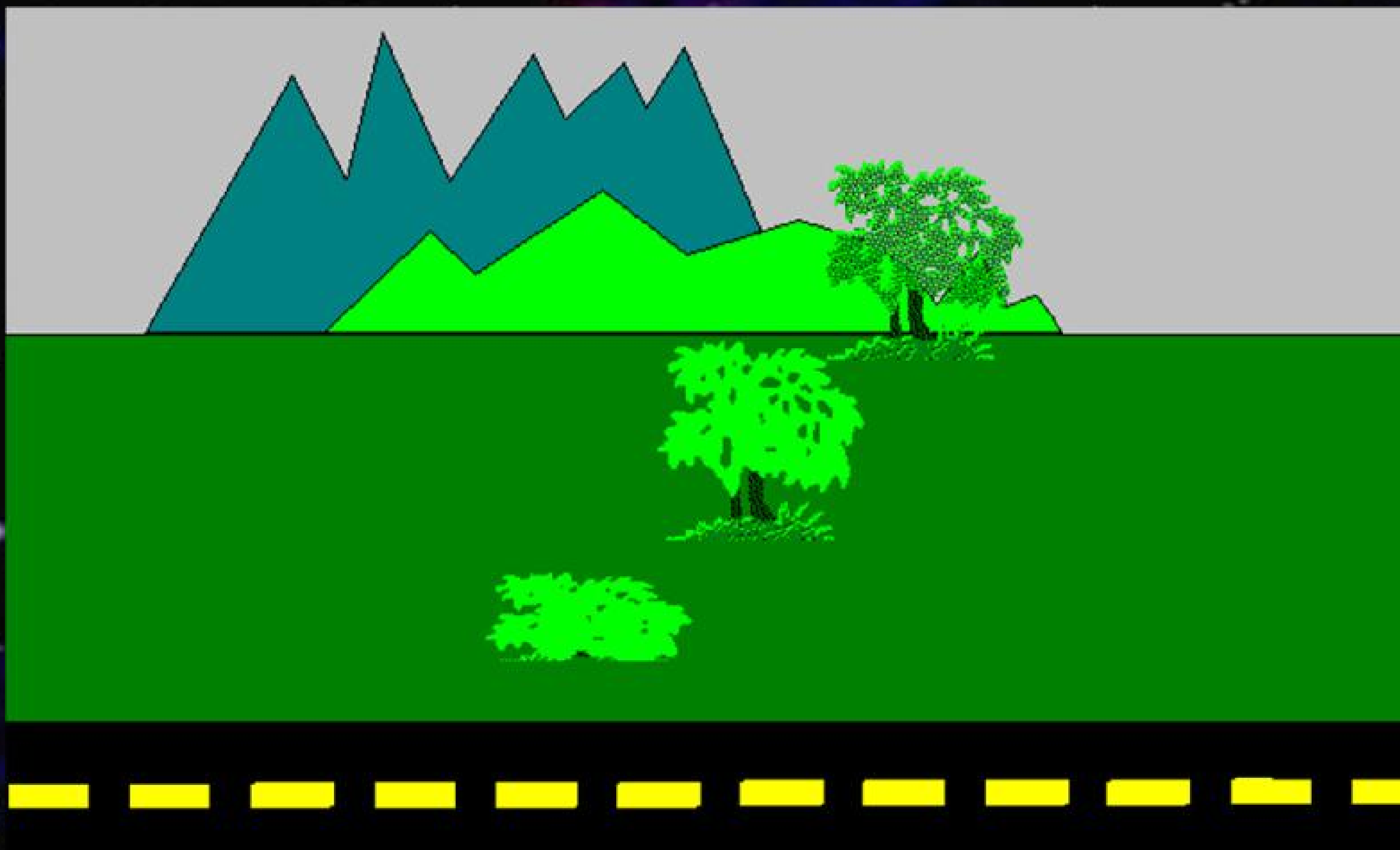
MASS SIZE ENERGY TEMPERATURE

DISTANCE CHEMICAL-COMPOSITION

MOTION EVOLUTION

Stellar Distances

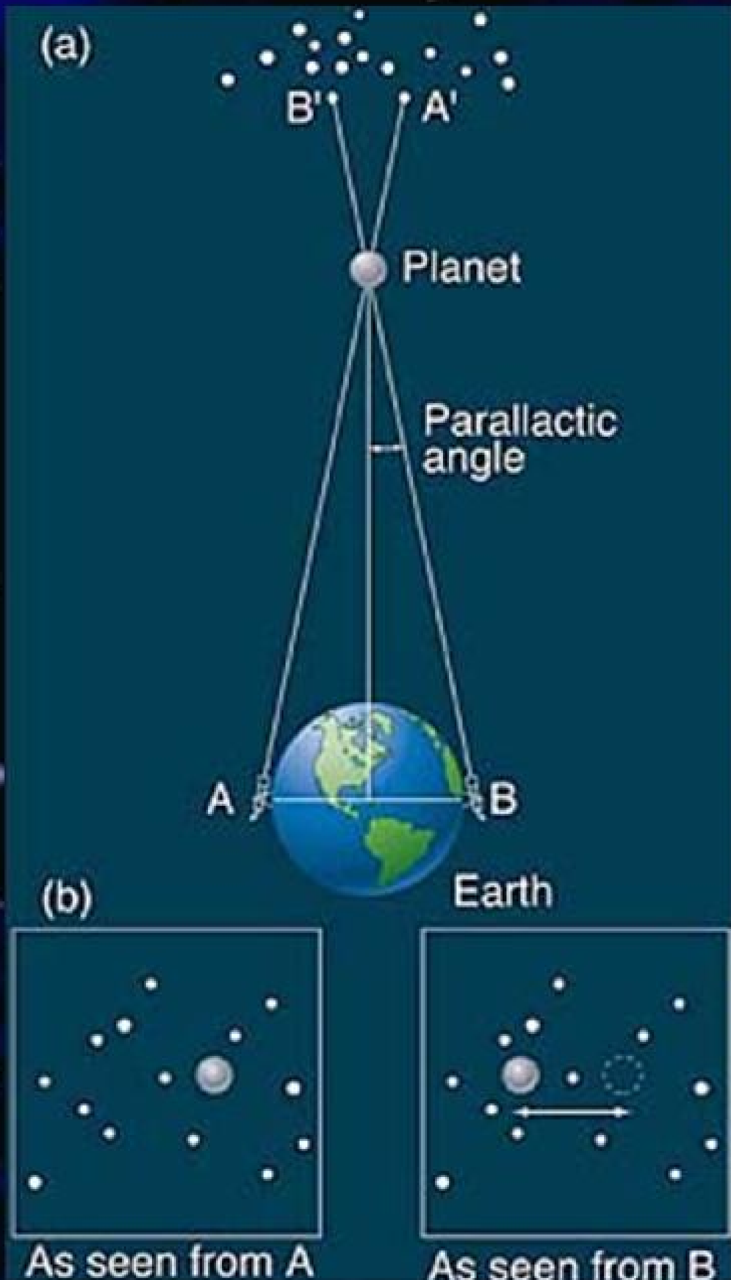
TRIGONOMETRIC PARALLAX



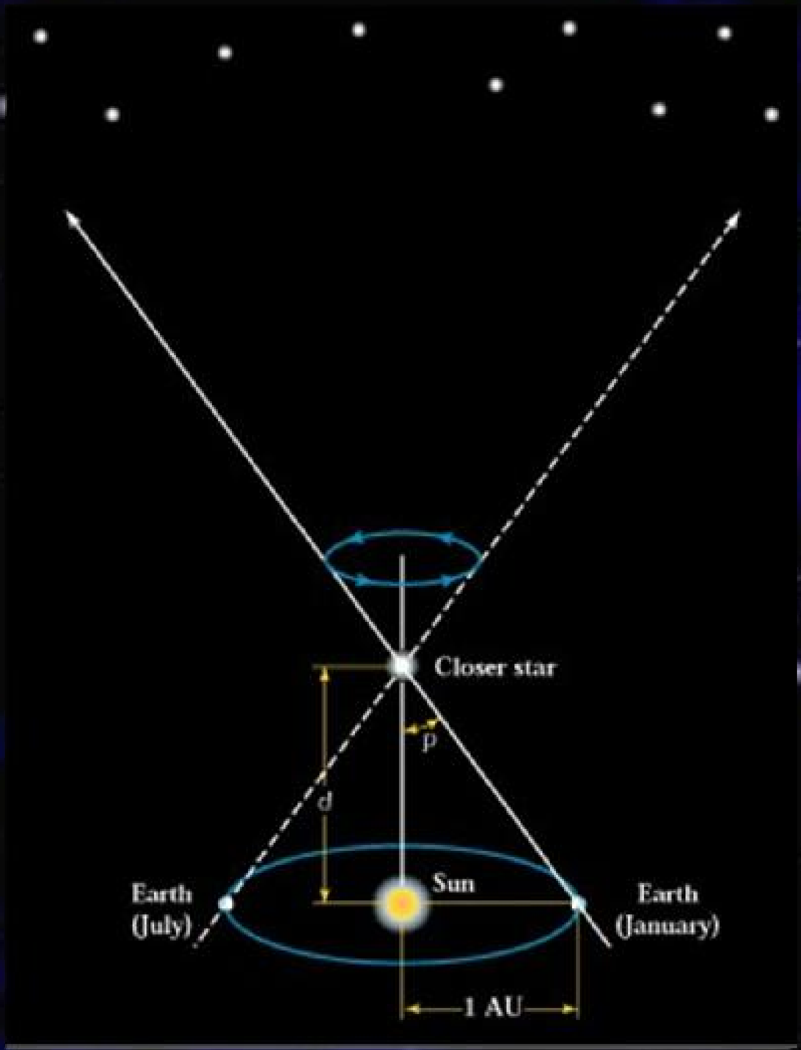
TRIGONOMETRIC PARALLAX

TRIGONOMETRIC PARALLAX

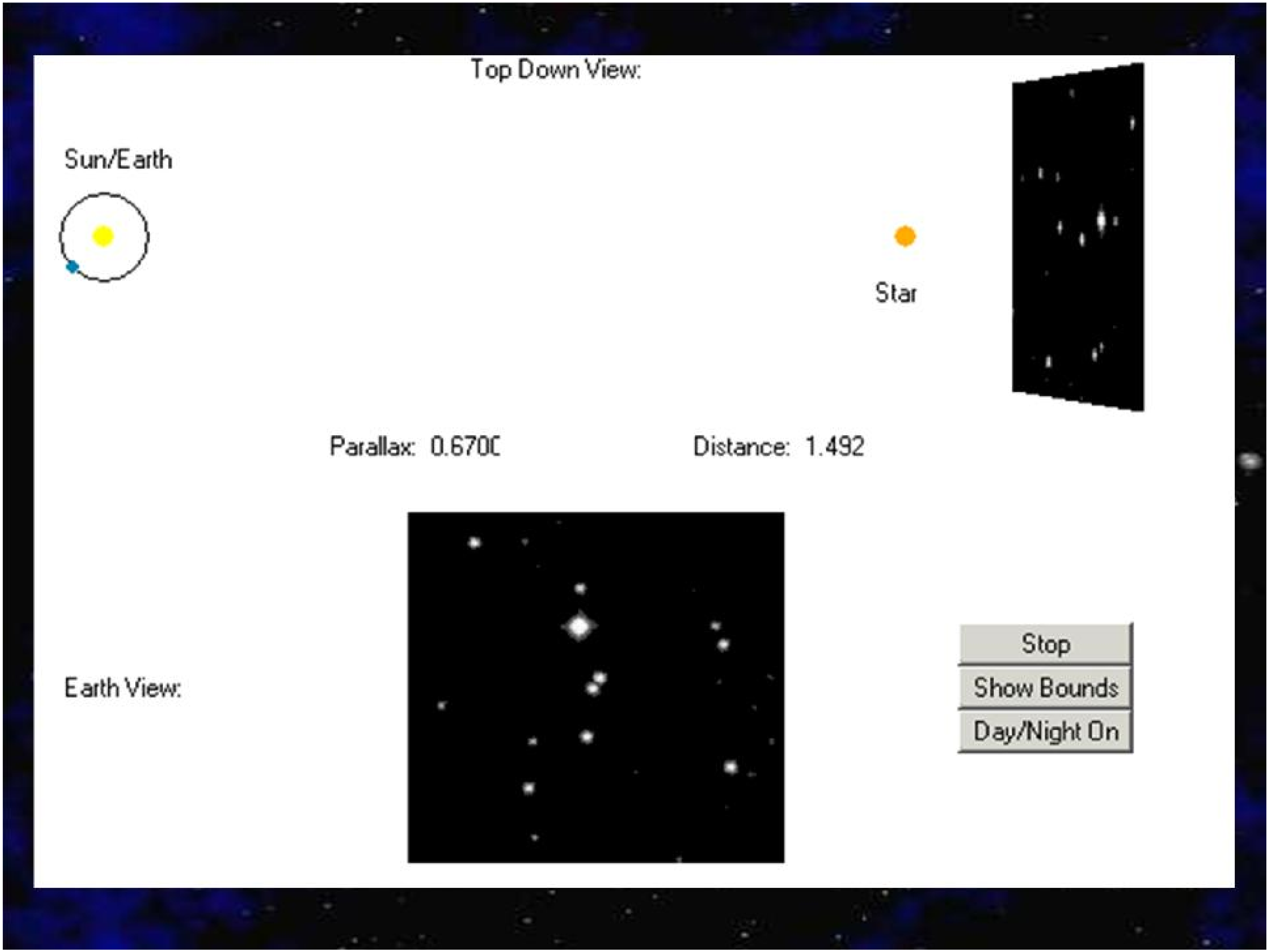
The apparent shift of a “nearby” object with respect to a distant background due to the observer’s own motion.

