Star: A spherical ball of gas/plasma that has obtained enough mass to being fusion in its core.

Solar system: A central star with planets and other objects that orbit it, all of which are bound by gravity to each other.

Galaxy: A large collection of millions or billions of stars that are gravitationally associated.

Universe: All existing matter, energy, and space as a whole; All matter, energy, and space that exists, or ever existed, or ever will exist.

How do scientists know if a deep space object is moving towards or away from Earth?

Doppler Effect

Doppler Effect: The observed change in frequency and wavelength of waves (sound or light) as seen or heard by the observer relative to the direction of the moving object that is emitting the waves.

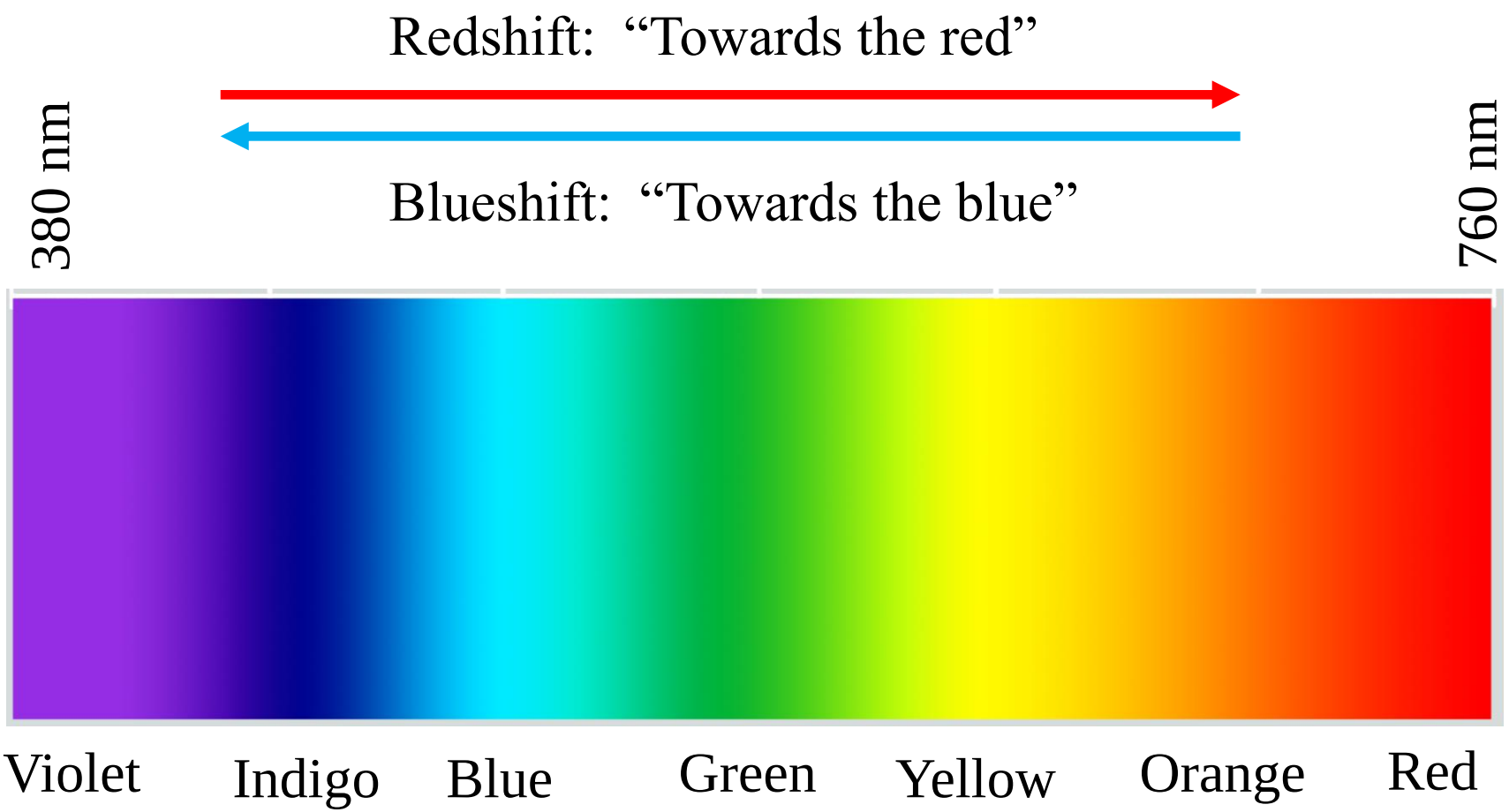
The actual frequency of wave emission by the source object is constant (never changes), however, the observed change in frequency is detected by the observer.

The source is stationary, therefore, there is no observed Doppler shift. The telescope will see the exact the same frequency of light on all sides of the stationary source. It is receiving light waves of the same wavelength at the same time intervals.

