Blueshift and Redshift In Small Angle Diffraction

Eric Su
eric.su.mobile@gmail.com
https://sites.google.com/view/physics-news/home
(Dated: July 3, 2019)

The observation of spectral shift in astronomy arises from the relative motion between the observed star and the earth. Both blueshift and redshift can be explained with the relative movement of the double-slit interference. In the rest frame of the star, the light passes through the slit to travel a straight path to reach the projection screen. The intersection of this path and the screen is shifted by the movement of the screen. If the screen moves away from the path, the spectrum will be shifted away from the center of the screen. This is known as redshift. If the screen moves toward the path, the spectrum will be shifted toward the center of the screen. This is known as blueshift. The spectrum not only shifts in position but also expands in size. The spectral shift is the result of the relative motion between the projection screen and the path of phase shift. It is not the result of any variation in the wavelength.

I. INTRODUCTION

The diffraction grating is essential in the study of galaxy spectrum. The intereference pattern generated by the diffraction grating often shows a spectral shift corresponding to the movement of the star. However, the movement is actually the relative motion between the star and the earth. Therefore, the spectral shift is conserved in the rest frame of the star as well as in the rest frame of the earth.

In the rest frame of the star, the diffraction grating moves toward or away from the star. The wavelength is not affected by the motion of the grating. The light travels from the slit on the grating to the projection screen (or CCD) to create a path of phase shift. The path is stationary relative to the star.

In the rest frame of the earth, the path of phase shift moves together with the star. It undergoes parallel transport along the radial direction toward the star. If the path is transported toward the screen, the intersection of the path and the screen will be closer to the center of the screen. The interference pattern shifts toward the center of the screen. If the path is transported away from the screen, the intersection of the path and the screen will move away from the center of the screen. The interference pattern shifts away from the center of the screen.

The resulting spectral shift is called either blueshift or redshift.

II. PROOF

A. Double-Slit inteference

A light emitter emits coherent light along the x-direction through a plate with two parallel slits to reach a projection screen. Both the plate and the screen are aligned with the y-z plane. The emitter, the plate, and the screen are all stationary relative to a reference frame F_1.

A series of alternating light and dark bands appear on the projection screen along the y-direction. Let the distance between the plate and the screen be D_0. The displacement of the light band from the center of the screen is y_0. The seperation between the parallel slits is d_0.

If $d_0 << y_0 << D_0$, the constructive interference can be described by the equation of phase shift[1] for the constructive phase difference as

$$y_0 = m * \lambda_1 * \frac{D_0}{d_0} \tag{1}$$

λ_1 is the wavelength in F_1. m is a positive integer.

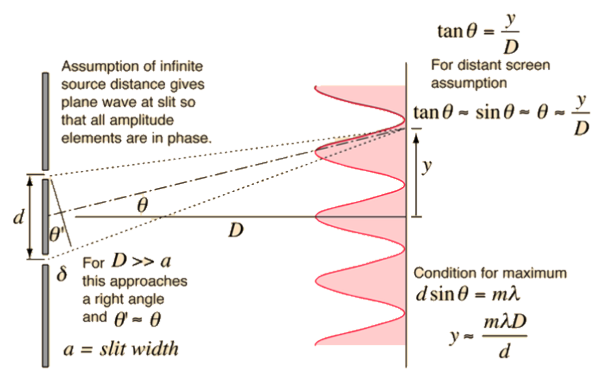

FIG. 1. Double Slit Interference

Light travels from the slit to the screen to create a path of phase shift. This path and the x-axis form an angle θ_0.

$$sin(\theta_0) = \frac{y_0}{D_0} = \frac{m * \lambda_1}{d_0} \tag{2}$$

B. Stationary Star

Let both the plate and the screen move at a constant velocity (v,0,0) relative to F_1. The rest frame of both the plate and the screen becomes F_2. The interference pattern is shifted as the result of the relative motion between F_1 and F_2. The equation of phase shift becomes

$$y_1 = m * \lambda_1 * \frac{D_1}{d_1} \tag{3}$$

The choice of inertial reference frame along the x-direction has no effect on the measurement along the y-direction.

$$d_1 = d_0 \tag{4}$$

The length is conserved in all inertial reference frames[6,9]. Let the elapsed time for the light to travel from the slit plate to the projection screen be T. The screen has moved a distance of $v*T$ by the time the light reaches the screen. The total distance in the x-direction for the light to travel from the plate to the screen is

$$D_1 = D_0 + v * T \tag{5}$$

From equations (1,3,4,5),

$$y_1 = m * \lambda_1 * \frac{D_0 + v * T}{d_0} \tag{6}$$

The displacement of light band shifts from y_0 to y_1 due to the relative motion between F_1 and F_2.

