

# The Expanding Universe

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IB PHYSICS | ASTROPHYSICS

# IB Physics Data Booklet

Sub-topic D.1 – Stellar quantities	Sub-topic D.2 – Stellar characteristics and stellar evolution
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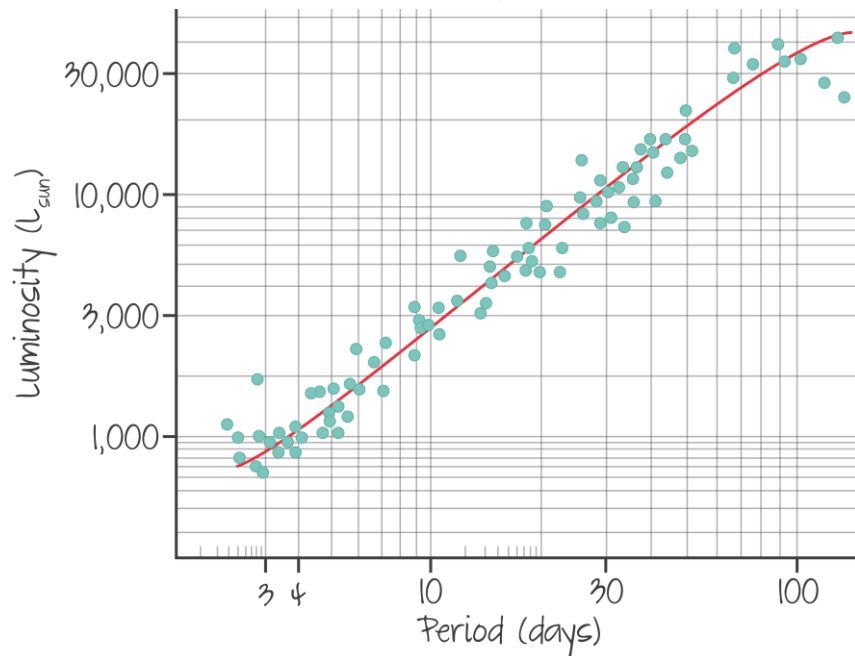
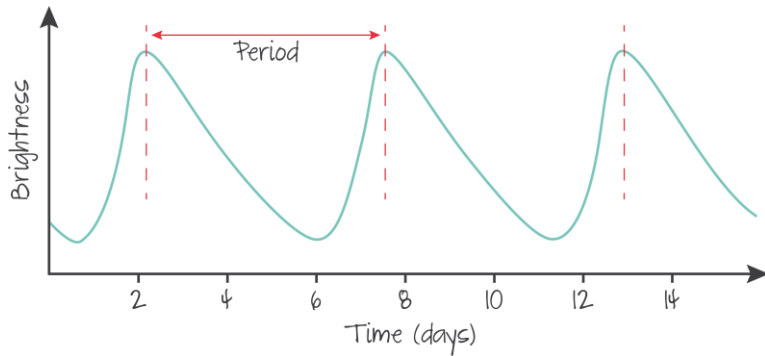
# Henrietta Swan Leavitt