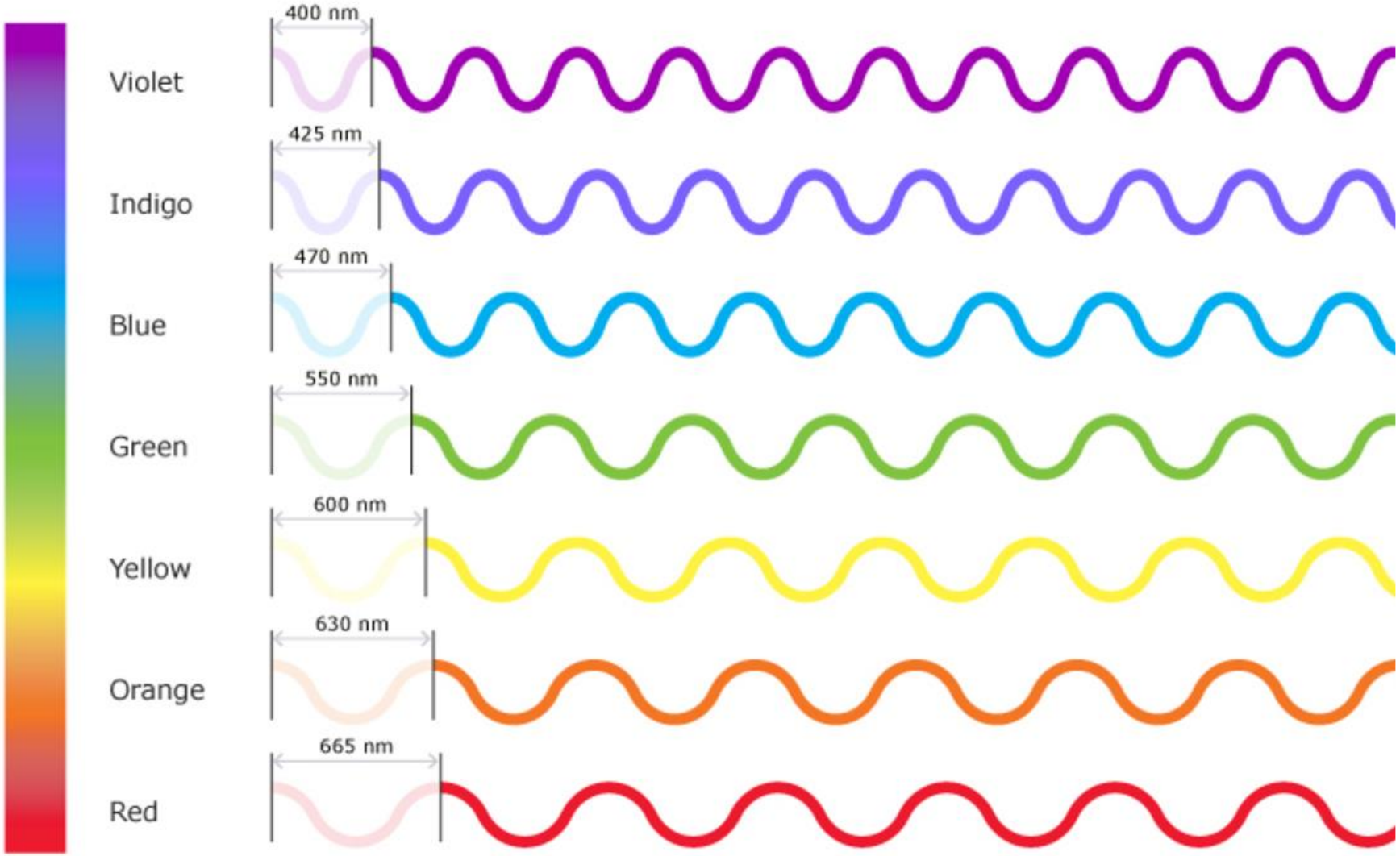
The telescope will observe a **Doppler "redshift".** It receives waves that are moving away from the source in the direction opposite that the source moves. The light waves are "spread out" with a longer wavelength (the distance between sequential waves). The frequency of light will be lower (**to the red**).

The telescope will observe a **Doppler "blueshift".** The light waves are moving away from the source in the same direction that the source moves. The waves are "bunched up" with a shorter wavelength (the distance between sequential waves). The frequency of light will be higher (**to the blue**).

The **visible spectrum** is the region of the electromagnetic spectrum that is visible to the human eye. The region is very narrow. *Red* has the *longest wavelengths* and the *lowest frequency*. Violet has the *shortest wavelengths* and the *highest frequency*.

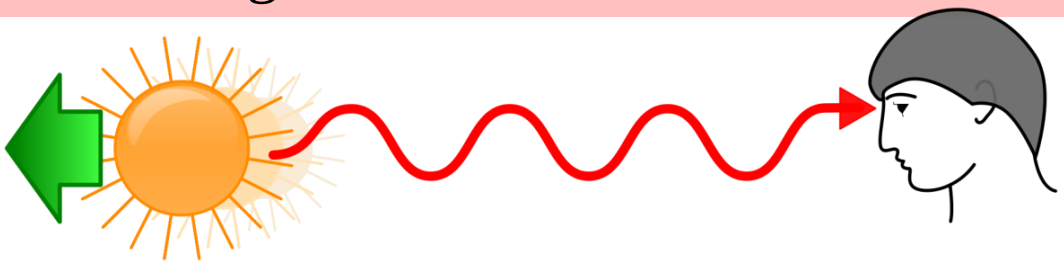


Relative comparison of wavelengths and frequencies of the pure colors in the visible spectrum.

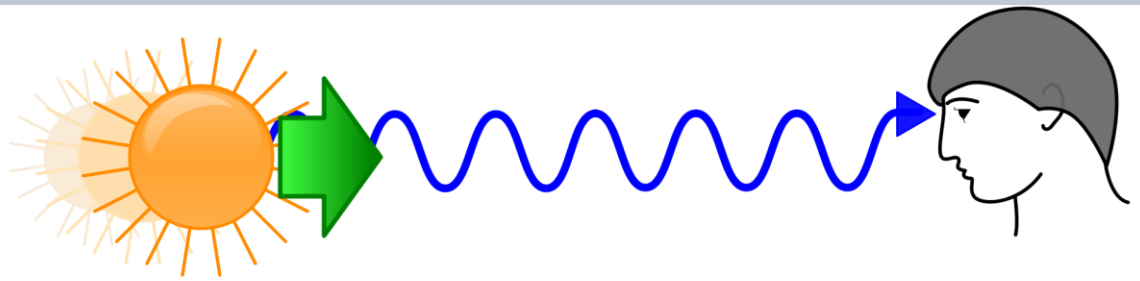


The appearance of light is also affected by Doppler effect phenomena. Light is a wave, and the relative motion of a light emitting object will affect the observed color of that object.

Light emitting object moves away from observer, the light appears to **redshift**. The observed wavelength of light becomes "redder", moves toward longer wavelengths.

