It may take endless wars and unbearable population pressure to force-feed a technology to the point where it can cope with space. In the universe, space travel may be the normal birth pangs of an otherwise dying civilization. A test. Some pass, some fail.

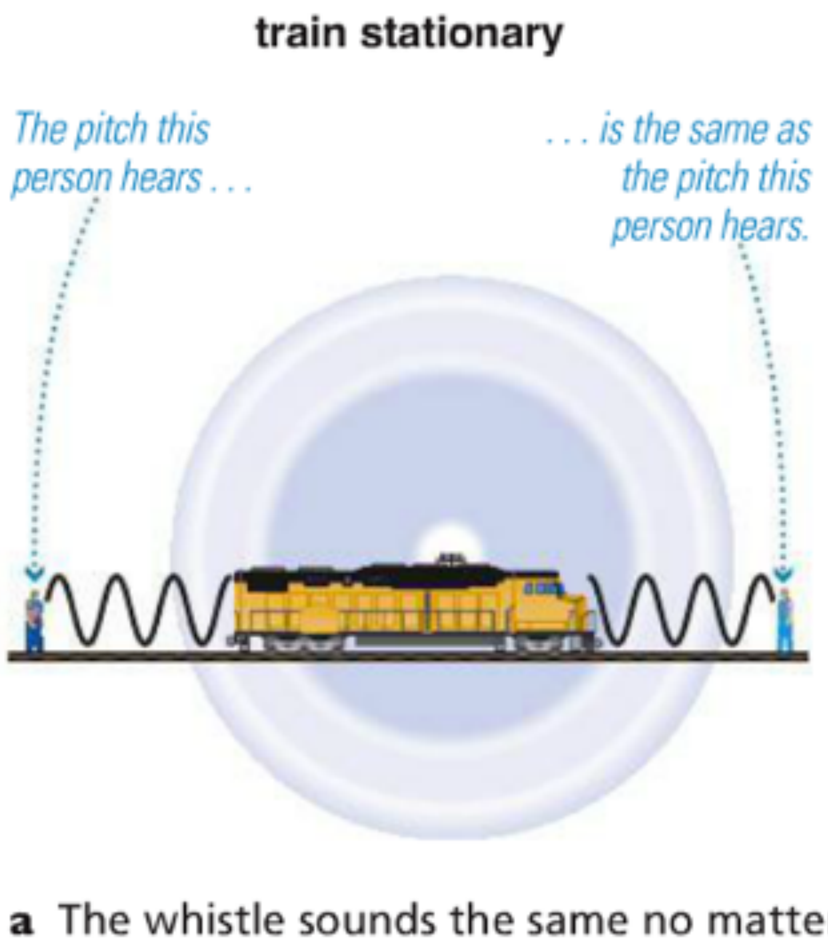
Robert Heinlein

Shifted to the Red

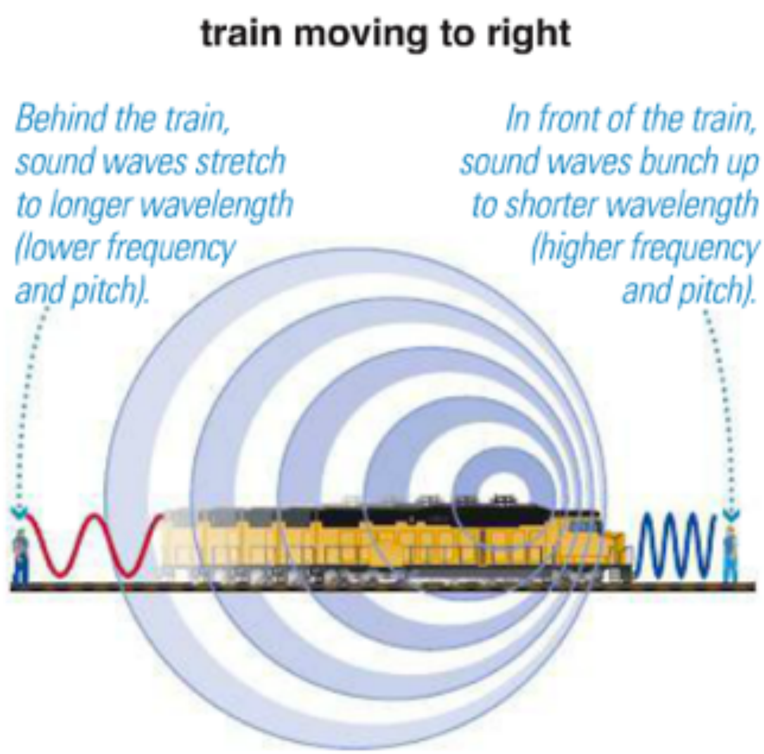
Astronomy 111 here. In this module we'll explore how light tells us the speed and rotation of an object.

