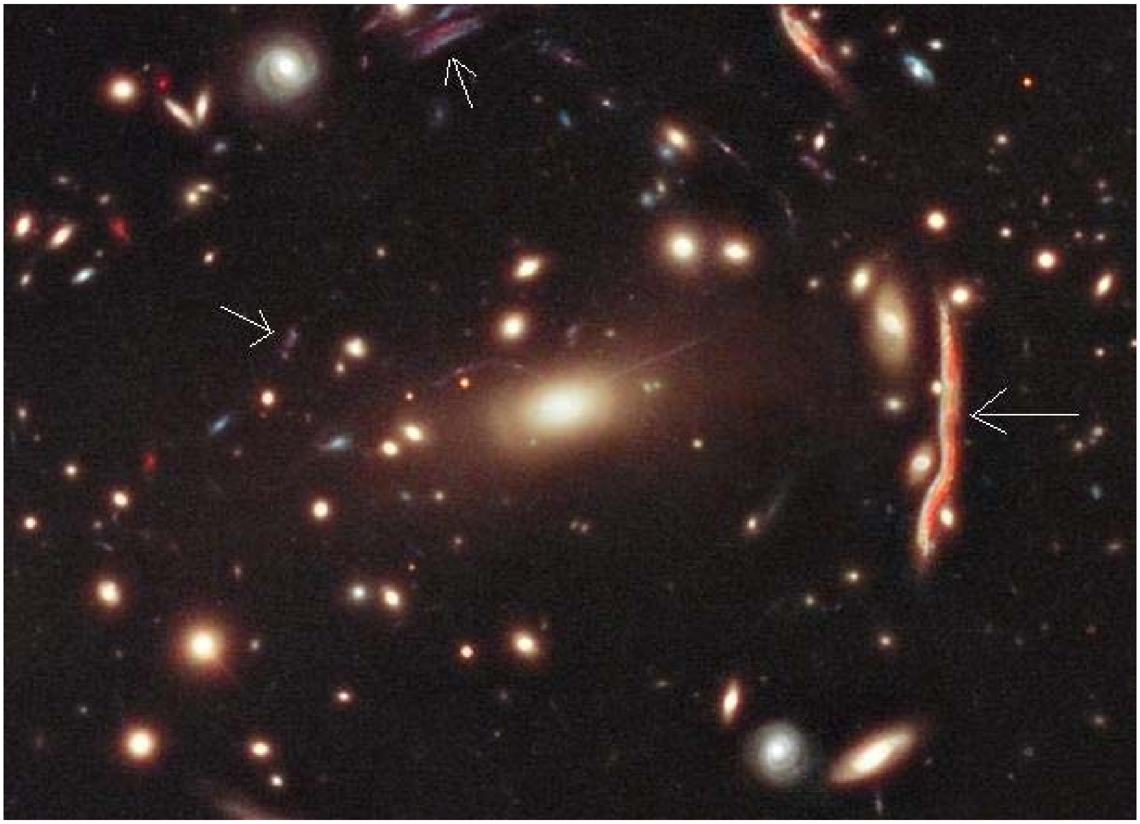
Mapping Dark Matter in a Distant Cluster



Decades after its discovery, astronomers still do not know the nature of dark matter; a form of 'matter' unlike anything familiar in every-day life to humans. It is commonly found mixed with ordinary matter inside great clusters of galaxies, however, there is often ten times more of it than luminous matter in stars. A detailed study of galaxy clusters such as MACS J1206.2 shown in the Hubble Telescope image above now shows how much dark matter can exist, and how it is spread through out such clusters. This cluster is located 4.5 billion light years from our Milky Way. It contains over 100 individual galaxies.

When light passes through a strong gravitational field it is bent. This causes the image of the source to become distorted. Astronomers have counted in the cluster image a total of 47 'ghost' images from 12 background galaxies behind this massive cluster. A few of these images is shown by the arrows above. A careful study of the number and shapes of these images lets astronomers estimate the total mass of the cluster inside spheres of different radii centered on the massive galaxy at the center of the cluster. They found that inside a radius of 515,000 light years the total mass is 1.3×10^{14} Msun; inside 312,000 light years the total mass is about 8.0×10^{13} Msun. Only about 10% of the total mass is in the form of stars and galaxies. (Note: The Milky Way has a mass of about 5.0×10^{11} Msun)

Problem 1 – From the mass data within the two radii, and comparing the density of matter found within the two concentric volumes, is the dark matter uniformly mixed within each cubic light year of the cluster's volume?

http://www.nasa.gov/mission_pages/hubble/science/dark-matter-survey.html
Ambitious Hubble Survey Obtaining New Dark Matter Census
Oct 13, 2011

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Answer: To determine whether dark matter is uniformly distributed in space, we can compare the average density of the total mass inside the first volume, with the total mass found within the shell of the second sphere.

Inner sphere:

Volume = $4/3\ \pi\ (312{,}000\ \text{ly})^3 = 1.3\text{x}10^{17}\ \text{ly}^3$.

Mass = 1.3×10^{14} Msun

Density = Mass/Volume
= $(8.0 \times 10^{13}\ \text{Msun}) / (1.3\text{x}10^{17}\ \text{ly}^3)$
= **$0.00062\ \text{Msun/ ly}^3$**

Outer shell between 515,000 and 312,000 light years

V = $4/3\ \pi\ (515{,}000)^3 - 4/3\ \pi\ (312{,}000)^3 = 4.4 \times 10^{17}\ \text{ly}^3$

The difference in mass residing in this shell volume is
M = 13×10^{13} Msun – 8.0×10^{13} Msun = 5×10^{13} Msun.

So the density of mass in this outer shell is just
D = 5.0×10^{13} Msun / 4.4×10^{17} Ly^3
= **$0.00011\ \text{Msun/Ly}^3$**.

From this we see that there is about 6 times more mass in the core volume than in the shell volume, so dark matter is not evenly spread through out every volume of space within the cluster.