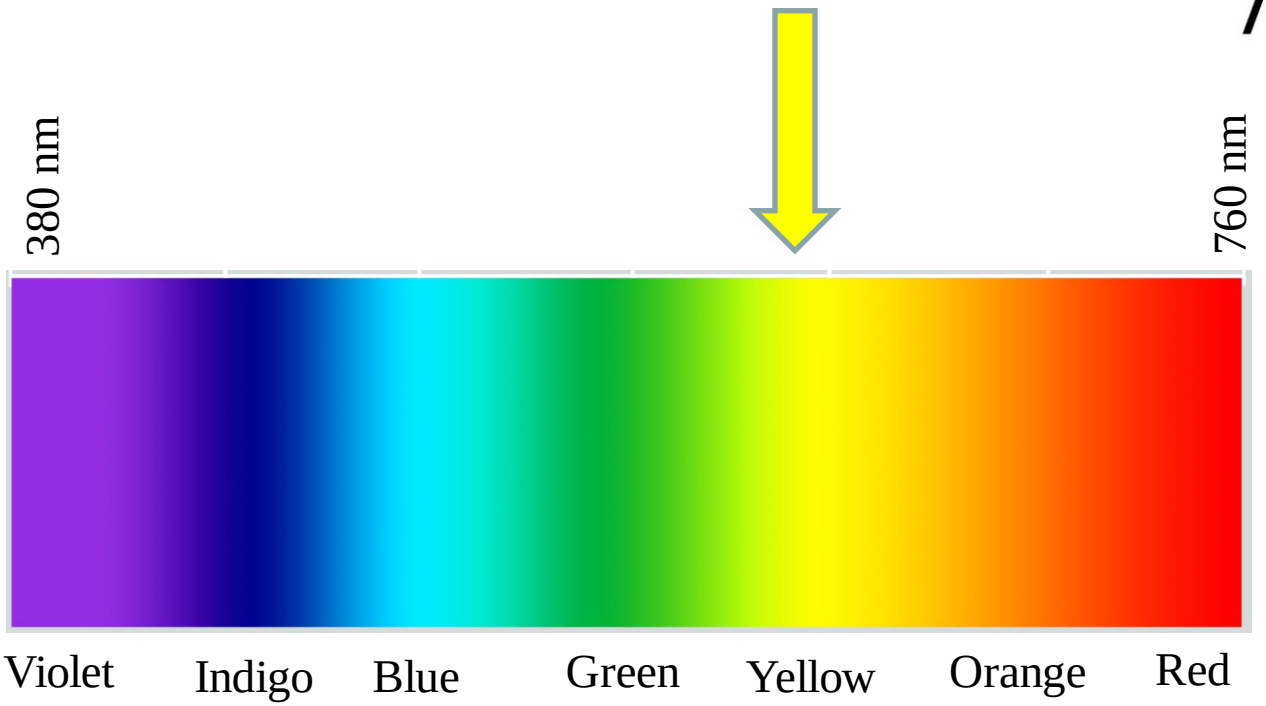


Light emitting object moves toward the observer, the light appears to **blueshift**. The observed wavelength of light becomes "bluer", moves toward shorter wavelengths

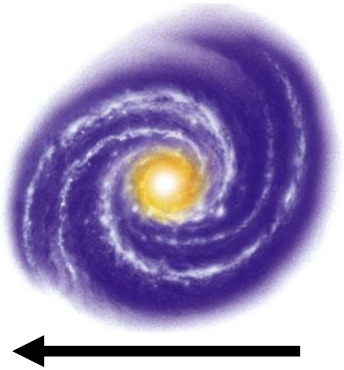


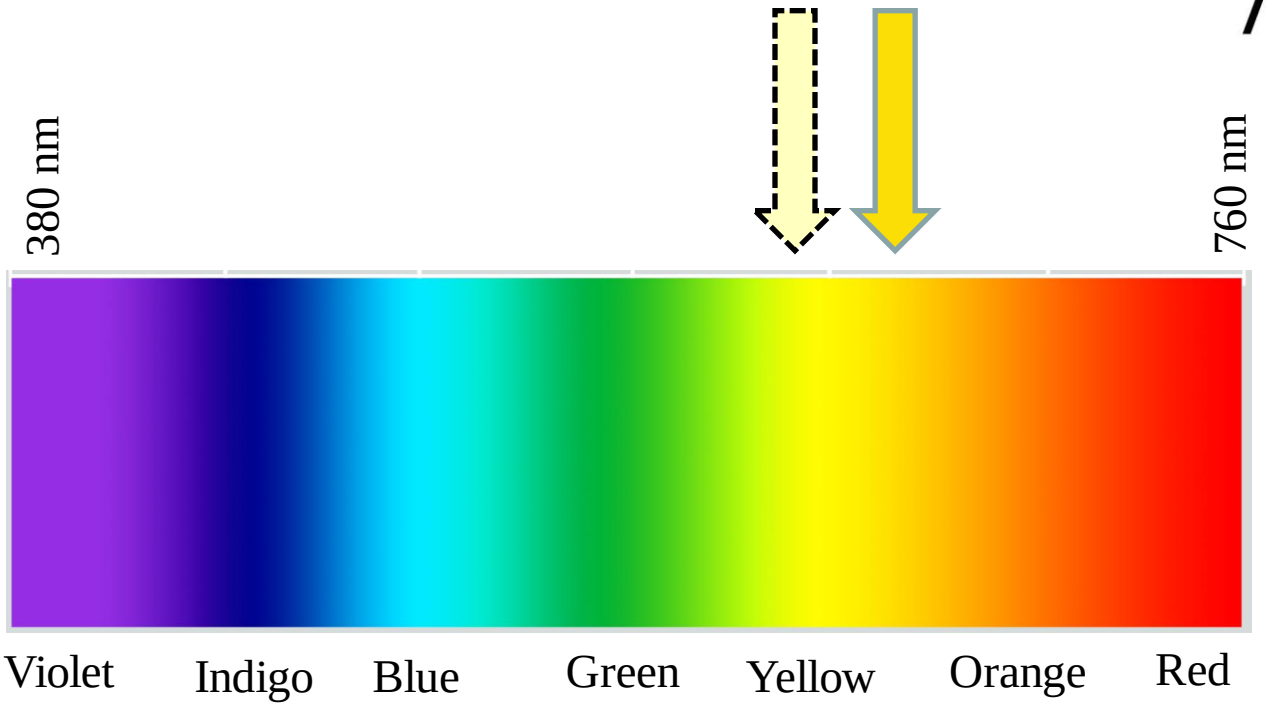
Real world example: A distant galaxy was “not moving” relative to the Earth. If we could measure its light, the peak emissions of light may have a color of yellow, around 580 nm. We would see its true color because there is no Doppler shift of its light.

