STARS - S02

Wladimir (Wlad) Lyra
Brian Levine

AMNH After-School Program

From last class

Stars are fusors in hydrostatic equilibrium

Four Hydrogen nuclei (protons) -> Helium nucleus.

Difference in mass is converted into energy.

Below 0.08 $M_\odot$, no nuclear fusion, above 120 $M_\odot$, no hydrostatic equilibrium

HR Diagram (Luminosity-Temperature) is a powerful tool to study stars

OBAFGKM – the spectral sequence

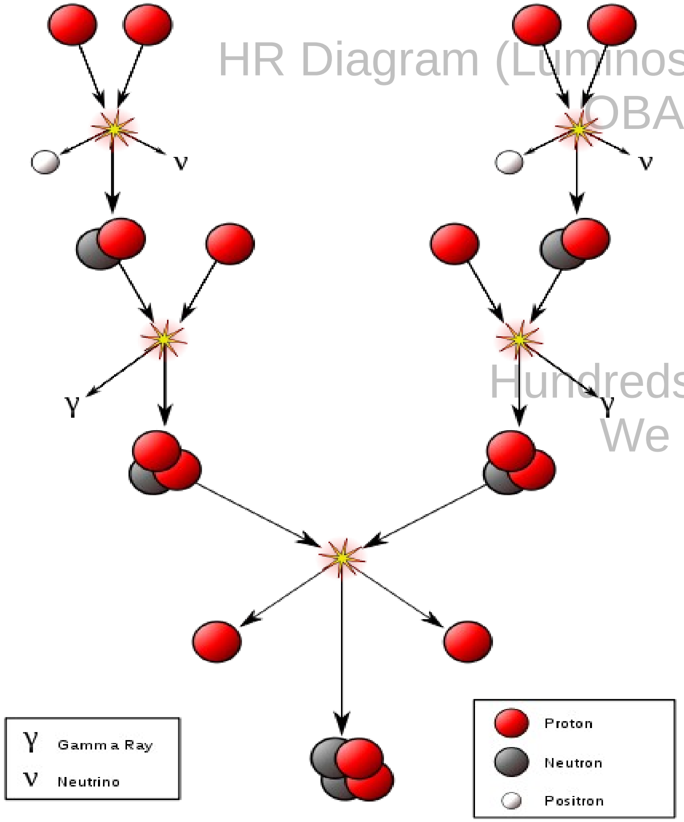
Hot stars – Blue

Cold stars – Red

Hundreds of billions of stars in the Milky Way

We only see 6000 in the night sky

Dust obscures our vision



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Oh Be A Fine Girl/Guy Kiss Me

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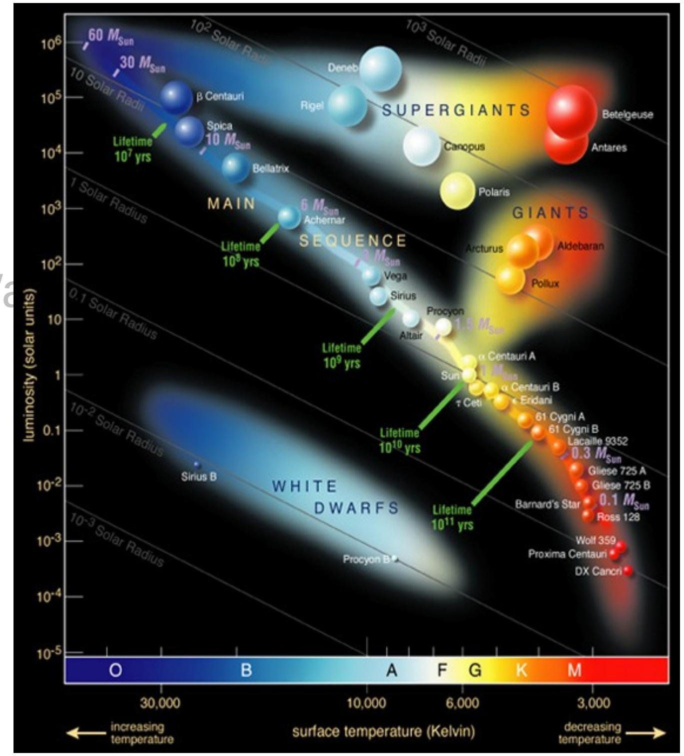

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GKM – the s

Hot star

Cold sta

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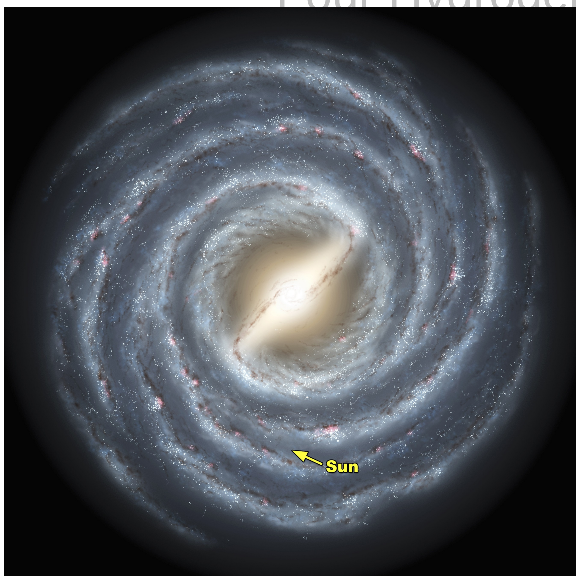
Globular clusters form c

Open clusters form continuously in the galaxy's disk

Most stars are in multiple systems



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Outline

- Math primer : logarithms and exponentials

- How bright are stars?
  - Apparent and absolute magnitudes
  - Flux
  - Luminosity

- Parallax and distances

- Thermal radiation
  - Stefan-Boltzmann law
  - Wien's law

Brian's examples

Logarithm identities

$$\boxed{\log xy = \log x + \log y} \iff 10^m 10^n = 10^{m+n}$$

$$\boxed{\log x/y = \log x - \log y} \iff 10^m/10^n = 10^{m-n}$$

$$\boxed{\log x^y = y \log x} \iff (10^m)^n = 10^{mn}$$

$$\boxed{10^{\log x} = x}$$

The logarithmic function
is the inverse of the exponential function!

A math primer: exponentials and logarithms

$$5^x = 7$$

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$$\log 5^x = \log 7$$

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A math primer: exponentials and logarithms

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$$x = \frac{\log 7}{\log 5} = 1.2090620$$

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$$\log_b x = n \quad \Longleftrightarrow \quad b^n = x$$

To say that

" **the logarithm of *x* at base *b* is *n*** "

means that

" **the base *b* to the power *n* is equal to *x*** "

What is the log of 1?

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$$x = 0$$

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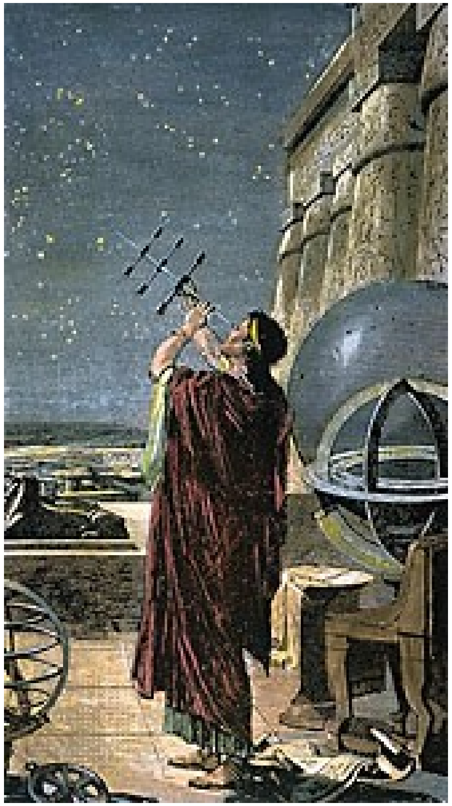
$$\boxed{\log_b 1 = 0}$$

Stellar Magnitudes

Now here goes something *really* ancient....

A guy called Hipparchus (190BC – 120BC) thought it a good idea to come up with the following scheme

- The brightest stars we see are of **first magnitude**
- Stars not so bright are of **second magnitude**
- The faintest stars we can see are of **sixth magnitude**



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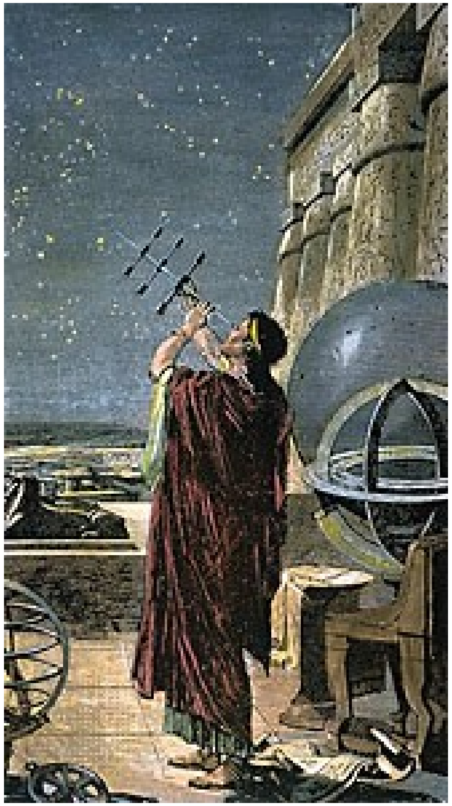

Bright - Magnitude 1
Dim - Magnitude 6

The scale is ***reverse!***

Big magnitude – Dim

Small (or negative) magnitude - Bright

Stellar Binocular

Magnitude 9

Amateur 6 inch

Magnitude 13

Hubble Space Telescope

Magnitude 30

Stellar Binocular

Magnitude 9

15 times dimmer than faintest for the naked eye

Amateur 6 inch

Magnitude 13

630 times dimmer than faintest for the naked eye

Hubble Space Telescope

Magnitude 30

$\mathbf{4 \times 10^9}$ times dimmer than faintest for the naked eye

The magnitude scale is *logarithmic!*

Why?

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Why?

Because the *eye's response* is (nearly) logarithmic

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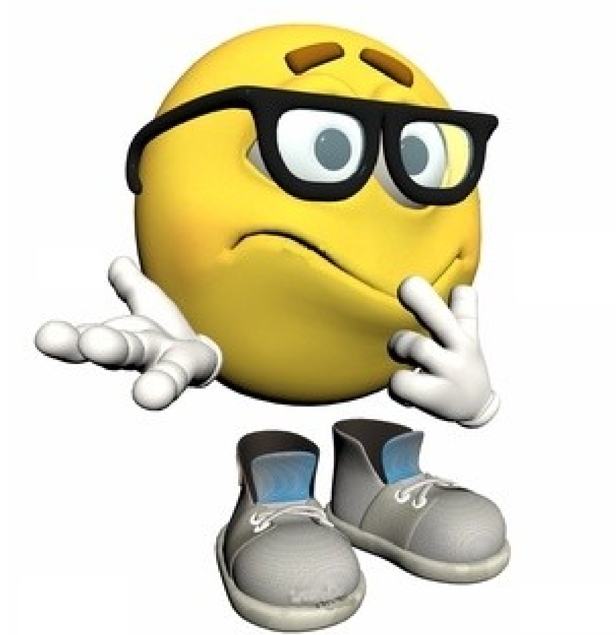

Really?

The Moon is 500,000 times dimmer than the Sun as seen from Earth

Yet one can read with nothing but moonlight....

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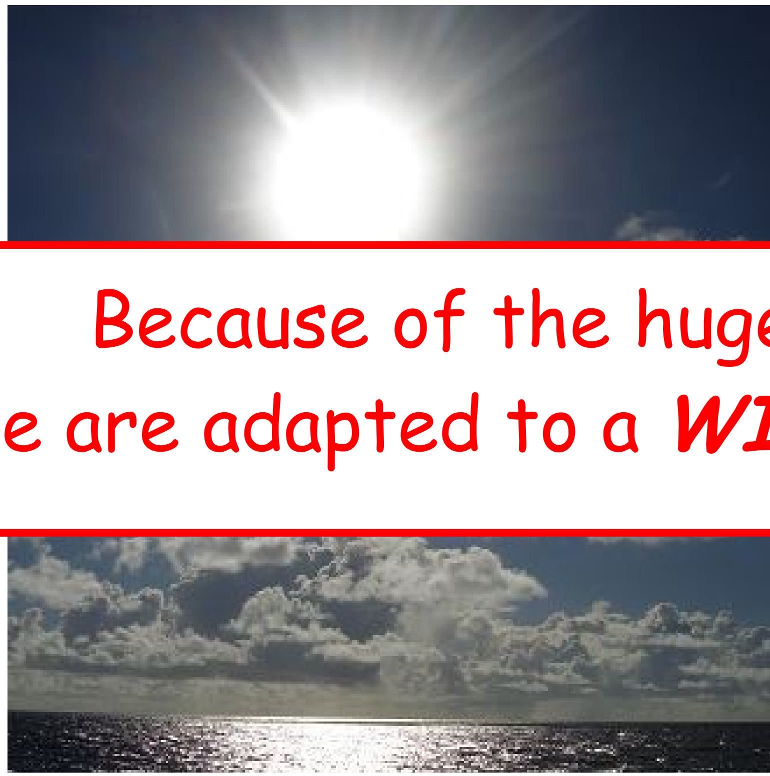
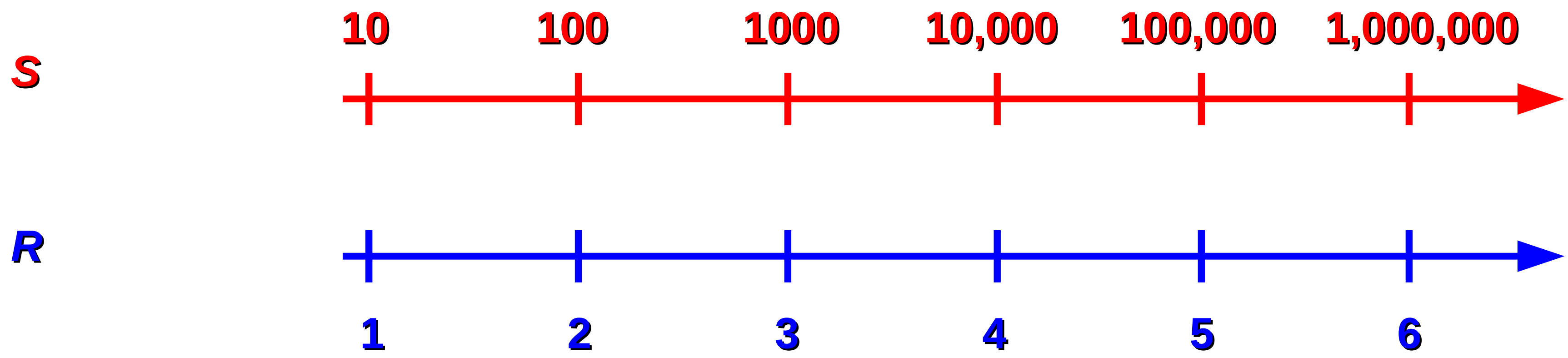