# Cepheid Variables



# “Standard Candle”

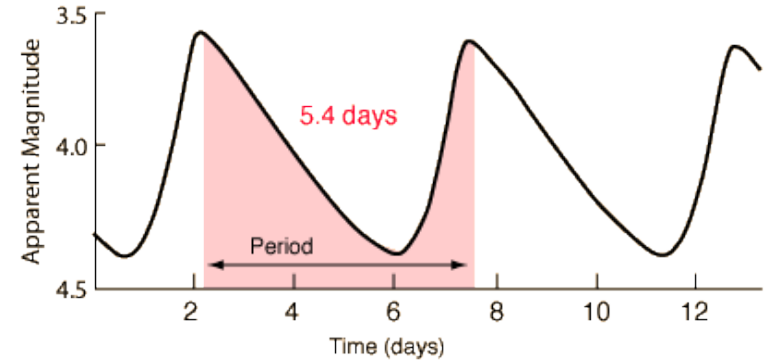
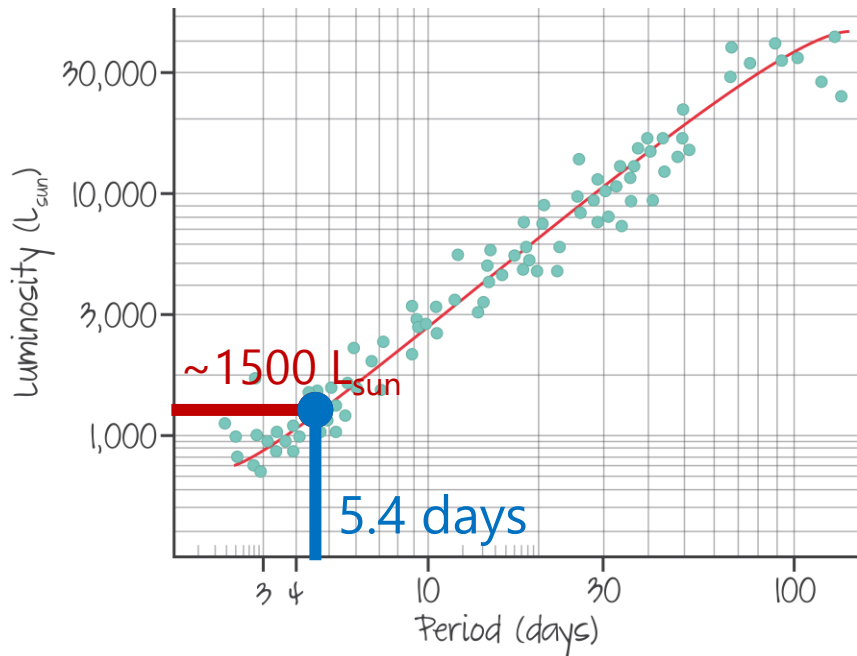


Cepheid Variables with longer brightness periods are more luminous

With this table, the luminosity of this “standard candle” can be determined as long as the period is known

# Cepheid Variables

$$1 L_{\text{sun}} = 3.84 \times 10^{24} \text{ W}$$



What is the distance of the Cepheid Variable with the period shown in the graph above? The brightness of this star is  $8 \times 10^{-10} \text{ W m}^{-2}$ .

$$L_{\text{star}} = 1500 \times (3.84 \times 10^{24})$$

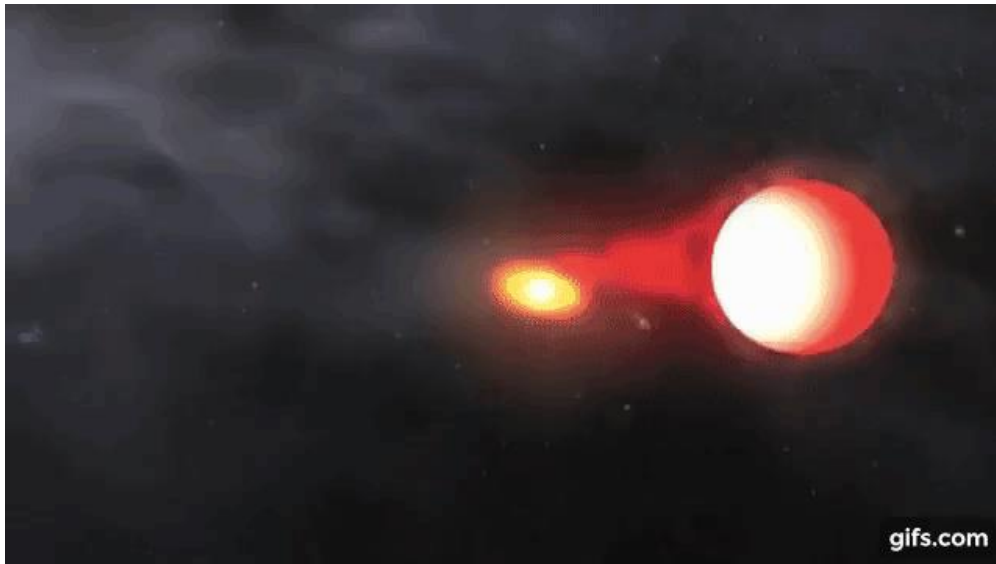
$$= 5.76 \times 10^{27} \text{ W}$$

$$b = \frac{L}{4\pi d^2} \rightarrow d = \sqrt{\frac{L}{4\pi b}} \rightarrow d = \sqrt{\frac{5.76 \times 10^{27}}{4\pi(8 \times 10^{-10})}} = 7.57 \times 10^{17} \text{ m}$$