Not moving

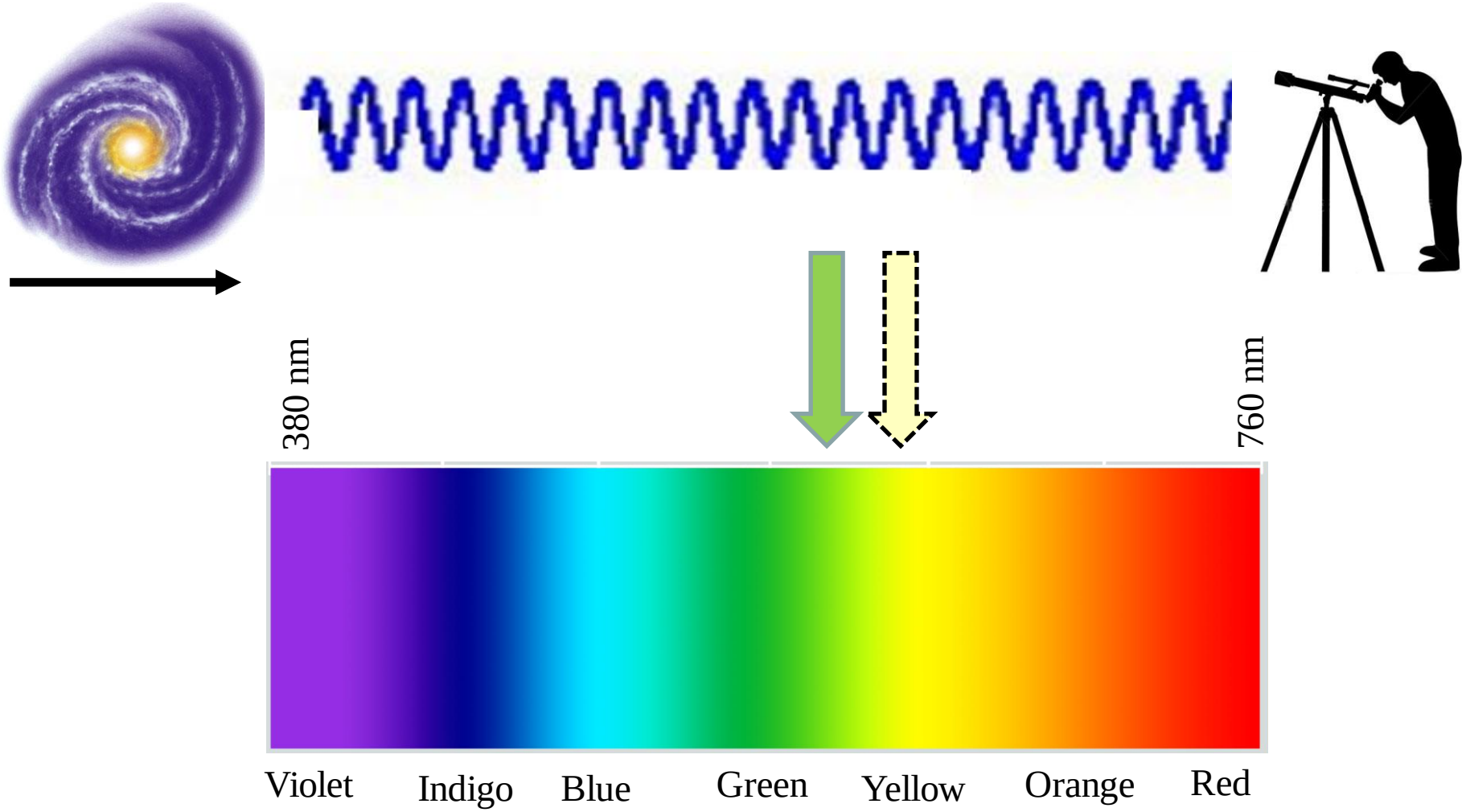


If a distant galaxy was moving away from the Earth (called receding), the peak emissions of light will have **“redshift”** or changed to a color of longer wavelength and lower frequency. The true yellow colored galaxy will appear slightly “orangish” yellow.





If a distant galaxy was moving towards the Earth, the peak emissions of light we observe will have **“blueshift”** or changed to a shorter wavelength and higher frequency. The true yellow colored galaxy will appear slightly “whitish” yellow.



Galaxies tend to have similar composition. Therefore, the starlight emitted from the galaxies should be very similar in their compositions.

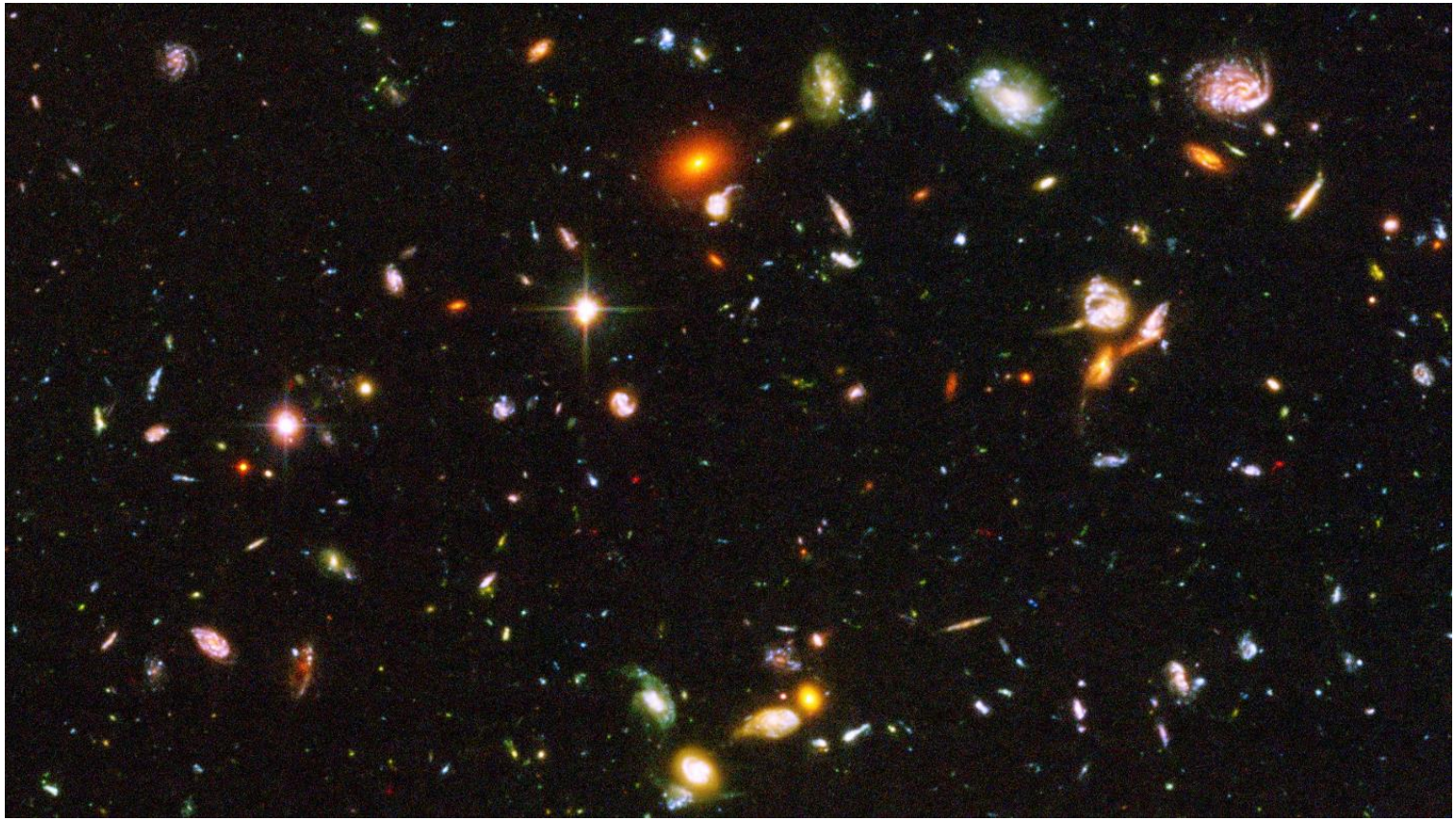
If galaxies are stationary, the light “fingerprints” from the starlight for all galaxies would be identical and at the same location on the visible emissions spectrum.