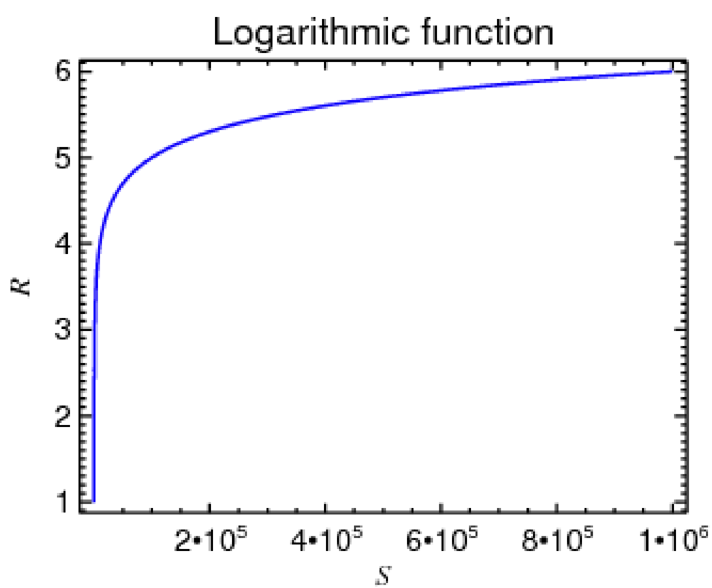
Because of the huge day-night contrast,
we are adapted to a ***WIDE RANGE*** in brightness

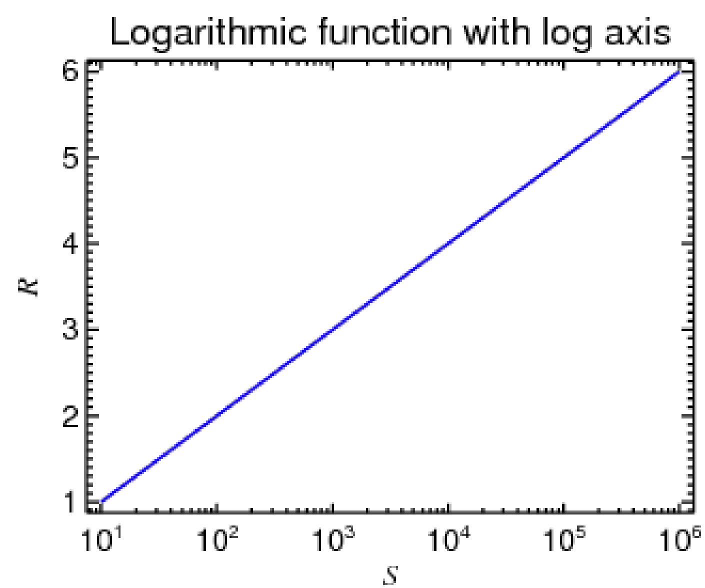
Yet one can read with nothing but moonlight....

For wide range, use a Logarithmic Axis



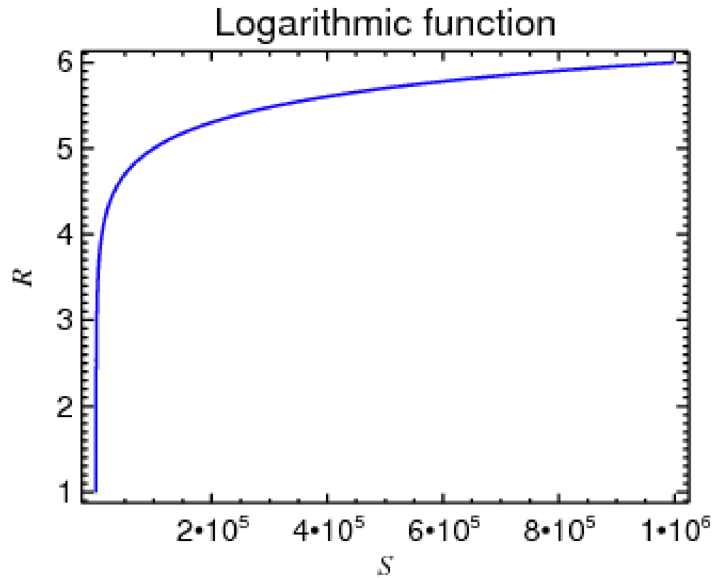
$$R = \log S$$

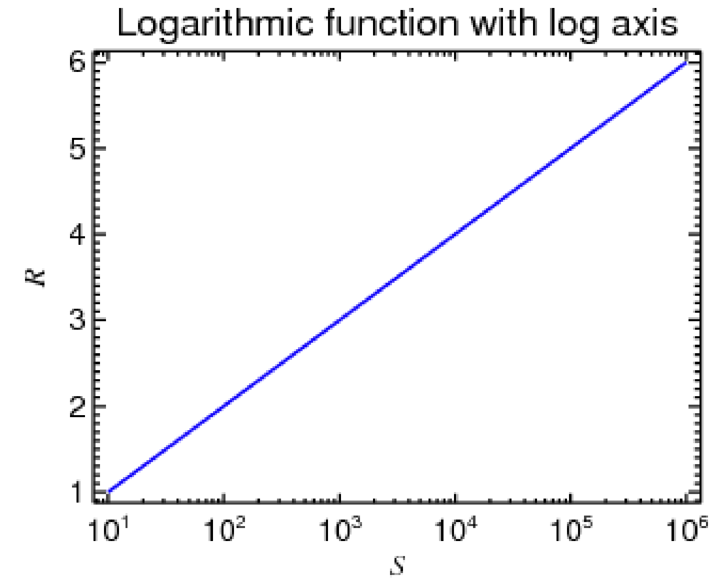




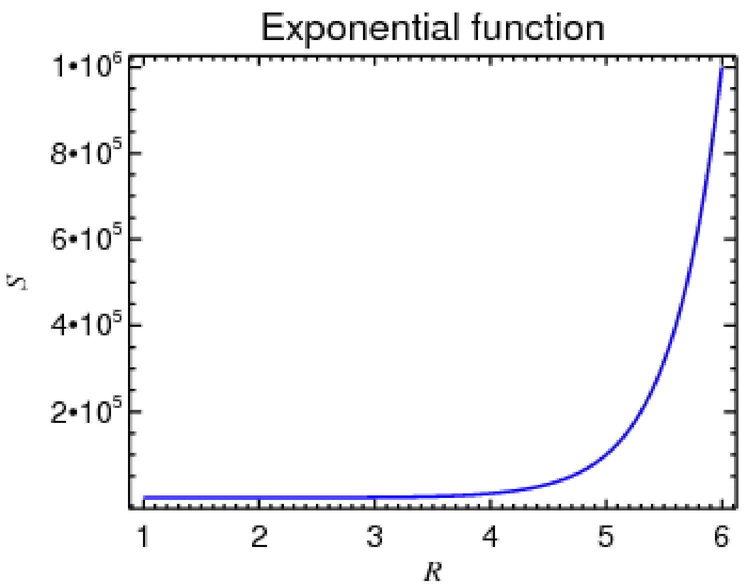
Logarithmic axes turn logs into straight lines

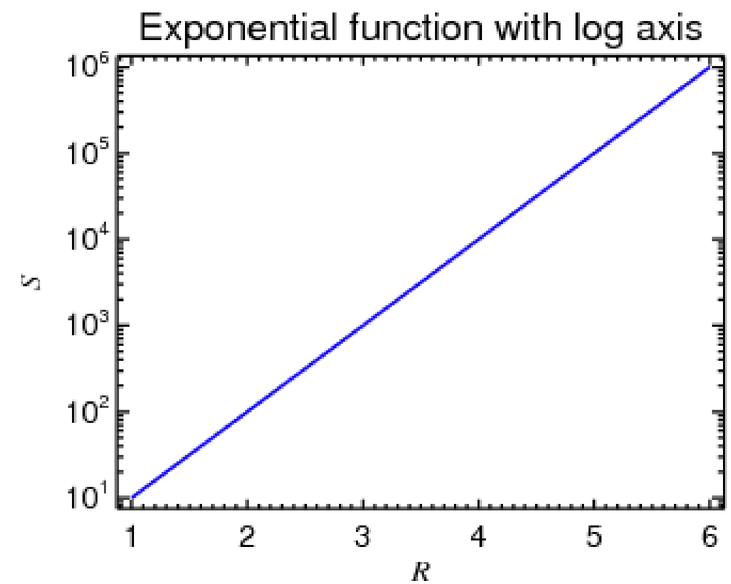
$$R = \log S$$


Logarithmic function
R
S
1
2
3
4
5
6
2•10^5
4•10^5
6•10^5
8•10^5
1•10^6


Logarithmic function with log axis
R
S
1
2
3
4
5
6
10^1
10^2
10^3
10^4
10^5
10^6

$$S = 10^R$$


Exponential function
S
R
2•10^5
4•10^5
6•10^5
8•10^5
1•10^6
1
2
3
4
5
6


Exponential function with log axis
S
R
10^1
10^2
10^3
10^4
10^5
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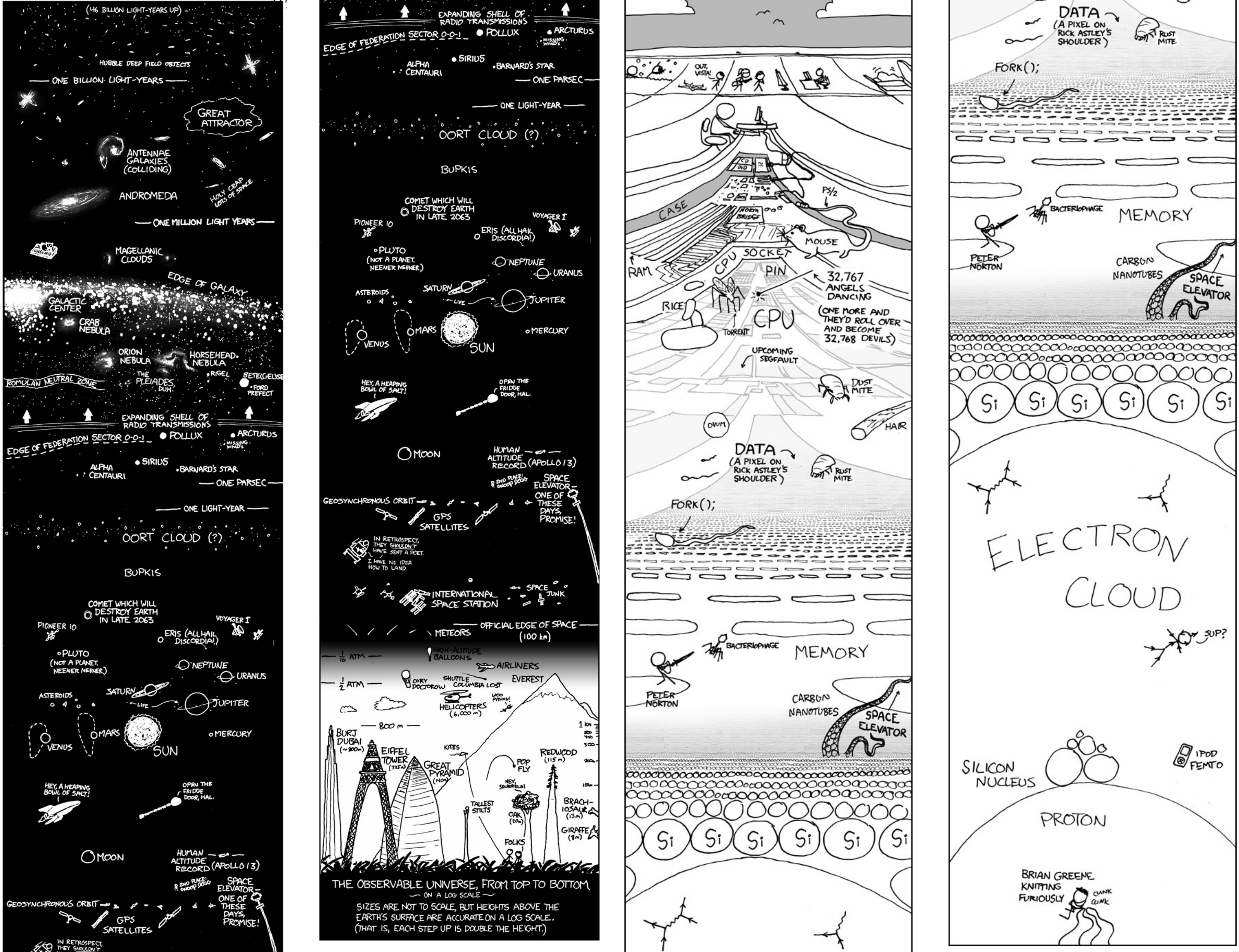
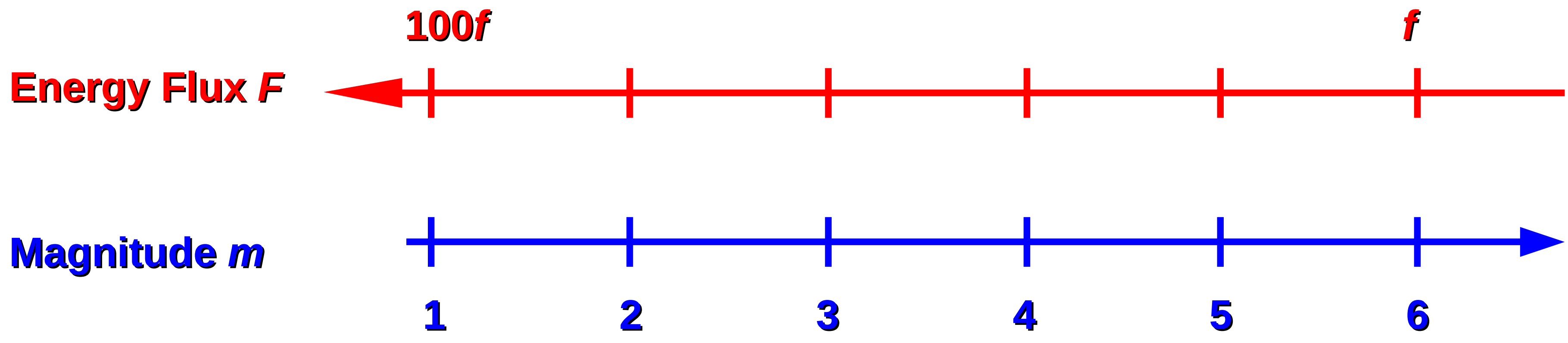
1
2
3
4
5
6



THE OBSERVABLE UNIVERSE, FROM TOP TO BOTTOM
— ON A LOG SCALE —
SIZES ARE NOT TO SCALE, BUT HEIGHTS ABOVE THE EARTH'S SURFACE ARE ACCURATE ON A LOG SCALE. (THAT IS, EACH STEP UP IS DOUBLE THE HEIGHT.)