The angle formed by the x-axis and the path of phase shift is θ_1.

$$sin(\theta_1) = \frac{y_1}{D_1} \tag{7}$$

From equations (2,3,4,7),

$$\theta_1 = \theta_0 \tag{8}$$

The direction of the path of phase shift is independent of the motion of the screen.

C. Stationary Earth

The spectral shift is conserved in all inertial reference frames. The earth is stationary in F_2. The motion of star results in the same spectral shift as

$$y_2 = m * \lambda_2 * \frac{D_2}{d_2} \tag{9}$$

The choice of inertial reference frame along the x-direction has no effect on the measurement along the y-direction.

$$y_2 = y_1 \tag{10}$$

$$d_2 = d_0 \tag{11}$$

The wavelength is conserved in all inertial reference frames[3-7].

$$\lambda_2 = \lambda_1 \tag{12}$$

The elapsed time is conserved in all inertial reference frames[8-12]. From equations (6,9,10,11,12),

$$D_2 = D_0 + v * T \tag{13}$$

From equations (9,10,11,12,13),

$$y_2 = m * \lambda_1 * \frac{D_0 + v * T}{d_0} \tag{14}$$

The angle formed by the x-axis and the path of phase shift is θ_2.

$$sin(\theta_2) = \frac{y_2}{D_2} \tag{15}$$

From equations (5,7,10,13,15),

$$\theta_2 = \theta_1 \tag{16}$$

The direction of the path of phase shift is conserved in both F_1 and F_2.

D. Redshift

In the rest frame of the earth, F_2, a star is observed to move away from the earth if

$$v > 0 \tag{17}$$

The path of phase shift moves together with the star in F_2. This causes the intersection of the path and the screen to move away from the center of the screen.

From equations (1,14),

$$y_2 - y_0 = m * \lambda_1 * \frac{v * T}{d_0} \tag{18}$$

The spectral shift ratio is

$$\frac{y_2 - y_0}{y_0} = \frac{v * T}{D_0} \tag{19}$$

The movement of the path of phase shift causes the displacement of the light band to increase. The inteference pattern is shifted away from the center of the screen. This is commonly known as redshift in astronomy.

E. Blueshift

In the rest frame of the earth, F_2, a star is observed to move toward the earth if

$$v < 0 \tag{20}$$

The path of phase shift moves together with the star in F_2. This causes the intersection of the path and the screen to move toward the center of the screen.

From equations (1,14),

$$y_0 - y_2 = m * \lambda_1 * \frac{-v * T}{d_0} \tag{21}$$

The spectral shift ratio is

$$\frac{y_0 - y_2}{y_0} = \frac{-v * T}{D_0} \tag{22}$$

The movement of the path of phase shift causes the displacement of the light band to decrease. The inteference pattern is shifted toward the center of the screen. This is commonly known as blueshift in astronomy.

F. Radial Velocity

Light travels from the slit to the screen during the elapsed time of T. From equation (6), this distance is

$$C * T = \sqrt{y_1^2 + (D_0 + v * T)^2} \tag{23}$$

The speed of light is C.

$$T = \frac{\sqrt{y_1^2 + (D_0 + v * T)^2}}{C} \tag{24}$$

For $y_1 << D_0$, T is approximately

$$T = \frac{\sqrt{(D_0 + v * T)^2}}{C} \tag{25}$$

$$T = \frac{D_0}{C - v} \tag{26}$$

Let z be the spectral shift ratio.

$$z = \frac{y_2 - y_0}{y_0} \tag{27}$$

From equations (19,27),

$$z = \frac{v * T}{D_0} \tag{28}$$

From equations (26,28),

$$z = \frac{v}{C - v} \tag{29}$$

$$v = C\frac{z}{1 + z} \tag{30}$$

The range of v is between 0 and C for positive z.

For $z << 1$,

$$v = C * z \tag{31}$$

For $z >> 1$,

$$v = C \tag{32}$$

G. Experimental Verification

The spectra of galaxies can vary greatly at different radial velocities at first glance. The spectra of the same galaxy are actually proportionally to each other. They differ in size but are still of the same shape.

From equations (8,16),

$$\theta_2 = \theta_0 \tag{33}$$

The spectrum not only shifts in position but also expands in size proportionally at greater radial velocity.

