Teaching Cosmology in High School

By Cruise Le Blanc + Heidi Wu

Outline

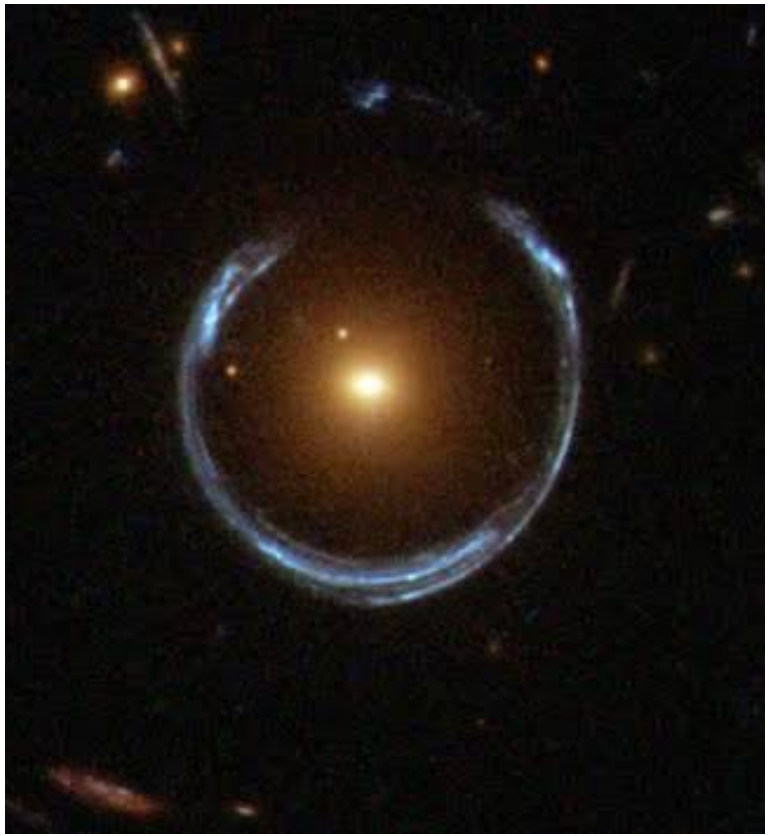
Lesson 1: Gravitational Lensing

Lesson 2: Doppler Effect and the Expansion of the Universe

Lesson 3: Rotation Curve and the Discovery of Dark Matter

Lesson 4: Virial Theorem: Hotter is More Massive