How about magnitudes?

A difference of five magnitudes amounts to a factor 100 in brightness



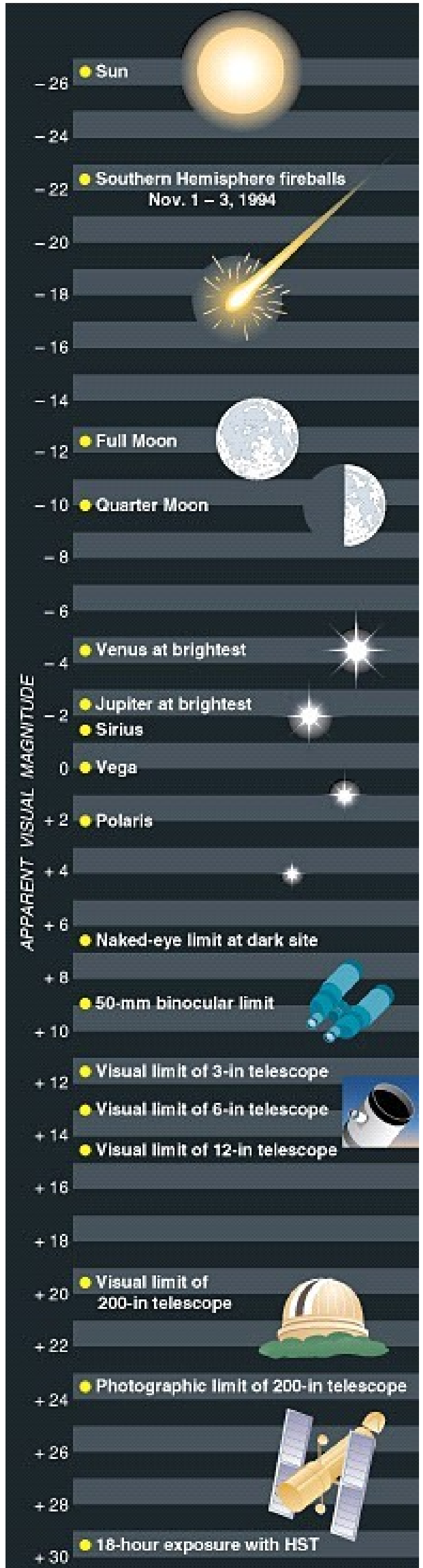
$$m = -2.5 \log F + C$$

m - stuff that Hipparchus came up with

F - stuff that has physical meaning

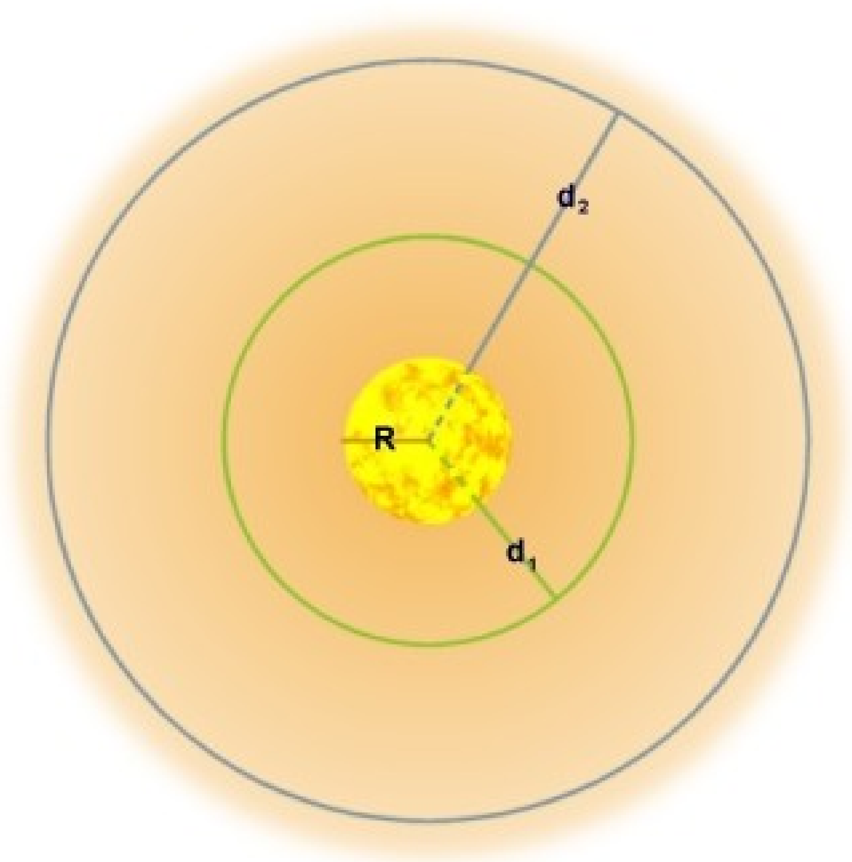
C - constant that make the two systems match

The system is tied so that Vega's magnitude is ZERO

-26		Sun
-22		
-18		Comet
-12		Full Moon
-10		Quarter Moon
-4		Venus at brightest
-2		Jupiter at brightest
0		Vega
2		Polaris
6		Naked-eye limit at dark site
9		50mm binocular limit
11		Visual limit of 3-in telescope
13		Visual limit of 6-in telescope
15		Visual limit of 12-in telescope
20		Visual limit of 200-in telescope
24		Photographic limit of 200-in telescope
30		18-hour exposure with HST

Now what is flux?

$$\text{Flux} = \frac{\text{Energy}}{\text{Time} * \text{Area}}$$



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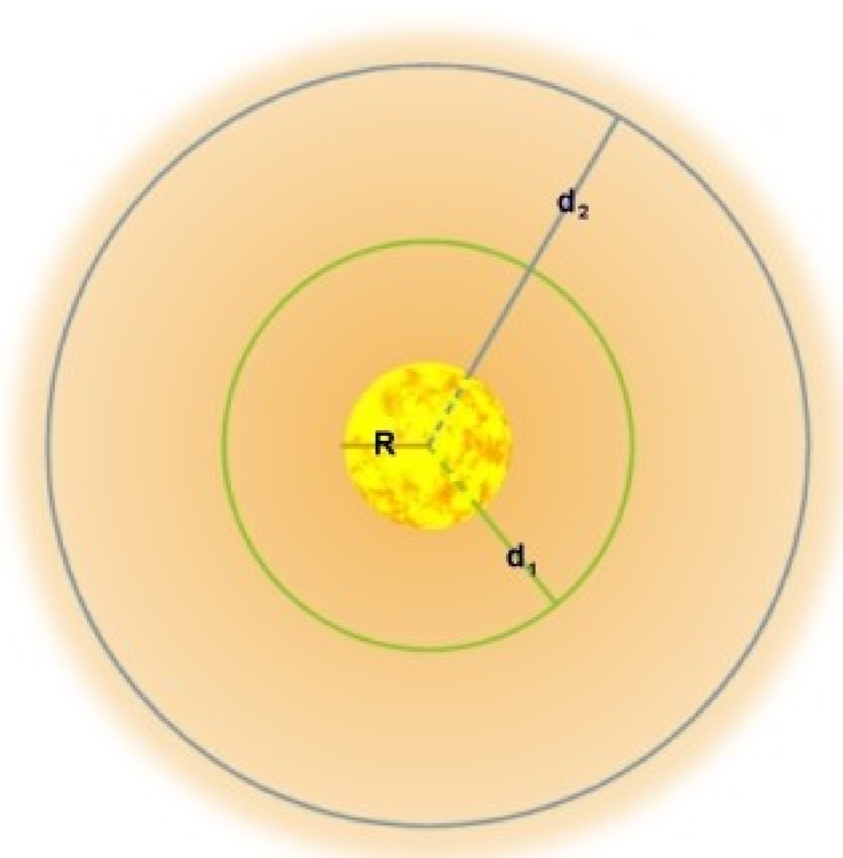

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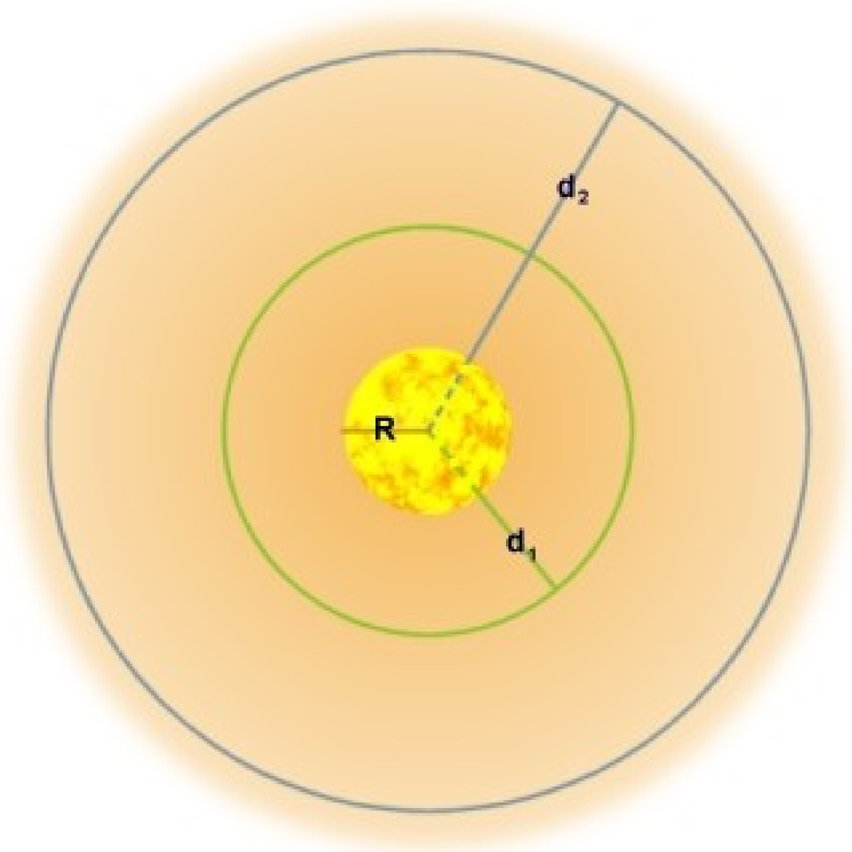

Energy is conserved...

So Area*Flux is constant

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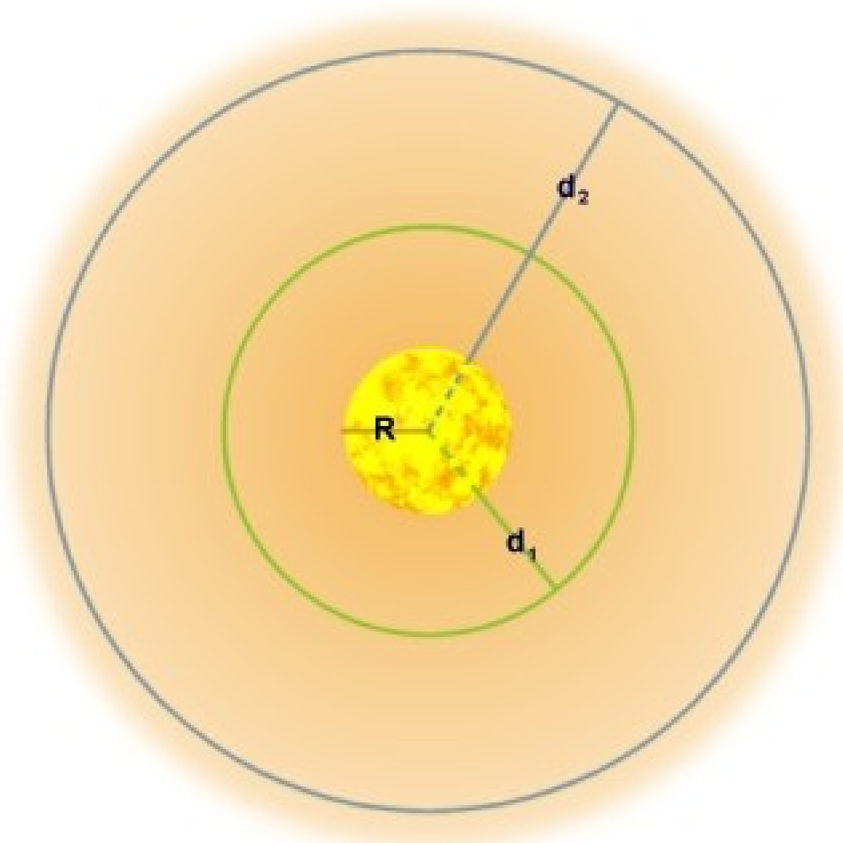

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(in astronomy called *Luminosity*)