If galaxies are moving away from the Earth, the light “fingerprints” from the starlight should shift to red (redshift).

If galaxies are moving towards the Earth, the light “fingerprints” from the starlight should shift to blue (blueshift)

Edwin Hubble (1923)

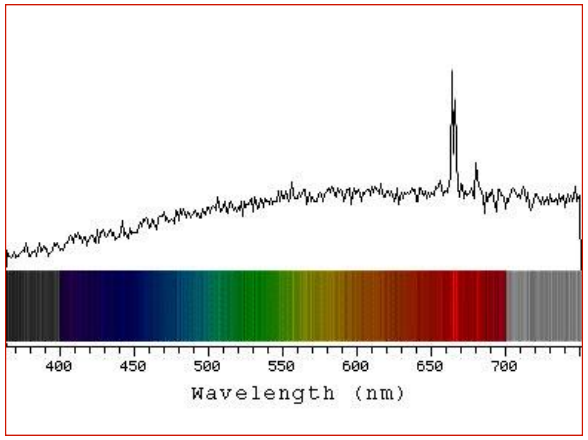
Using a giant reflecting (mirror) telescope at **Mt. Wilson Observatory**, Hubble focused the telescope at the hundreds of smudges in the night sky.

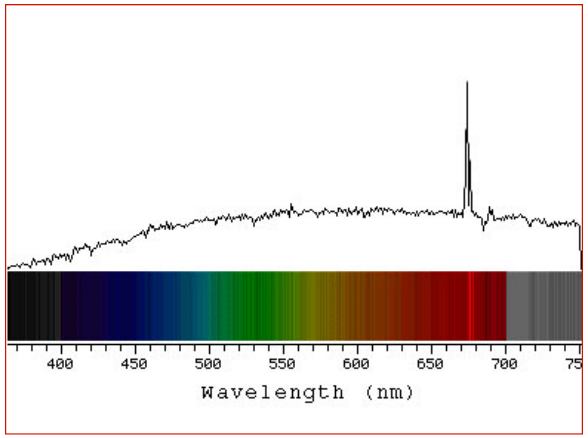


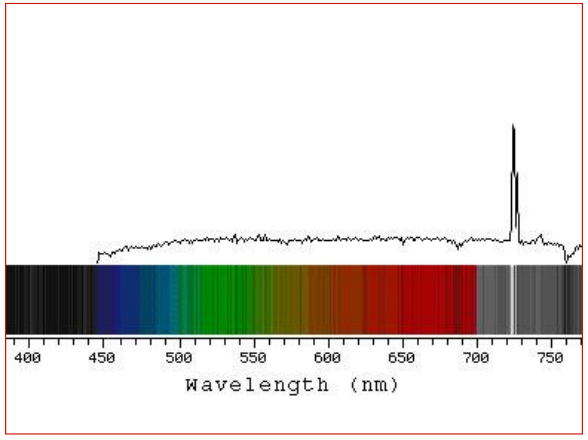
The night sky was filled with thousands of galaxies of different shapes and sizes.

The galaxies also appeared to be at different distances away from Earth.

The Universe is Larger than the Milky Way Galaxy





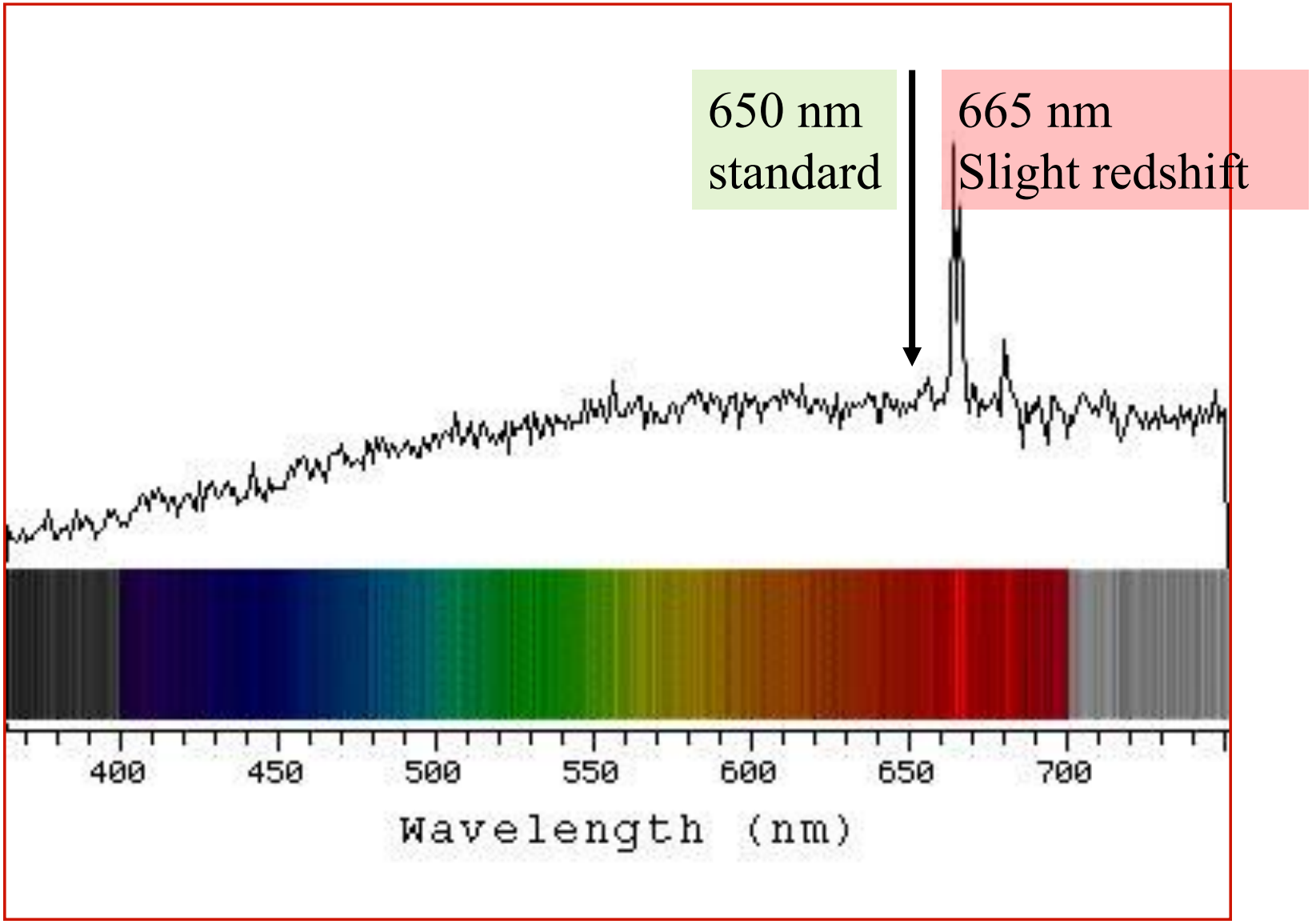


Hubble used emissions spectra "fingerprints" from the starlight from the galaxies.