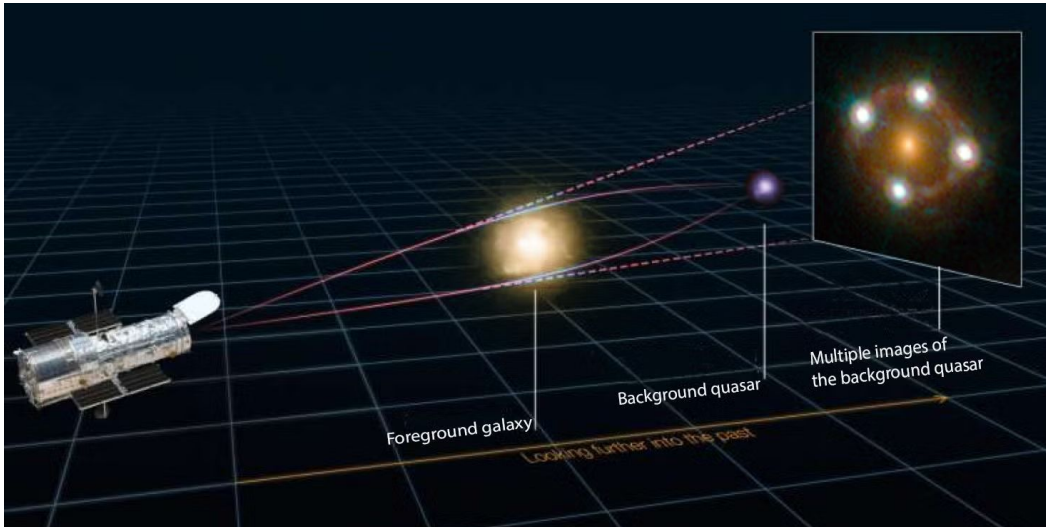
Lesson 1: Gravitational Lensing

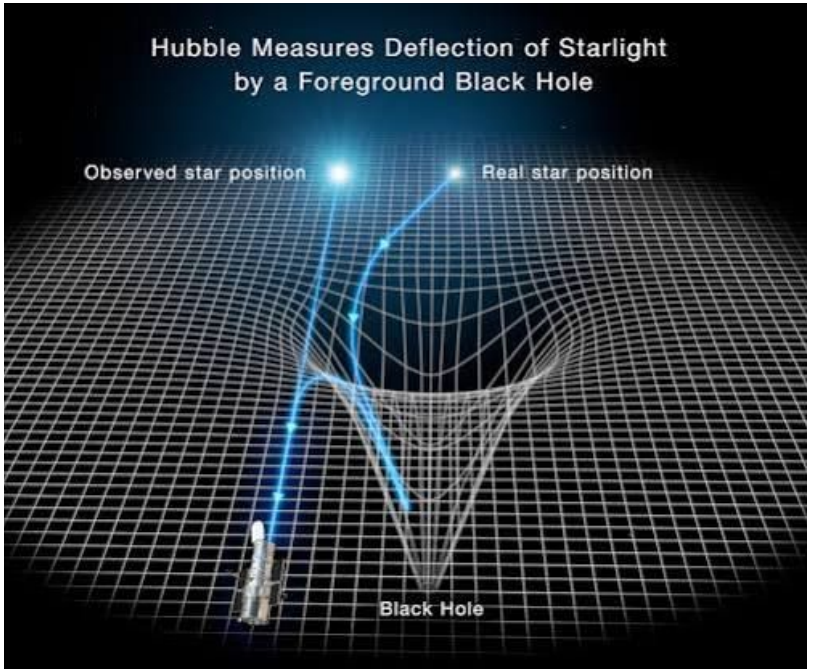


High School Physics (11-12)

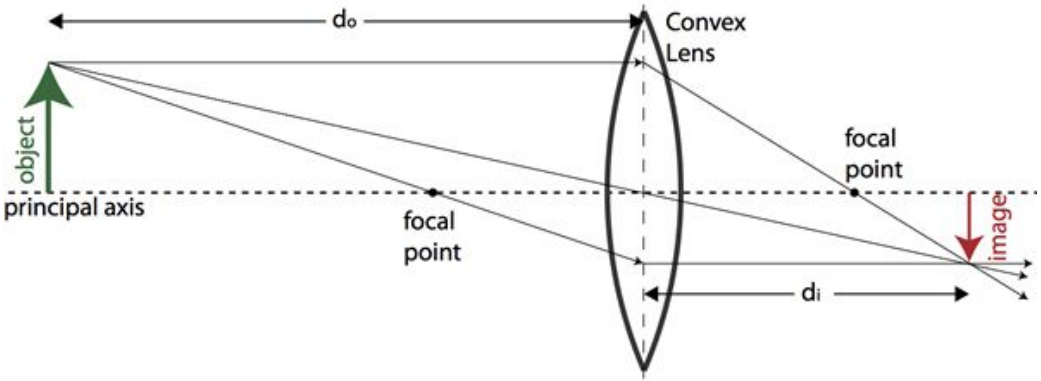
Objective: Students will investigate the characteristics and behaviors of gravitational lensing and the distortion of space time.