To be blunt, the Doppler Effect tells us how fast an object is moving toward or away from us.

It's also something you know intrinsically because you've been making the sound all your life. For example, right now, out loud, make the sound of a motorcycle coming up to you, passing you, and going away from you. Go ahead. Do it. What's the sound that you make? The pitch first gets higher as the motorcycle approaches you and then the pitch gets lower as the bike recedes into the distance. So you know what the Doppler Effect is. We're just going to formalize it a little bit here and apply the same idea to light.



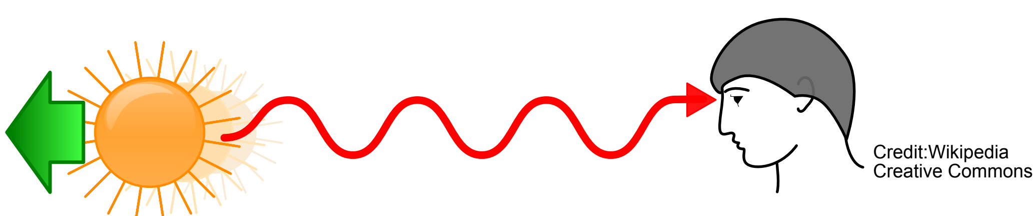
a The whistle sounds the same no matter where you stand near a stationary train.



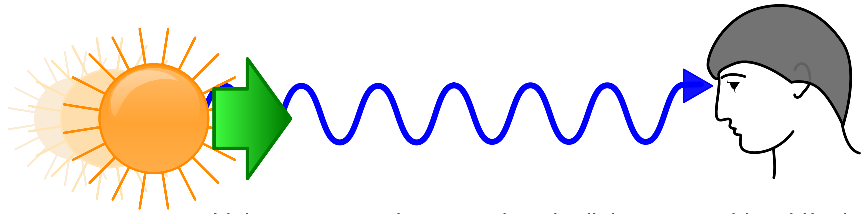
b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

The image above shows what happens with sound waves, which is what we just did. If a train blasts its horn and it's just sitting there not moving relative to the observer, then everybody hears the same pitch.

If the train starts moving toward one of the observers, as in the image above, then the observer in front of the train is going to hear the train coming toward him. The sound waves pile up ahead of the train. The wavelengths get shorter and the frequency - the pitch - becomes higher. Make the sound of an approaching object again. At the other end, if the train is moving away from one of the observers, then the sound waves get stretched out. The wavelengths get longer, the pitch lower. Make the sound of a receding object again.