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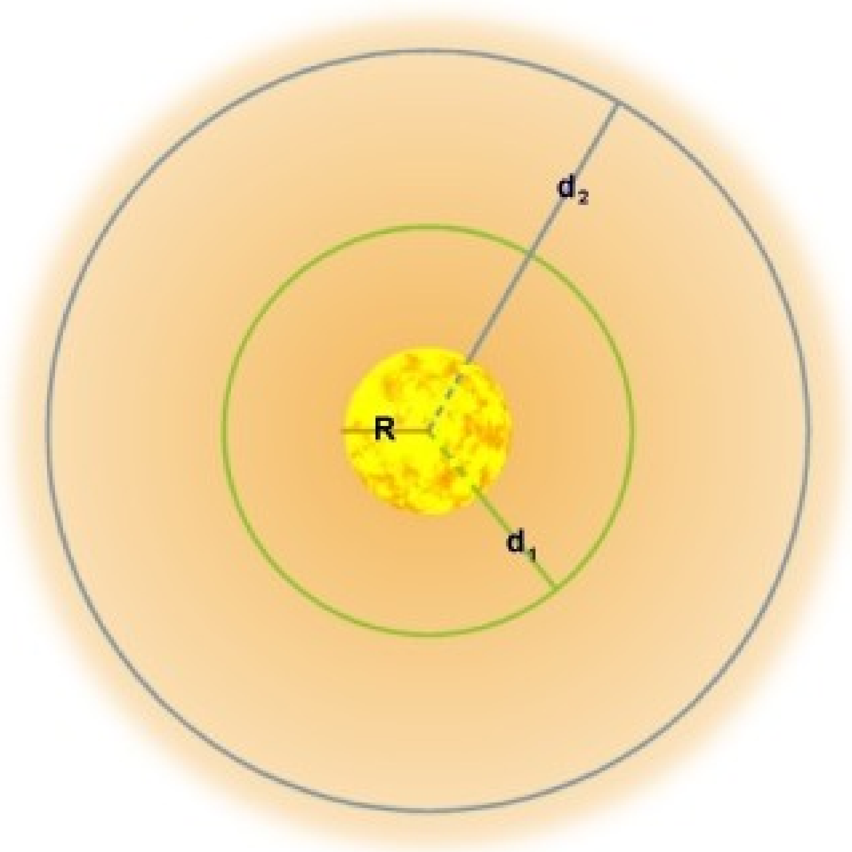

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Luminosity = Area*Flux = Const

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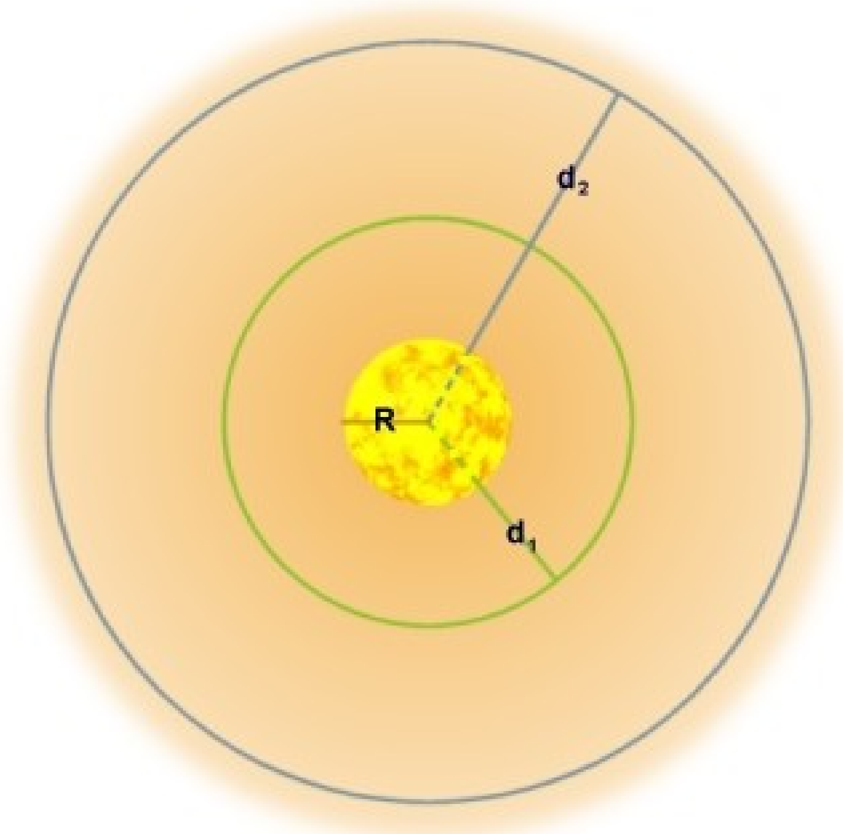
Luminosity = Area*Flux = Const

$$L = 4\pi R^2 F_R$$
$$= 4\pi d_1^2 F_1$$
$$= 4\pi d_2^2 F_2$$

$$\boxed{F(r) \propto 1/r^2}$$



The flux follows an inverse square law!

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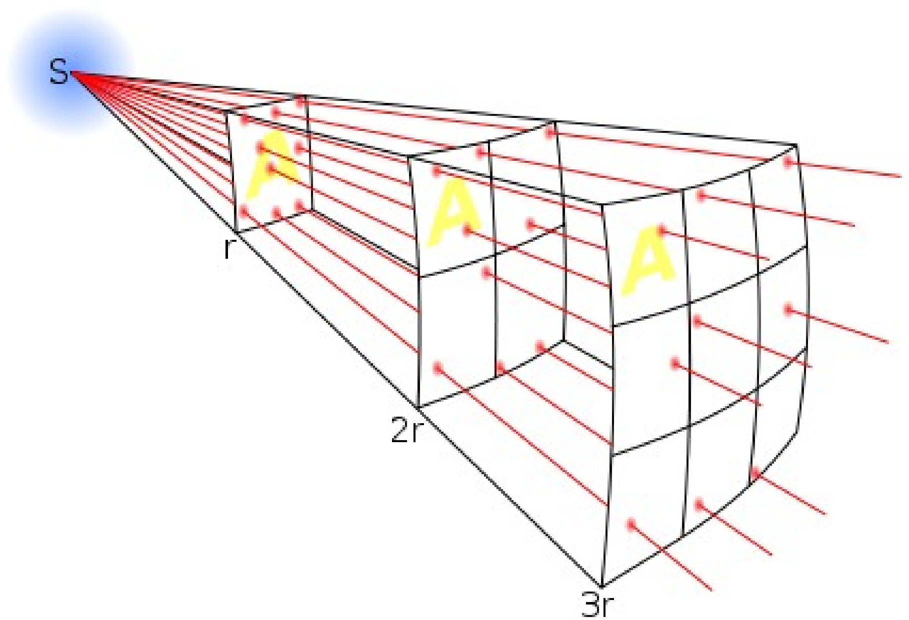

The flux follows an inverse square law!

As distance increases, the same energy spreads through a larger area

Flux follows an inverse square law

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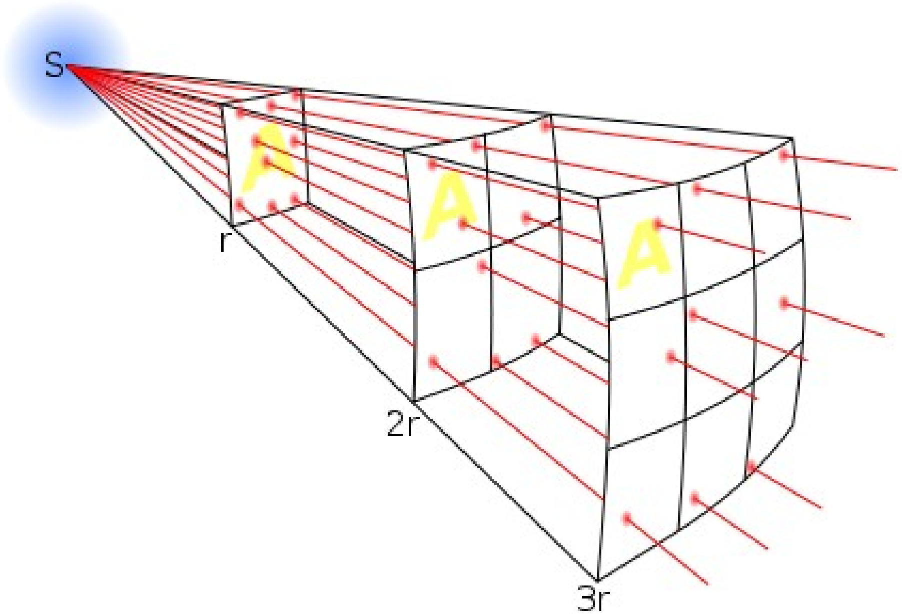
$$m = -2.5 \log F + C$$



As distance increases, the same energy spreads through a larger area

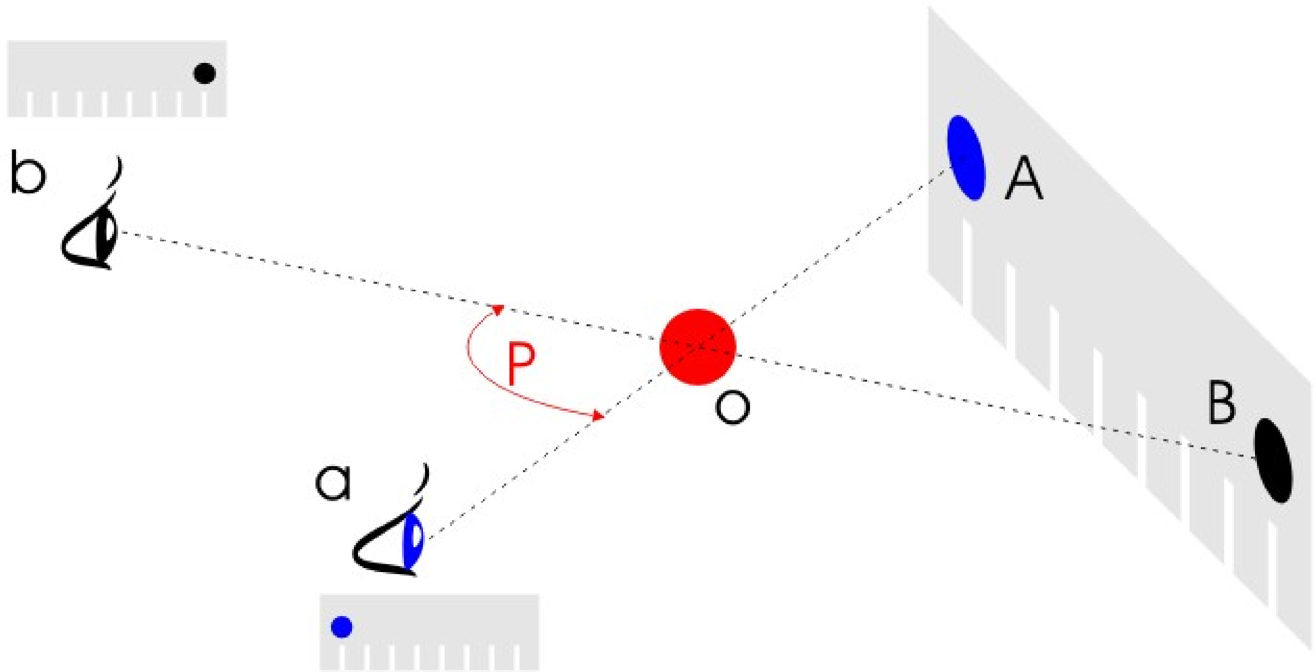
- Flux, thus the magnitude, depends on ***distance***.

- The stellar magnitudes we ***measure*** are therefore ***apparent***, because stars are at different distances from us.

- For an ***absolute*** magnitude, we need a ***standard distance***.

Astronomical distances or...
say goodbye to *light-year*

Parallax



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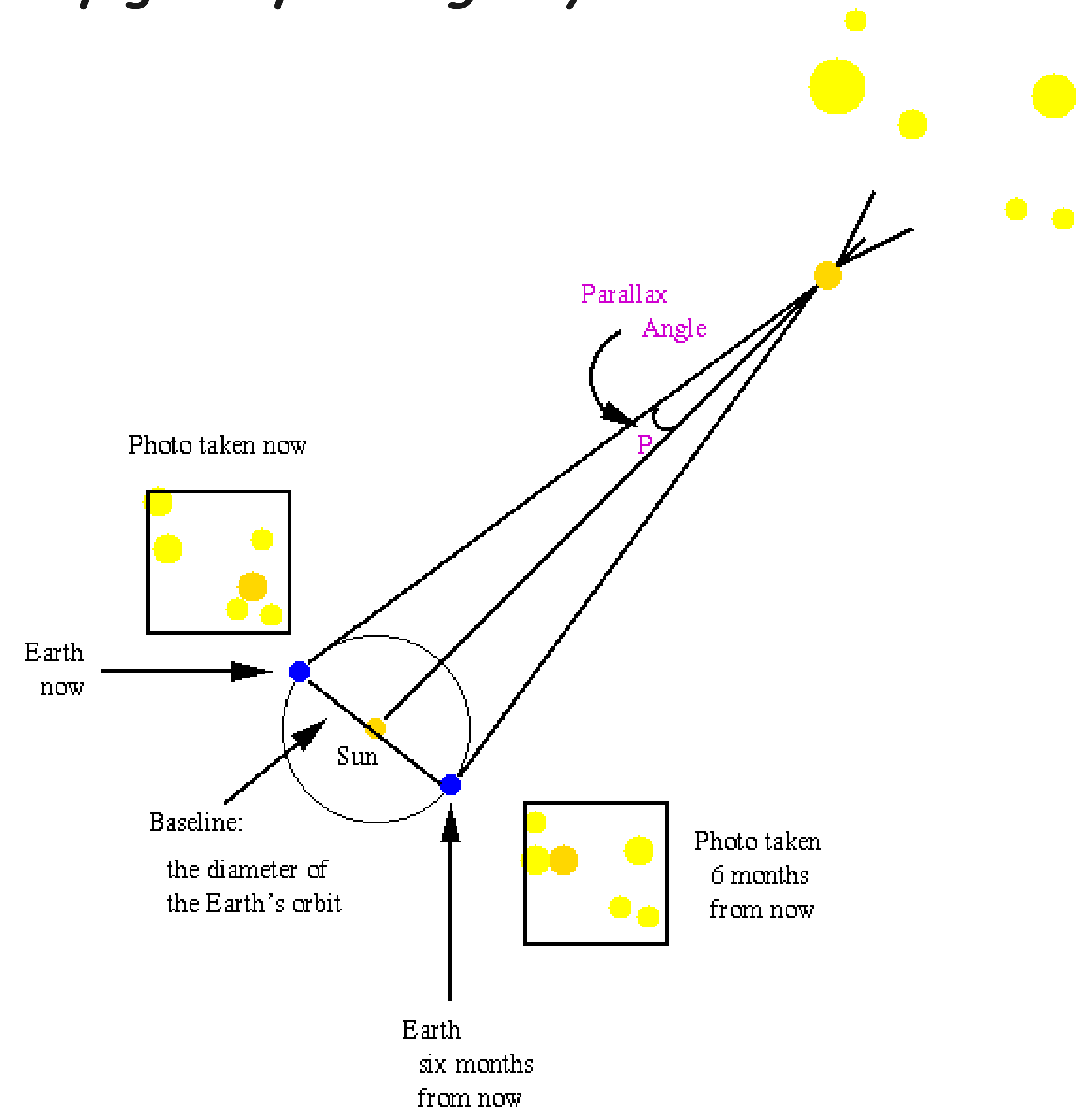
Parallax (p)