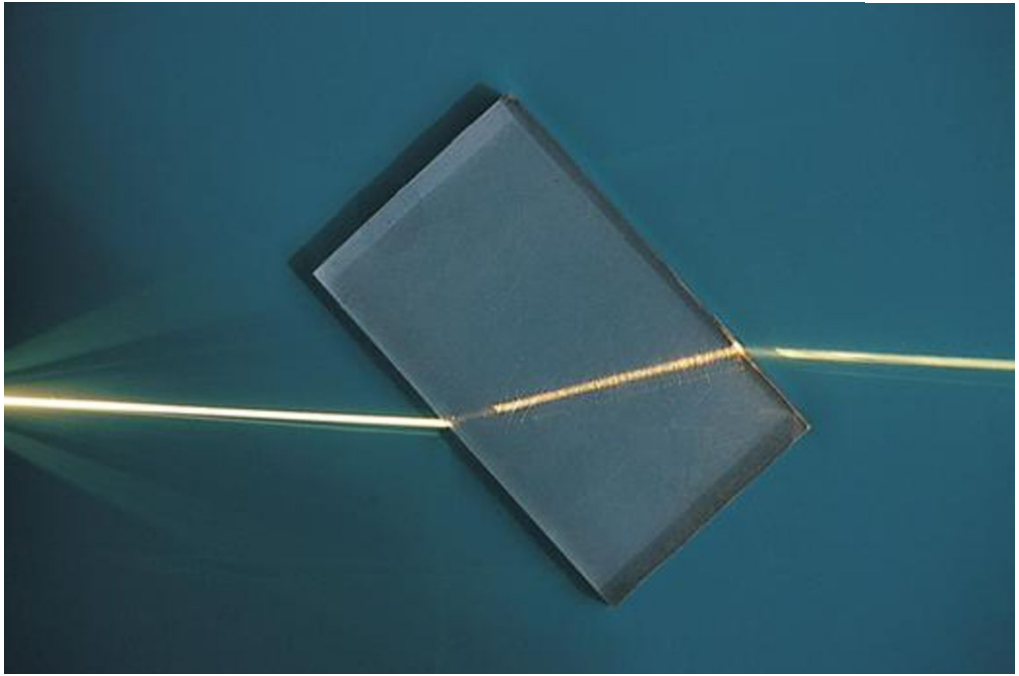
Light traveling through bending space

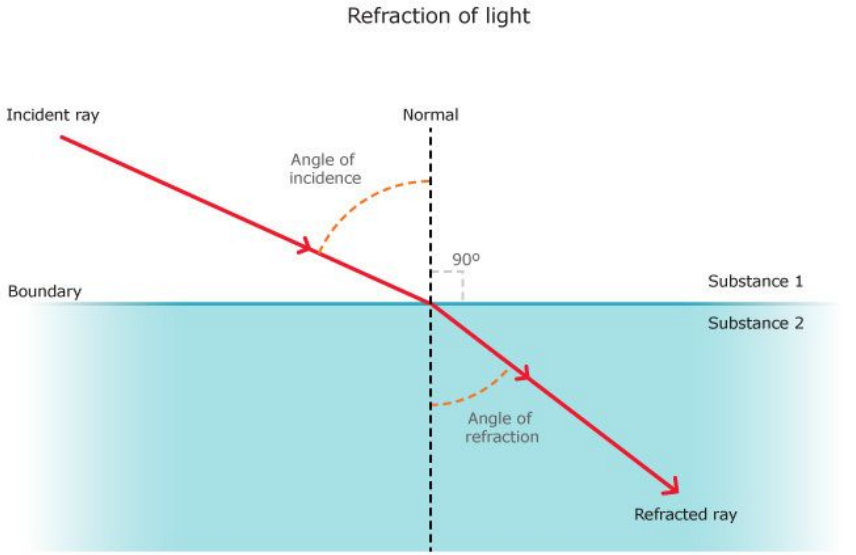




Light bent by medium





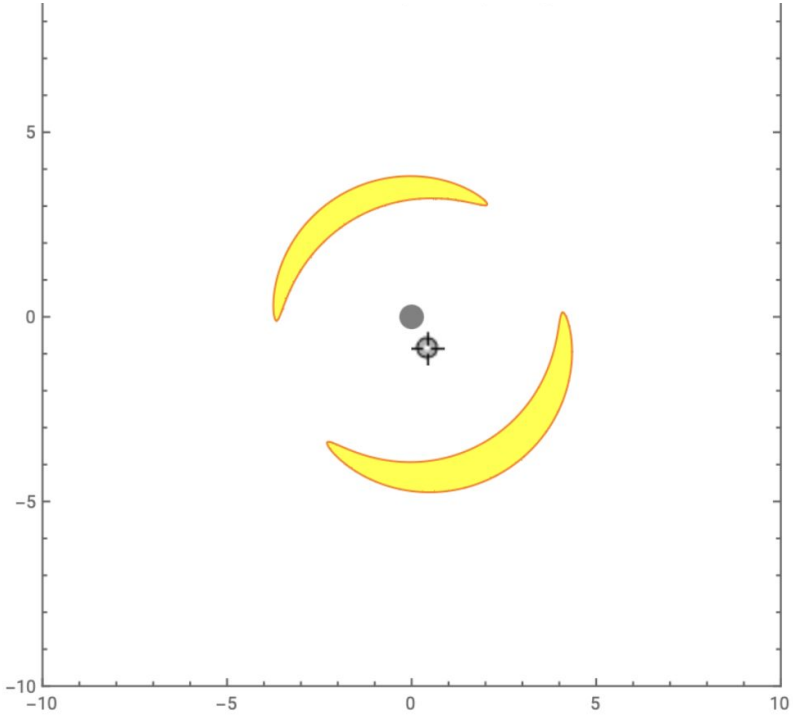


Activities

1. Wine glasses showing distorted images
    a. Flash light
    b. Polka dots
2. Computer simulation 1: [Link]
    a. Source distance
    b. Source offset
    c. Cluster distance
    d. Cluster mass
3. Computer simulation 2: [Link]
    a. Can you figure out what parameters create the observed lensing?