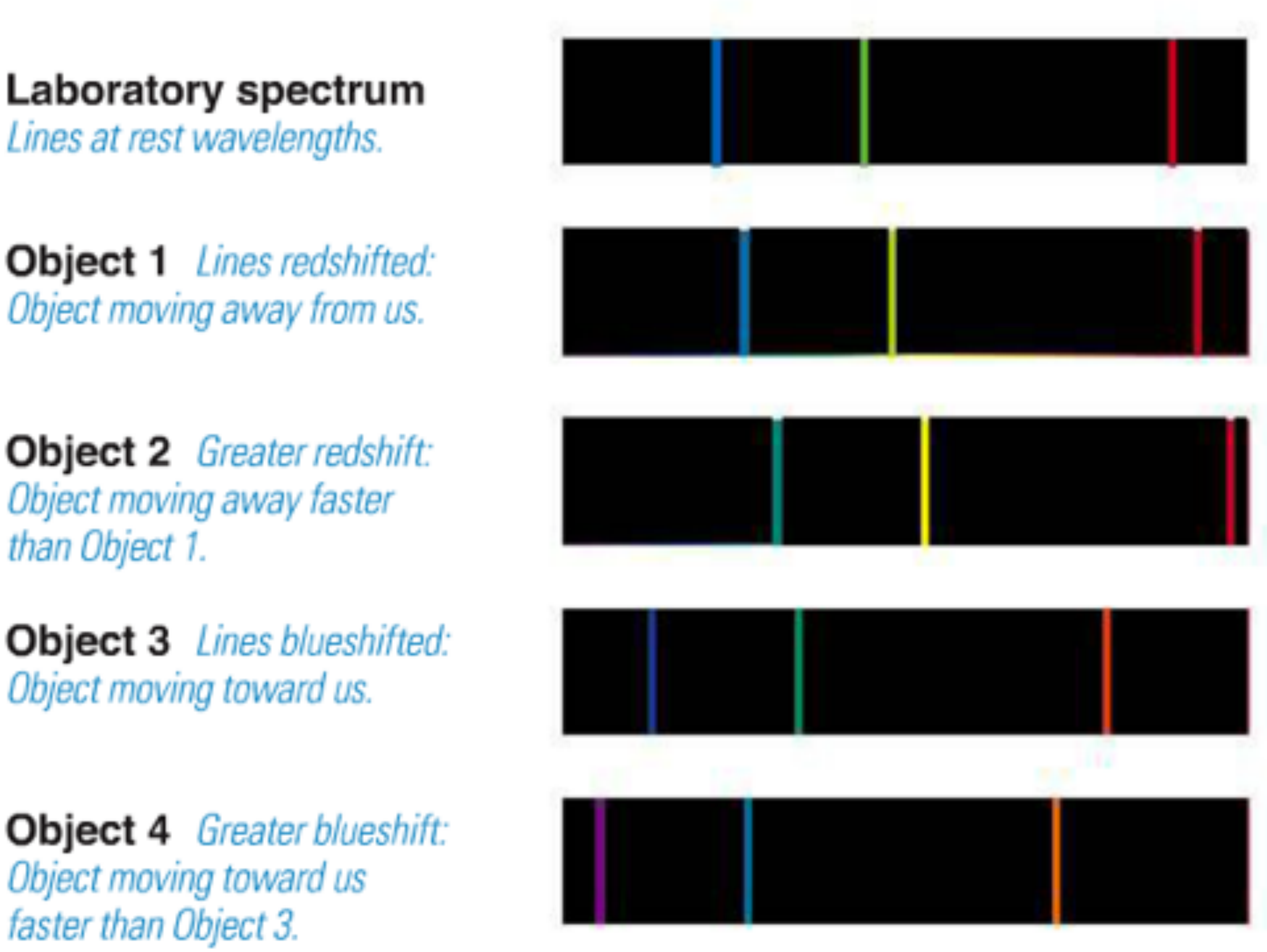


Light source moving away so the light appears redshifted.



Light source moving toward so the light appears blueshifted.

Light does the same thing, as suggested by the image above. Objects moving toward us have their wavelengths compressed. We call this a blue shift. Light is shifted towards the blue end of the spectrum. Objects moving away from us have their wavelengths stretched out. We call this a red shift. Light is shifted towards the red end of the spectrum.



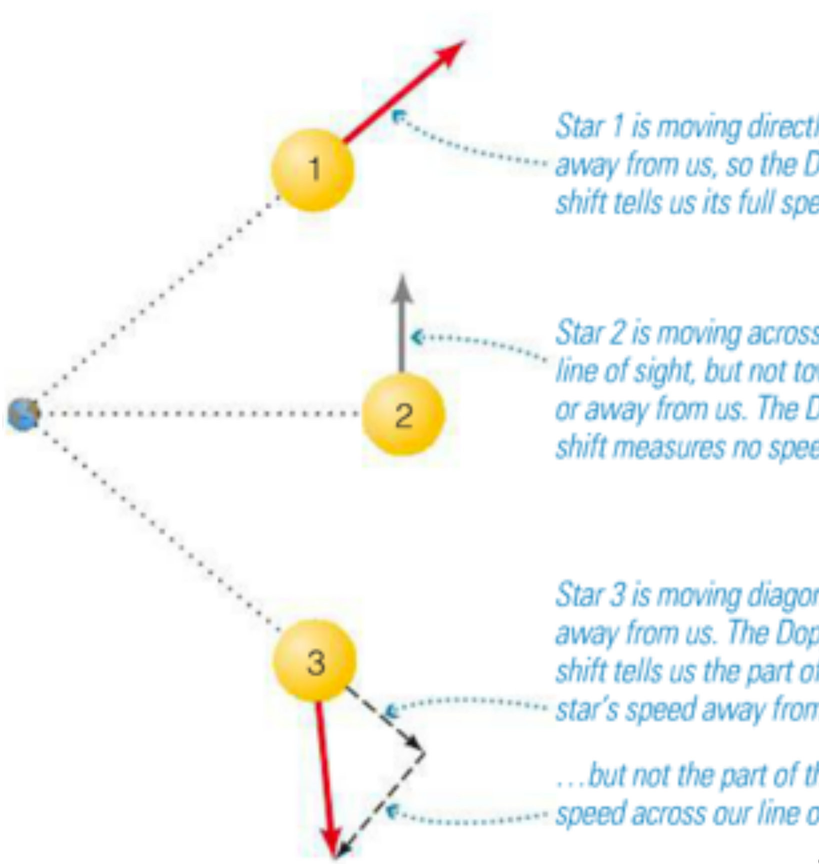
We don't listen to the light, of course. We use spectral lines. The image above shows a laboratory spectrum at rest. If the object is moving away from us, those absorption lines, those dark lines, shift toward redder and redder wavelengths. And so the faster the object recedes from us, the larger the shift. This a red shift. That doesn't mean that the lines are red. It just means they are shifted toward the red, toward longer wavelengths. Conversely, the bottom part of the image above shows the spectral lines shifted towards the blue when an object is approaching us. Away - Red, Toward - Blue.