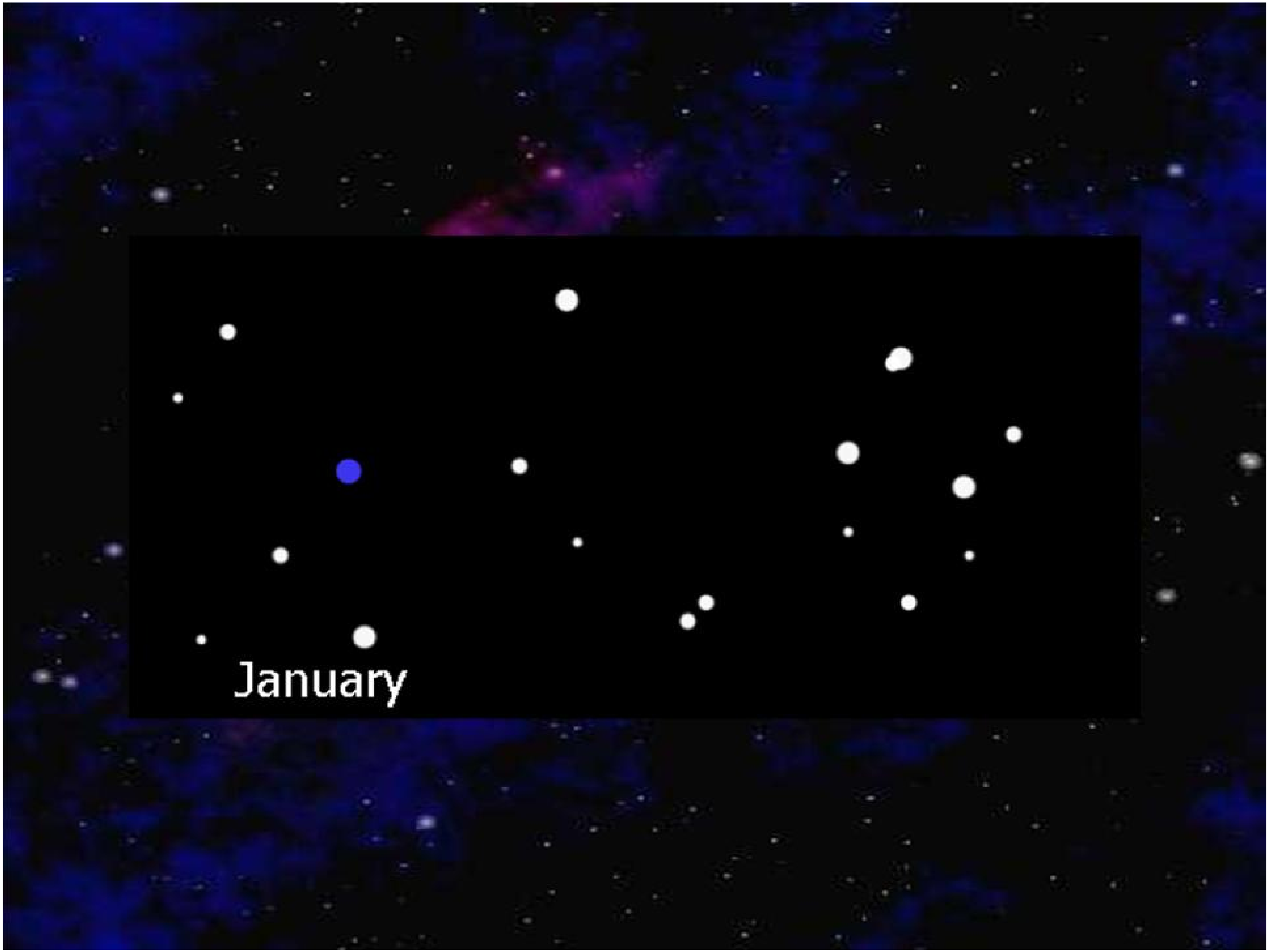


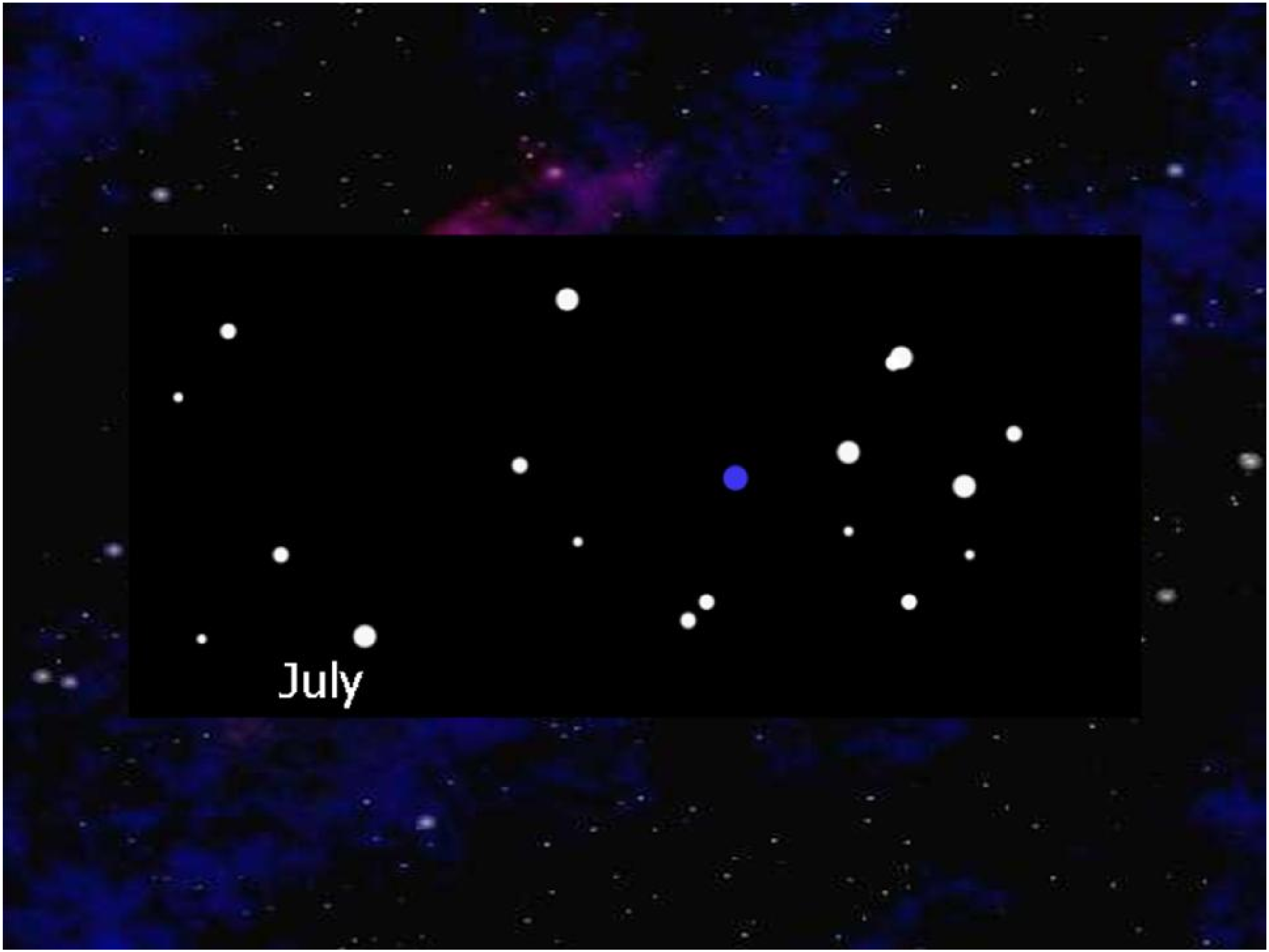
$$d \propto \frac{1}{p}$$

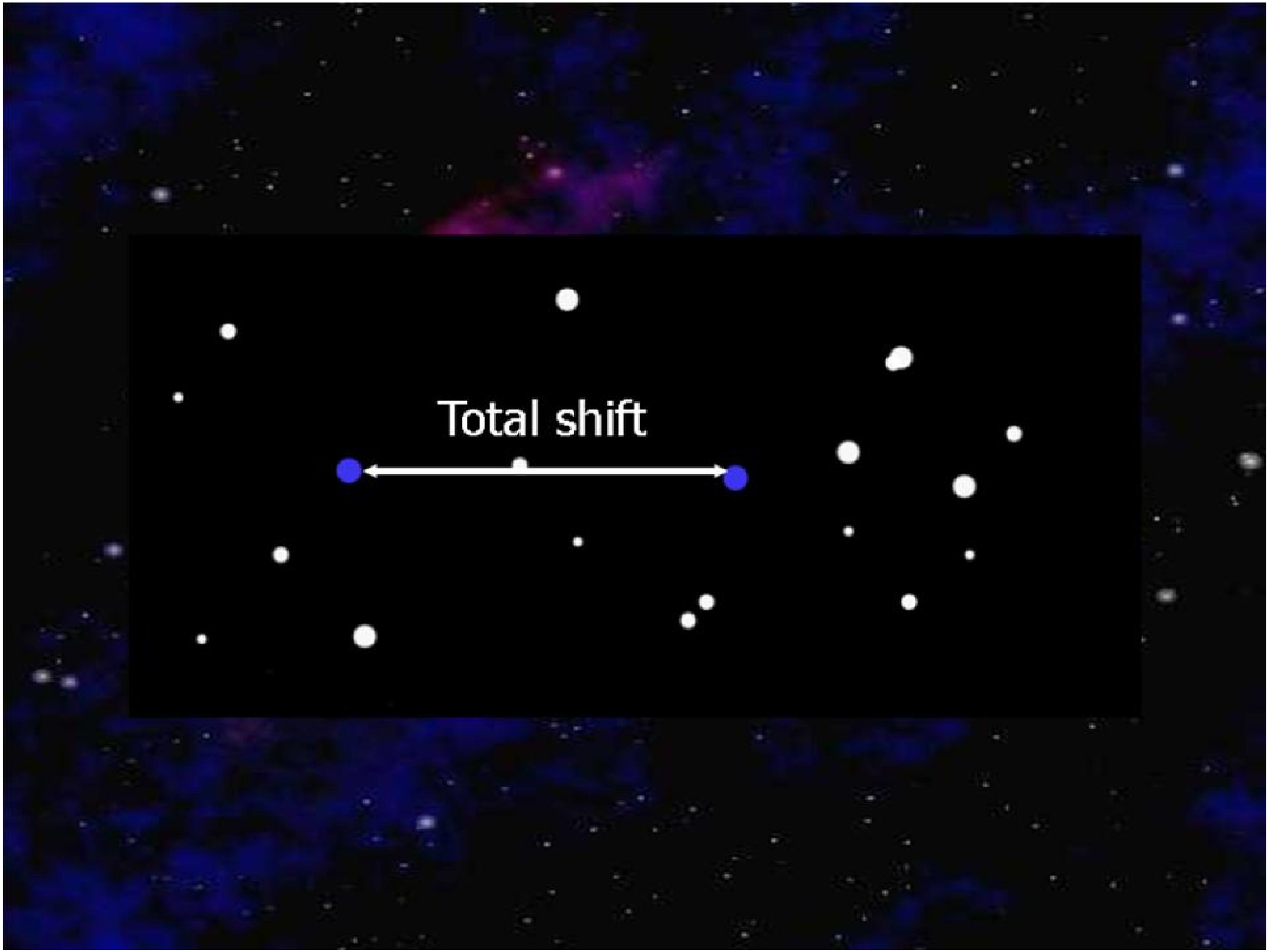


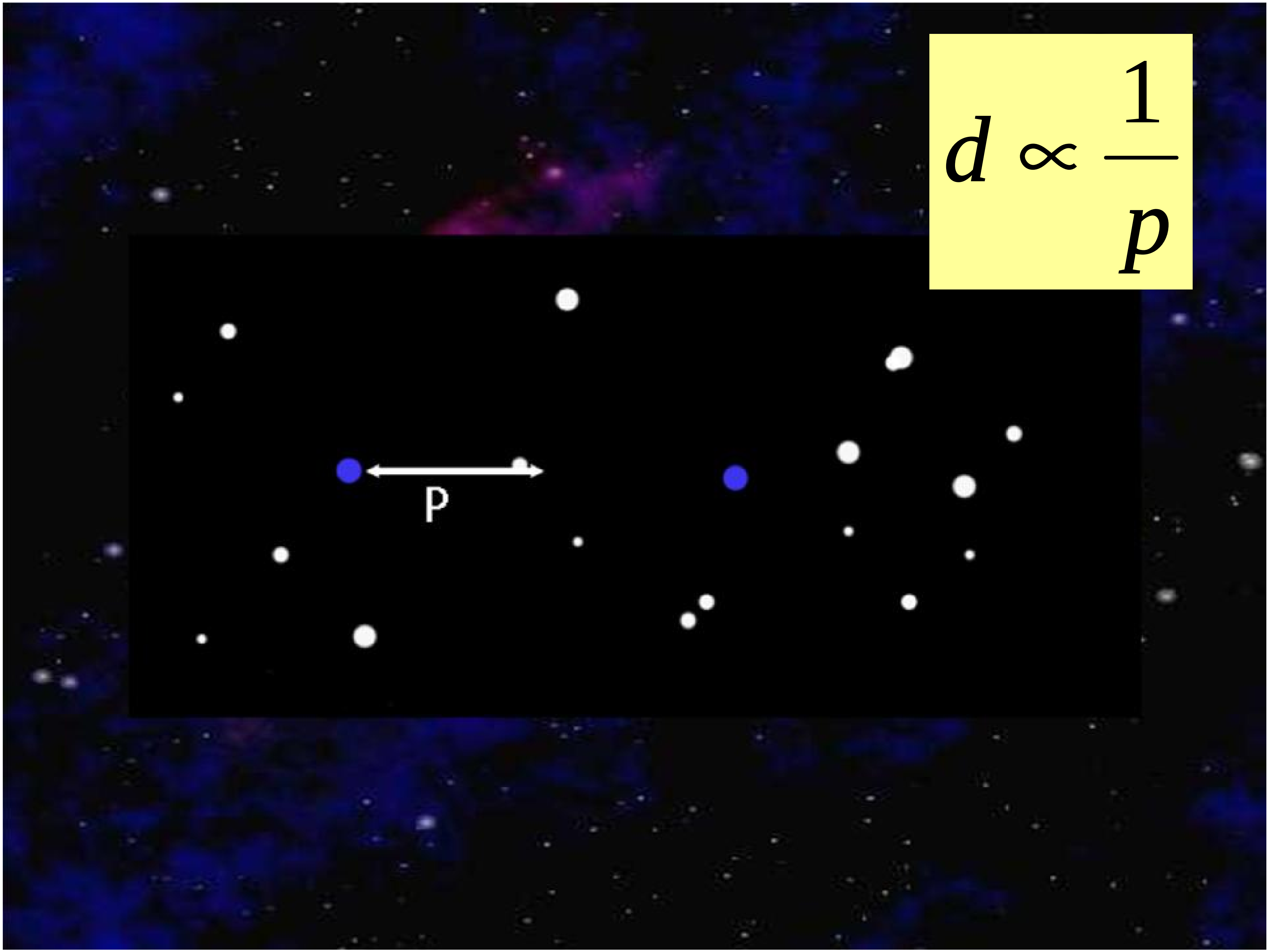
$$d \propto \frac{1}{p}$$


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


January


July


Total shift



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

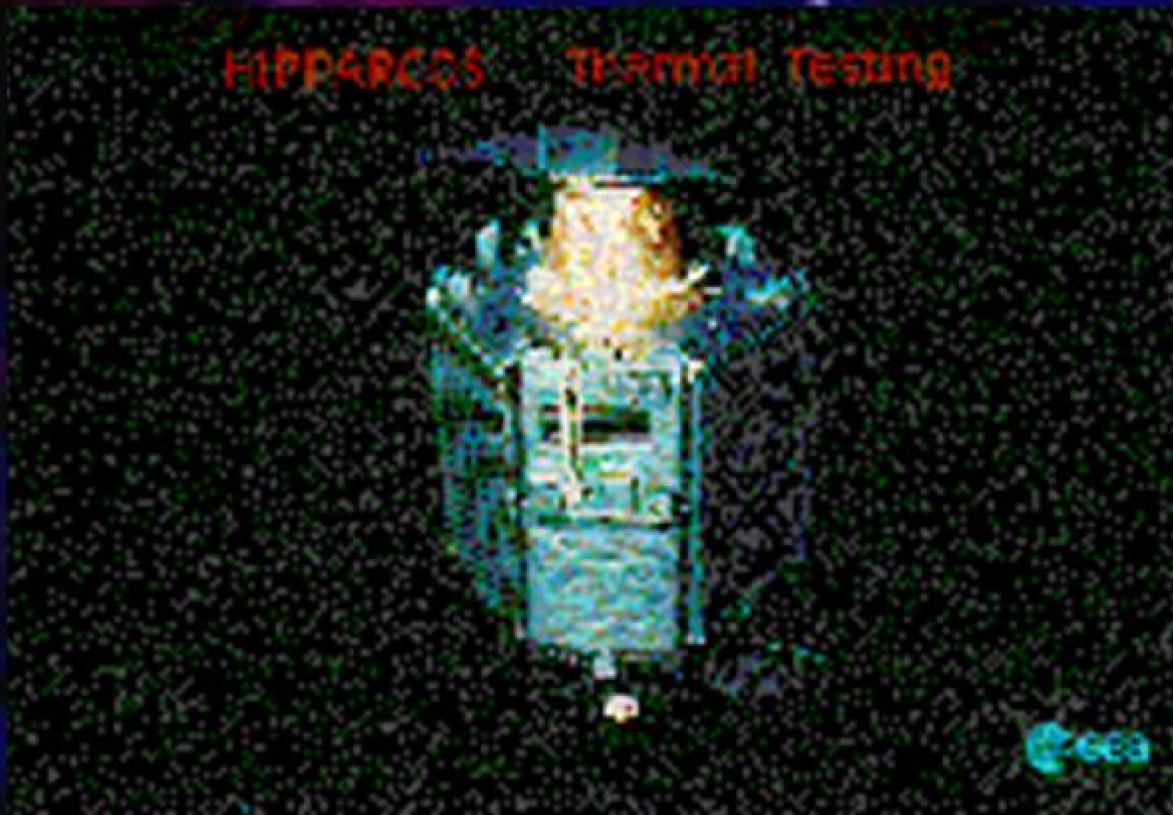
What are the limitations of Trigonometric Parallax?

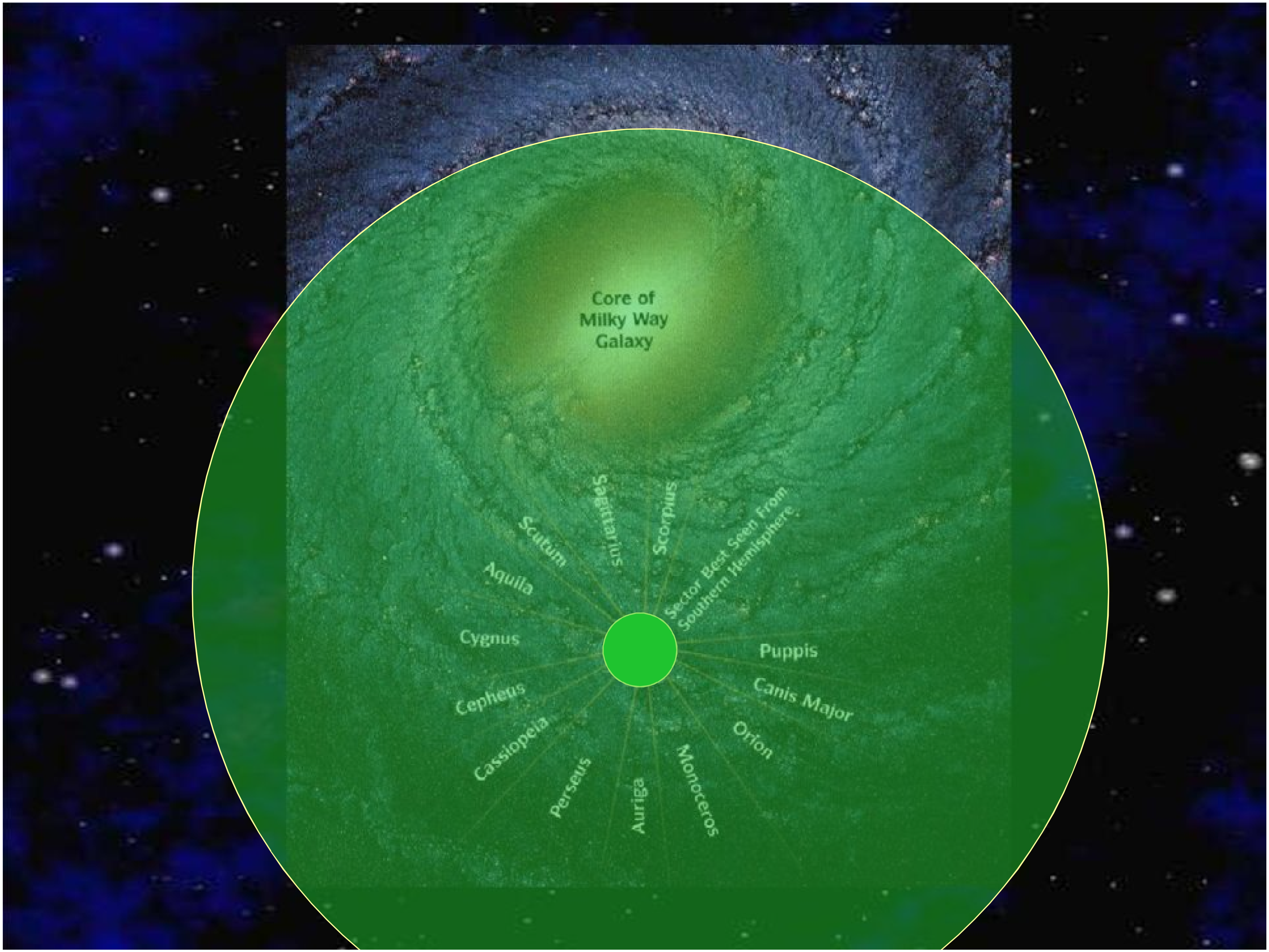
Only works for the nearest stars

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




Core of
Milky Way
Galaxy
Sagittarius
Scorpius
Sector Best Seen From
Southern Hemisphere
Scutum
Aquila
Cygnus
Puppis
Cepheus
Canis Major
Cassiopeia
Orion
Perseus
Auriga
Monoceros

Is there another way to measure distances to stars?

(apparent brightness)

—

(true energy given off)

$\propto$

(distance)

APPARENT MAGNITUDE (m)

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

THE MAGNITUDE SCALE

Hipparchus (2nd Century B.C.)