Materials

- Wine glass or glass with a similar base
- Sticky notes
- Individual computers, Chromebooks, iPads, with internet capability
- Printed out images of gravitational lensing, Resource (provided)
- Printed out worksheets (provided)
- Two gravitational lensing simulations (provided)



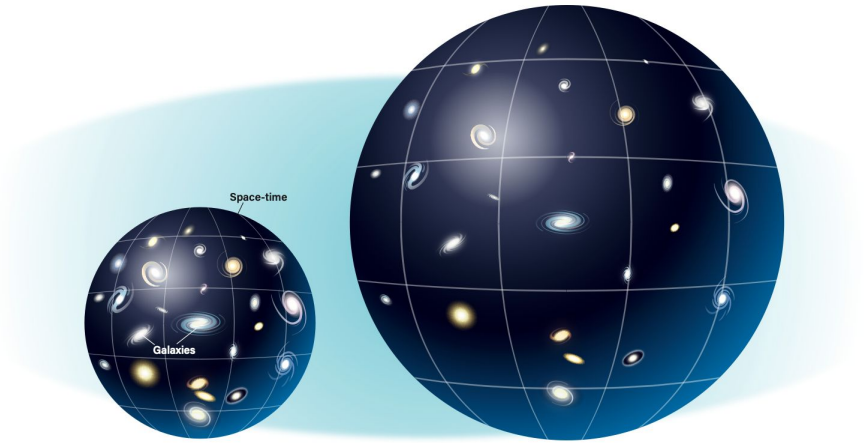
Lesson 2: Doppler Effect and the Expansion of the Universe

High School Physics (11-12)

Objective: Students will investigate the Doppler effect and its relation to red and blue shifts and Hubble's Law.

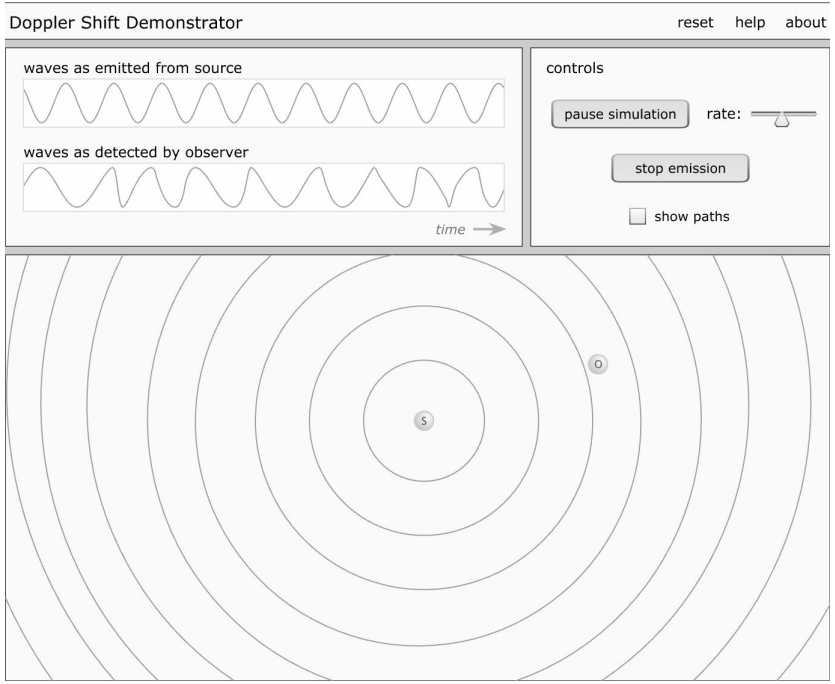
Doppler Effect: $f = \left(\frac{v_m \pm v_r}{v_m \mp v_s} \right) f_0$

Hubble's Law: $v = H_0 d$



Activities:

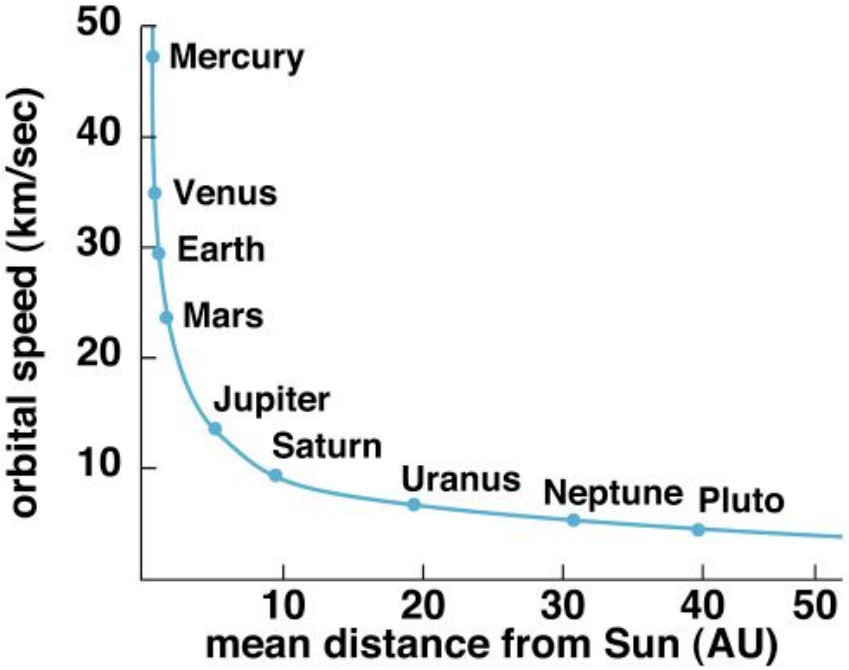
1. Computer simulation of ripples: [Link]
    a. Source wave
    b. Observed wave
2. Balloons
    a. Distance between spots
3. Rubber band (with worksheet)
    a. Distance between lines