This is exactly what the policeman uses. When they shine their radar gun at you, it is sending out a known wavelength. The light wave hits your car and bounces the signal back to the radar gun. The wavelength shifts because of your motion. The size of the shift is what tells the policeman your speed. How that's done is given by

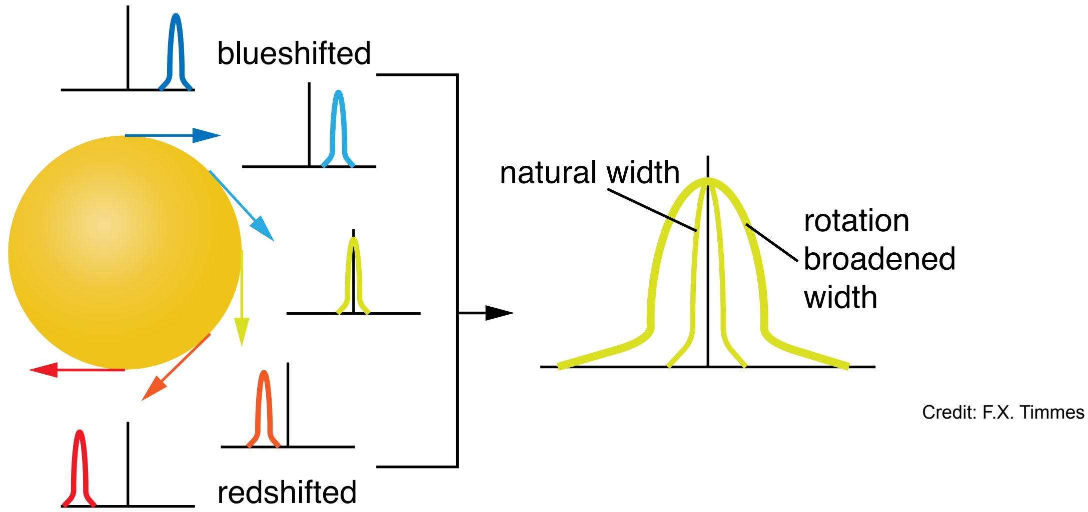
$$\text{speed} = [(\text{shifted wavelength} - \text{rest wavelength}) / \text{rest wavelength}] \times c$$

$$v/c = \Delta\lambda/\lambda_0$$

How fast you're going is equal to the size of the shift of the wavelength divided by the original wavelength times the speed of light. This is what the policeman's radar unit is basically doing. It knows what wavelength is being sent. It receives the shifted wavelength upon reflection off your car. Unit applies this little formula. Hopefully you are driving below the posted speed limit.



Now, a Doppler shift only tells you motion directly toward or away from you. If you have an object that is moving across your line of sight, then there's no Doppler shift because it's not moving toward or away from you. You only pick up that component of the motion that is toward or away from you. This is what the illustration above is showing.



The Doppler shift can also tell us how fast something is rotating. Because if something is rotating — think of a ball when it's rotating — part of the ball is coming toward you, so you're going see a blue shift from that part of the ball. Another part of the ball, or planet as shown in the illustration above, is going to be moving away from you, so you’ll see a red shift.

When you add all these shifts together you get what is called a Doppler broadened line. In effect you don't just see one spectral line. You see a superposition of spectral lines from different parts of the object. The faster an object spins the wider the line. So it is the width of the Doppler broadened line that tells us how fast the object is rotating.

Carpe Diem! Bye Bye.