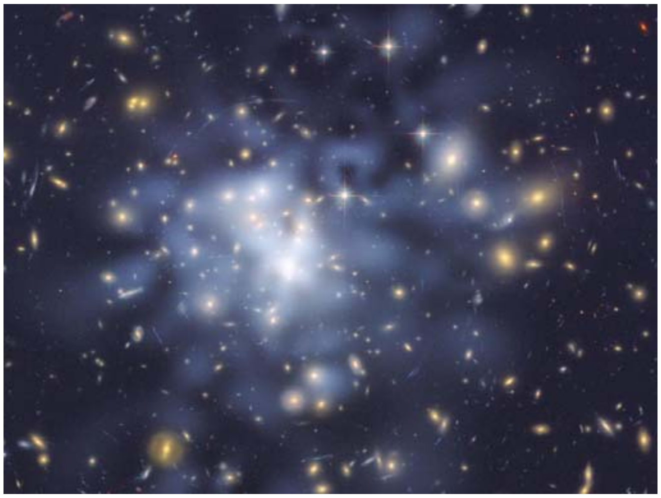
Hubble Detects More Dark Matter



This NASA Hubble Space Telescope image shows the distribution of dark matter in the center of the giant galaxy cluster Abell 1689. This cluster contains about 1,000 galaxies and trillions of stars, and is located 2.2 billion light-years from Earth.

Dark matter is an invisible form of matter that accounts for most of the universe's mass. Hubble cannot see the dark matter directly, but used the distorted images of background galaxies to infer its location.

Astronomers used the observed positions of 135 distorted images of 42 background galaxies to calculate the location and amount of dark matter in the cluster. They superimposed a map of these inferred dark matter concentrations, tinted blue, on an image of the cluster taken by Hubble's Advanced Camera for Surveys. If the cluster's gravity came only from the visible galaxies, the galaxy image distortions would be much weaker, and the corresponding area in the image above would be black. The map reveals that the densest concentration of dark matter is in the cluster's core.

Problem 1 - The escape speed of a body located R meters from a second body with a mass of M kilograms can be given by the basic 'escape velocity' equation:

$$V = \sqrt{\frac{2GM}{R}}$$

where the constant of gravity given by G = 6.66 x 10^{-11}. We can re-write this more conveniently for a cluster of N galaxies each with an average mass of 10 billion stars, and an average star mass of 2 x 10^{30} kg, and a cluster radius of R light years (1 light year = 9.4 x 10^{15} meters)

$$V = 17,000\sqrt{\frac{N}{R}} \quad \text{km/sec}$$

Show that the second equation is related to the first one as indicated.

Problem 2 - An astronomer counts the galaxies in two clusters and measures the average radius of each galaxy cluster. The astronomer also measures the average speeds of the galaxies in each cluster and finds that for Cluster A: R= 10 million, N= 1000, V= 300 km/s, and for Cluster B: R= 5 million light years, N= 350, V= 140 km/s. For which cluster does the measured average speed not match the expected speed based on the visible, countable, masses found in the galaxies?

Problem 3 - How many extra 'invisible' galaxies would the discrepant cluster have to have in order for the mass of the cluster to be consistent with the observed speeds of its visible galaxies? (This is the 'dark matter' problem, originally called the 'missing mass' problem, and indicates that extra gravitating mass is present that is not in the form of ordinary stars and gas within the visible galaxies.)

Problem 1 - Answer: The escape speed of a body located R meters from a second body with a mass of M kilograms can be given by the basic 'escape velocity' equation:

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$$V = \sqrt{\frac{2(6.66x10^{-11})(N)(10billion)(2x10^{30})}{9.4x10^{15}(R)}} \quad \text{so} \quad V = 17,000,000\sqrt{\frac{N}{R}} \text{ meters/sec}$$

And so in kilometers/sec we have:

$$V = 17,000\sqrt{\frac{N}{R}} \text{ km/sec}$$

Problem 2 - An astronomer counts the galaxies in two clusters and measures the average radius of each galaxy cluster. The astronomer also measures the average speeds of the galaxies in each cluster and finds that for Cluster A: R= 10 million, N= 1000, V= 300 km/s, and for Cluster B: R= 5 million light years, N= 350, V= 140 km/s. For which cluster does the measured average speed not match the expected speed based on the visible, countable, masses found in the galaxies?

Answer: Cluster A: V(predicted) = 17,000 $(1000/10 \text{ million})^{1/2}$ = 170 km/s

Cluster B: V(predicted) = 17,000 $(350/5 \text{ million})^{1/2}$ = 140 km/s

Although the average measured speed of the galaxies in Cluster B are identical to the predicted speed given the size and mass of this cluster, for Cluster A, its measured galaxy speeds are much higher than the speed deduced from the clusters visible galaxies and size, so **Cluster A is the discrepant one**.

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Answer: In order to make the average speeds of the galaxies in Cluster A (300 km/s) match the expected speed for a cluster with this many visible galaxies (V=170 km/s) we have to add more mass in the form of Dark Matter.

$$300 = 17,000\sqrt{\frac{n}{10million}}$$ so n = 3114 galaxies-worth of equivalent mass. Since only N=1000 is accounted for, we need to add a **Dark Matter equivalent to about 2114 extra galaxies,** or about m(Dark) = 2114 galaxies x 10 billion stars/galaxy = 2.1 x 10^{13} stellar masses-worth of Dark Matter.