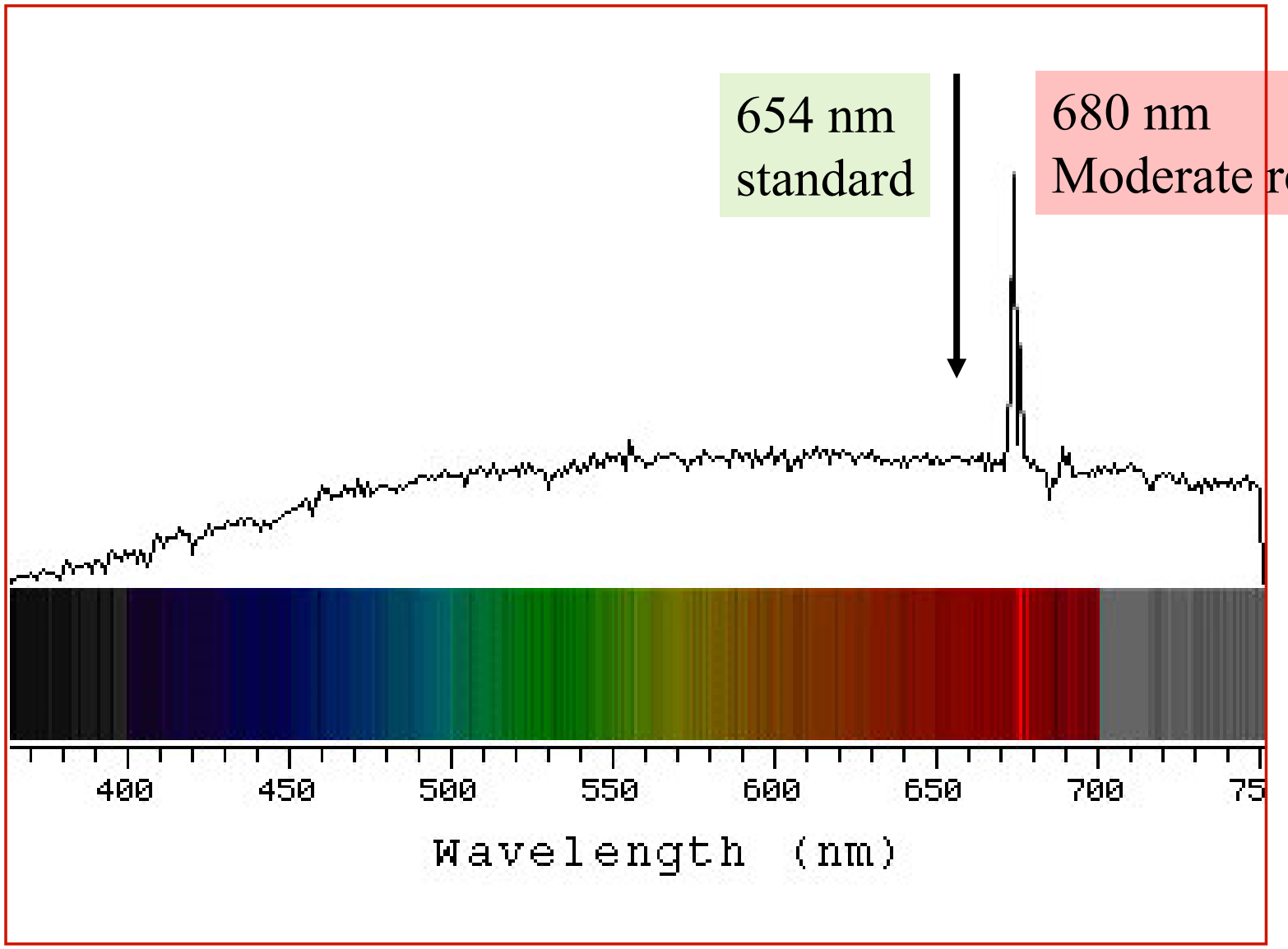
He compared the standard emissions spectrum "fingerprint" for a hydrogen lamp (not moving) the those of the galaxies.

The position (wavelength, frequency) of the peak hydrogen emission line was at different places on the spectrum for different galaxies.

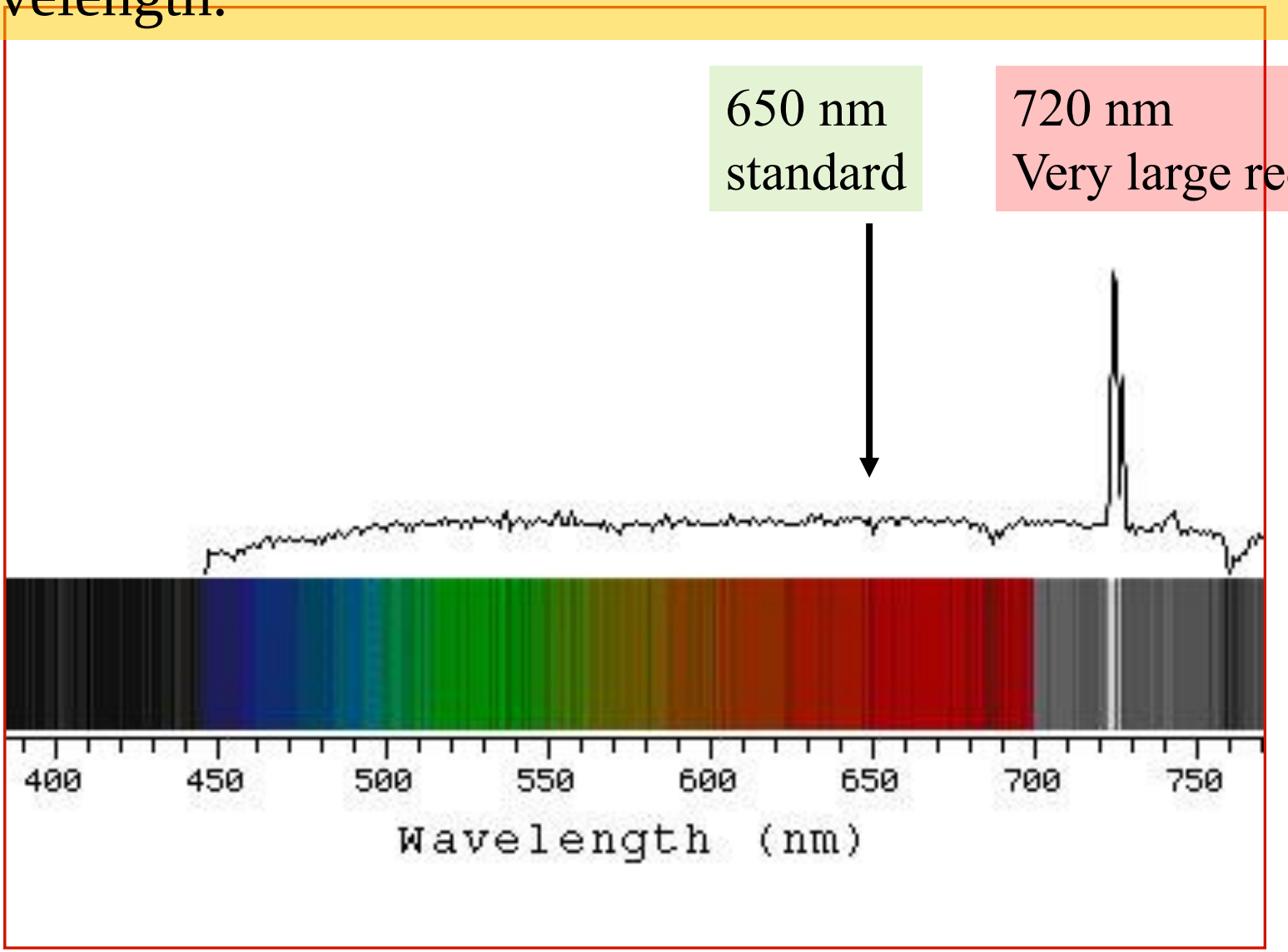
Lesser redshift: Galaxy that is moving away from Earth with a *slow velocity*. Smaller difference in wavelength.