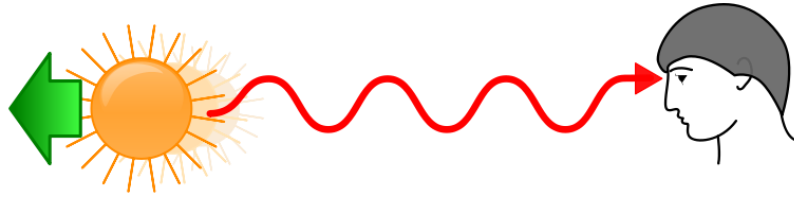
# Type Ia Supernova

A type Ia Supernova forms when a white dwarf accretes matter from a companion star until it exceeds the Chandrasekhar limit and explodes

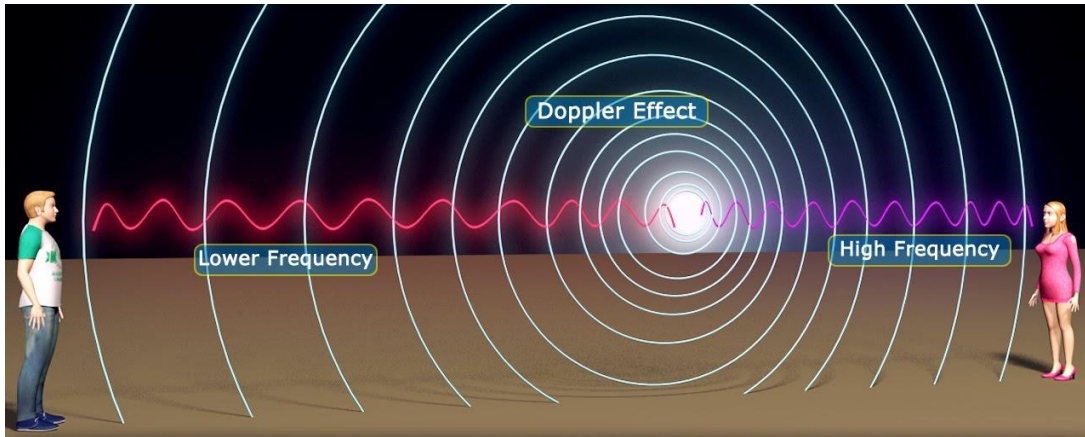
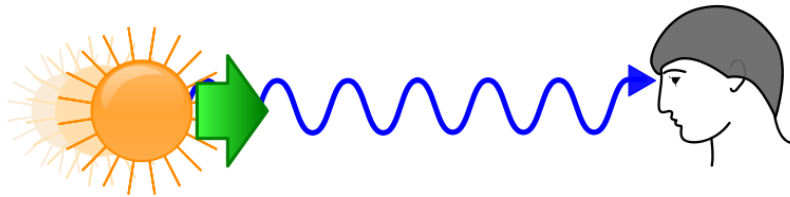
These supernovae have a constant luminosity so their brightness can be analyzed as a standard candle much like the Cepheid Variables