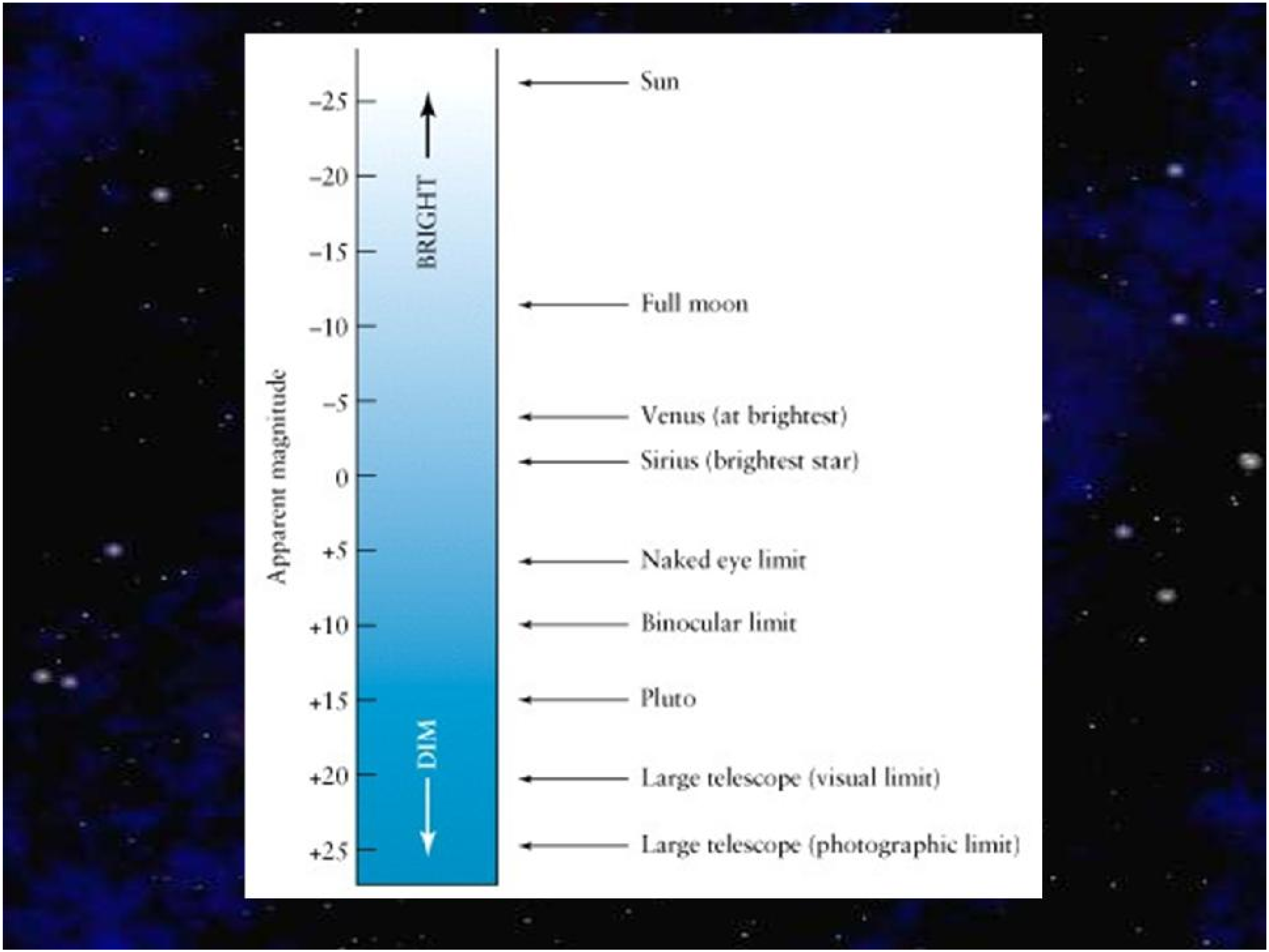
Brightest stars ð 1st magnitude

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

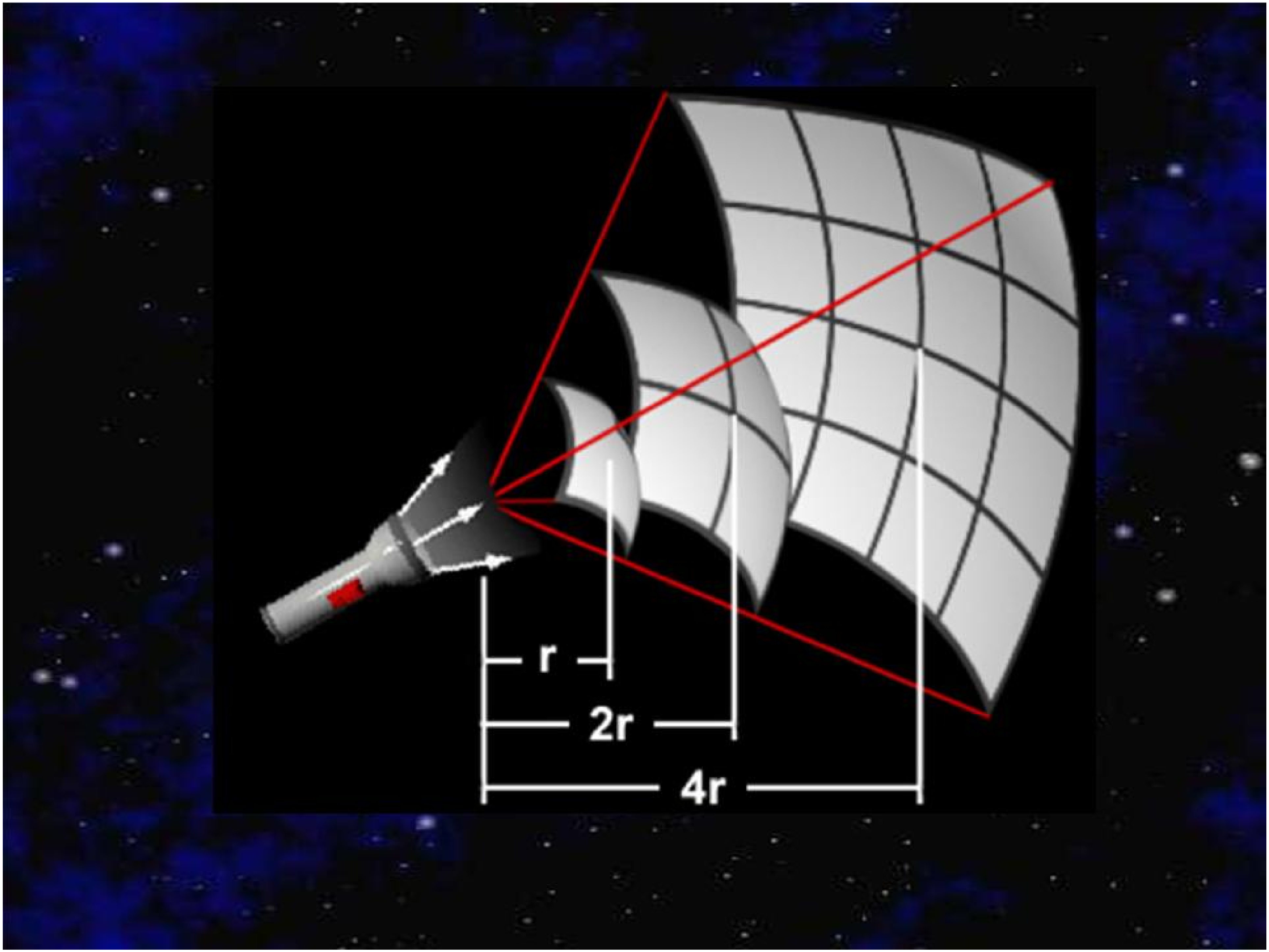
Luminosity vs. brightness

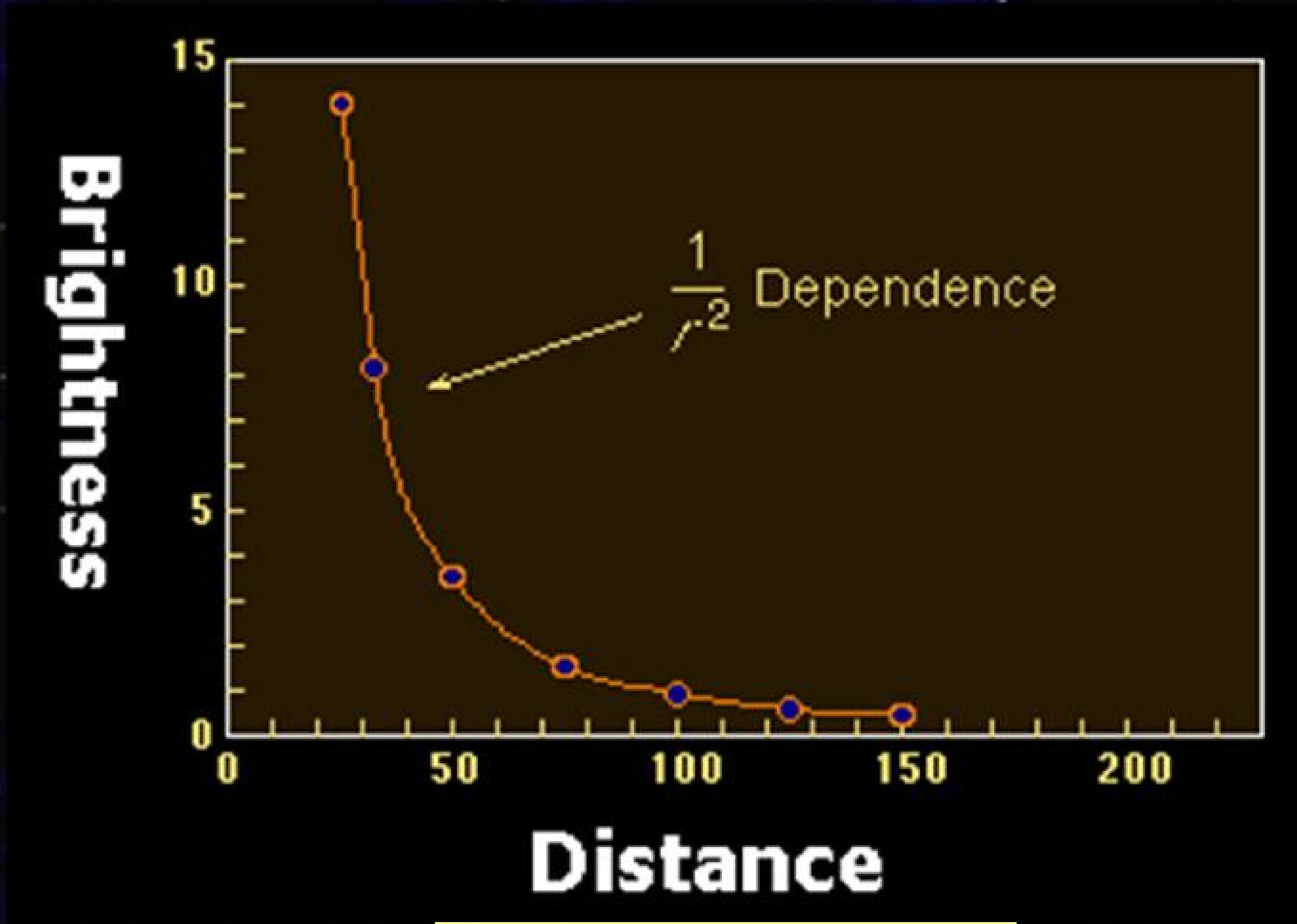
LUMINOSITY:

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

$L_{¤} = 3.9 \times 10^{26}$ watts

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

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

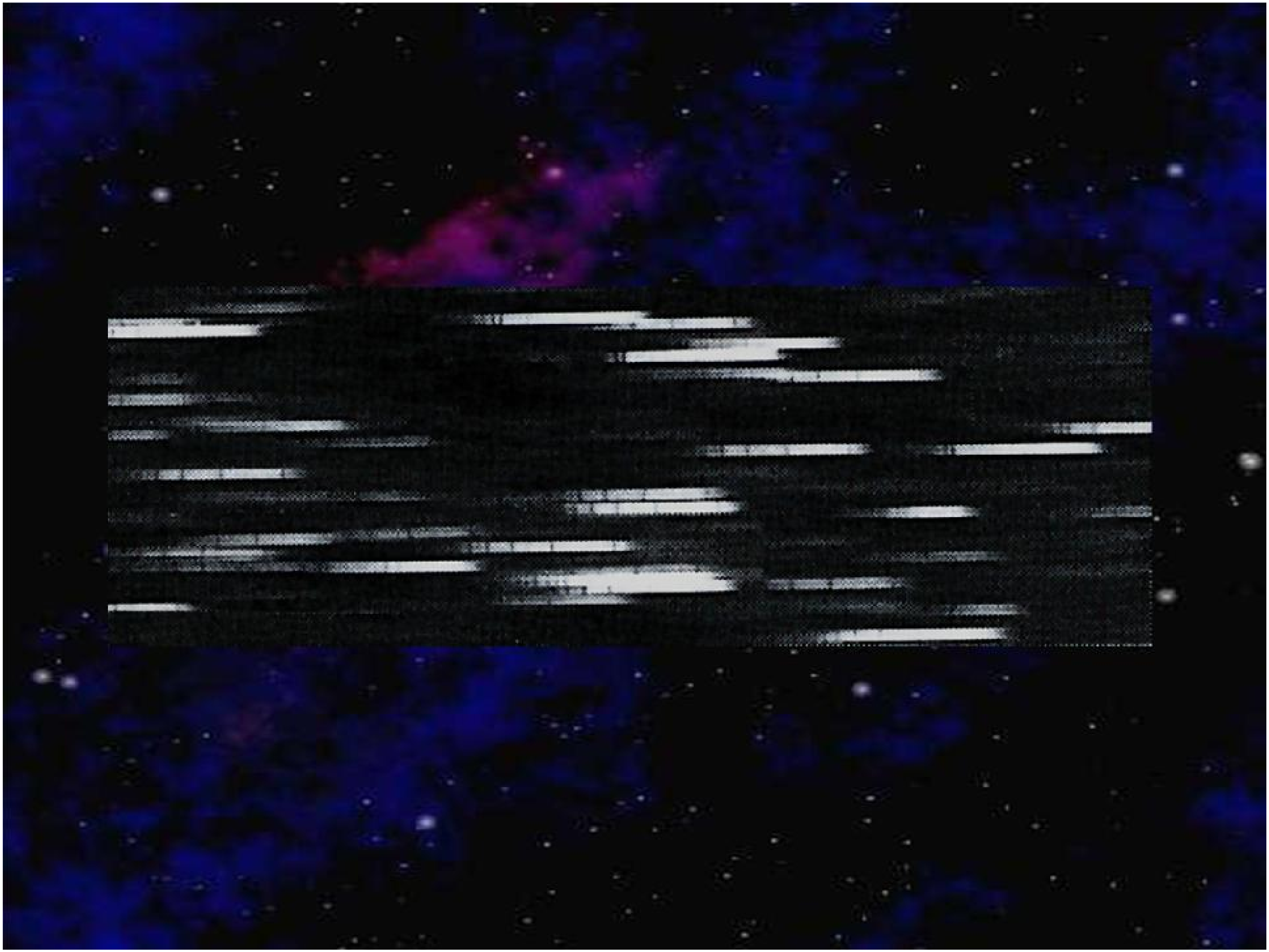
The least luminous stars $L = 0.0001\ L_{¤}$

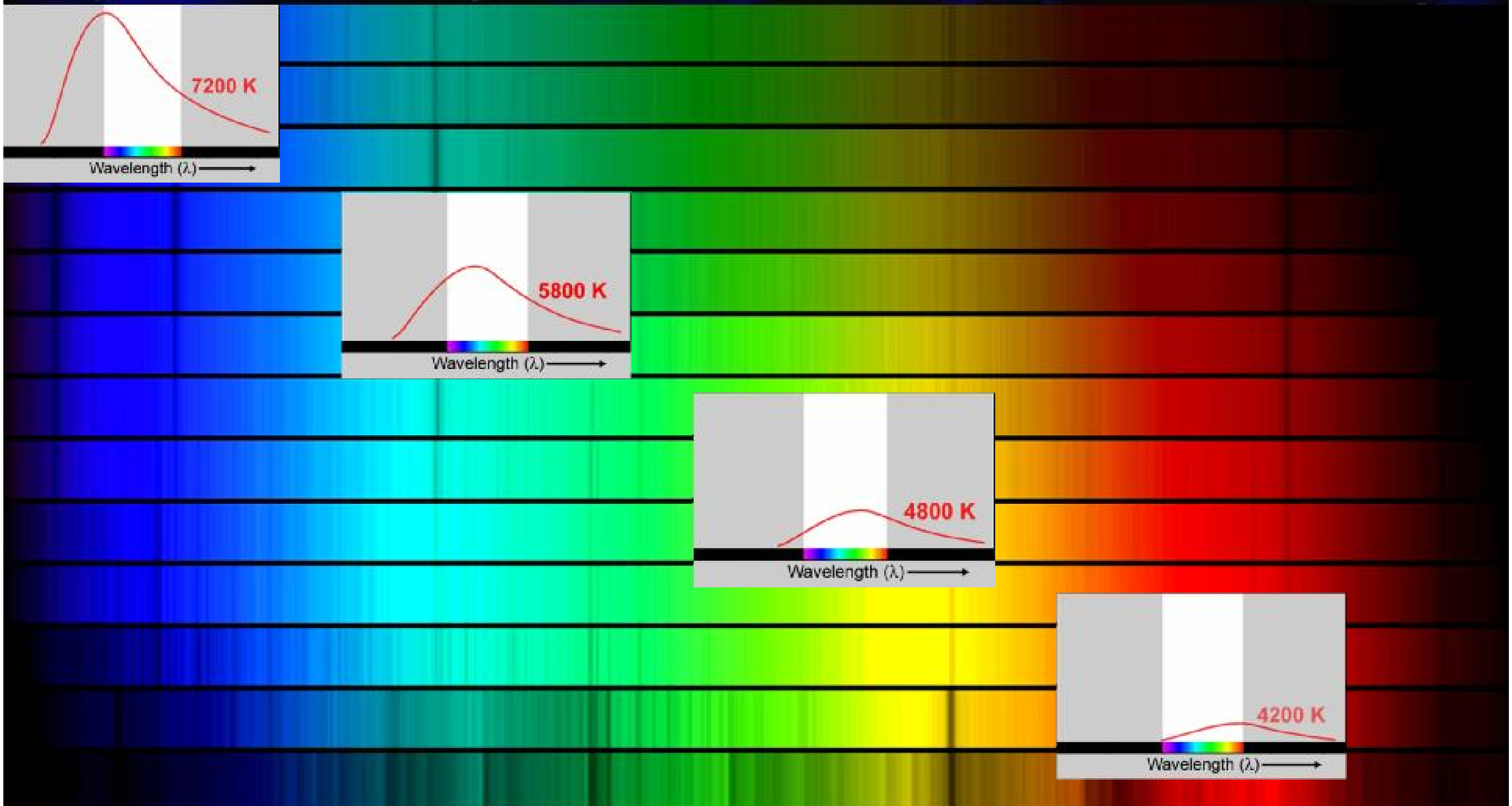
If Absolute Magnitude is related to the amount of energy a star is emitting...