Moderate redshift: Galaxy that is moving away from Earth with a *faster velocity*. Greater difference in wavelength.

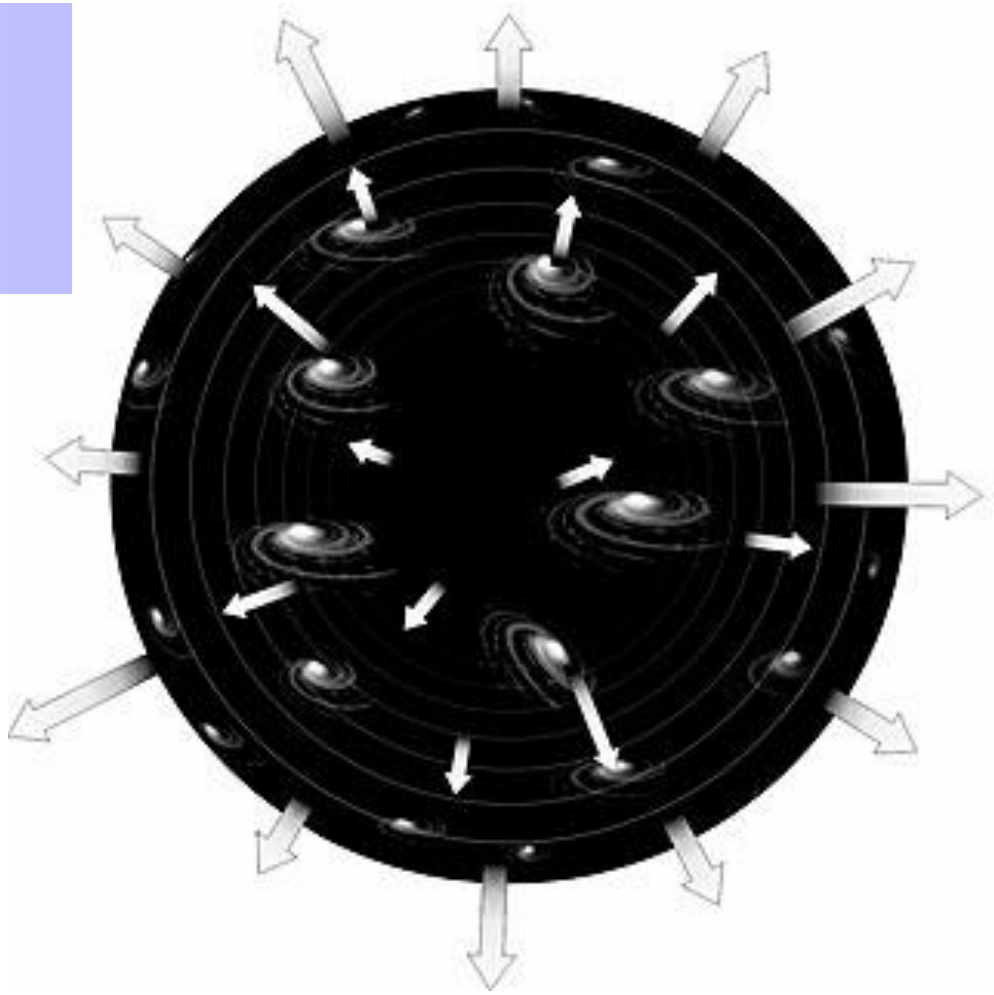


Very large redshift: Galaxy that is moving away from Earth with a *very fast velocity*. Very large difference in wavelength.



1. All galaxies are **receding** from Earth. All galaxies are moving away from Earth. The emission spectra were "redshifted".