# Doppler Effect



Red-shifted

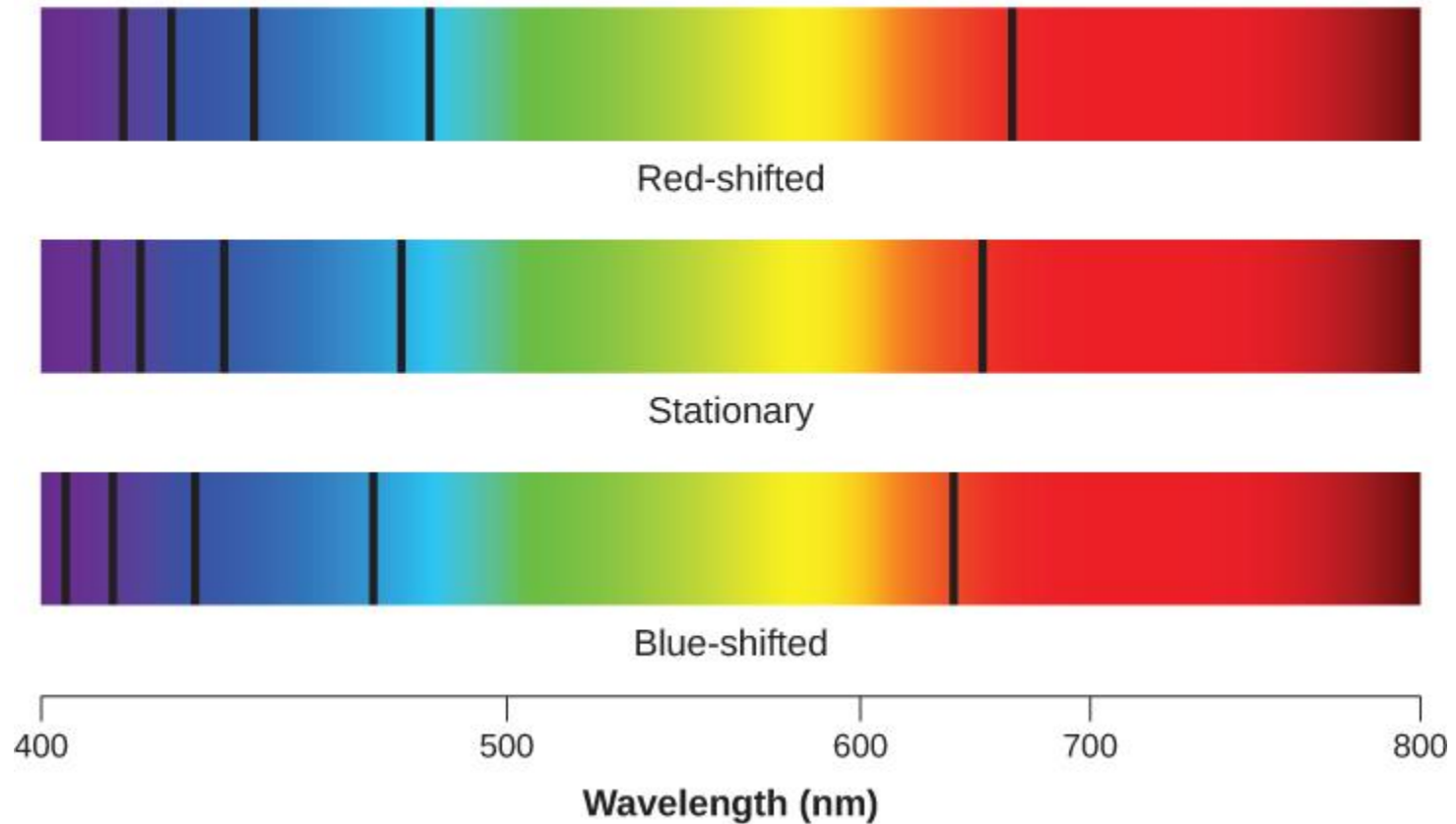


Fun Science: Light



# Red Shift, Blue Shift

## The Doppler Shift



# Calculating Redshift

Change in Wavelength

Velocity of the Source

Redshift

Wavelength Emitted

Speed of Light  
( $3.00 \times 10^8 \text{ m s}^{-1}$ )

$$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$$

The diagram illustrates the calculation of redshift. It features the equation  $z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$ . The variable  $z$  is labeled 'Redshift' in red.  $\Delta\lambda$  is labeled 'Change in Wavelength' in magenta.  $\lambda_0$  is labeled 'Wavelength Emitted' in purple.  $v$  is labeled 'Velocity of the Source' in blue.  $c$  is labeled 'Speed of Light' in green, with the value  $(3.00 \times 10^8 \text{ m s}^{-1})$  written below it. Arrows of corresponding colors point from the text labels to the respective variables in the equation.