Then

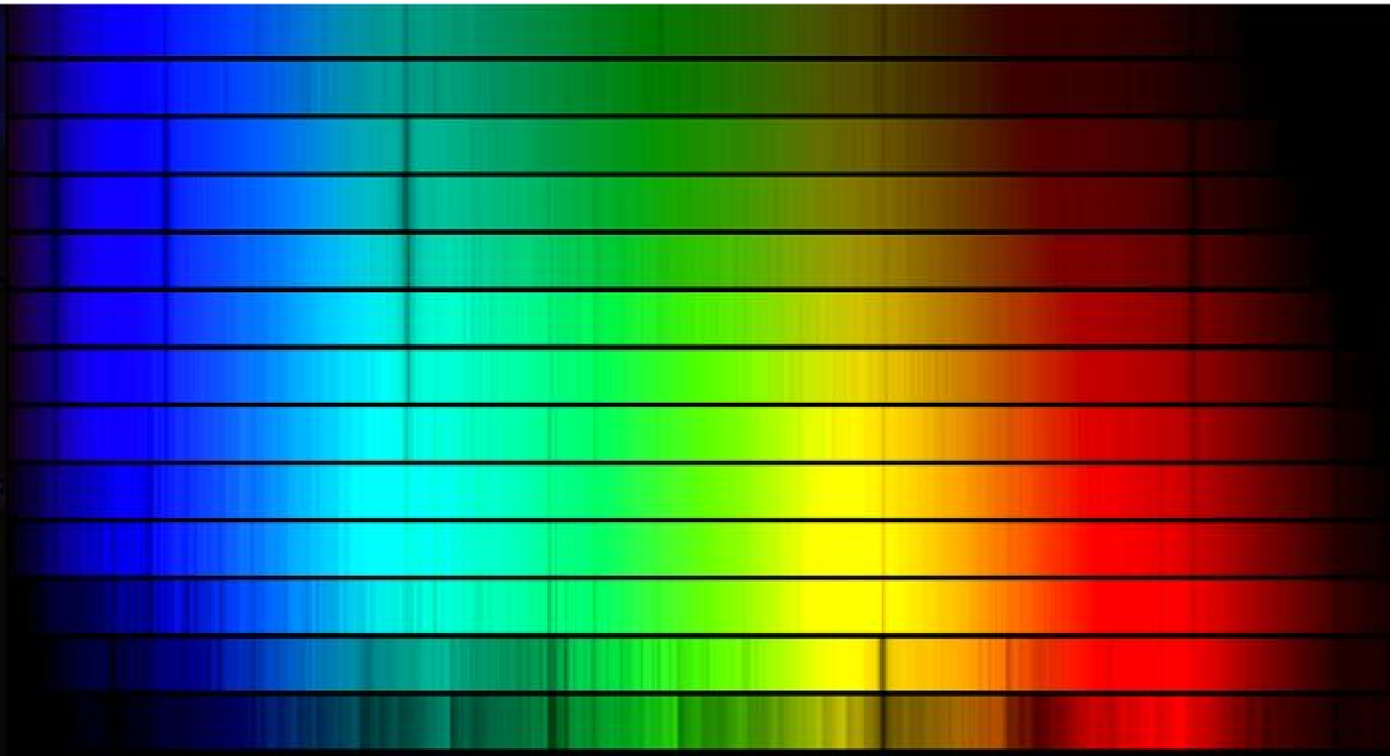
Absolute Magnitude µ Luminosity

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





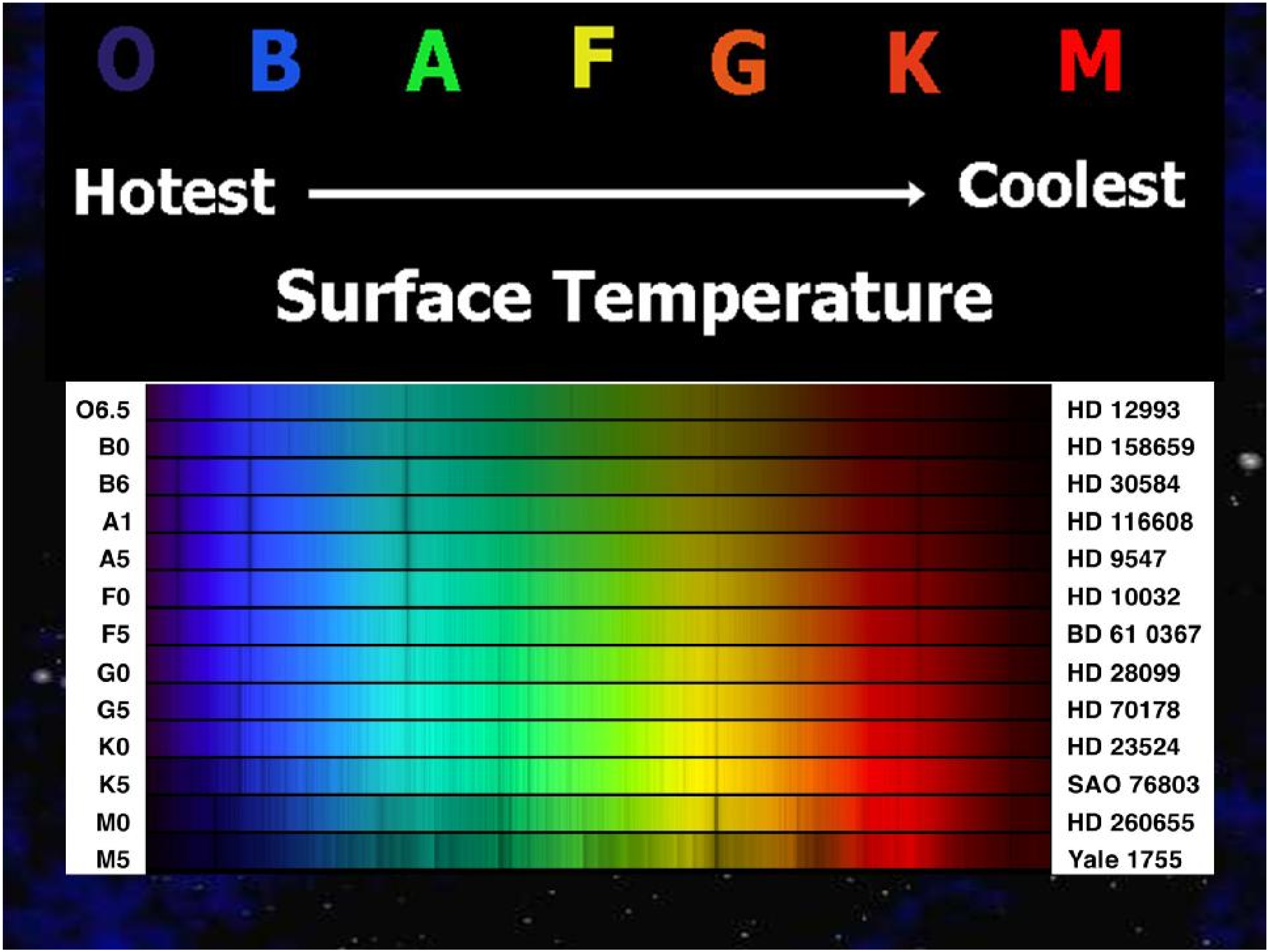
Every star's spectrum has characteristics that allow it to be categorized.