2. Galaxies are **diverging**. All galaxies are moving apart from each other

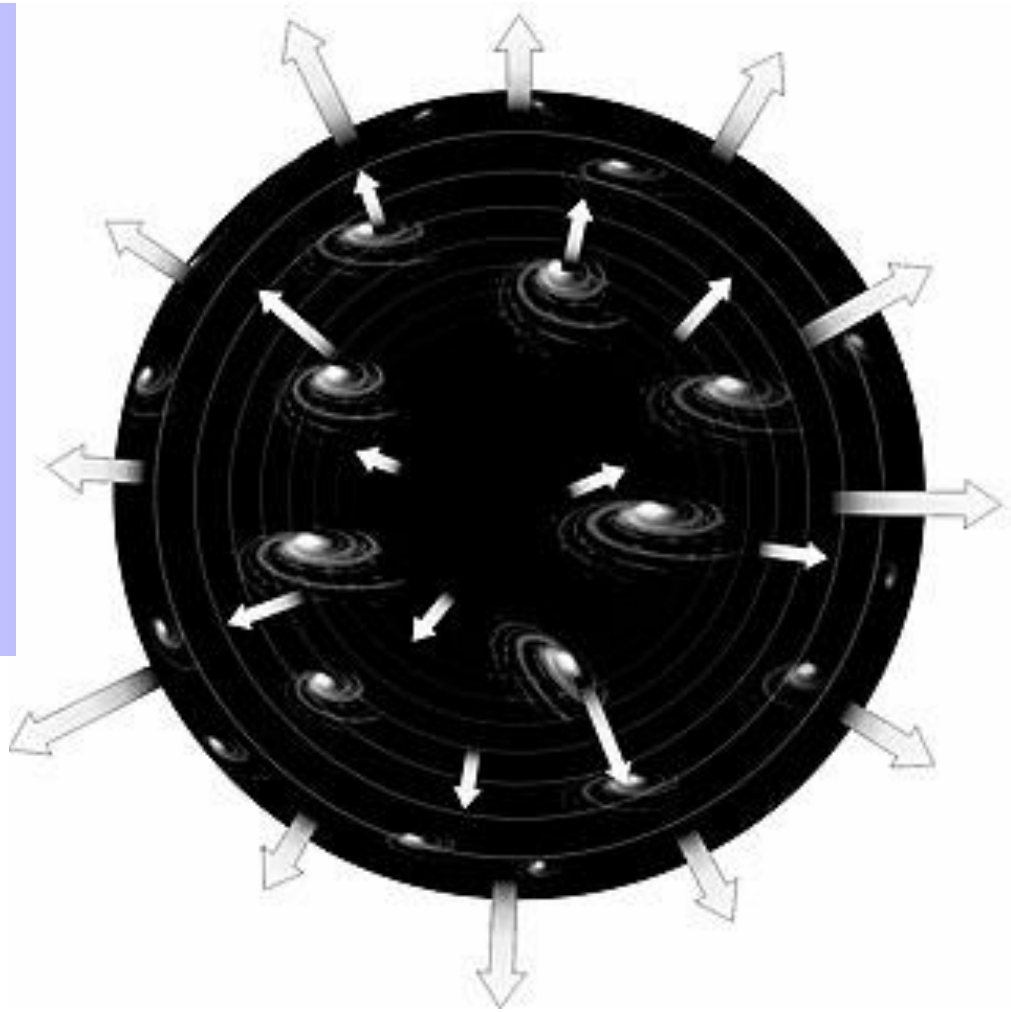


3. Galaxies that are closer to Earth are moving away at slower velocities.

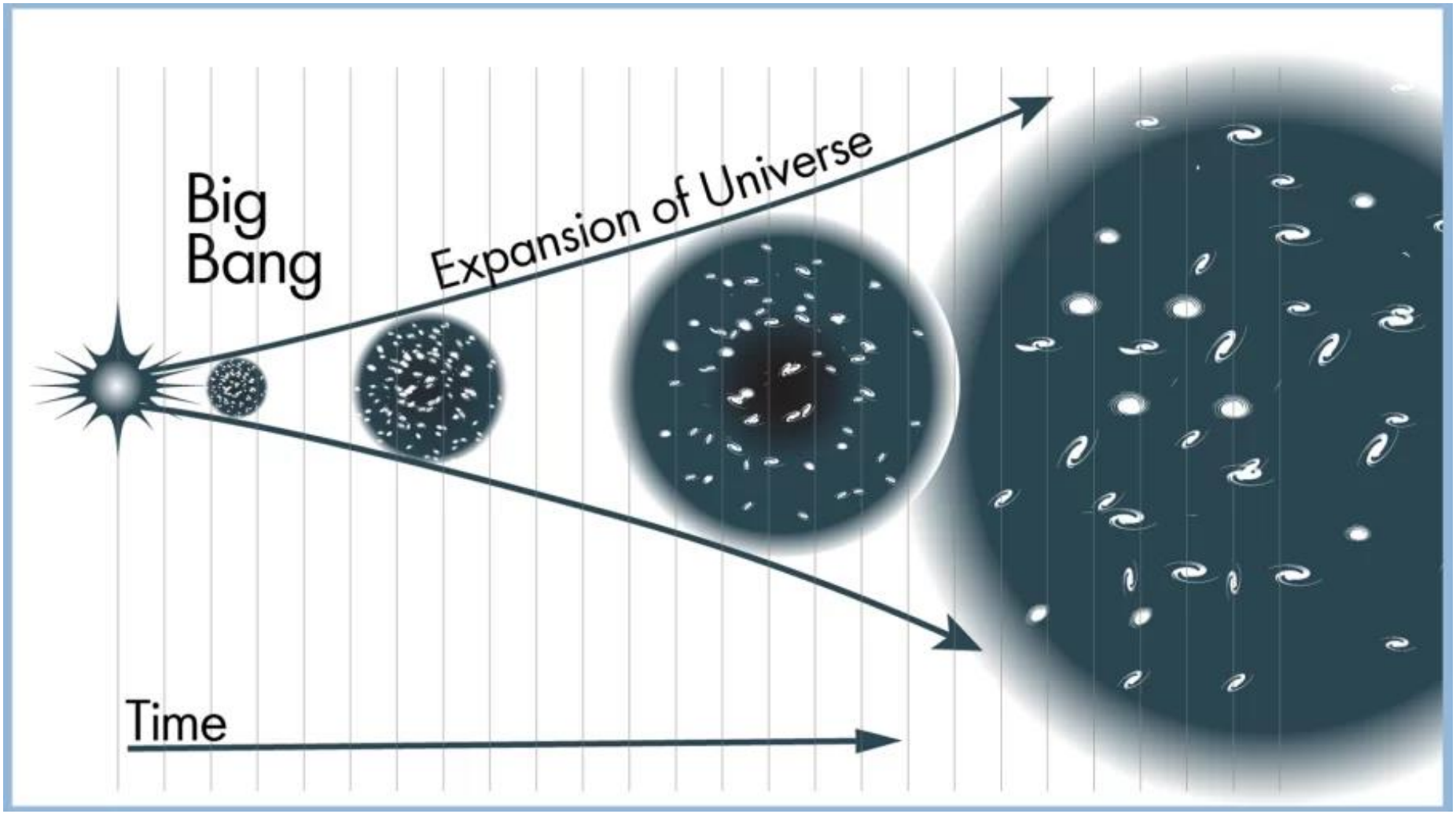
4. Galaxies farther from the Sun are moving away at faster velocities.

5. Galaxies are **accelerating with time**. The velocity that they recede with is getting faster. Galaxies are moving apart faster and faster.

6. Galaxies that are at the ***edge of the observable universe (~13.7 billion light years away)*** are accelerating to velocities approaching the speed of light.



Hubble's observations provide indirect and foundational evidence of the ***Big Bang Hypothesis*** and the modern **theory of the expanding universe**.



- The observable universe is NOT static in size.
- Galaxies are moving farther and farther apart with time.
- Galaxies are moving away from each other faster and faster with time.
- The volume of space is also expanding with time.
- There must have been a centralized “point” in space where everything began.
- The proposed age of the observable universe is 13.7 BY.