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# Calculating Redshift

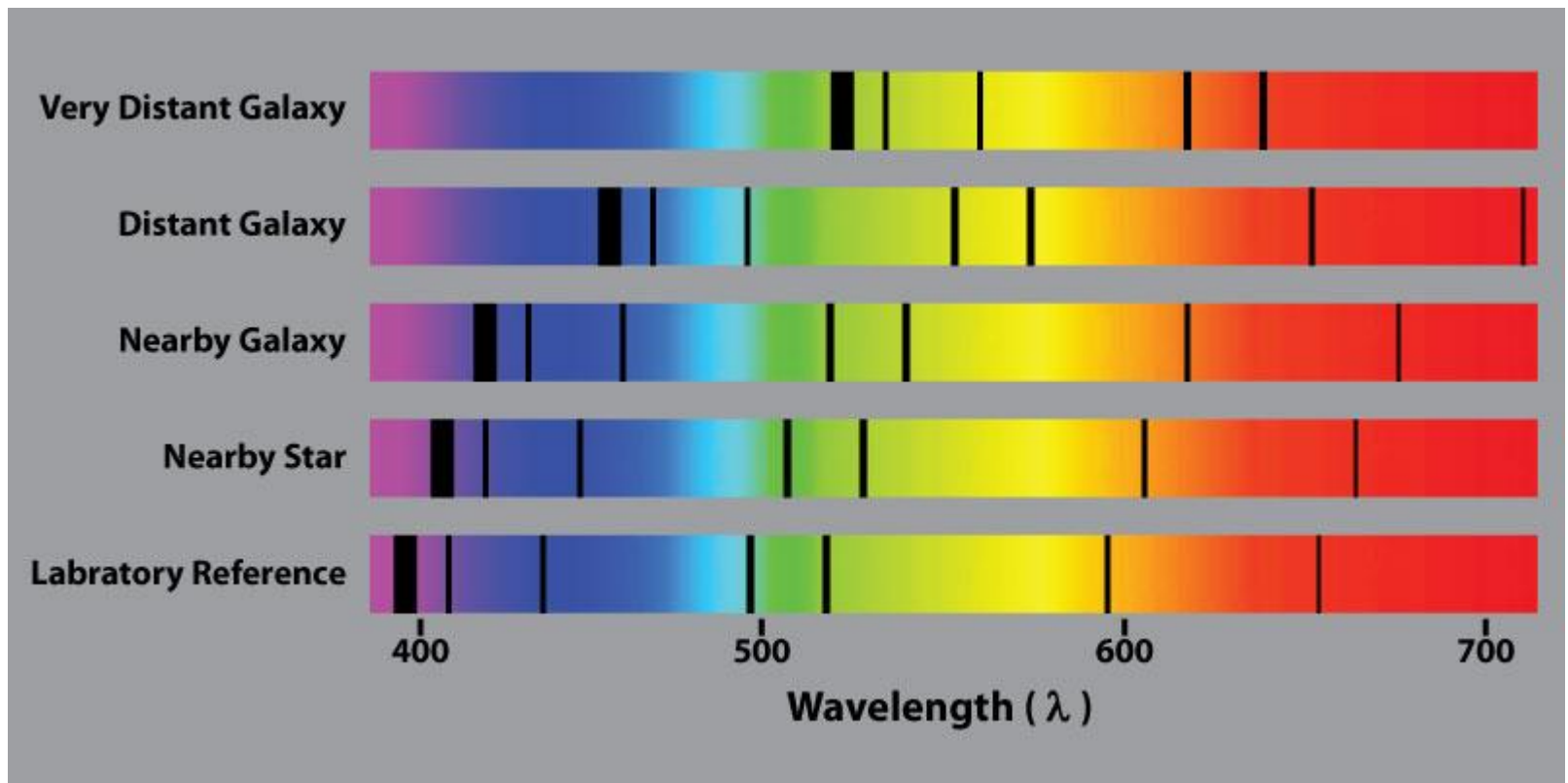
A characteristic absorption line often seen in stars is due to ionized helium. It occurs at 468.6 nm. If the spectrum of a star has this line at a measured wavelength of 499.3 nm what is the recession speed of the star?

$$\frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c} \quad \frac{499.3 - 468.6}{468.6} \approx \frac{v}{3.00 \times 10^8}$$