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

Hottest ↓ 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

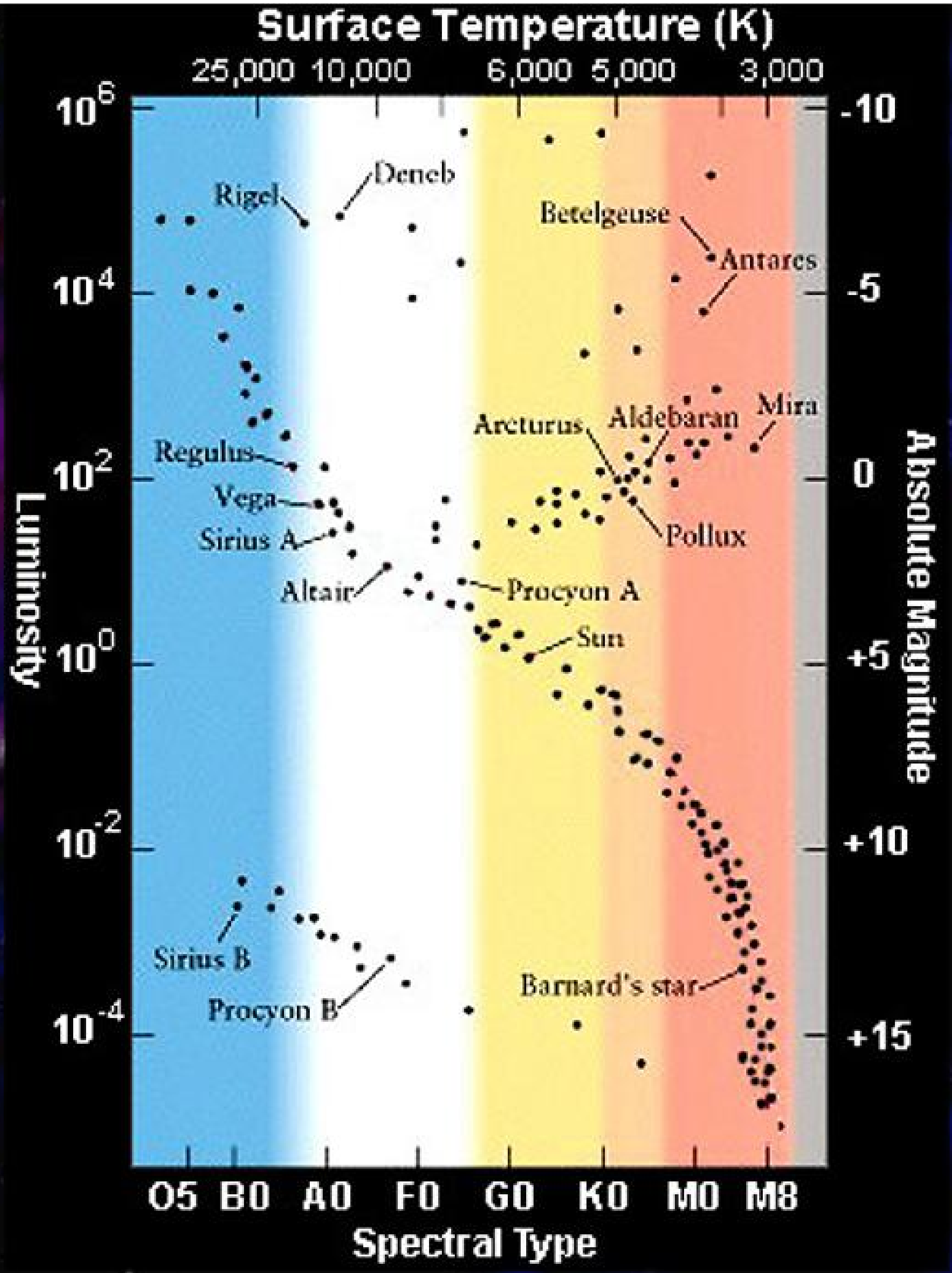
Henry Norris Russell

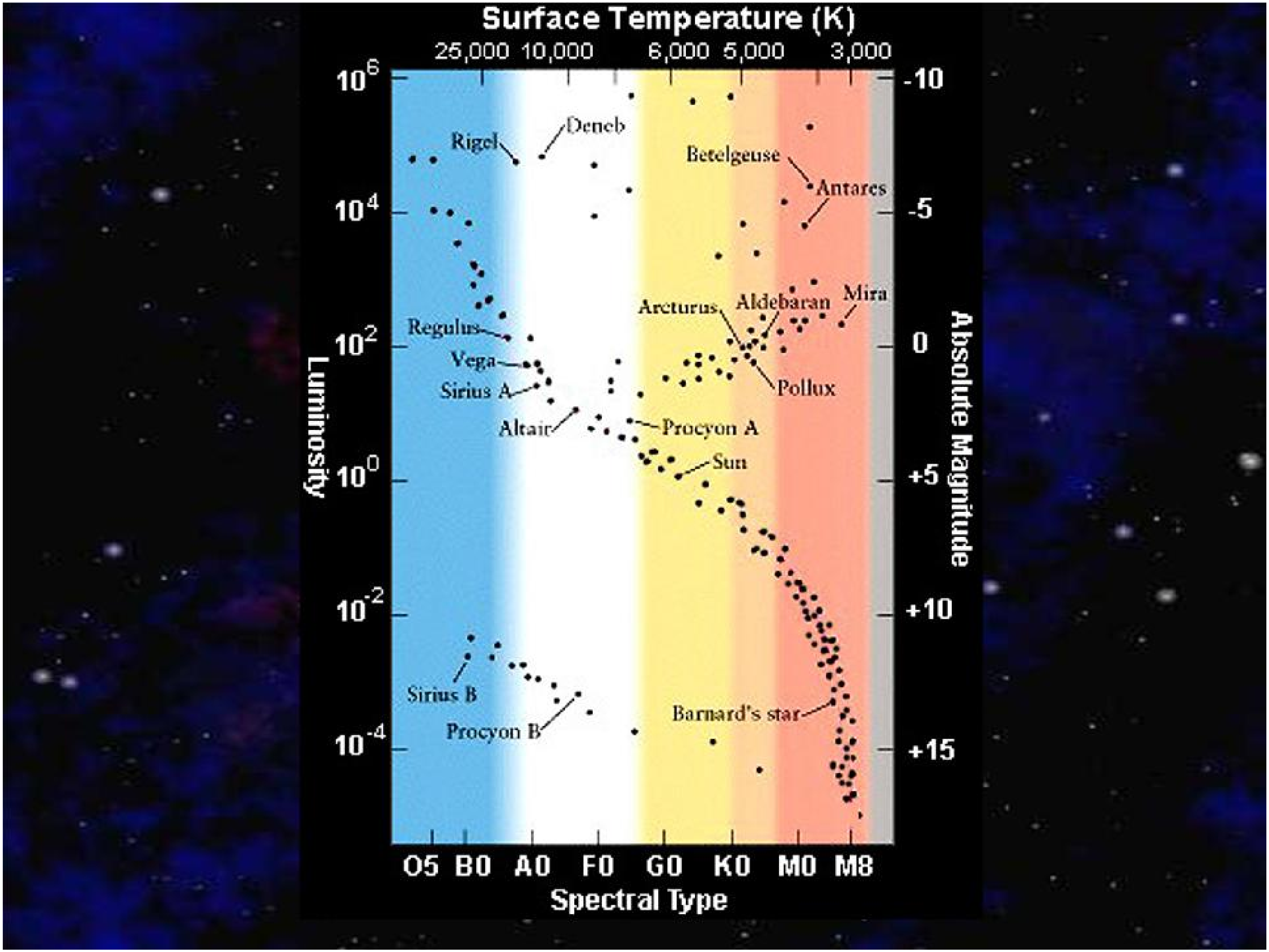
Hertzsprung & Russell

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

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

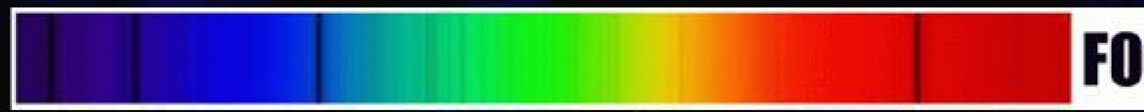
The Hertzsprung – Russell Diagram

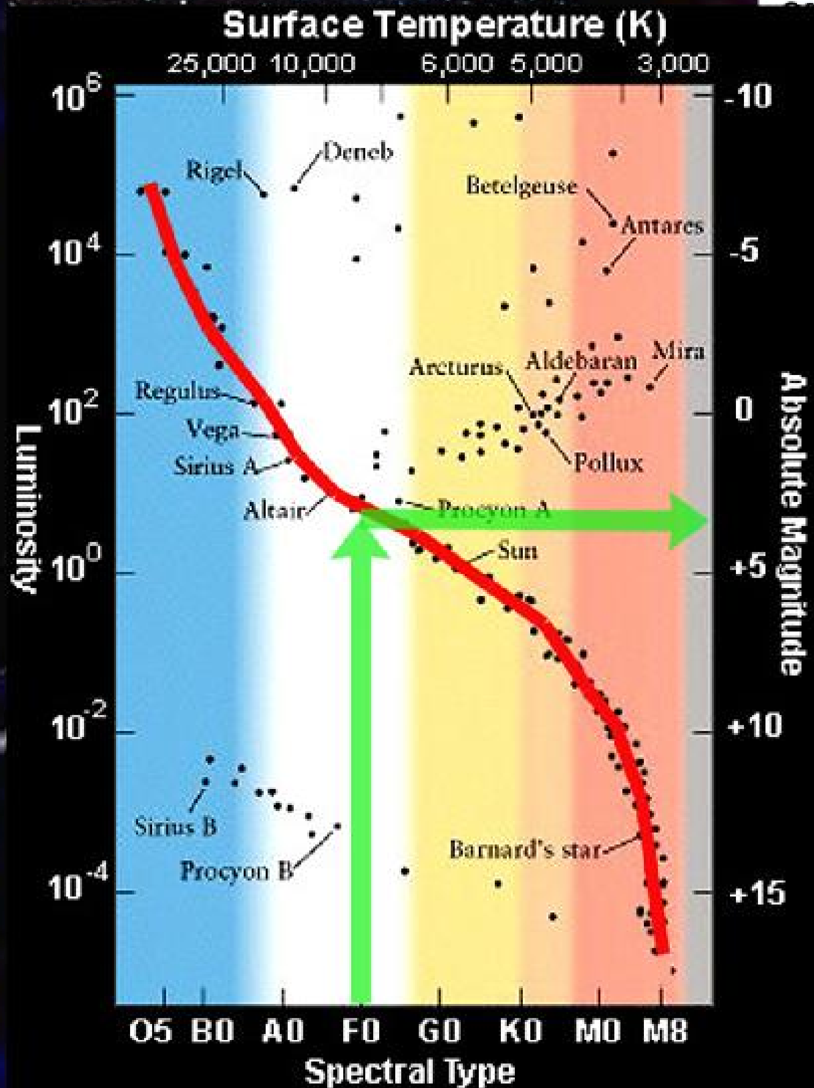


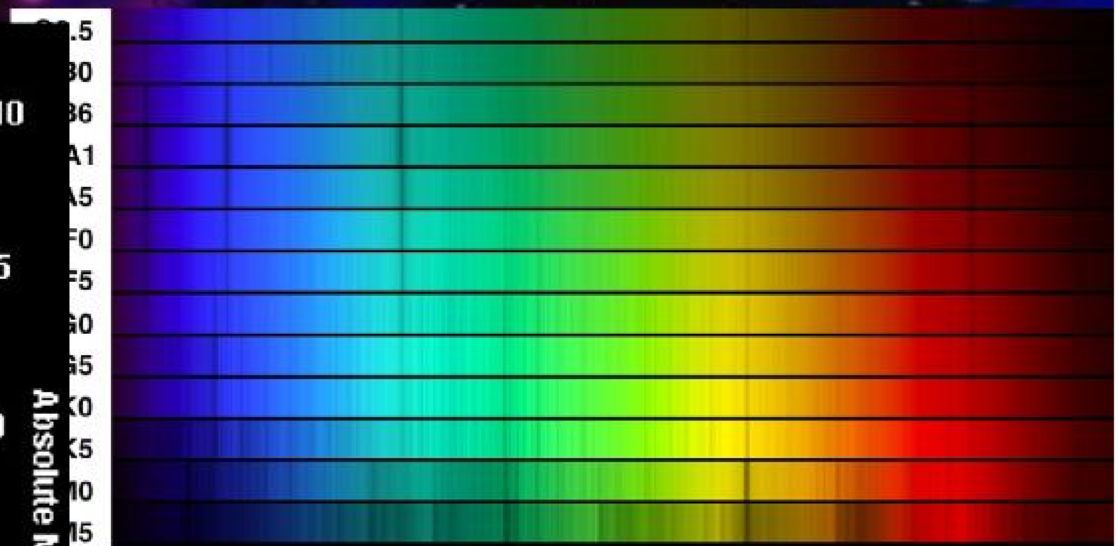


Surface Temperature (K)
25,000 10,000 6,000 5,000 3,000
Luminosity
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
Absolute Magnitude
-10
-5
0
+5
+10
+15
Rigel
Deneb
Betelgeuse
Antares
Mira
Arcturus
Aldebaran
Regulus
Vega
Sirius A
Pollux
Altair
Procyon A
Sun
Sirius B
Procyon B
Barnard's star
O5 B0 A0 F0 G0 K0 M0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