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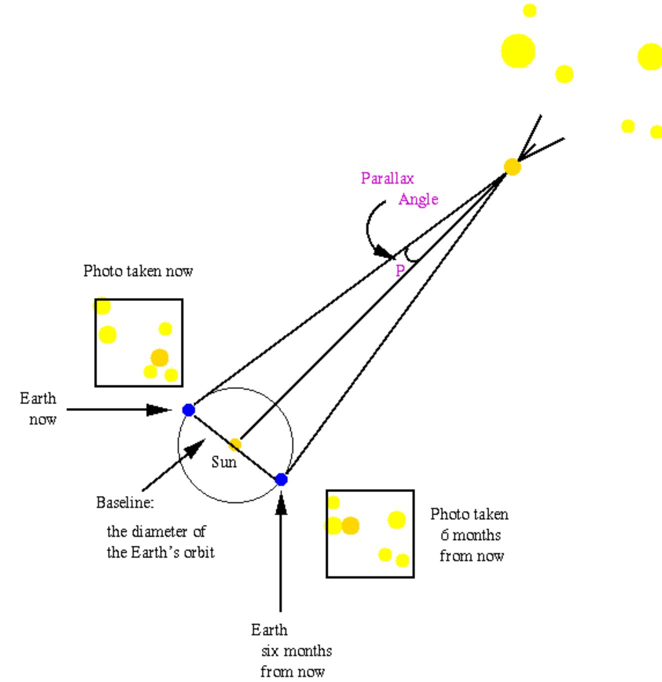

Parsec (pc)

Distance at which
the parallax is one arcsecond

1 pc = 3.26 ly

$$d\ (\mathrm{pc}) = 1/p$$

(by definition)

Astronomical distances or...
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Parallax (p)

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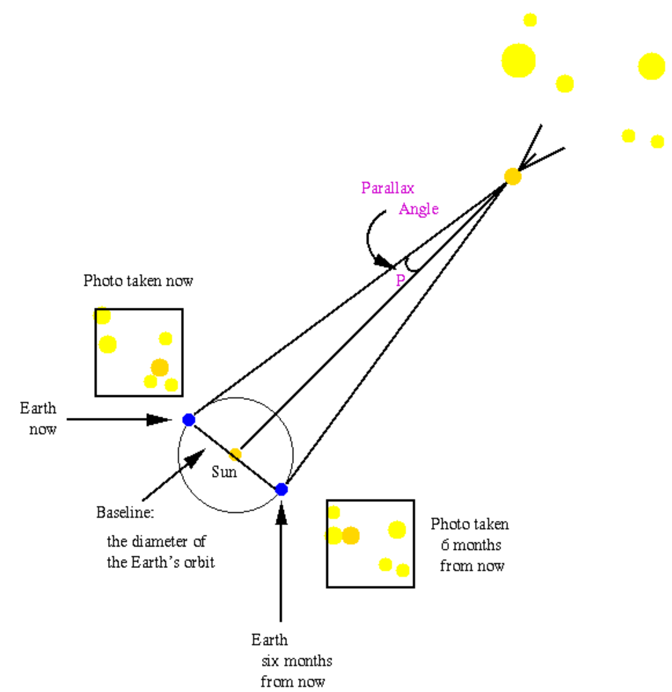

Define a standard distance where to compare magnitudes

D=10 pc

Apparent magnitude

The magnitude of a star as we see it.

$$m = -2.5\log\left(\frac{L}{4\pi d^2}\right) + C$$

Absolute magnitude

The magnitude a star would have if placed 10 pc away

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

$$d\,(pc) = 10^{0.2(m-M)+1}$$

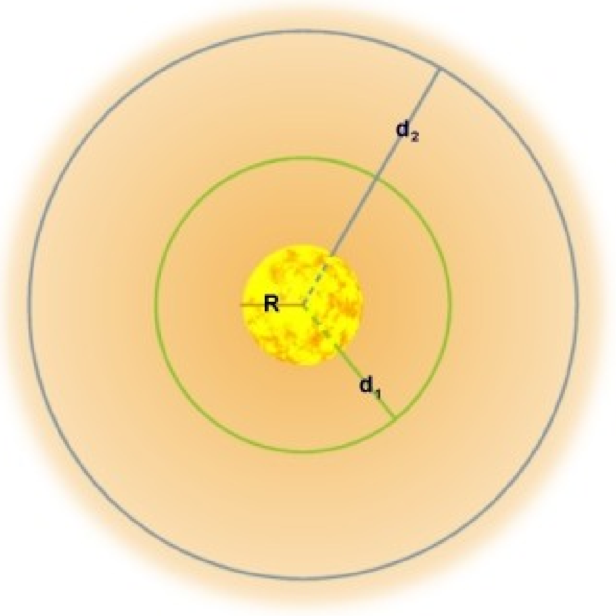
$\mu = m - M$

Distance modulus

Luminosity

At the surface of the star, $L = 4\pi R^2 F_R$

What is the flux at the surface of the star?



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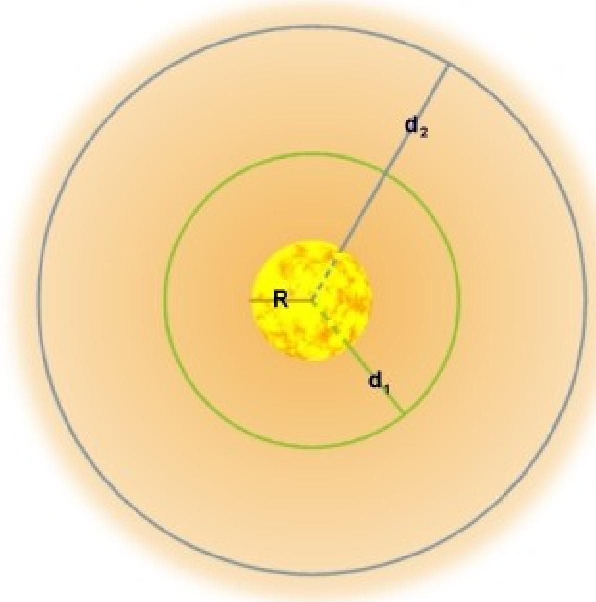

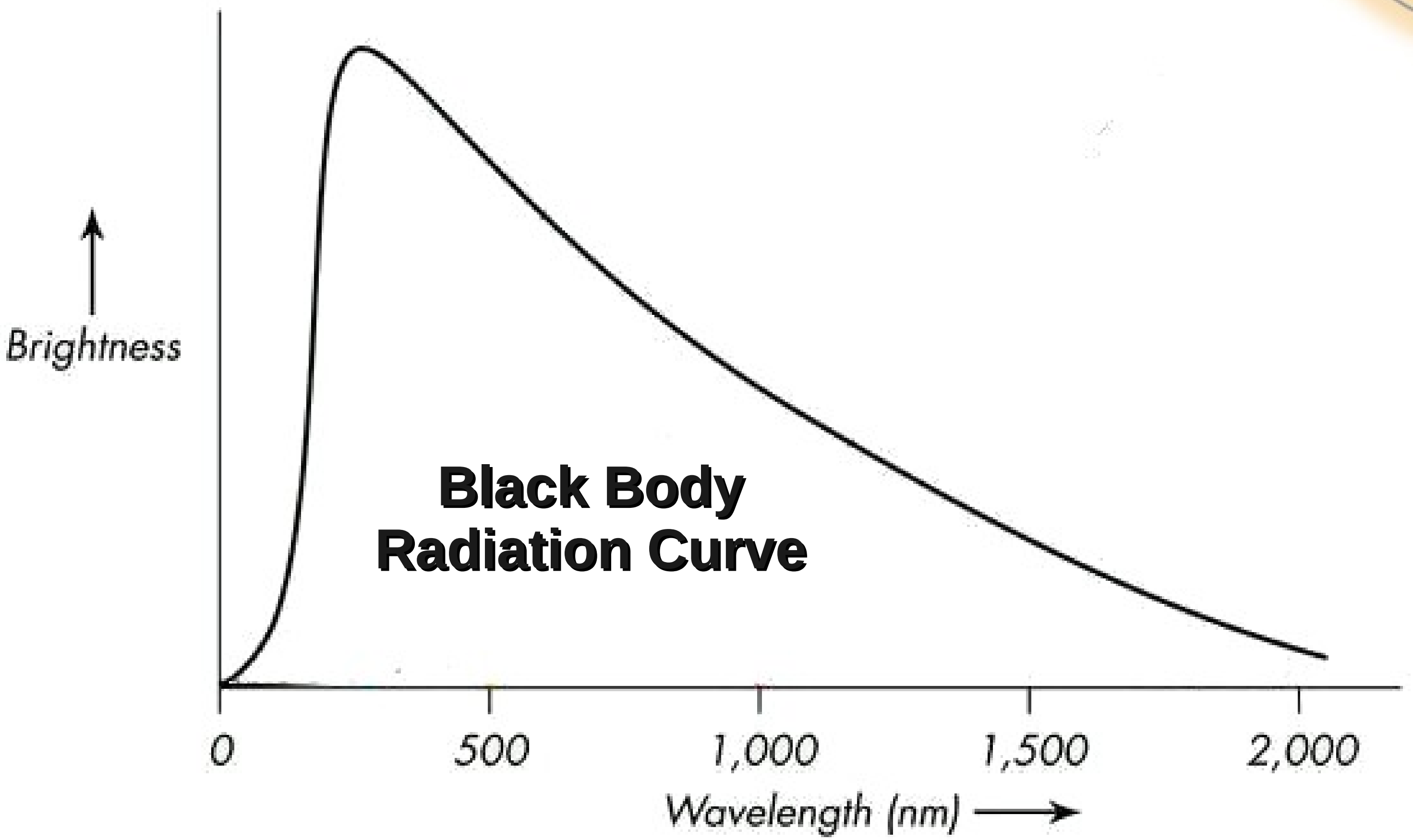

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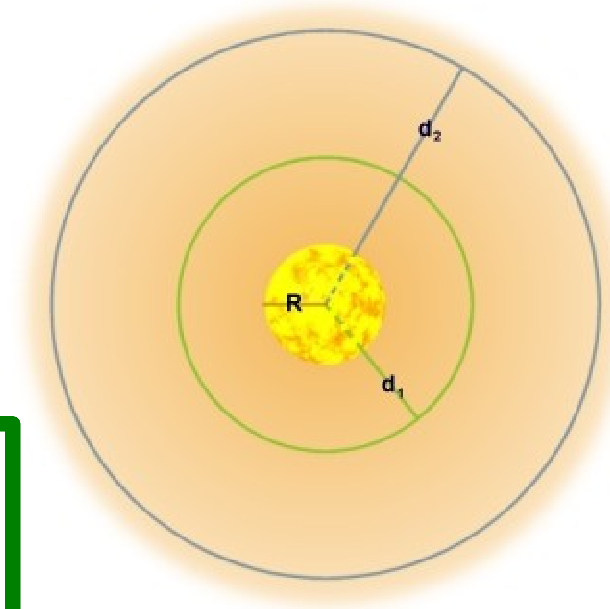
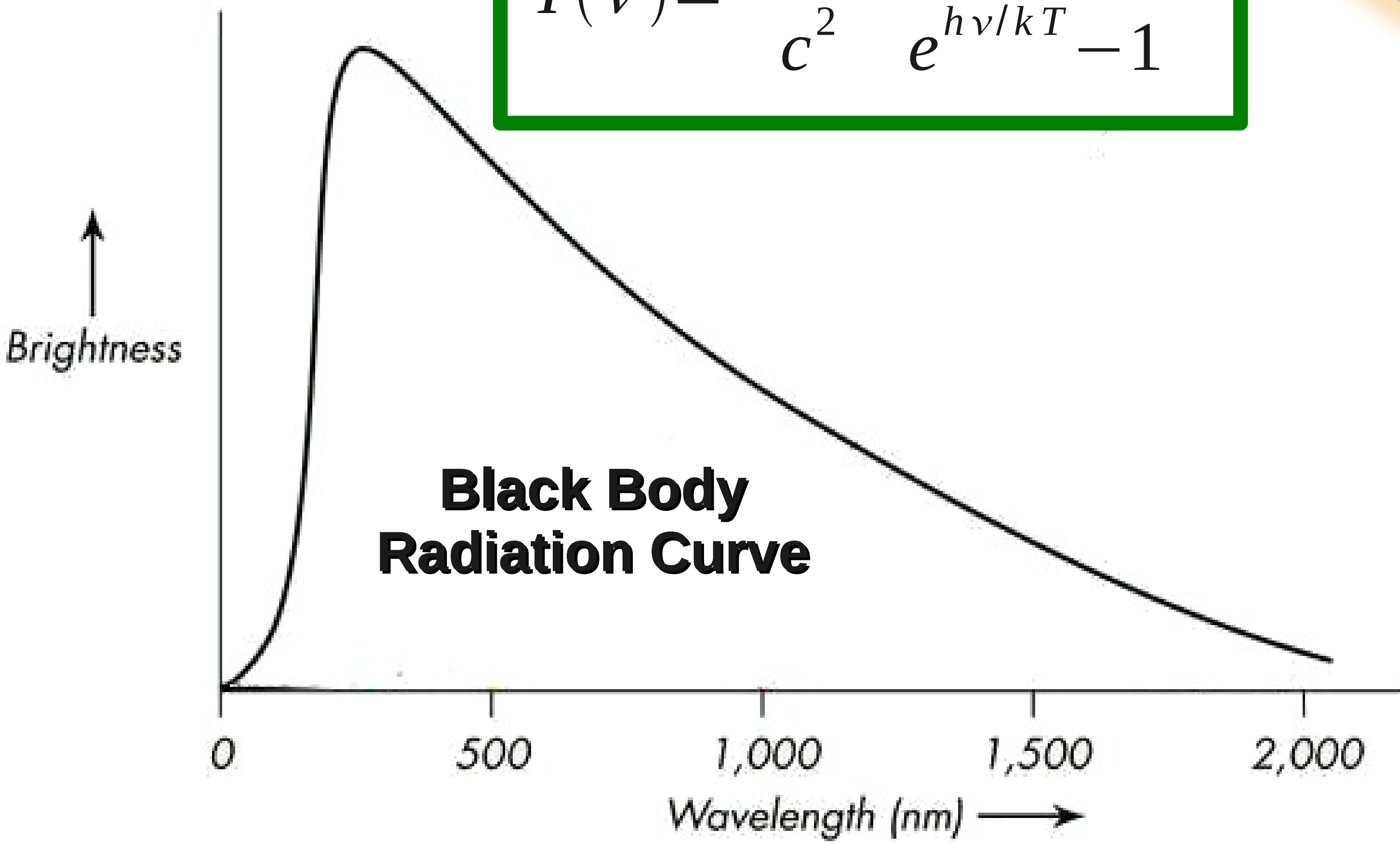