Materials

- Doppler effect simulation
- Individual computers, Chromebooks, iPads, with internet capability
- Balloon with spots
- Pump for the balloons
- Thick rubber bands that have been cut into strips with five lines drawn on them about 2 cm apart
- Rulers
- Stop watches
- Worksheet (provided)

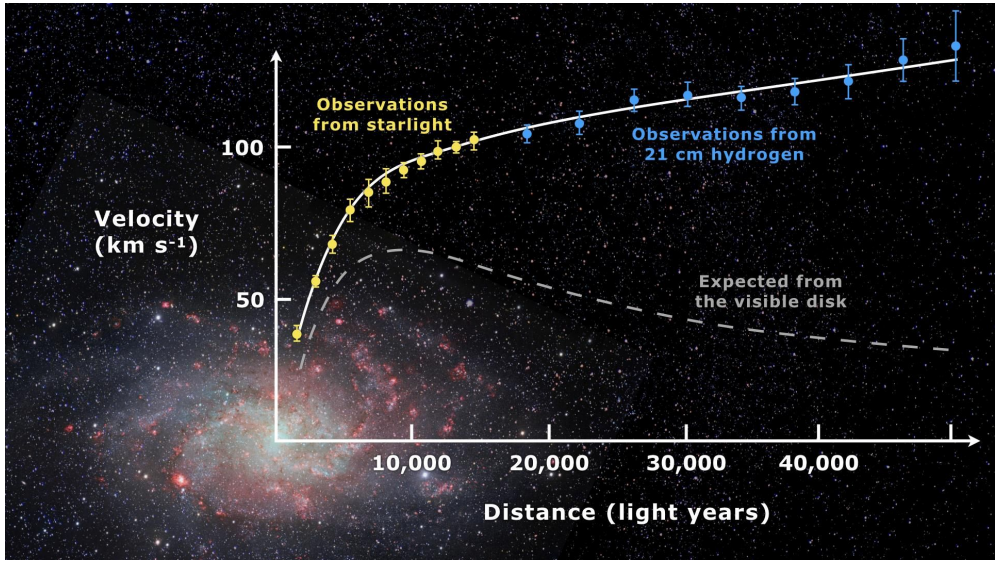
Lesson 3: Rotation Curve and the Discovery of Dark Matter

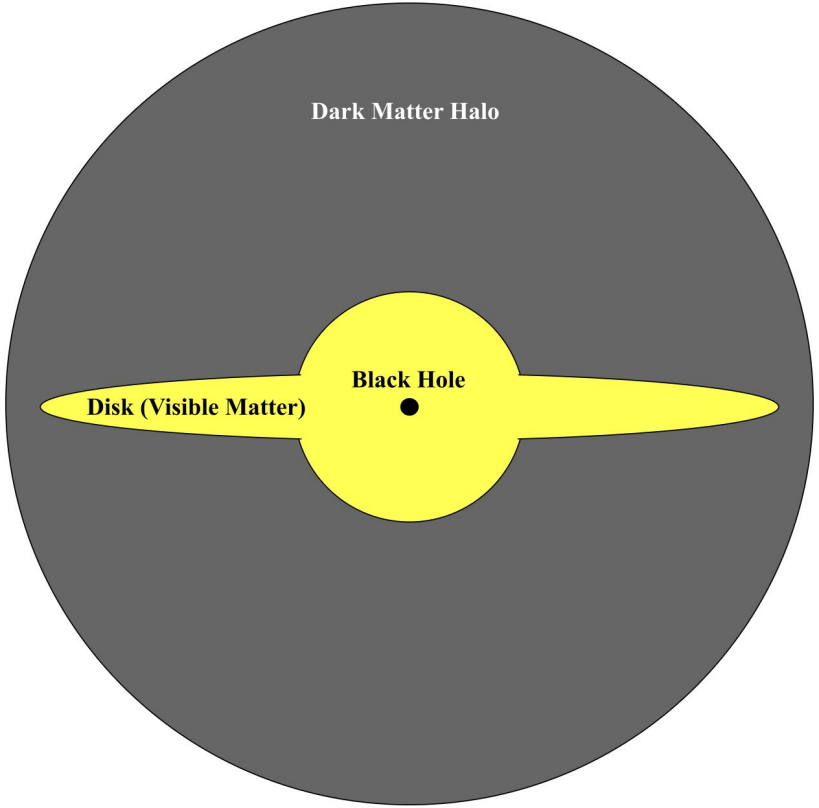


High School Physics (11-12)

Objective: Students will investigate circular motion and rotational speed, and how to use them to infer the gravitational force and matter distribution. Students will understand the physics behind the discovery of dark matter.