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

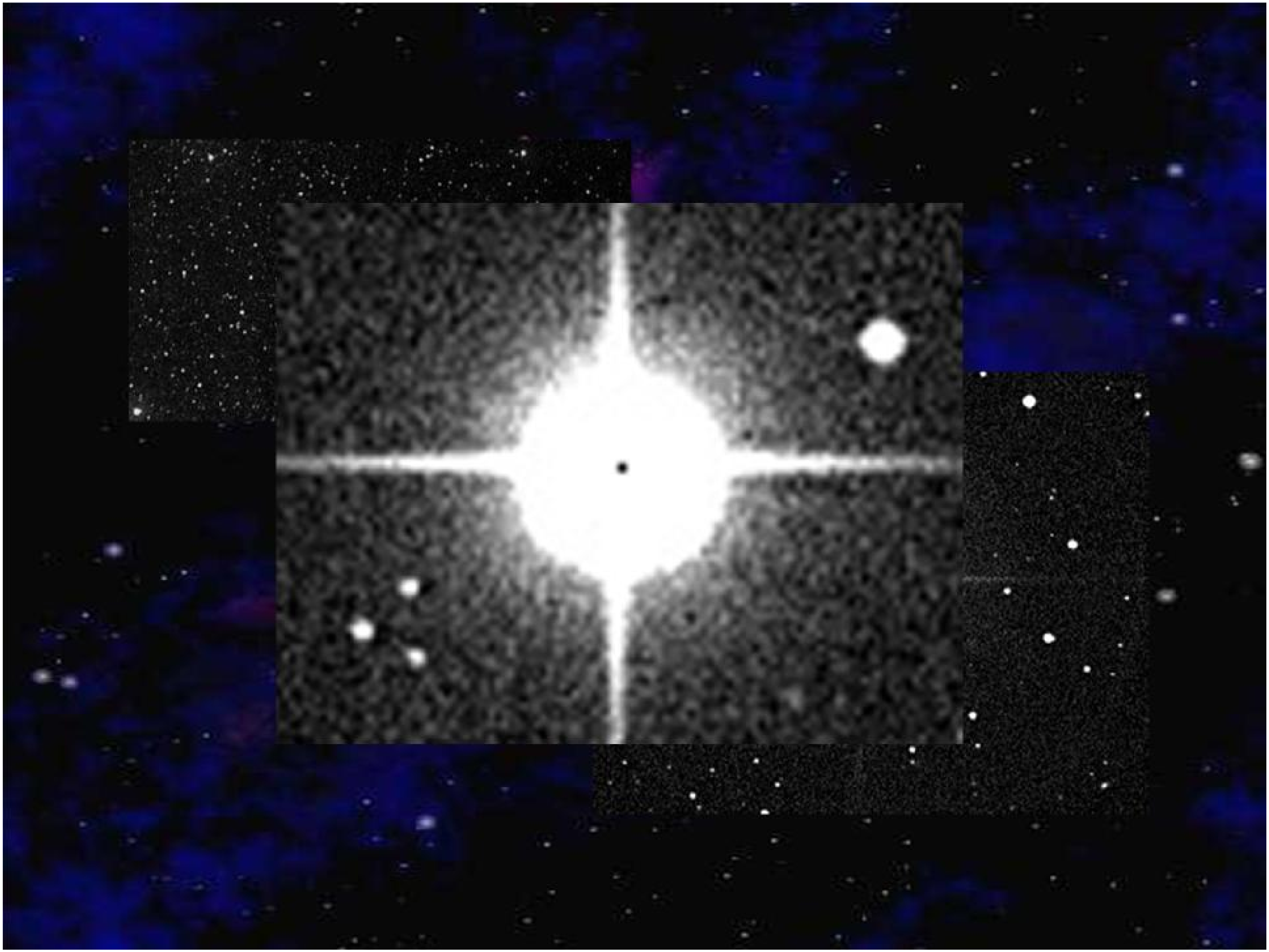


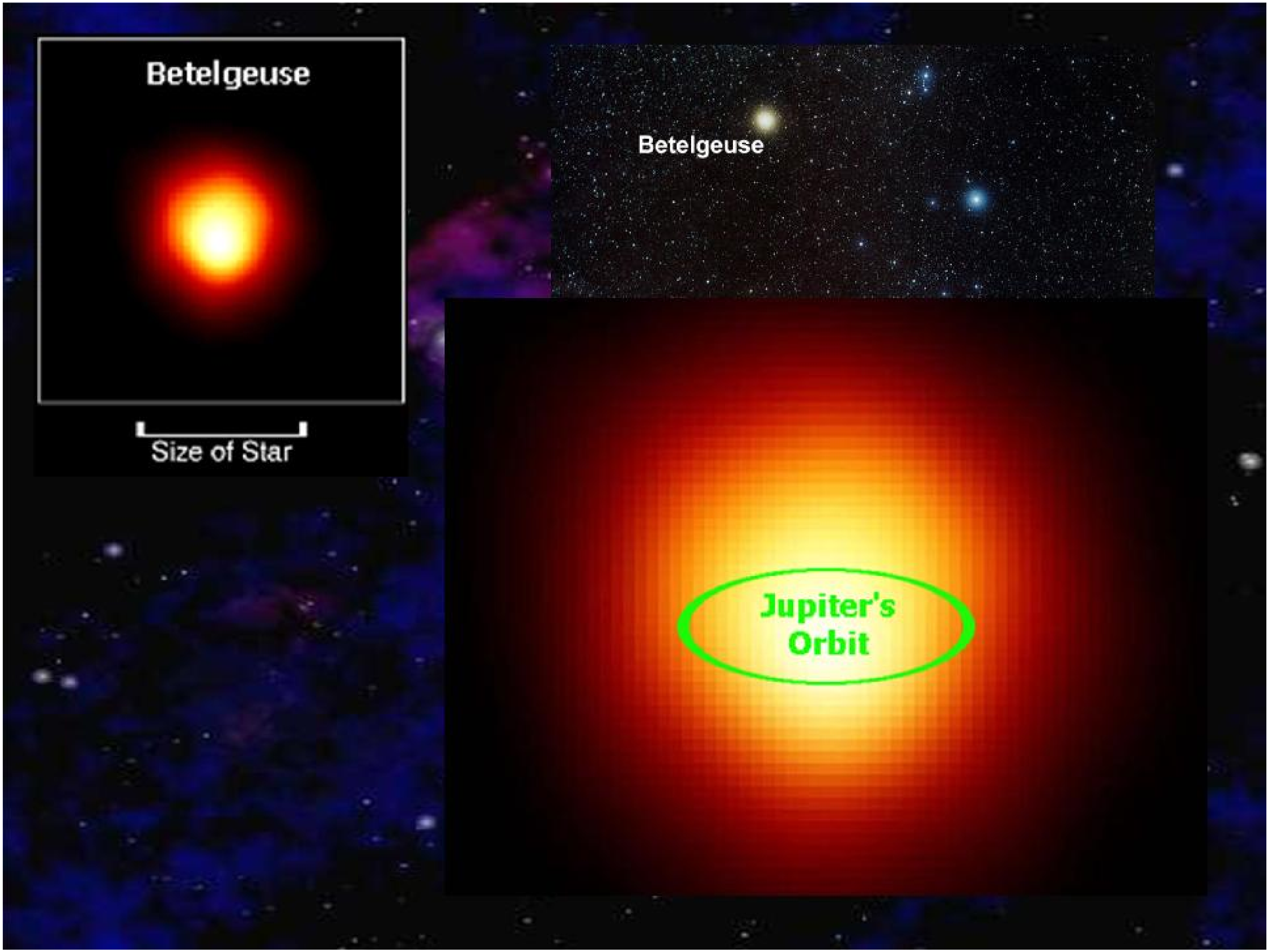




$$m - M = 5\log d - 5$$

Spectroscopic Parallax




Betelgeuse
Size of Star
Betelgeuse
Jupiter's
Orbit

Temperature – Radius – Luminosity Relationship

$$L = 4pR^2 s T^4$$

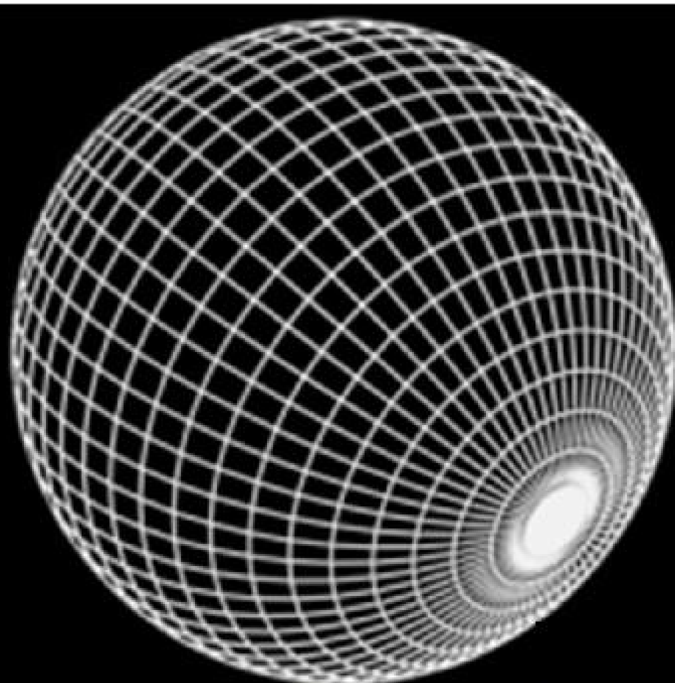
L = luminosity of the star

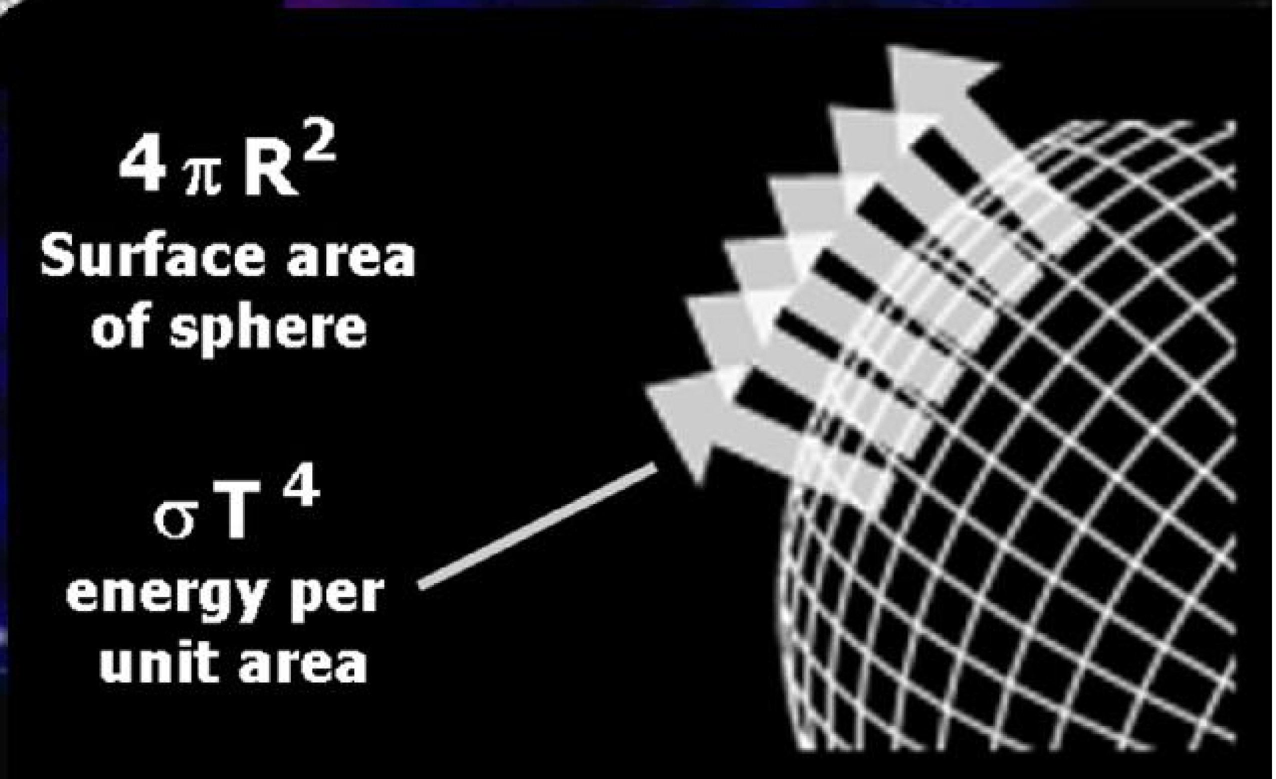
R = radius of the star

T = surface temperature of the star

π,σ = constants

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