Planck law

$$\boxed{I(\nu) = \frac{2h\nu^2}{c^2}\frac{h\nu}{e^{h\nu/kT} - 1}}$$



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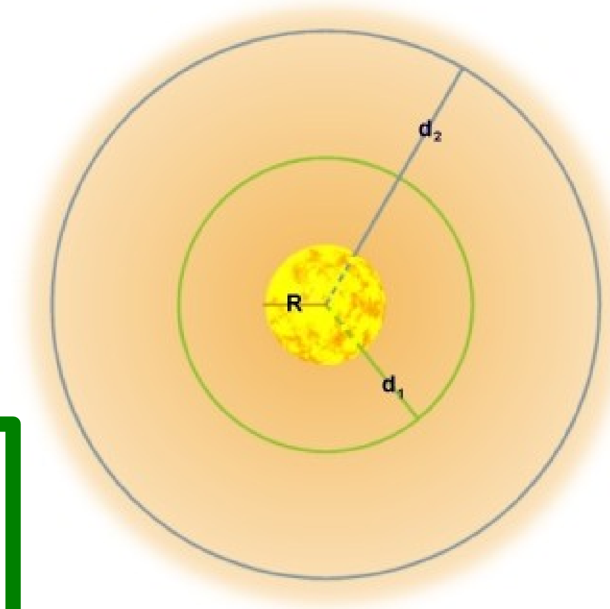

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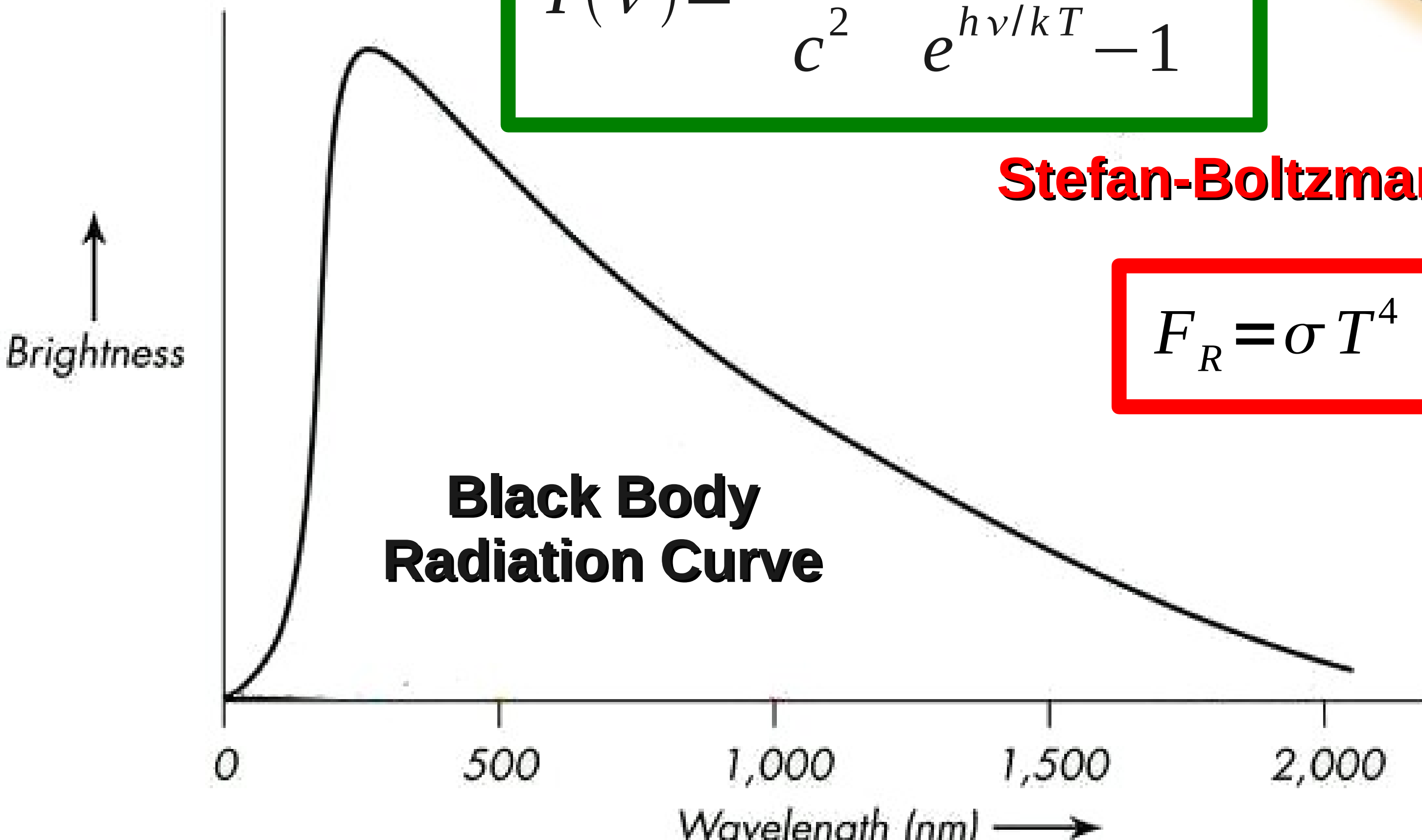
$$I(\nu) = \frac{2h\nu^2}{c^2} \frac{h\nu}{e^{h\nu/kT} - 1}$$

Stefan-Boltzmann law

$$F_R = \sigma T^4$$



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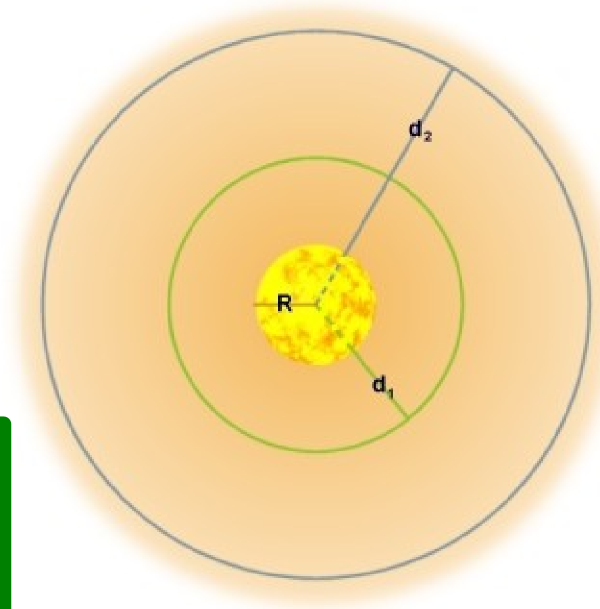

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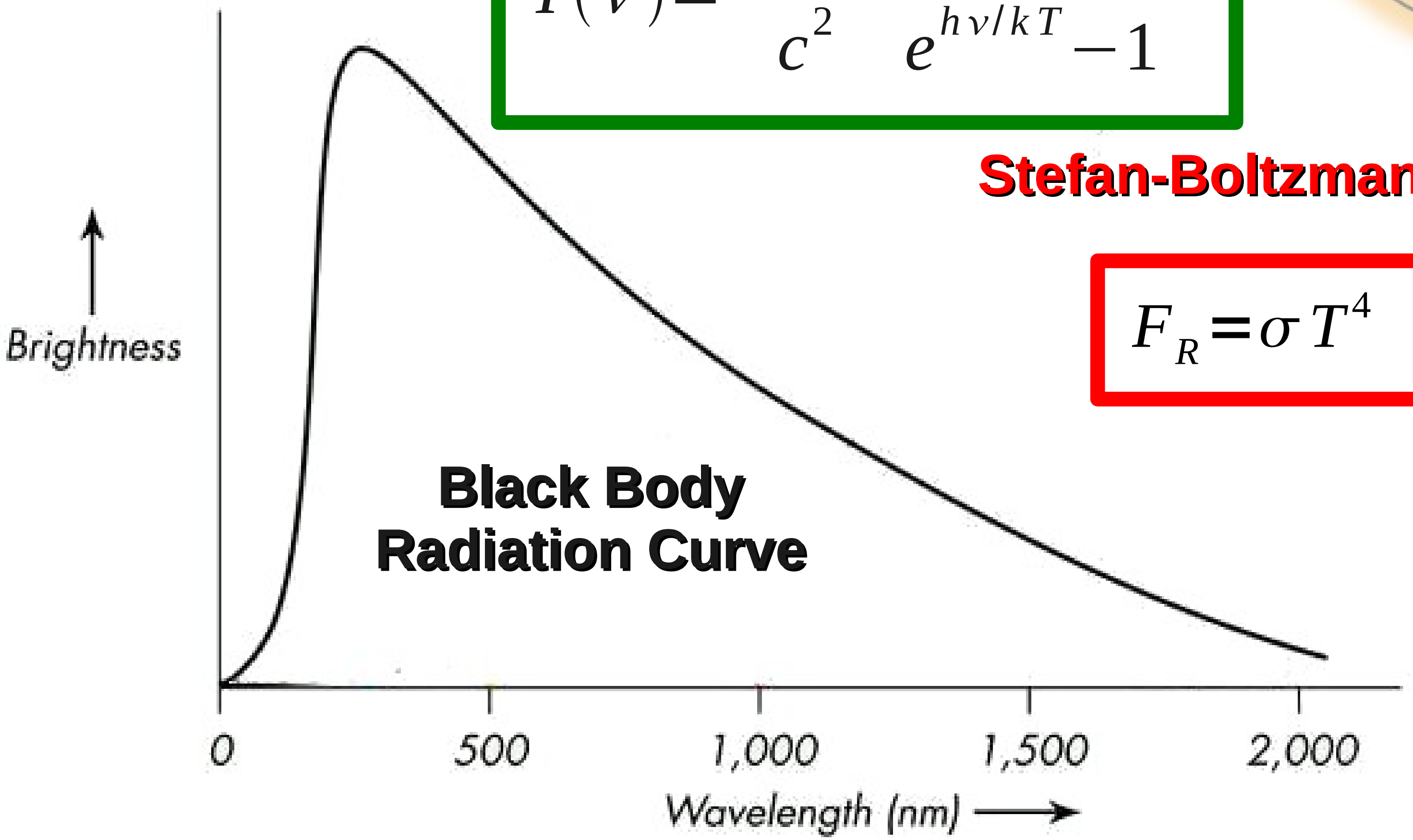