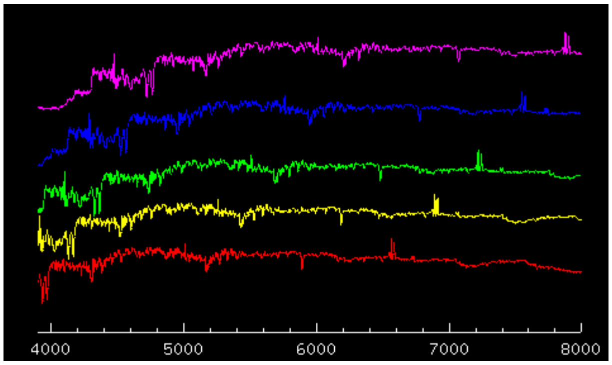

FIG. 2. A galaxy spectrum at four different redshifts

H. Doppler Effect

Let the observed frequency of the light from the distant star be f_1 in F_1 but f_2 in F_2. According to the Doppler effect[2], the frequency decreases if the star is moving away from the earth.

$$f_2 < f_1 \tag{34}$$

The frequency increases if the star is moving toward the earth.

$$f_2 > f_1 \tag{35}$$

The speed of the star light in F_1 is

$$c_1 = f_1 * \lambda_1 \tag{36}$$

The speed of the star light in F_2 is

$$c_2 = f_2 * \lambda_2 \tag{37}$$

From equations (12,34,36,37), the speed of star light decreases if redshift is observed.

$$c_2 < c_1 \tag{38}$$

From equations (12,35,36,37), the speed of star light increases if blueshift is observed.

$$c_2 > c_1 \tag{39}$$

III. CONCLUSION

The spectral shift is the manifestion of the relative motion between the projection screen and the path of phase shift. The intersection of the screen and the path becomes a function of the relative motion between the star and the earth.

The intersection moves closer to the center of the screen if the screen moves closer to the path. The blueshift is observed.

The intersection moves away from the center of the screen if the screen moves away from the path. The redshift is observed.

The spectral shift ratio is unique to the movement of the star. For large ratio exceeding 1, the radial velocity approaches the speed of light. The range of the radial velocity is between 0 and the speed of light.

The wavelength is conserved in all reference frames. The relative motion of the star affects the frequency of its light but not the wavelength. The apparent frequency of the star light is different from the original frequency. The apparent wavelength is identical to the original wavelength.

[1] "Double Slit Interference", http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/slits.html
[2] Possel, Markus (2017). "Waves, motion and frequency: the Doppler effect". Einstein Online, Vol. 5. Max Planck Institute for Gravitational Physics, Potsdam, Germany. Retrieved September 4, 2017.
[3] Su, Eric: Double Slit Interference and Doppler Effect. viXra: Relativity and Cosmology/1906.0352 (2019). http://vixra.org/abs/1906.0352
[4] Su, Eric: Standing Wave And Doppler Effect. viXra: Relativity and Cosmology/1906.0101 (2019). http://vixra.org/abs/1906.0101
[5] Su, Eric: Conservation of Wavelength In Reference Frame. viXra: Relativity and Cosmology/1904.0443 (2019). http://vixra.org/abs/1904.0443
[6] Su, Eric: Displacement And Wavelength In Non-Inertial Reference Frame. viXra: Relativity and Cosmology/1902.0452 (2019). http://vixra.org/abs/1902.0452
[7] Su, Eric: Standing Wave and Reference Frame. viXra: Relativity and Cosmology/1712.0130 (2017). http://vixra.org/abs/1712.0130
[8] Su, Eric: Time In Non-Inertial Reference Frame. viXra: Relativity and Cosmology/1902.0002 (2019). http://vixra.org/abs/1902.0002
[9] Su, Eric: Time Coordinate Transformation From Reflection Symmetry. viXra: Relativity and Cosmology/1901.0001 (2019). http://vixra.org/abs/1901.0001
[10] Su, Eric: Time and Relative Reflection Symmetry. viXra: Relativity and Cosmology/1812.0248 (2018). http://vixra.org/abs/1812.0248
[11] Su, Eric: Time and Reference Frame. viXra: Relativity and Cosmology/1807.0027 (2018). http://vixra.org/abs/1807.0027
[12] Su, Eric: Time Transformation Between Inertial Reference Frames. viXra: Relativity and Cosmology/1801.0328 (2018). http://vixra.org/abs/1801.0328
[13] Eric Su: List of Publications, http://vixra.org/author/eric_su