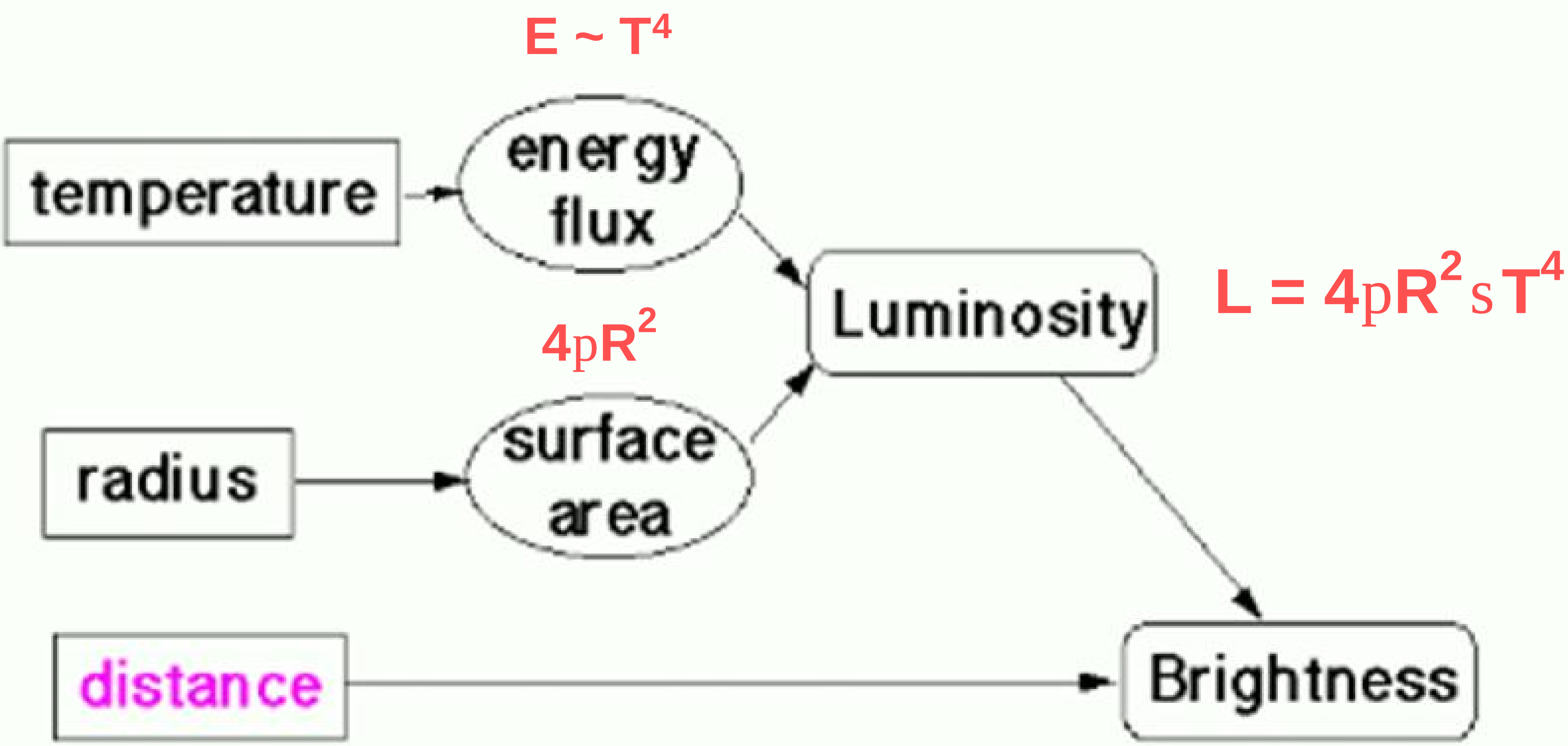


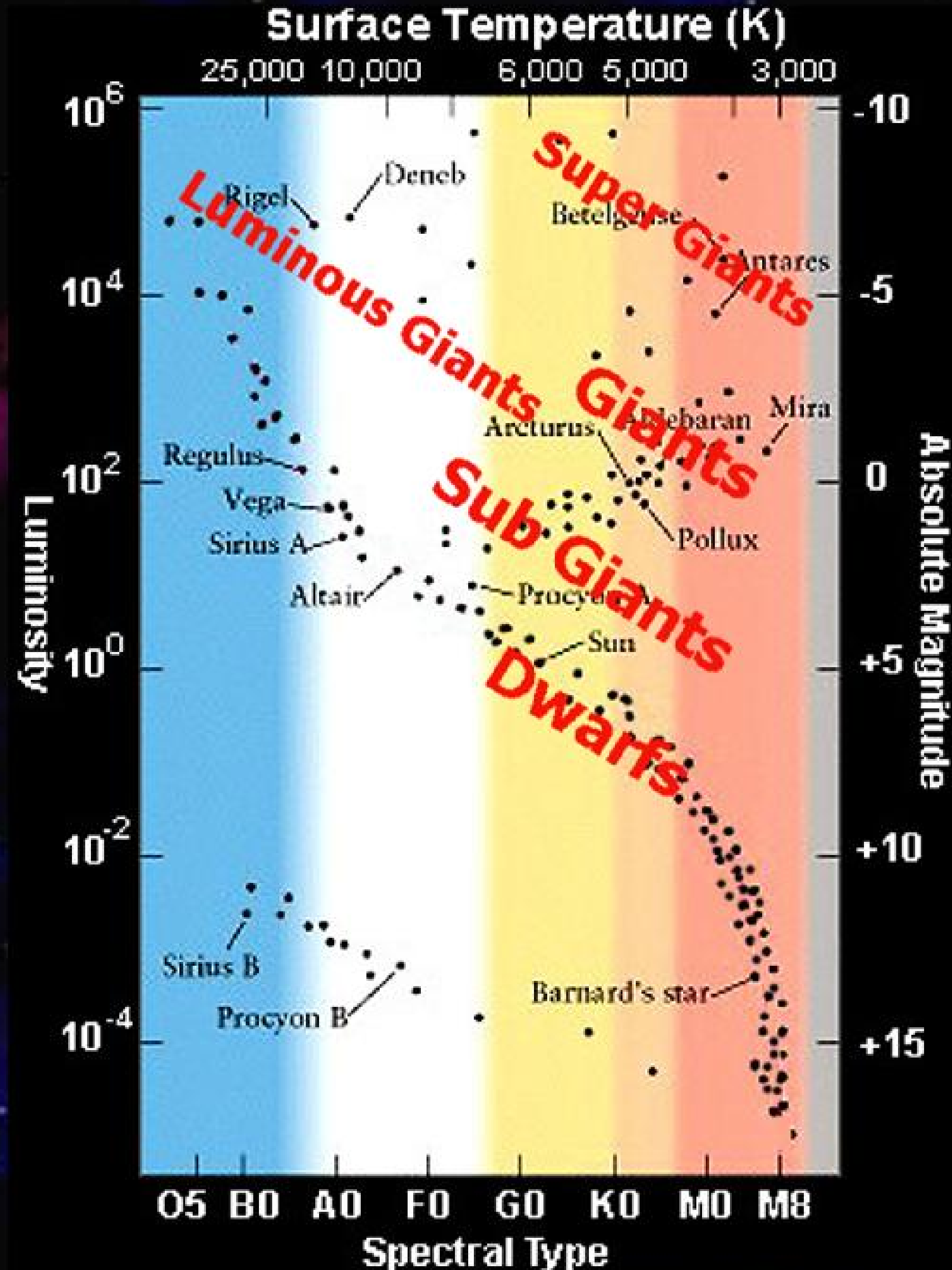


$$R = \sqrt{\frac{L}{4 p s T^4}}$$

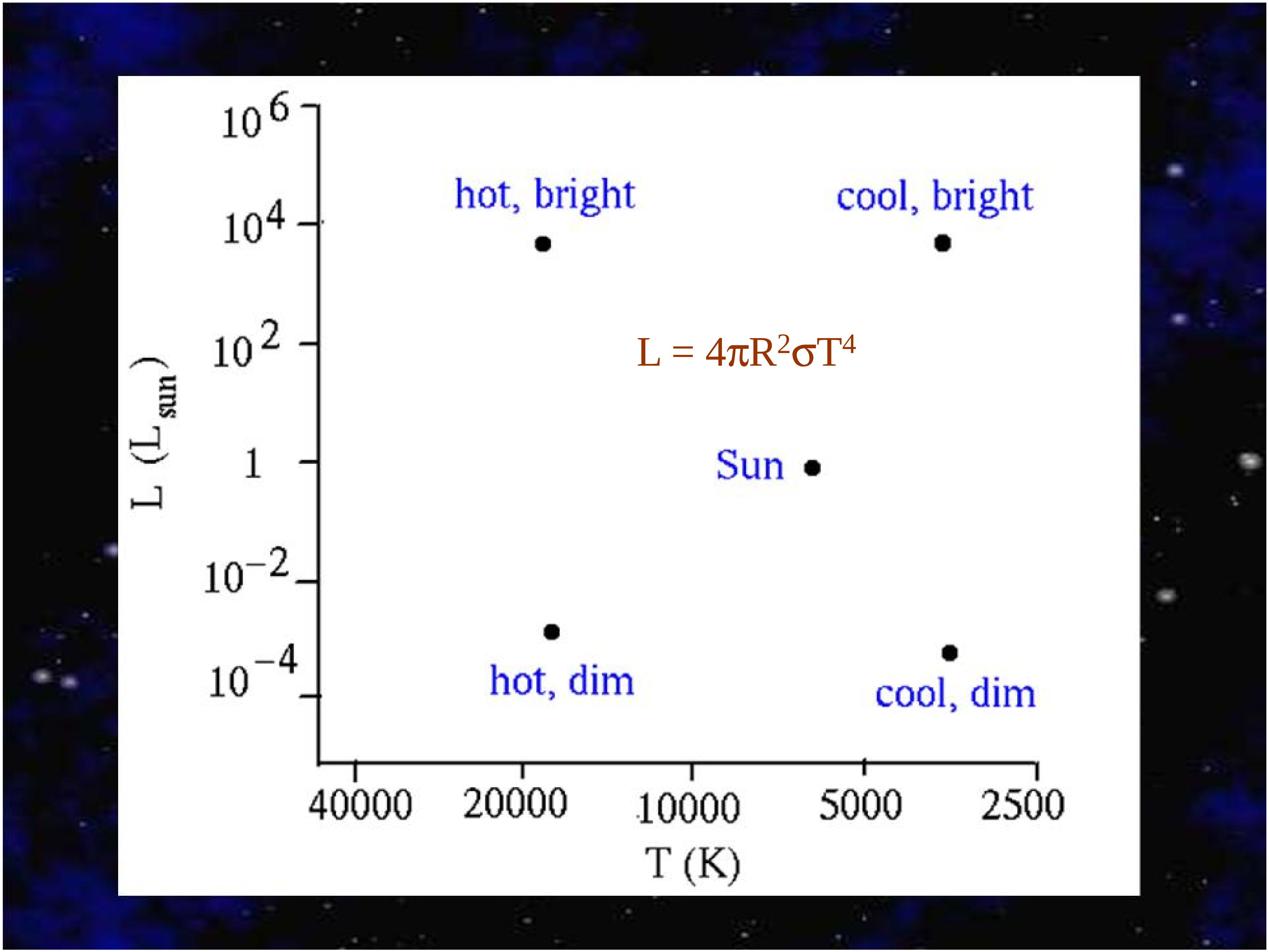
$$R \propto \frac{L}{T}$$

Luminosity and Brightness





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



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

Luminosity Classes

I Super Giants

II Luminous Giants

III Giants

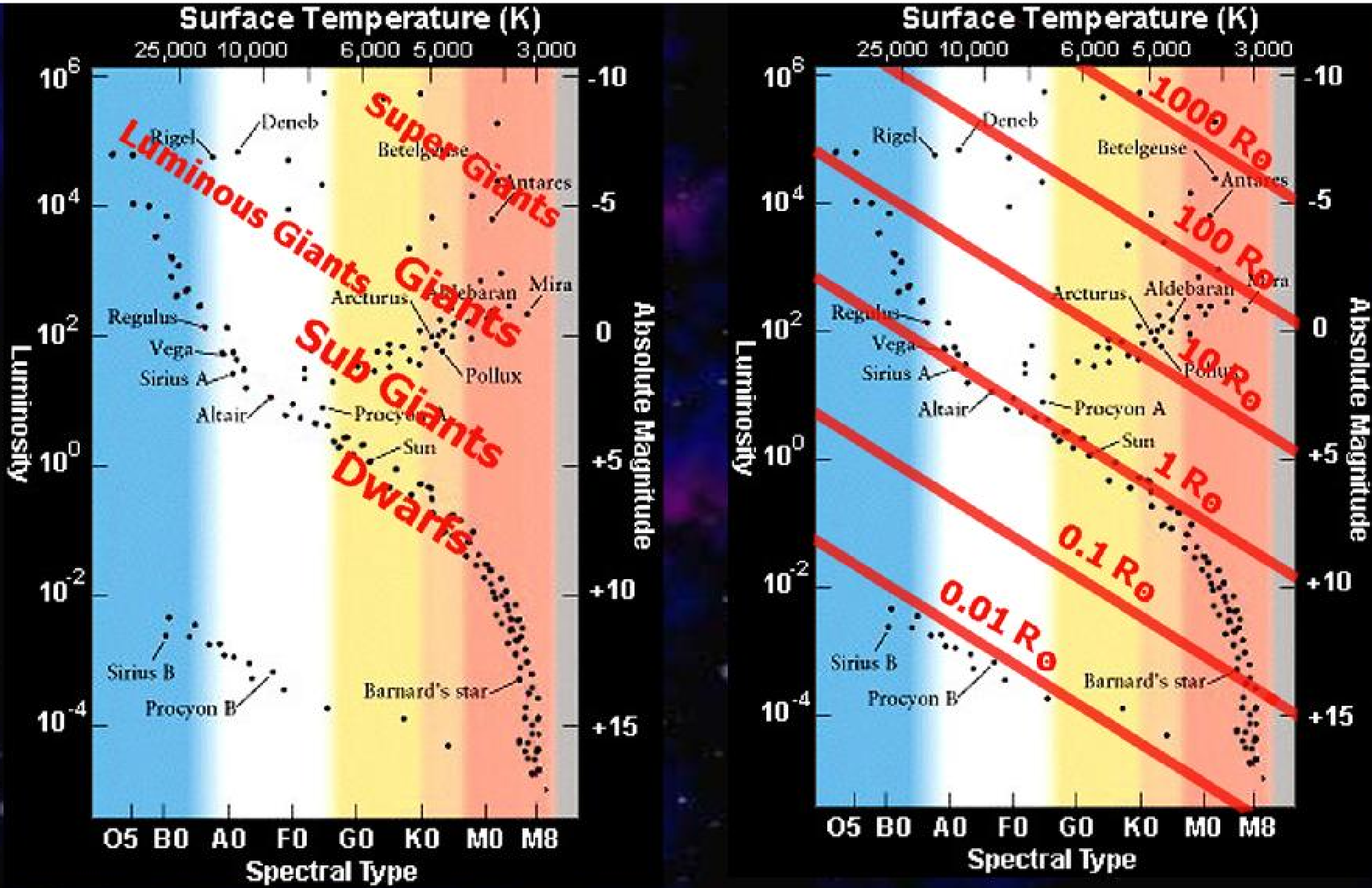
IV Sub Giants

V Dwarfs

The Sun is a Dwarf…

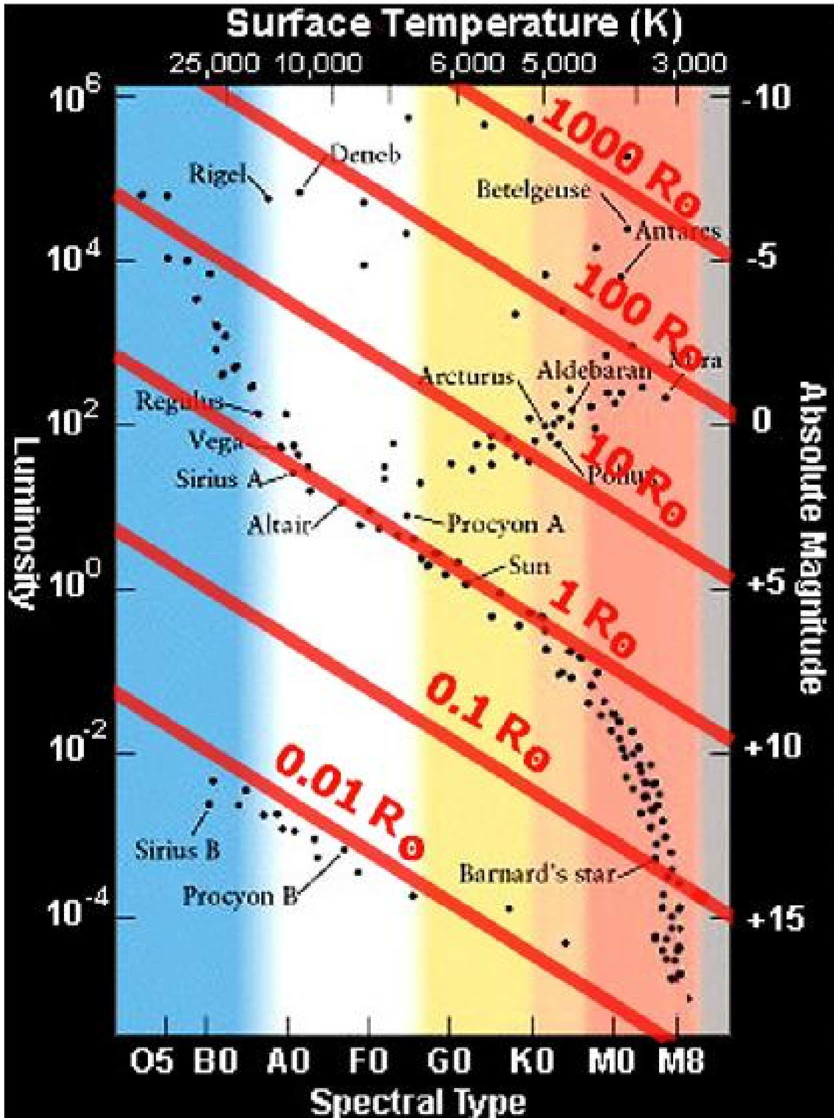
So finally, stars can be classified...