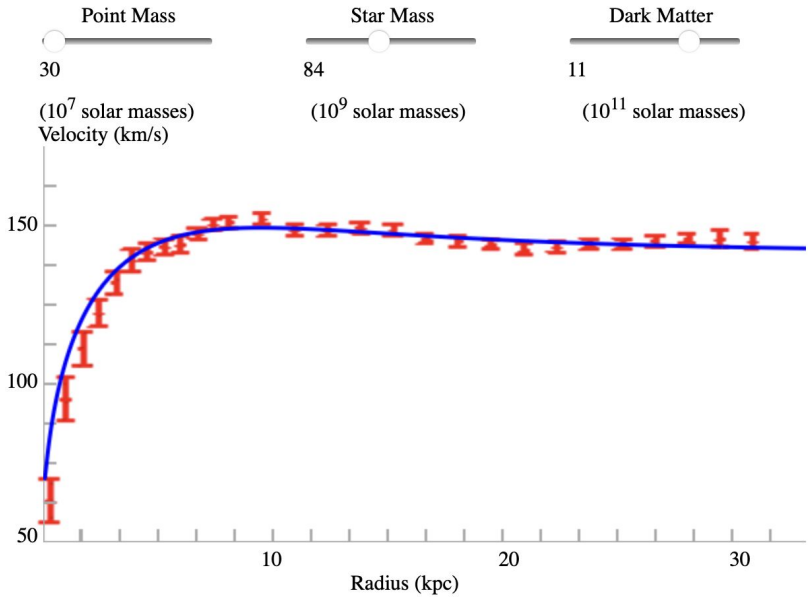
Galaxy Rotation Curve and the Discovery of Dark Matter

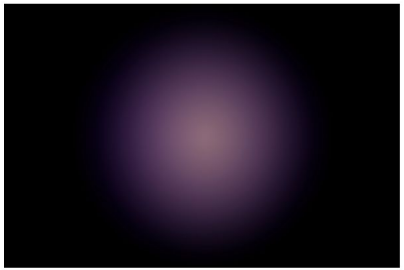


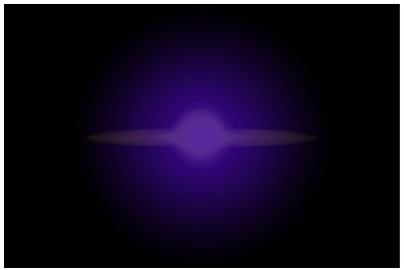


Activities

1. Meter stick and string
2. Computer simulation: Build your galaxy! [Link]
3. Make your rotation curve:
   a. Solid body rotation
   b. Point mass
   c. Extended mass







Materials

- Meter stick (preferably two meter sticks taped together)
- Rope or string about the same length as the meter stick (or the two meter sticks)
- Printed out worksheet (provided)
- Galaxy curve simulation (provided)
- Individual computers, Chromebooks, iPads, with internet capability

Calculation

Solid-body rotation

$$\frac{GM_{enc}}{r^2}m = \frac{mv^2}{r}, \text{ where } M_{enc} = \frac{4}{3}\rho\pi r^3$$

$$\Rightarrow \frac{4}{3}G\rho\pi r^2 = v^2$$

Therefore $v \propto r$.