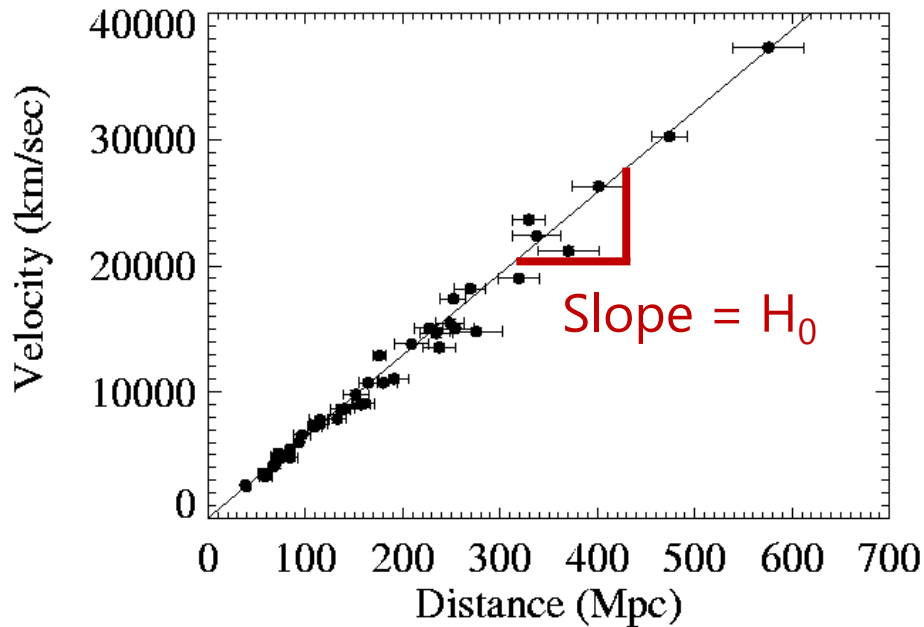
$$v = 1.97 \times 10^7 \text{ m s}^{-1}$$

# Hubble's Big Discovery

Edwin Hubble discovered that the amount of redshift changed by the distance



# The Universe is Expanding



$$v = H_0 d$$

$$H_0 \approx 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

*\*current value is not necessarily constant*

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# Using the Hubble “Constant”

Estimate the distance from the Earth to a galaxy with a recessional velocity of  $150 \text{ km s}^{-1}$

$$v = H_0 d \rightarrow d = \frac{v}{H_0} = \frac{150 \text{ km s}^{-1}}{70 \text{ km s}^{-1} \text{ Mpc}^{-1}} = 2.14 \text{ Mpc}$$

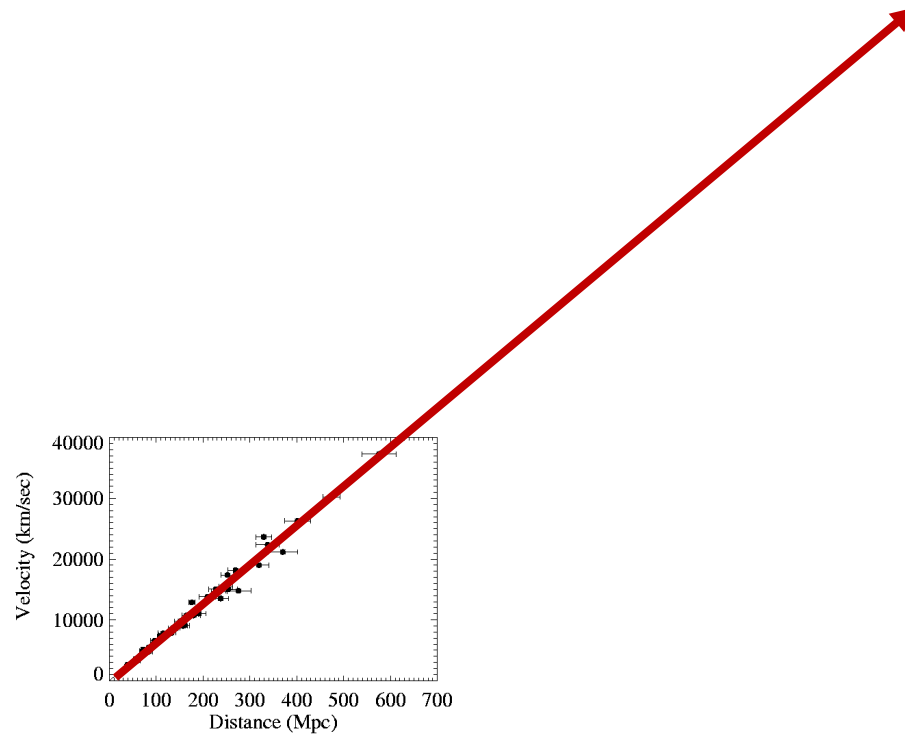
If a galaxy is 20 Mpc from Earth, how fast will it be receding?