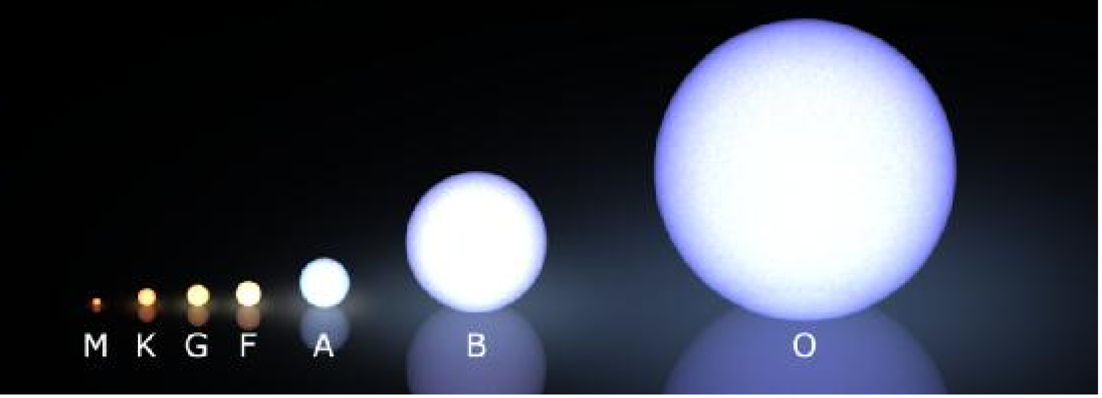
- By spectral type (OBAFGKM)
- Luminosity class (I,II,III,IV,V)



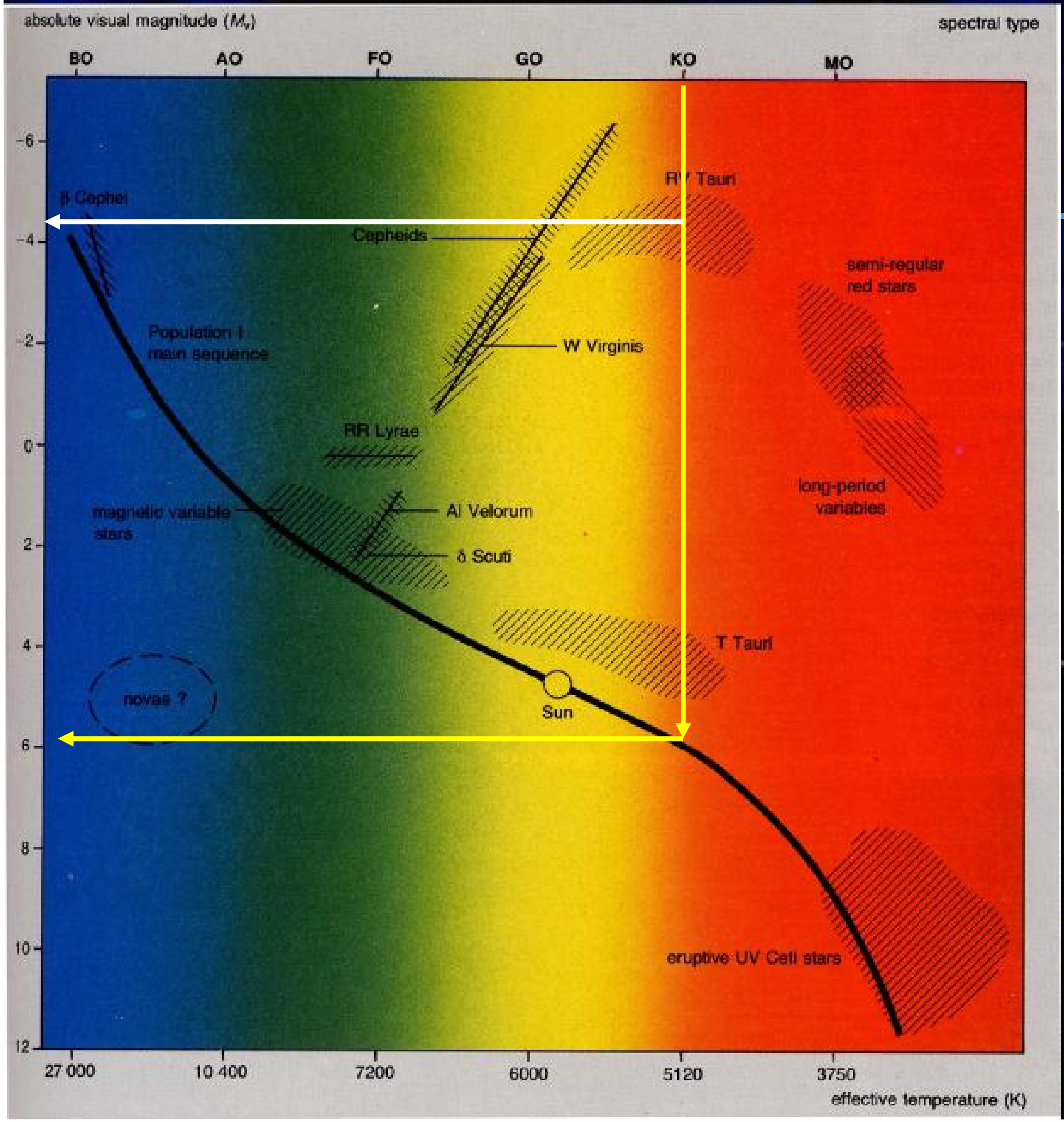
Betelgeuse: M1 I

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
Arcturus
Aldebaran
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

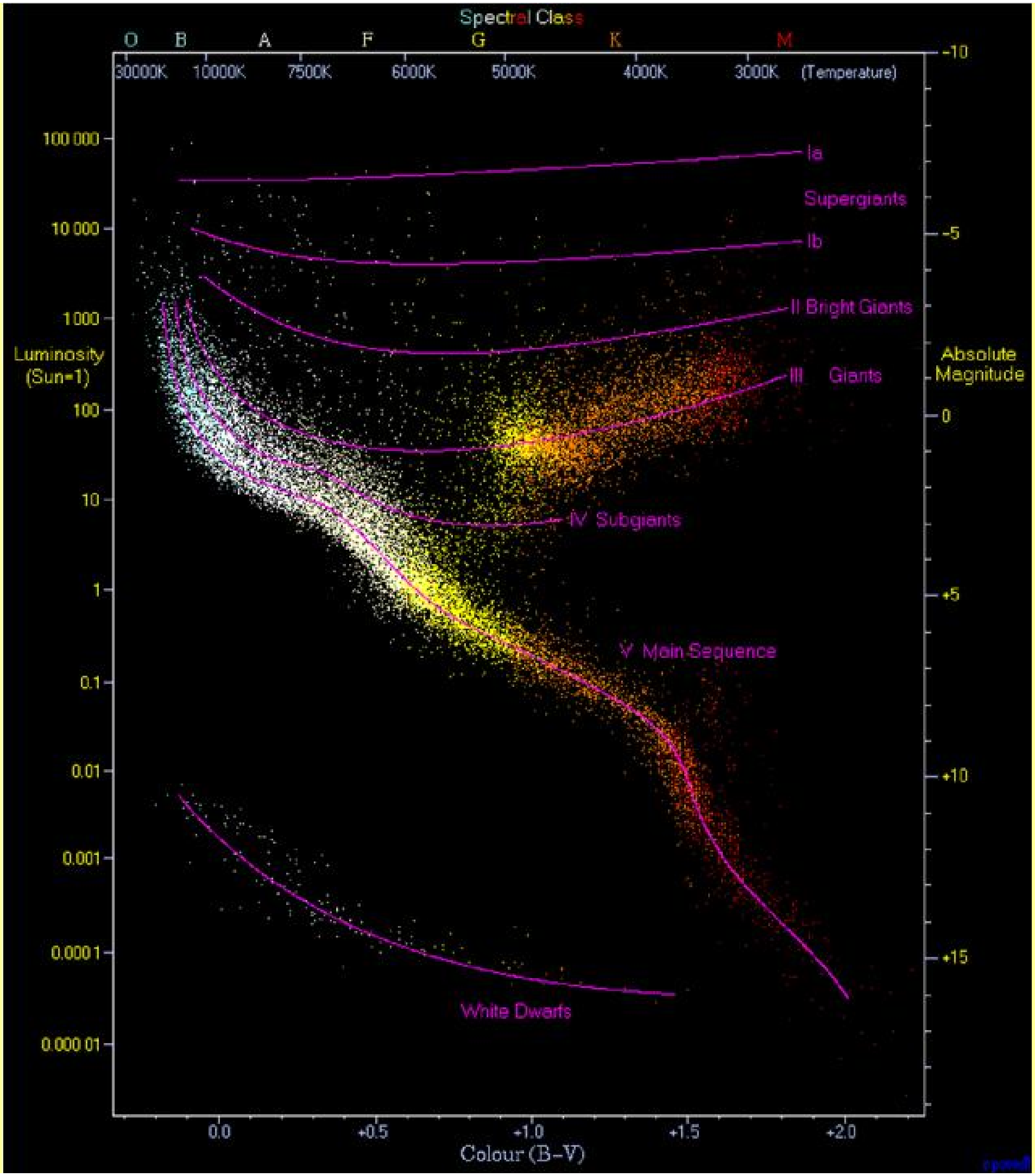
Example: Record spectrum of star and find it is K0 V type

Read off Mv

Determine visual mag, m_v

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

100 fold error in d



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