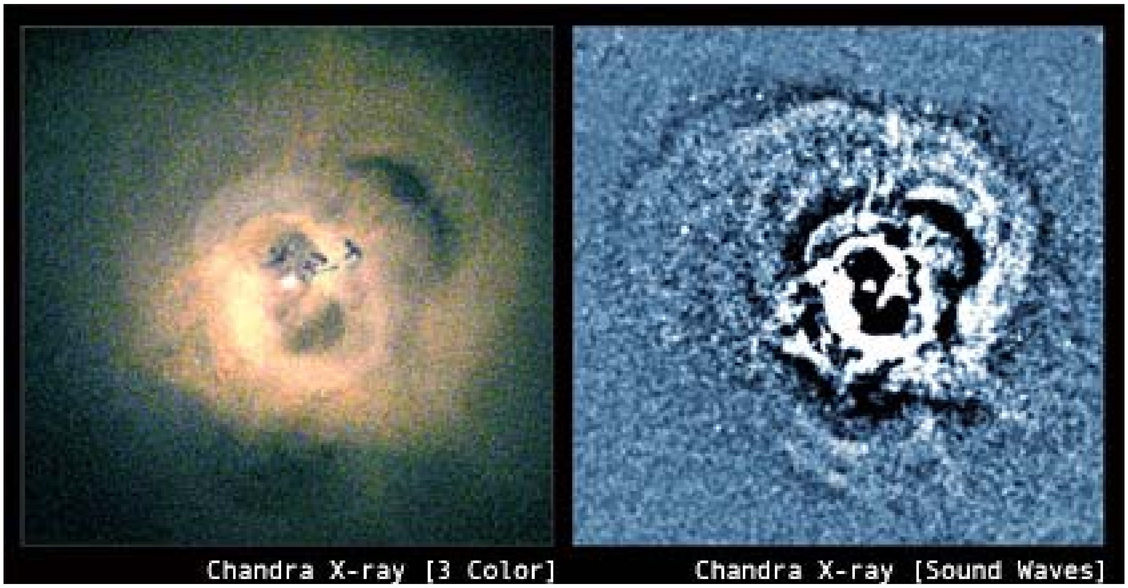

In September 2003, the Chandra Observatory took an x-ray image of a massive black hole in the Perseus Galaxy Cluster located 250 million light years from Earth. Although it could not see the black hole, it did detect the x-ray light from the million-degree gas in the core of the cluster. Instead of a featureless blob, the scientists detected a series of partial concentric rings which they interpreted as sound waves rushing out from the vicinity of the black hole as it swallowed gas in a series of explosions. The image above left shows the x-ray image, and to the right, an enhanced version that reveals the details more clearly.

Problem 1 - The image has a physical width of 350,000 light years. Using a millimeter ruler, what is the scale of the image in light years/millimeter?

Problem 2 - Examine the image on the right very carefully and estimate how far apart the consecutive crests of the sound wave are in millimeters. What is the wave length of the sound wave in light years?

Problem 3 - The wavelength of middle-C on a piano is 1.3 meters. If 1 light year = 9.5×10^{15} meters, and if 1 octave represents a change by a factor of 1/2 change in wavelength, how many octaves below middle-C is the sound wave detected by Chandra?

Problem 1 - The image has a physical width of 350,000 light years. Using a millimeter ruler, what is the scale of the image in light years/millimeter?

Answer: The width is approximately 70 millimeters wide, so the scale is 350,000 light years / 70 millimeters = **5,000 light years/millimeter**.

Problem 2 - Examine the image on the right very carefully and estimate how far apart the consecutive crests of the sound wave are in millimeters. What is the wave length of the sound wave in light years?

Answer: Depending on where the student makes the measurement, such as the set of two bright parallel features on the lower part (7-o'clock position) of the image, the separations will be about 6 millimeters, so the wavelength is 6 mm x (5,000 light years/ 1 mm) = **30,000 light years!**

Problem 3 - The wavelength of middle-C on a piano is 1.3 meters. If 1 light year = 9.5 x 10^{15} meters, and if 1 octave represents a change by a factor of 1/2 change in wavelength ,how many octaves below middle-C is the sound wave detected by Chandra?

Answer: The sound wave has a wavelength of 30,000 light years x (9.5 x 10^{15} meters / 1 light year) = 2.9 x 10^{20} meters. Octaves are determined in terms of powers of two changes in sound waves so that a wavelength change from 32 meters to 16 meters = 1/2, from 32 meters to 8 meters = 1/2 x 1/2 = 1/4 or 2^{-2}, and so on. Middle-C has a wavelength of 1.3 meters, so the Perseus Cluster sound wave differs from middle-C by a factor of 2.9 x 10^{20} meters /1.3 meters = 2.2 x 10^{20} times. We have to find N such that 2^N = 2.2 x 10^{20} . Using a calculator and repetitive multiplications (or visit the power-of-two table at http://web.njit.edu/~walsh/powers/) we get the table below:

N	factor
10	1,024
30	1.07 x 10^{9}
40	1.1 x 10^{12}
57	1.4 x 10^{17}
68	2.9 x 10^{20}

So the answer is approximately **68 octaves below middle-C**.

Note to Teacher: A tremendous amount of energy is needed to generate the cavities, as much as the combined energy from 100 million supernovae. For more information, visit the Chandra web page at http://chandra.harvard.edu/press/03_releases/press_090903.html