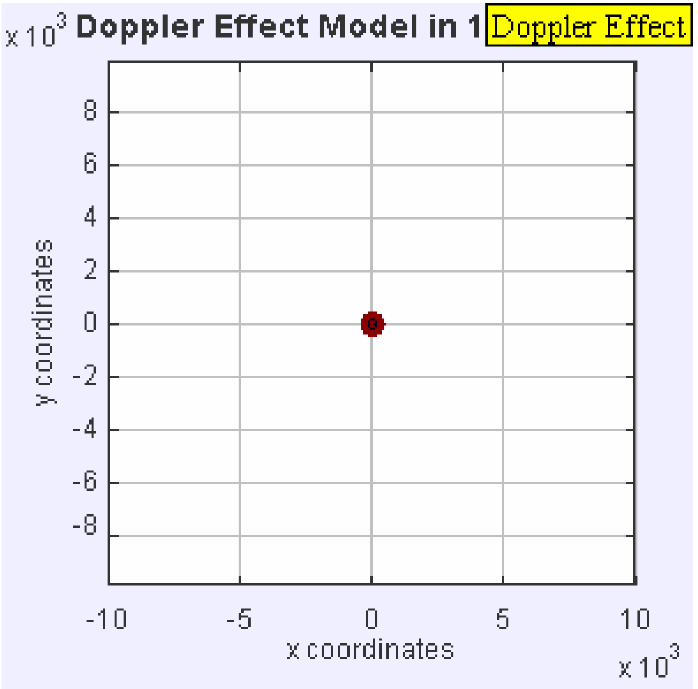
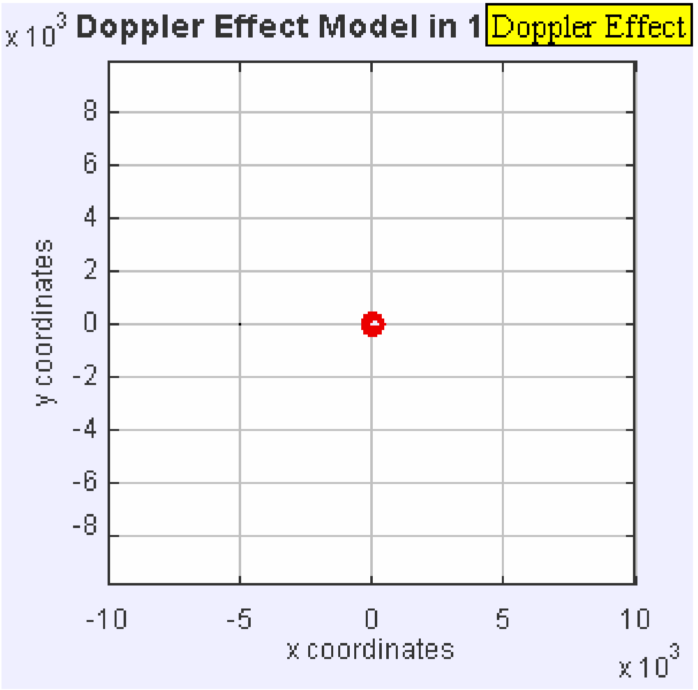
An introduction to
Redshift

Zach Meisel
Ohio University - ASTR1000

Doppler effect for sound

- The doppler effect is a shift in the frequency of a wave due to motion between the wave source and the observer
- Waves leave a wave source (e.g. a speaker) with some speed (e.g. the speed of sound).
- But, a moving wave source can chase after a wave front traveling a particular direction, closing the distance between the wave source and the wave front,
  while increasing the distance between the wavefront traveling in the opposite direction,
  and not changing the distance form the wave fronts traveling in the perpendicular direction.
- An and observer measuring the frequency of waves will see:
  - higher frequency if the wave source is moving toward them
  - lower frequency if the object is moving away from them
  - no change in frequency if the object is moving perpendicular to them





