The most distant galaxy cluster yet has been discovered by combining data from NASA's Chandra X-ray Observatory and optical and infrared telescopes. The cluster is located about 10.2 billion light years away, and is observed as it was when the Universe was only about a quarter of its present age. The galaxy cluster, known as JKCS041, beats the previous record holder by about a billion light years. Galaxy clusters are the largest gravitationally bound objects in the Universe.

JKCS041 was originally detected in 2006 in a survey from the United Kingdom Infrared Telescope (UKIRT). The Chandra data were the final - but crucial - piece of evidence that showed JKCS041 was, indeed, a genuine galaxy cluster. Clusters of galaxies have such strong gravitational fields that they can serve as a bottle for very high temperature gas. These gases often emit x-ray light that can be detected by observatories such as Chandra. The discovery of such a high-temperature gas between the galaxies in JKCS041 supports the original idea that the galaxies seen in that direction are, in fact, members of a cluster. From the X-ray information, astronomers can also measure the total mass of the entire cluster that is responsible for creating the gravitational field holding the gas in place.

**Problem 1** - The Chandra satellite detected x-rays coming from the region of the sky containing the galaxy cluster JKS041. The electrons in the gas are emitting the X-rays, and colliding at high speed with the protons in the gas. The energy of the x-rays at the time they were emitted by the hot gas was 21,400 electron Volts (eV). This energy is shared equally between the electrons and protons. The speed of a proton is related to its kinetic energy by $E = 1/2mV^2$ where E is the energy in Joules, V is the proton speed in meters/sec, and m is the mass of a proton ($m = 1.7 \times 10^{-27}$ kg). About how fast are the protons moving? (Note: 1 eV = $1.6 \times 10^{-19}$ Joules)

**Problem 2** -The escape velocity (in km/s) from a body is given by $V = 0.17 (M/R)^{1/2}$ where M is the mass in multiples of the mass of our sun, and R is the average distance, in light years, between the body and the gas particle. Example, for the Milky Way, R = 50,000 light years and M = 300 billion so V = 420 km/sec. Compared to the sun, about how much mass do you need to confine the gas cloud observed by Chandra, if the cluster of galaxies has a radius of about 1 million light years A) in units of the sun's mass? B) In terms of the number of Milky Way galaxies where 1 Milky Way is about $2 \times 10^{12}$ solar masses?

**Problem 1** - The Chandra satellite detected x-rays coming from the region of the sky containing the galaxy cluster JKS041. The electrons in the gas are emitting the X-rays, and colliding at high speed with the protons in the gas. The energy of the x-rays at the time they were emitted by the hot gas was 21,400 electron Volts (eV). This energy is shared equally between the electrons and protons. The speed of a proton is related to its kinetic energy by $E = 1/2mV^2$ where E is the energy in Joules, V is the proton speed in meters/sec, and m is the mass of a proton ($m = 1.7 \times 10^{-27}$ kg). About how fast are the protons moving that are producing the X-ray light seen by Chandra? (Note: 1 eV = $1.6 \times 10^{-19}$ Joules)

Answer: The information given in the problem is that:

The x-ray energy is 21,400 eV
1 eV = $1.6 \times 10^{-19}$ Joules of energy
The electrons carry ½ of the x-ray energy
The protons carry ½ of the x-ray energy
The mass of a proton is $1.7 \times 10^{-27}$ kilograms

The formula requires the energy, E, in units of Joules, so we first have to convert 21,400 eV to Joules. E = 21,400 eV x ($1.6 \times 10^{-19}$ Joules /1 eV)
= $3.4 \times 10^{-15}$ Joules.
This is the total energy, so protons only carry half of this so that E = **$1.7 \times 10^{-15}$ Joules**

Next, we use the formula $E = 1/2mV^2$ and solve for V to get $V = (2E/m)^{1/2}$ and substitute the known values for m and E to get $V = (2 \times 1.7 \times 10^{-15} \text{ Joules}/ 1.7 \times 10^{-27} \text{ kg})^{1/2}$ = **1,400,000 m/sec or 1,400 km/s.**

**Problem 2** -The escape velocity (in km/s) from a body is given by $V = 0.17 (M/R)^{1/2}$ where M is the mass in multiples of the mass of our sun, and R is the average distance, in light years, between the body and the gas particle. Example, for the Milky Way, R = 50,000 light years and M = 300 billion so V = 420 km/sec. Compared to the sun, about how much mass do you need to confine the gas cloud observed by Chandra, if the cluster of galaxies has a radius of about 1 million light years, A) in units of the sun's mass? B) In terms of the number of Milky Way galaxies where 1 Milky Way is about $2 \times 10^{12}$ solar masses?

Answer: Solve the stated equation for M to get $M = R (V/0.17)^2$. For R = 1 million light years and V = 1,400 km/sec, then A) **M = 70 trillion suns** and B) N = 70 trillion suns x (1 Milky Way/2 trillion suns) so this is about **35 Milky Ways**. Note, some of this mass is actually in the 16 large galaxies that make up the cluster. Some of it is in the hot cloud of x-ray emitting gas, and some of it may be in Dark Matter.

**Note: For more information about this discovery, read the Chandra Press release at: http://www.nasa.gov/mission_pages/chandra/news/09-086.html**

**According to the research paper by S. Andreon, B. Maughan, G. Trinchieri, and J. Kirk "JKCS041: a color-detected galaxy cluster at z=1.9 with deep potential well as confirmed by x-ray data" published in the journal Astronomy and Astrophysics, October 2009, the estimated mass based on careful modeling of the data indicated a range between 30 trillion and 670 trillion suns.**