Non-solid-body rotation

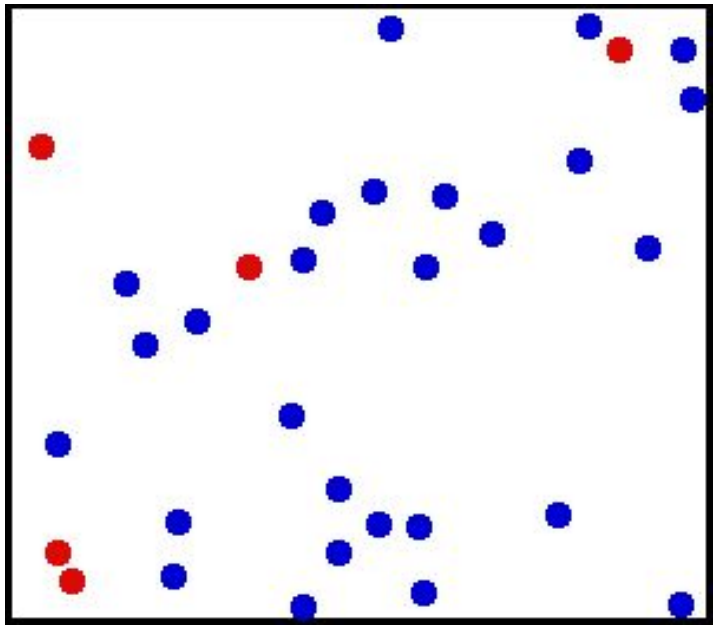
$$\frac{GMm}{r^2} = m\frac{v^2}{r}$$

$$\Rightarrow \frac{GM}{r} = v^2$$

$$\Rightarrow v^2 \propto \frac{1}{r}$$

Therefore $v \propto \frac{1}{\sqrt{r}}$

Lesson 4: Virial Theorem: Hotter is More Massive



High School Physics (11-12)

Objective: Students will investigate the relation between temperature and random motion of molecules/atoms. Students will learn how kinetic energy and gravitational potential energy are related to each other. Students will learn how to relate temperature and gravitational potential.

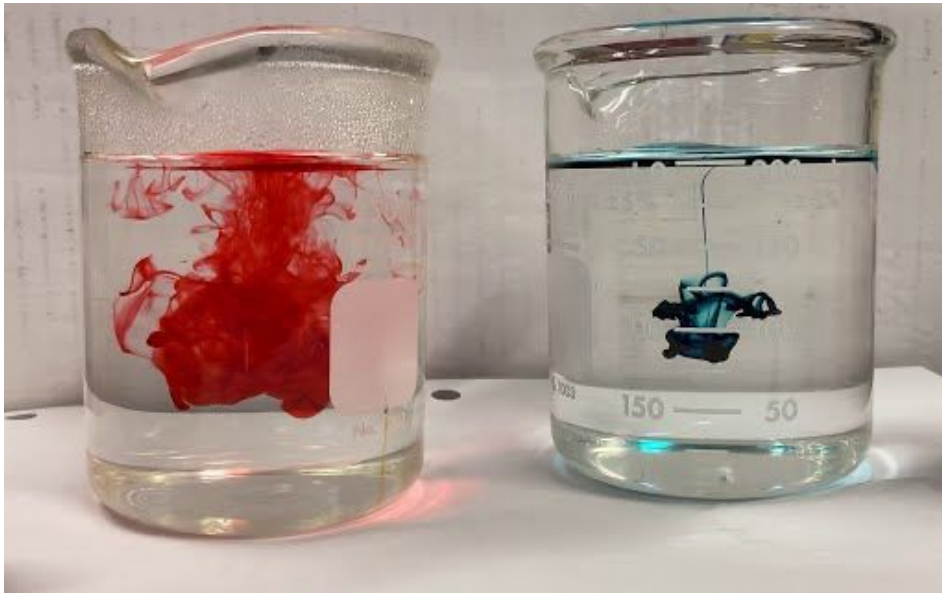
2K + U = 0

$$k_B T \approx \frac{GMm_p}{R}$$

Activities

1. Food coloring in hot vs. cold water
    a. Does the food coloring spread faster in hot or cold water?
2. Marble and track
    a. At what height can a marble complete a loop?
3. Final problem
    a. How hot is a galaxy cluster?
    b. How fast are galaxies in a cluster?