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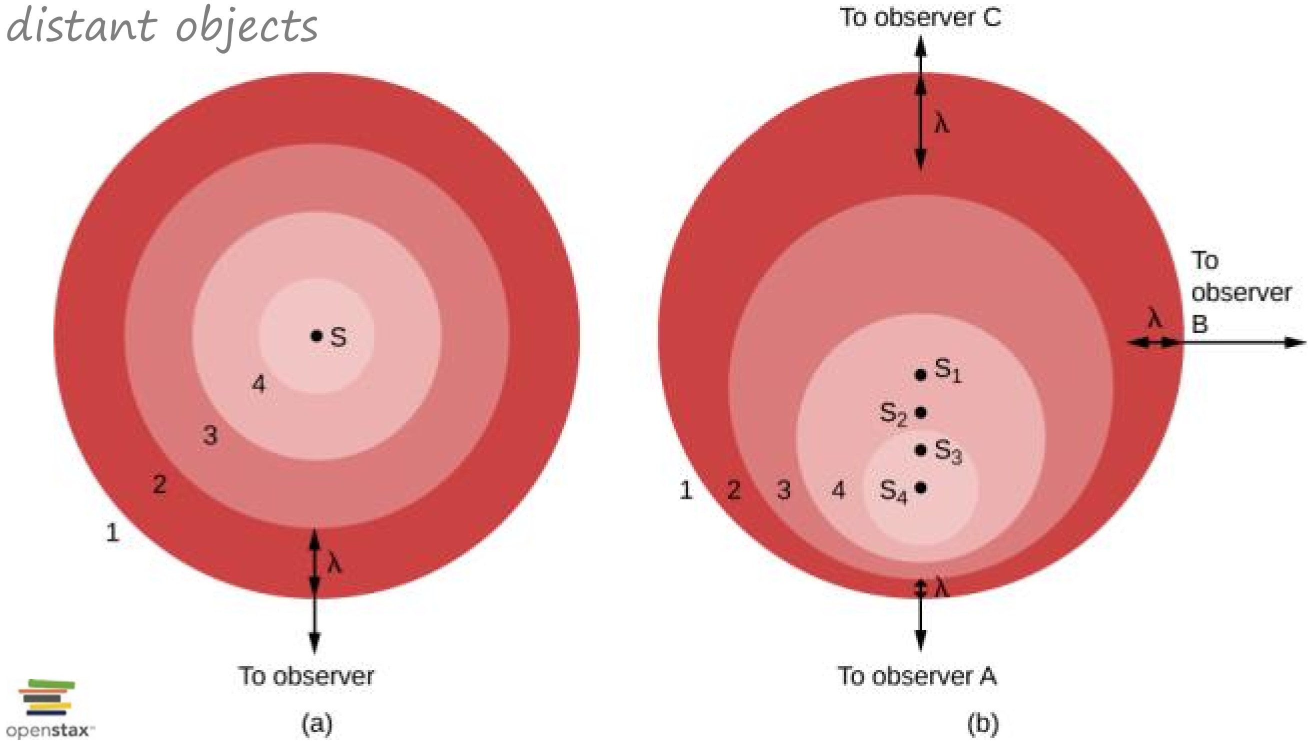
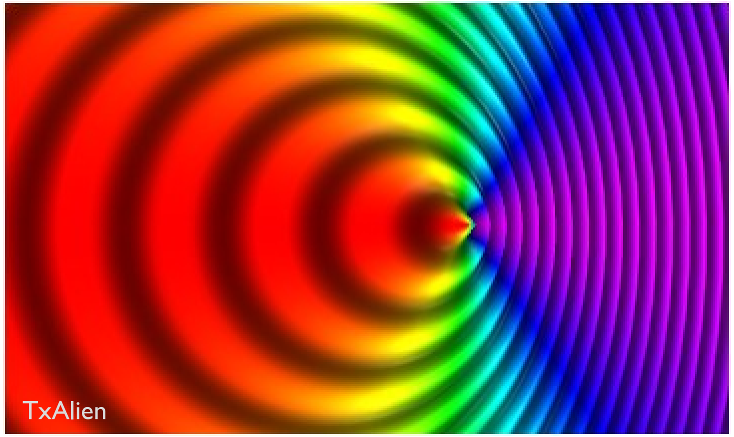
Doppler effect for **light**

- Light is a wave and subject to the same compression/stretching due to motion between the observer and the source
- The amount the wavelength is stretched ("red-shift") or compressed ("blue shift") is determined by the relative radial velocity v between the observer and object
  - $\Delta\lambda = \lambda \frac{v}{c}$ where λ is the wavelength for a stationary source and c is the speed of light