$$v = H_0 d = (70 \text{ km s}^{-1} \text{ Mpc}^{-1})(20 \text{ Mpc}) = 1400 \text{ km s}^{-1}$$



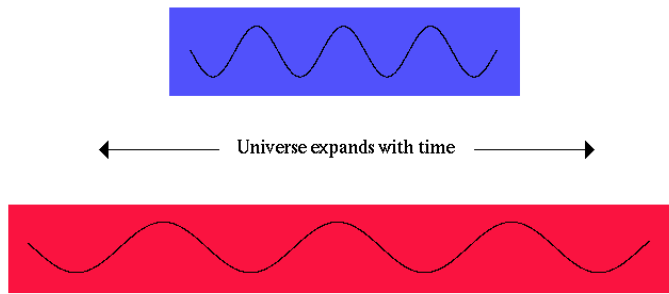
# Calculating Redshift

Nothing can go faster than the speed of light so the Doppler effect can't really hold up...



# Calculating Redshift

Think of the wavelength change due to the stretching of space-time



Cosmological  
Redshift

Current  
Universe Size  $[R = 1]$

$$z = \frac{R}{R_0} - 1$$

The equation shows the redshift  $z$  as the ratio of the current universe size  $R$  to the cosmic scale factor  $R_0$  minus 1. A pink arrow points from the text 'Current Universe Size' to the variable  $R$ . A blue arrow points from the text 'Cosmic Scale Factor' to the variable  $R_0$ . A red arrow points from the text 'Cosmological Redshift' to the variable  $z$ .

Cosmic Scale Factor

Size of the universe at the time the light was emitted (relative to the current size)

# Calculating Redshift

If the redshift  $z = 3$ , what was the scale factor at the time that the light was emitted?

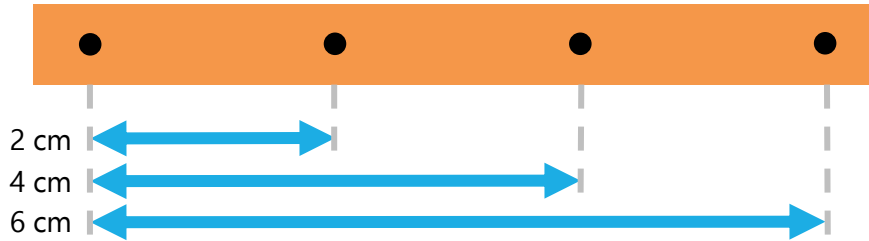
$$z = \frac{R}{R_0} - 1$$

$$3 = \frac{1}{R_0} - 1$$

*Note: This means that to result in this cosmological redshift, the light had to have been emitted when the universe was a quarter of the size it is now*

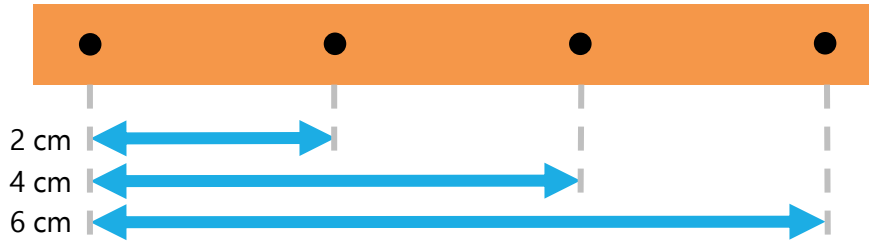
$$R_0 = \frac{1}{4} = 0.25$$

# The Universe is Expanding



Think of a rubber band with marks when it is stretched out... Relative to the first dot, which dot moves the fastest?

# The Universe is Expanding



Think of a rubber band with marks when it is stretched out... Relative to the first dot, which dot moves the fastest?



The farthest dot moves away the fastest

# The Universe is Expanding