Stefan-Boltzmann law

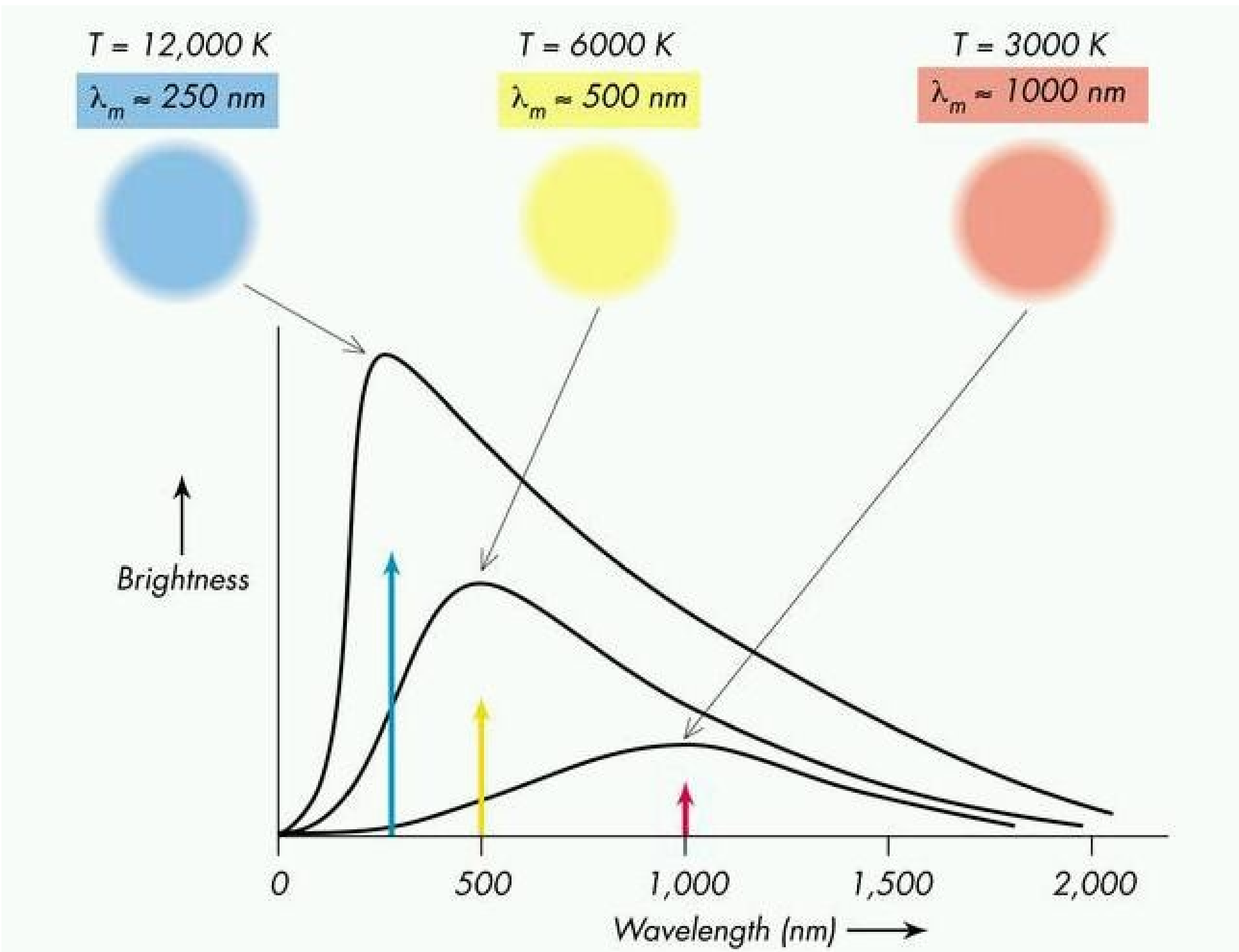
$$\boxed{F_R = \sigma T^4}$$

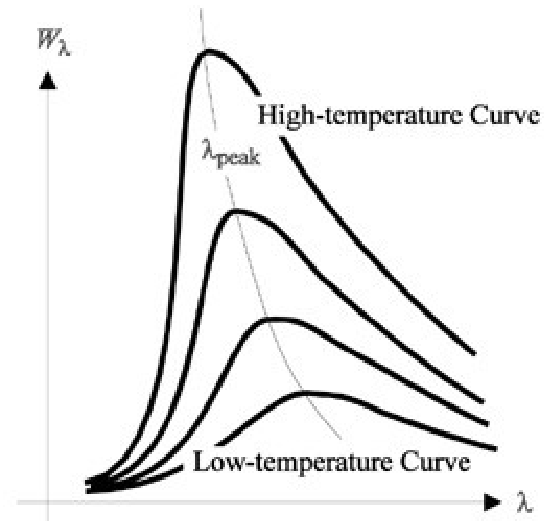
Luminosity

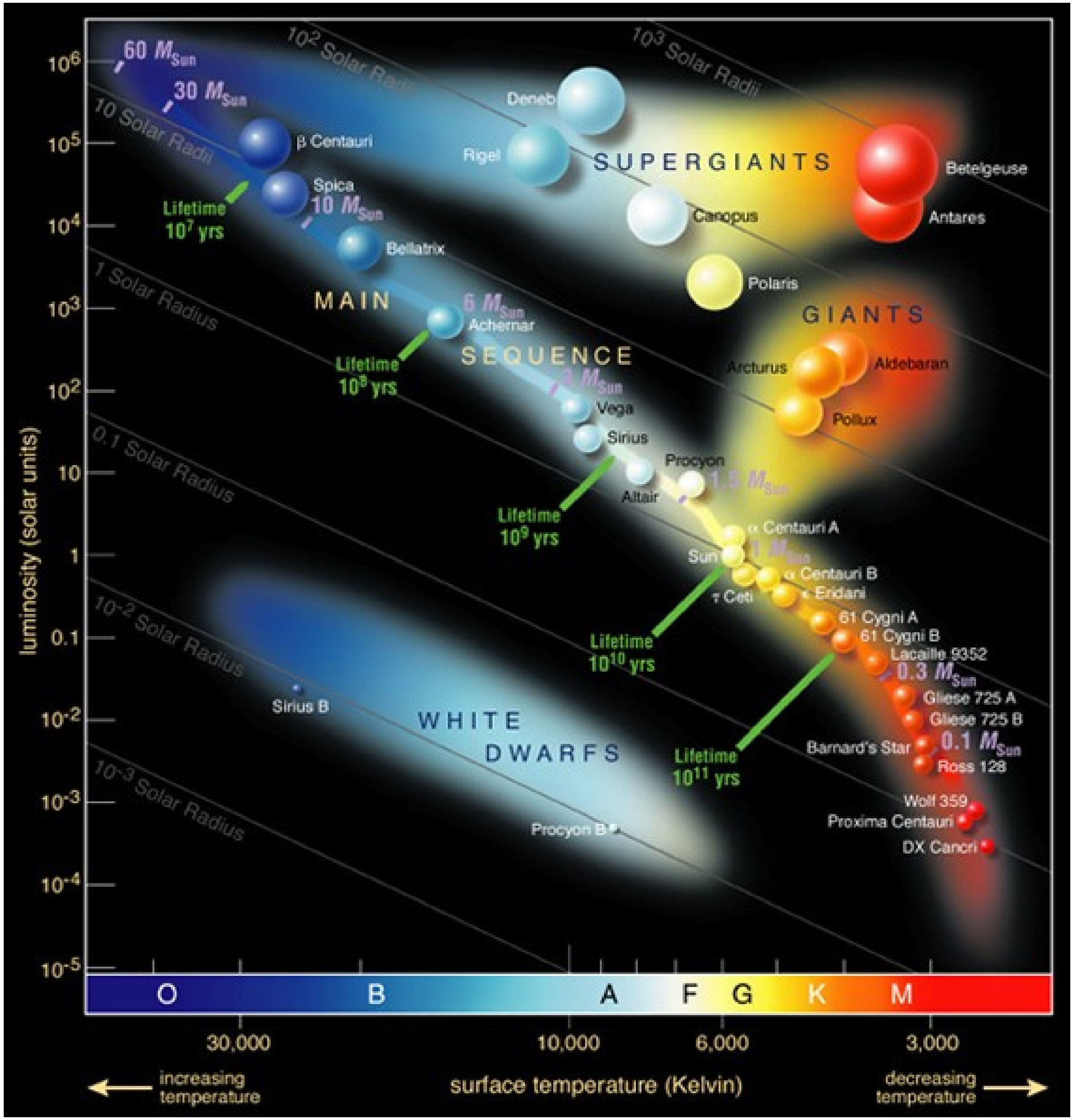
$$\boxed{L = 4\pi R^2 \sigma T^4}$$

Wien's displacement law

$$\lambda_{max} T = const = 2.898 \times 10^{-3}\, m\, K$$







$$L = 4\pi R^2 \sigma T^4$$

$$\lambda_{max} \propto 1/T$$

- **Luminosity is a function of radius and a strong function of temperature**
- **The wavelength of peak brightness goes bluer as the temperature rises**

Let's summarize

Logarithms convert multiplications into additions
Useful when dealing with numbers that span a large range (many orders of magnitude)

$$\boxed{\log xy = \log x + \log y} \iff 10^x 10^y = 10^{x+y}$$

or 100 in brightness

with the square of the distance

Parallax: apparent movement of a star as the Earth moves around its orbit
Parsec: distance where the parallax angle is one arcsec = 3.26 ly

Absolute magnitude: Magnitude from the standard distance of 10 parsecs

Black body (thermal) radiation: a property of nature, every body with a temperature emits thermal radiation.

Steffan-Boltzmann law: thermal radiation is a strong function of temperature

Wien's law: peak wavelength is uniquely determined by temperature

Luminosity is a function of radius and a strong function of temperature

Let's summarize

Logarithms convert multiplications into additions
Useful when dealing with numbers that span a large range (many
magnitude)

Magnitude scale: A reverse scale
Logarithmic: 5 magnitudes mean a factor 100 in brightness

Physical brightness is called Flux, falls with the square of the dista

Big magnitude – Dim

Parallax: apparent movement of a star as the Earth moves around
Parsec: distance where the parallax angle is one arcsec = 3.26 ly

Small (or negative) - Bright

Absolute magnitude: Magnitude from the standard distance of 10

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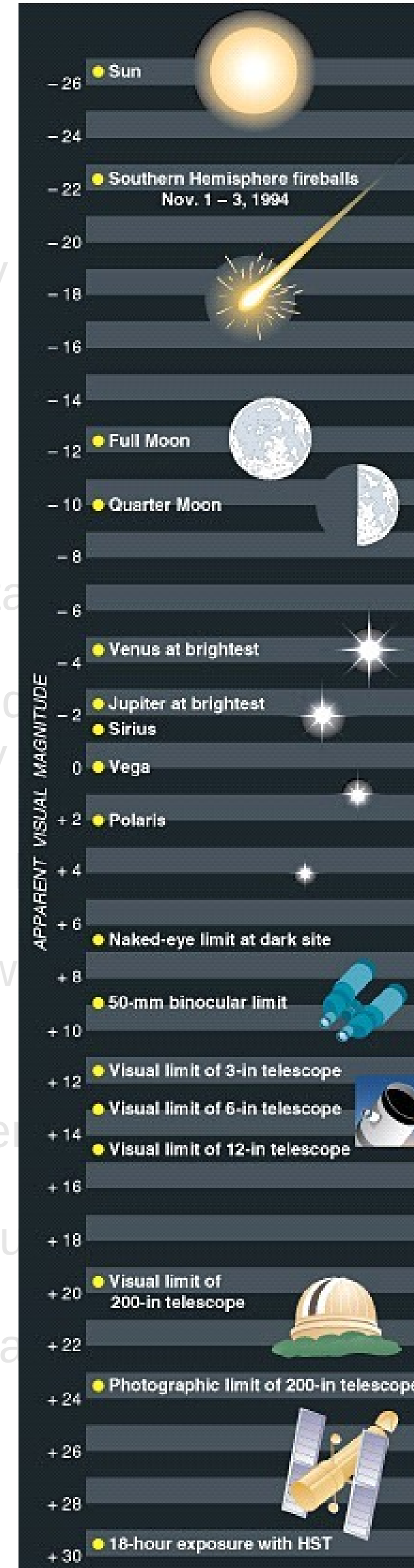
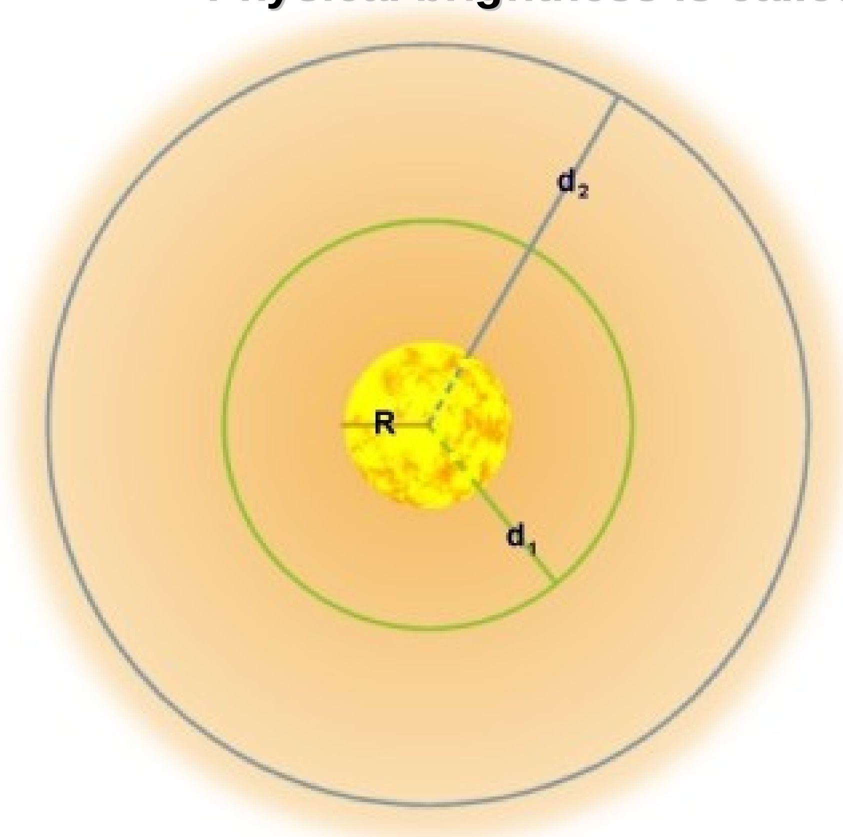


Let's summarize

$$\text{Flux} = \frac{\text{Energy}}{\text{Time} * \text{Area}}$$

Physical brightness is called Flux, falls with the square of the distance



$$F(r) \propto 1/r^2$$

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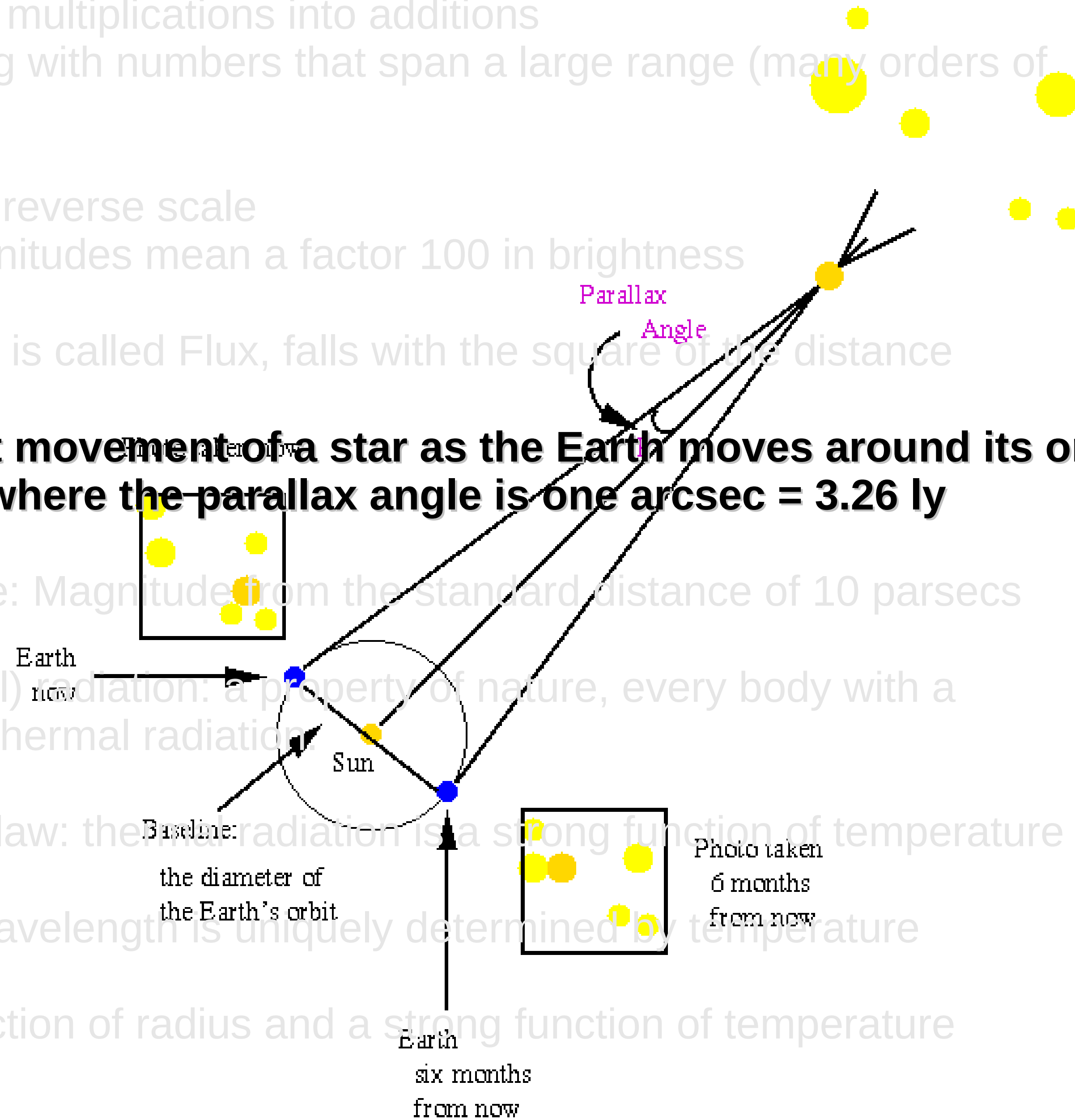