true for v<<c and not too distant objects

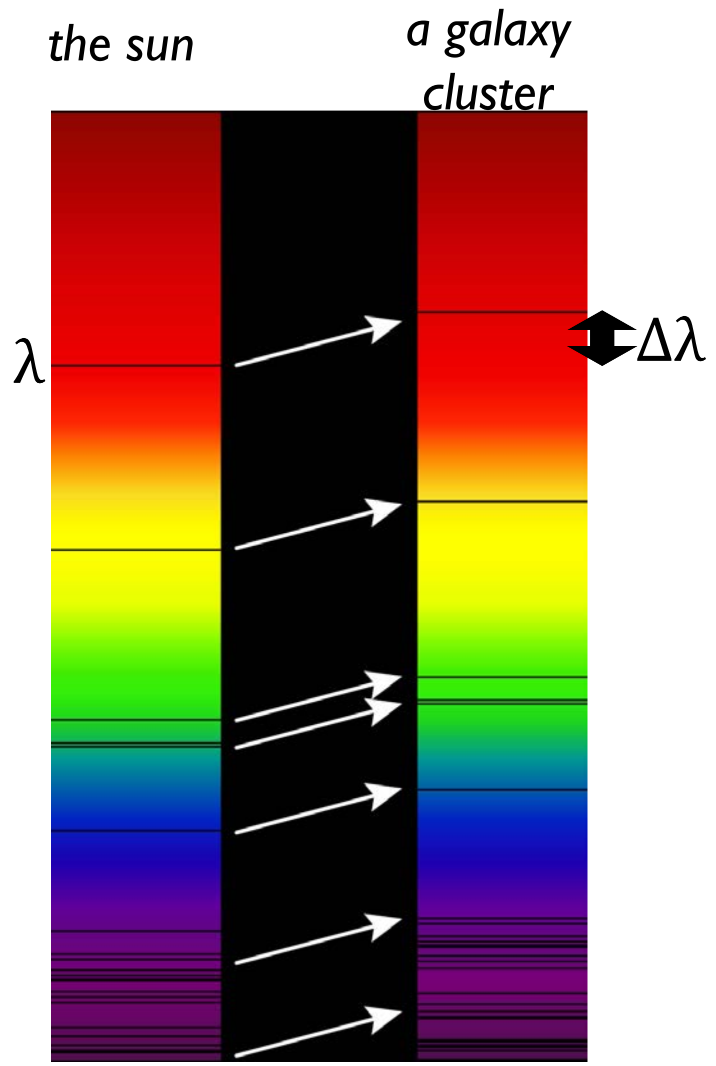


"red-shift" *"blue-shift"*



Consequence for astronomy: *velocity determination*

- Since $v = c\frac{\Delta\lambda}{\lambda}$, the wavelength shift tells us the *radial* velocity of an object
- The "redshift" is defined as $z = \frac{\Delta\lambda}{\lambda}$
- Example:
  - A spectral line, known to be intrinsically at 400 nm, is observed at 410 nm.
    How fast is this object moving away from us?
    - $v = c\frac{\Delta\lambda}{\lambda} = (2.998 \times 10^8\ m/s)\left(\frac{410\ nm - 400\ nm}{400\ nm}\right)$
      - $= 0.025c \approx 7.5 \times 10^6 \frac{m}{s} = 7.5 \frac{Mm}{s}$
    - Is this the object's total velocity?
      - Not necessarily! This is the velocity along the direction of motion between us and the object. (i.e. the radial velocity)