Temperature is related to how fast the molecules move



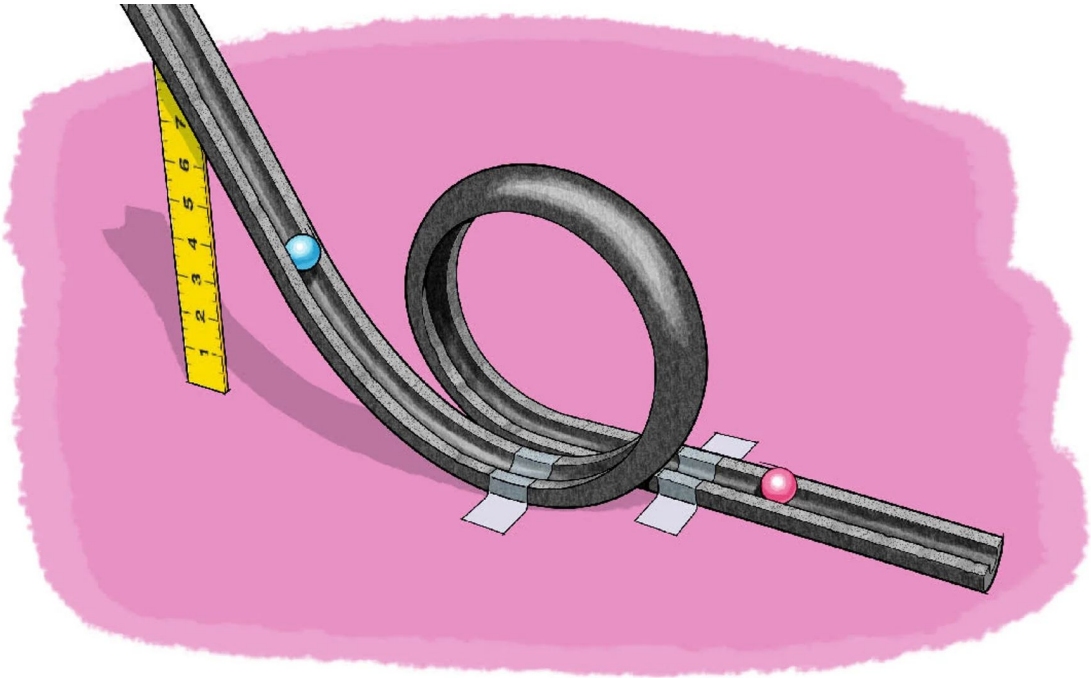
Temperature is the measure of the average kinetic energy of particles in a given area.

$$\frac{1}{2}mv^2 = \frac{3}{2}k_{\mathrm{B}}T.$$

Gravitational energy can be converted to kinetic energy

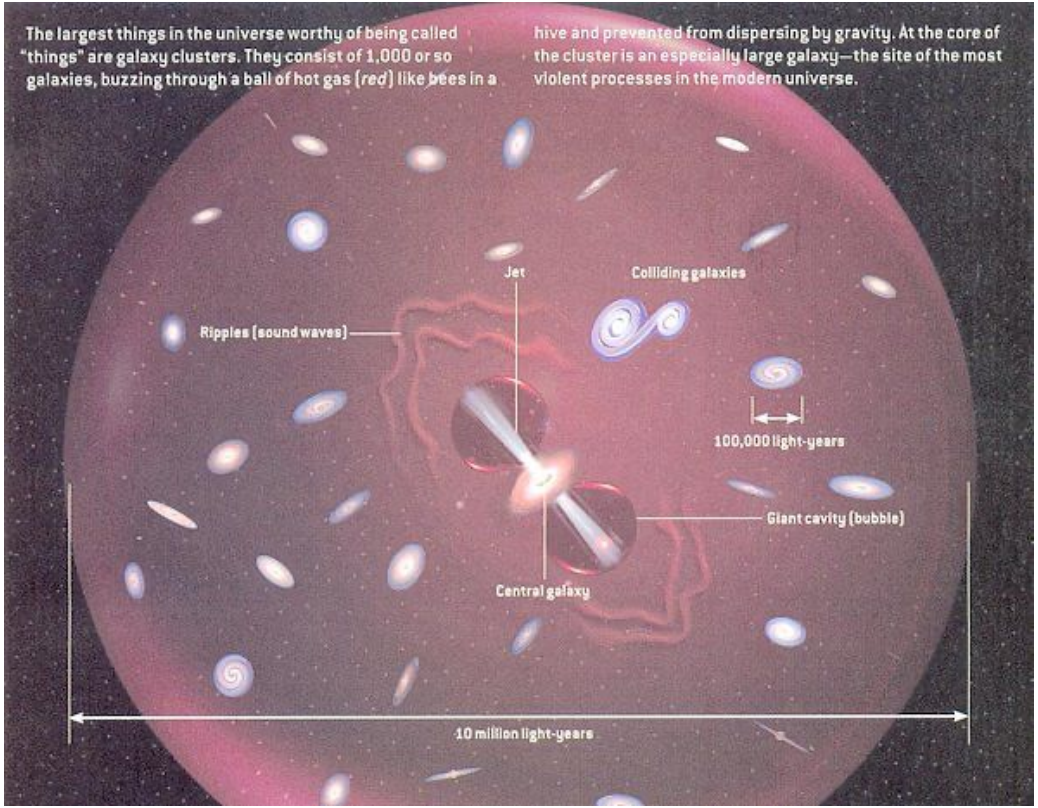
In a closed system, total energy is conserved. Energy can be converted from potential energy to kinetic energy and vice versa.

$$\frac{1}{2}mv^2 = mgh$$



Materials

- Two clear beakers or bowls
- Hot plate or access to a microwave
- Food coloring
- Marble track with a loop
- Marble



Questions?

Checklist of equipment:

- Wine glass
- Balloon
- Balloon pump
- Beakers filled with water
- Hot plate
- Marble track
- Marble
- Copies of each lesson