Let's summarize

Apparent magnitude

The magnitude of a star as we see it.

$$m = -2.5\log\left(\frac{L}{4\pi d^2}\right) + C$$

Absolute magnitude

The magnitude a star would have if placed 10 pc away

$$M = -2.5\log\left(\frac{L}{4\pi D^2}\right) + C$$

Absolute magnitude: Magnitude from the standard distance of 10 parsecs

$$d(pc) = 10^{0.2(m-M)+1}$$

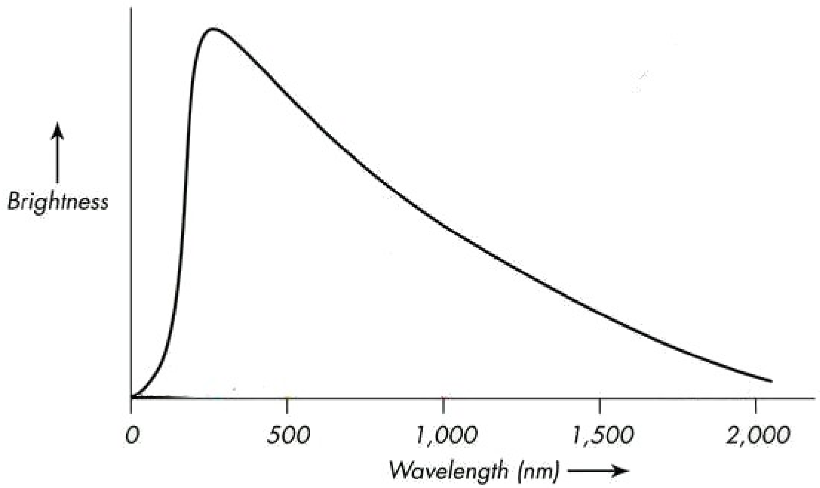
$\mu = m - M$

Distance modulus

Let's summarize

ɔ additions

ɔt span a large range (many orders of



ctor 100 in brightness

s with the square of the distance

r as the Earth moves around its orbit

ngle is one arcsec = 3.26 ly

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Let's summarize

additions
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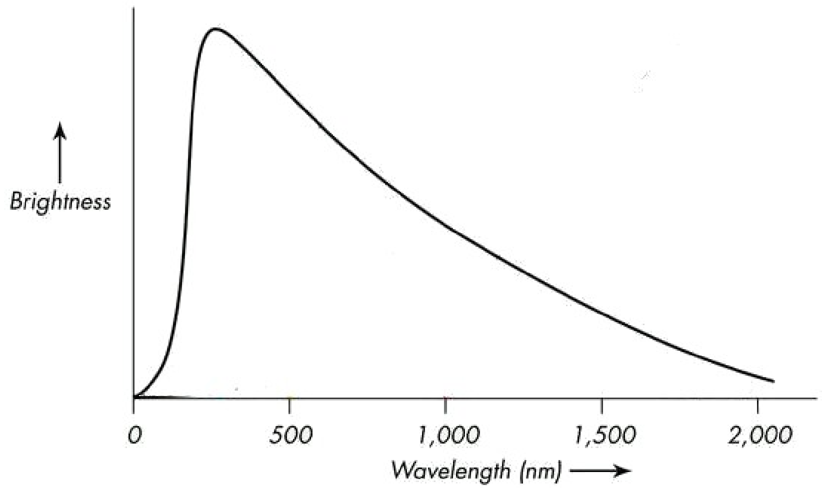

ctor 10

$$\boxed{F_R = \sigma T^4}$$

s with t … distance

r as the Earth moves around its orbit
ngle is one arcsec = 3.26 ly

the standard distance of 10 parsecs

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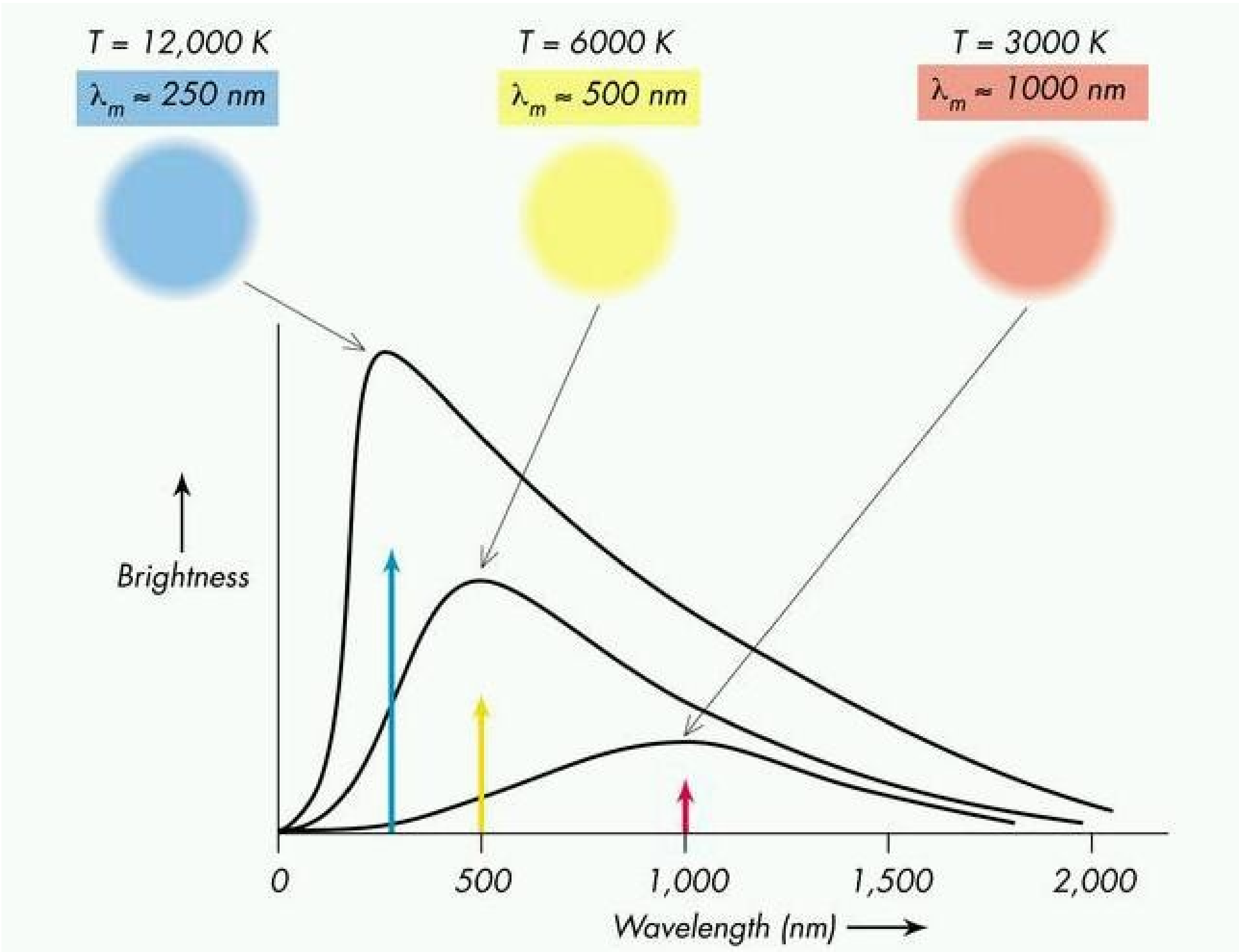
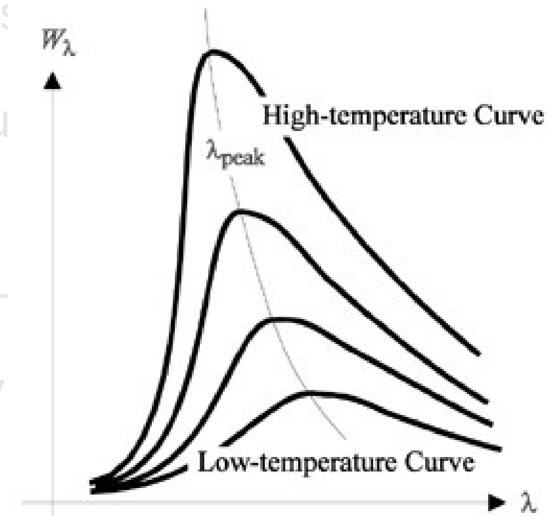


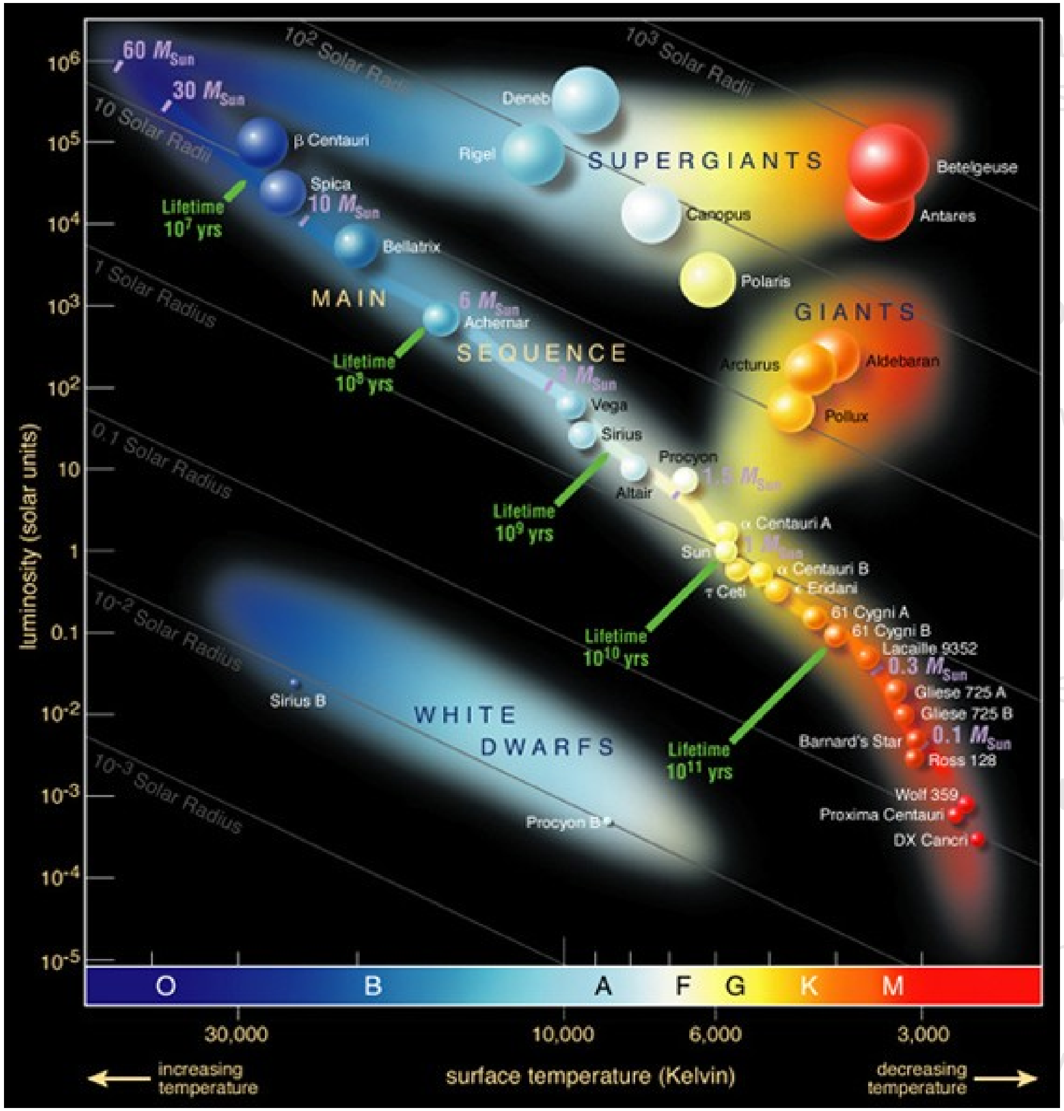


Wien's displacement law: peak wavelength is uniquely determined by temperature

Luminosity is a function of radius and a strong function of temperature

$$\lambda_{max} T = const = 2.898 \times 10^{-3}\, m\, K$$

Let's summarize



$$L = 4\pi R^2 \sigma T^4$$

$$\lambda_{max} T = const = 2.898 \times 10^{-3}\, m\,K$$

Luminosity is a function of radius and a strong function of temperature
The wavelength of peak brightness goes bluer as the temperature rises