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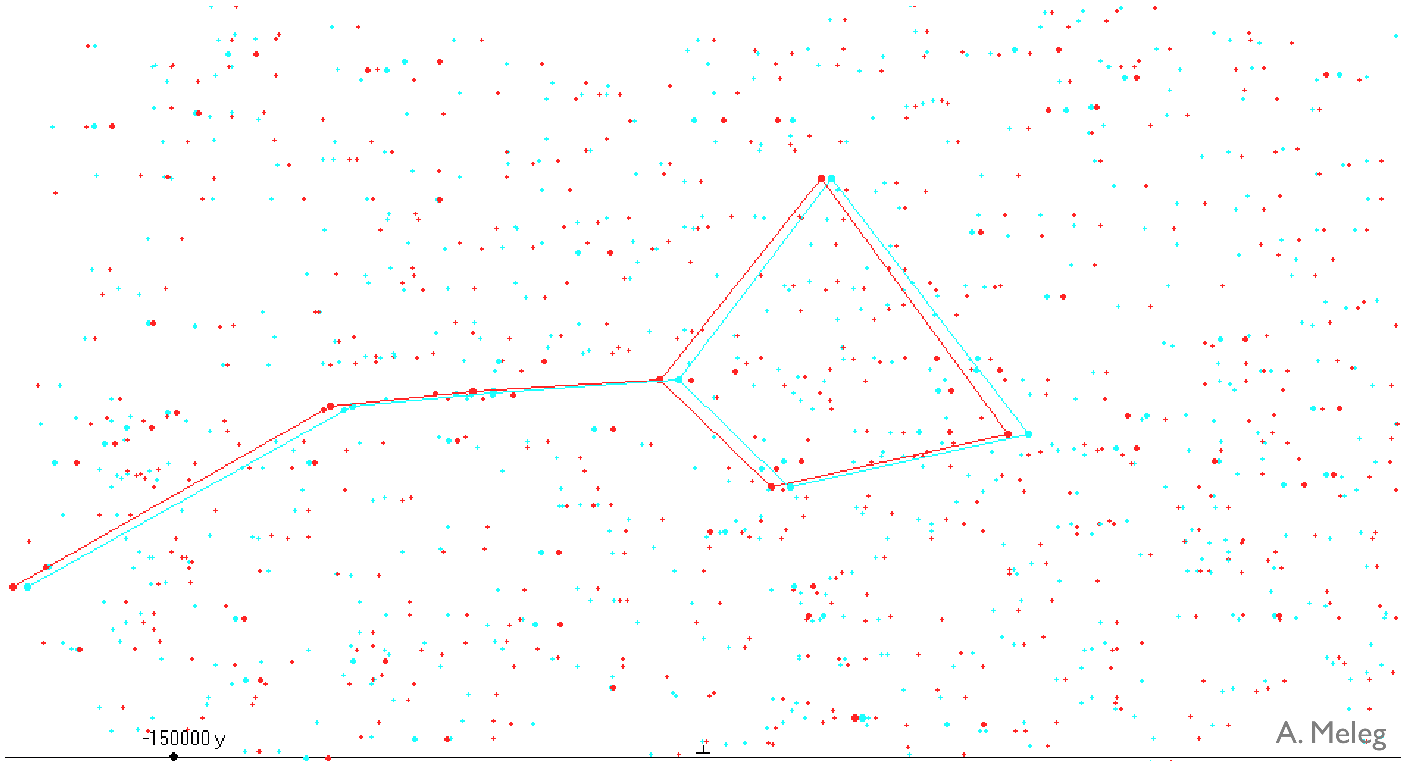
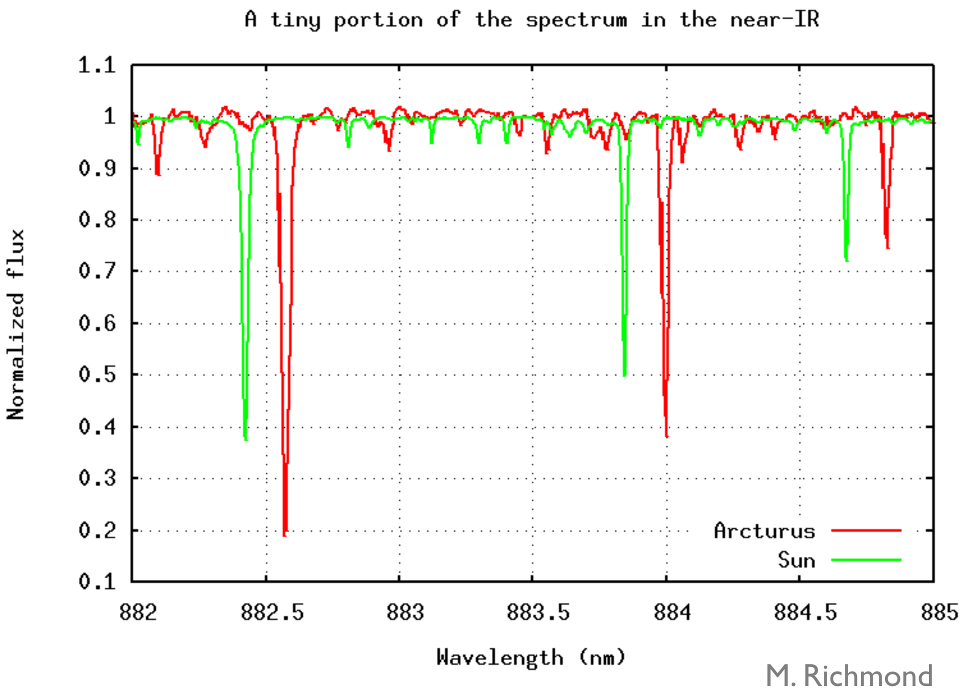
Consequence for astronomy: *velocity determination*

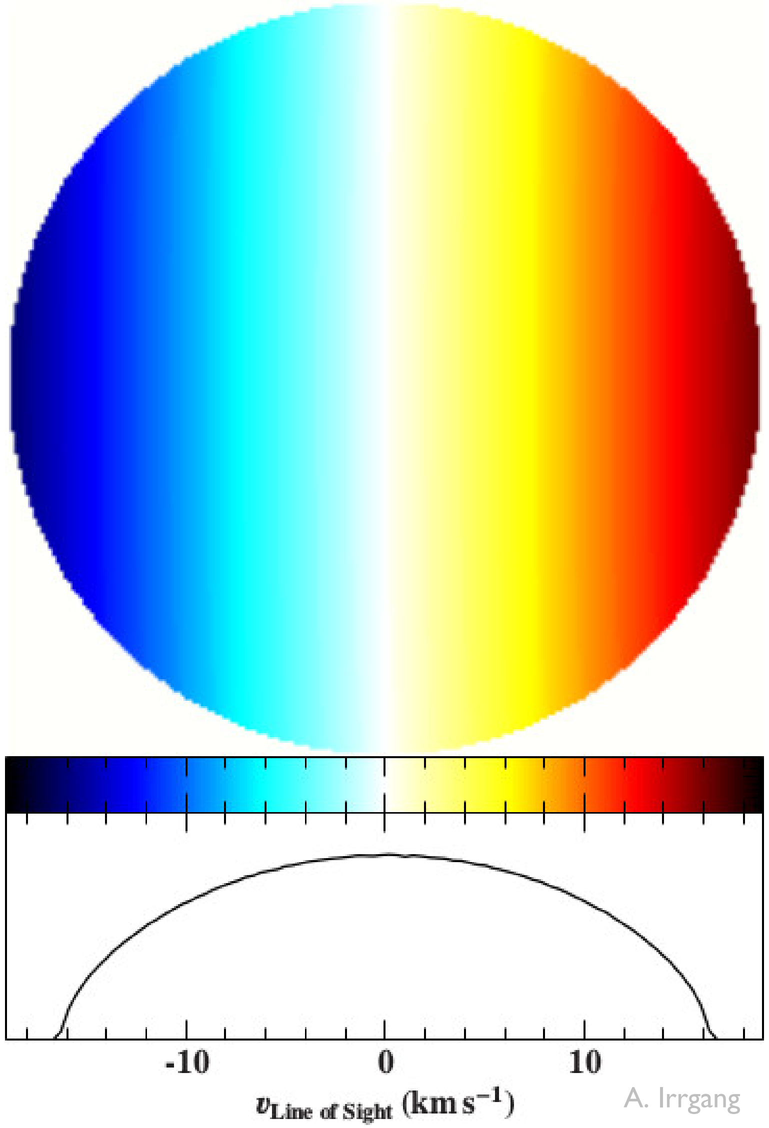
- We can use the doppler shift to determine the motion of stars
- For instance, the Big Dipper will look smashed in 150,000 years





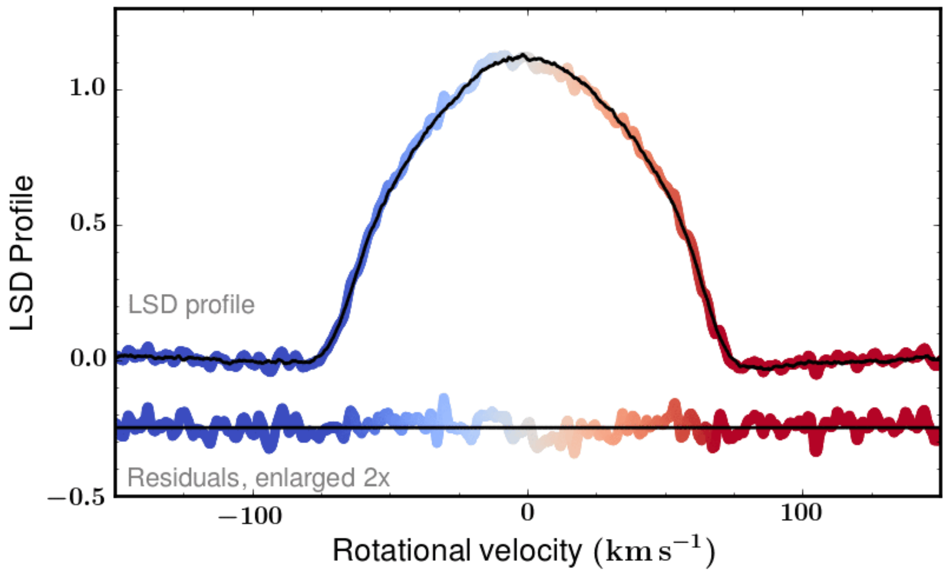
Consequence for astronomy: *rotation determination*

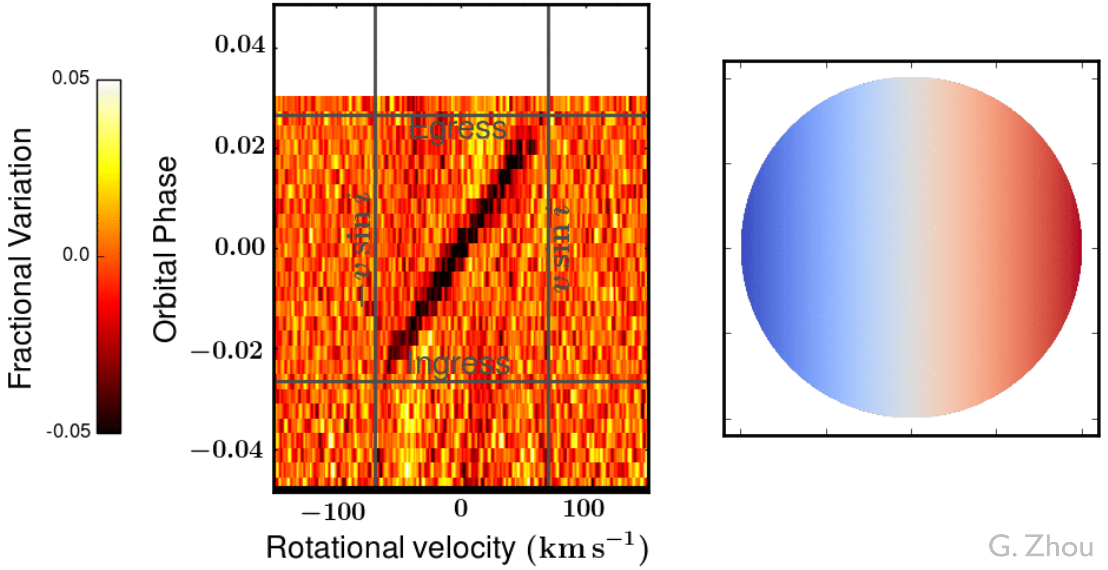
- When a star is rotating, part of the atmosphere is moving toward the observer, while part is moving away
- This means one side will be redshifted and the other will be blue shifted
- However, we can't choose to view one part of the star, so instead the spectral line appears much broader, because we see the redshifted and blue shifted (and unshifted) parts at the same time
- The width of broadening is related to the rotation rate



Consequence for astronomy: *planet detection*

- A planet orbiting a distant star will block some of that star's light if it passes in between us and the star
- This will temporarily block some light with a given red-shift, modifying the shape of the doppler-broadened spectral line





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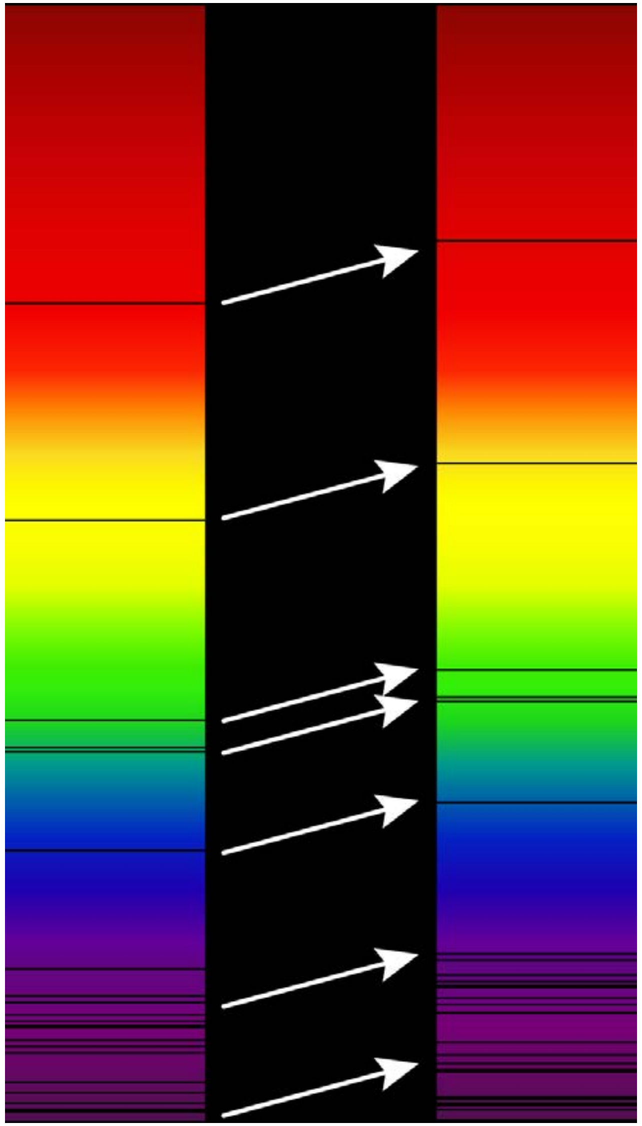
Consequence for astronomy: *spectrum interpretation*

- Since spectral lines can be shifted due to radial velocity, it's not enough to look for a single spectral line.
- Several lines need to be observed to identify a spectral pattern and then the wavelength shift can be identified.



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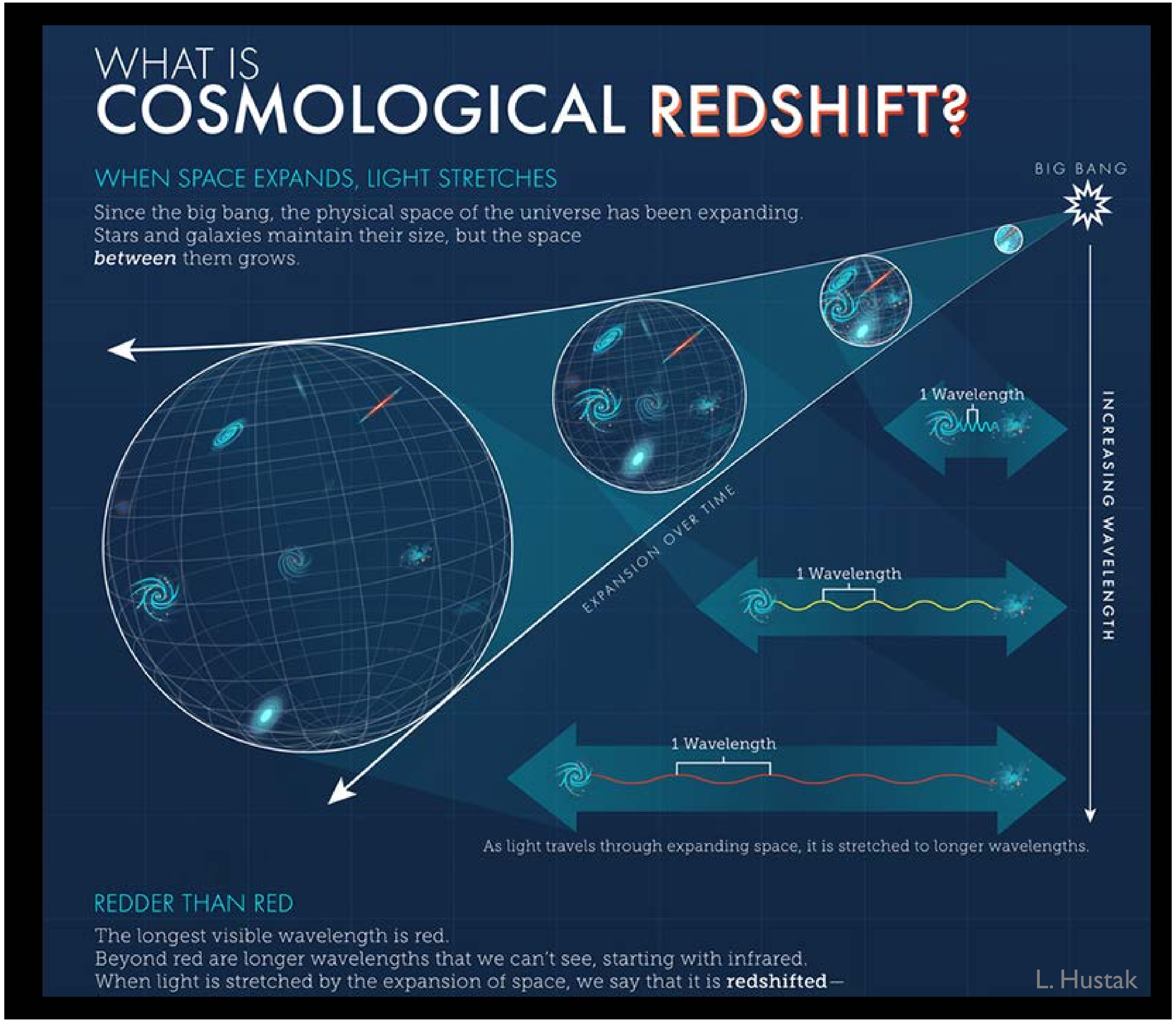
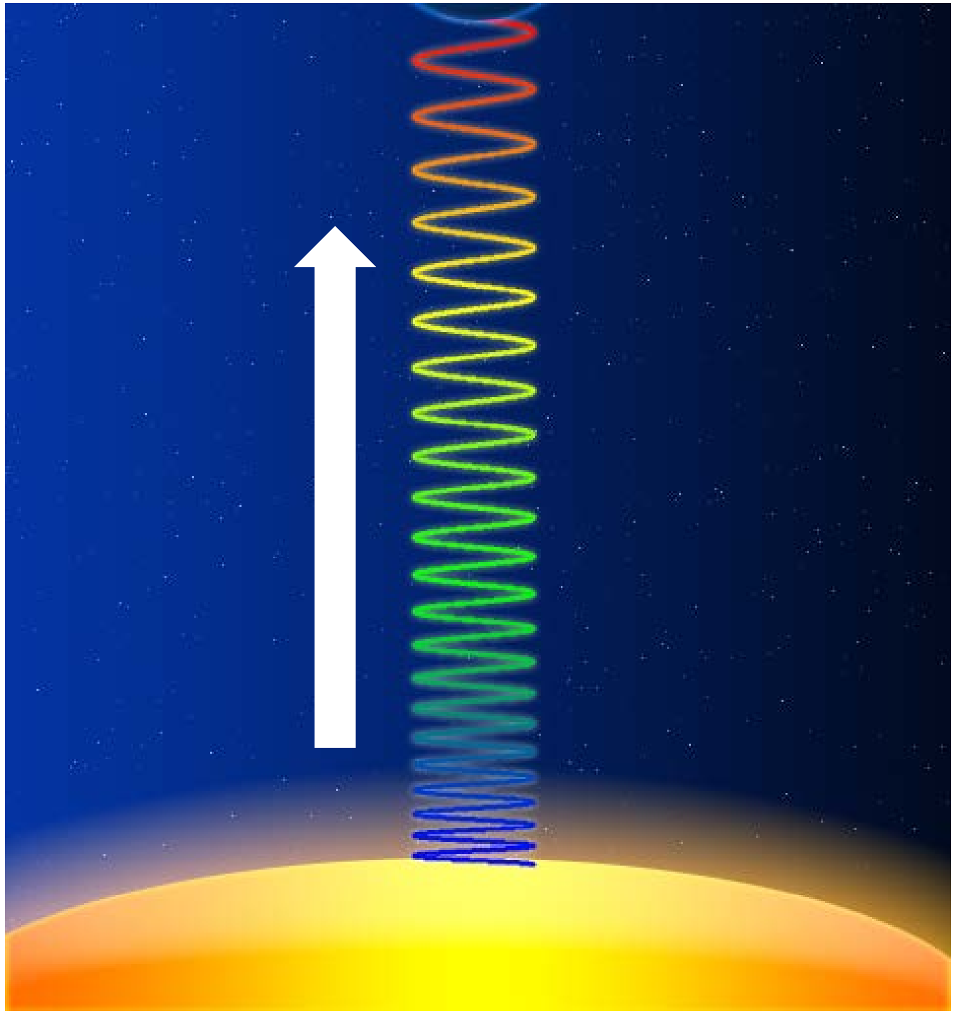
Cosmological redshift and distance determination

- The universe is constantly expanding, so everything is moving away from us
- Space is physically stretching light traveling through it, expanding the wavelength
- So, redshift can be used as a measure of distance
  - This is known as "cosmological redshift" and is useful for stuff that's far away (distant galaxies).
  - For close by objects, e.g. stars in our galaxy,
    this effect is tiny and the doppler redshift from local relative motion is far more important



Gravitational redshift

- The equivalence principle is the concept that acceleration due to gravity and physical acceleration are equivalent from a physics perspective
- Therefore, near an object with a strong gravitational pull (e.g. a neutron star), light experiences acceleration towards the massive object it is escaping
- This results in a doppler shift, red shifting light escaping a massive, dense object



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