Frozen Hydrogen-Helium Snowballs for Galactic Dark Matter*

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Abstract

Most of the mass in galaxies is distributed in a halo larger than the galaxy itself, but not associated with stars or other known physical objects. Most candidates for this "dark matter" are novel fundamental particles or primordial black holes, rather than ordinary atoms. On the contrary, it is suggested here that dark matter in these extragalactic halos may comprise comet-like frozen hydrogen snowballs. If their temperature is close to that of cosmic black-body radiation (2.7K), these snowballs should be stable for long time periods. Recent observations suggest that similar hydrogen snowballs may exist in cold interstellar regions. If these snowballs can also trap helium atoms (which may be tested in cryogenic laboratory experiments), this could account for the invisible missing mass.

Gravitational Evidence for Dark Matter

There are two great mysteries in gravitation, known as "dark matter" and "dark energy." They are often confused in the public media, but in fact, they are virtually opposites. Dark matter (also known as "missing mass") refers to the unknown basis for gravitational attraction within galaxies and local clusters [1]. Dark matter could be solved by finding additional matter which is otherwise invisible in and near galaxies. In contrast, dark energy refers to the unknown basis for gravitational repulsion between very distant galactic clusters. Solving dark energy may require adjusting the equations for gravitation on the cosmological scale. The present analysis deals only with dark matter, with no implications for dark energy.

The problem of the missing mass goes back decades to observations of the orbital velocity of galactic components. It is well known from Kepler's 3rd law that the orbital period T is proportional to the 3/2 power of the orbital radius R:

$$T^2 = 4\pi^2 R^3/(GM), \tag{1}$$

where G is the universal gravitational constant and M is the total mass inside the orbit. This allows one to estimate the mass of the sun, for example. But when this equation is applied to the Milky Way or other galaxies, it does not work properly. First, it yields a radius-dependent M(R)

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that covers regions of space where there is no visible matter. Second, the value of M is about an order of magnitude larger than the estimated mass of all the visible stars in the galaxy.

This inferred missing mass is present in a distributed region around a galaxy, and is sometimes referred to as a "dark matter halo" [2], although nothing is glowing. For example, the Milky Way is a spiral with radius R ~ 10^5 light years ~ 10^{18} km, with a mass of stars M ~ 10^{12} solar masses ~ 2×10^{42} kg [3]. In contrast, the dark matter halo seems to be a sphere with R about 10x larger, ~ 10^{19} km, and a M about 5x larger, ~ 10^{43} kg.

Alternative Explanations for Dark Matter

What could account for this discrepancy? One possibility is that Newton's laws of gravitation should be modified on the galactic scale. This is the basis for the Modified Newtonian Dynamics (MOND) theory of Milgrom [4]. This seems like a rather extreme solution, when other possibilities may still exist.

Alternatively, Newton's Laws may be correct, and the distributed mass is invisible. Proposed invisible matter might include MACHOs, massive compact halo objects such as primordial black holes or cold dark matter. Another approach consists of novel fundamental particles that interact gravitationally but not electromagnetically, such as WIMPs (weakly interacting massive particles) or sterile neutrinos. However, there is very little direct evidence for either MACHOs or WIMPs, and no solution is favored.

The simplest explanation is that dark matter consists of the same kind of matter that exists in stars, namely hydrogen and helium atoms. While nuclear fusion in stars tends to increase the helium concentration, about 90% of the nuclei are hydrogen (almost all protons), and about 9% are helium (mostly He-4). The rest of the atoms total less than 1%, and can be ignored here.

So let us first imagine a dilute gaseous mixture of H_2 and He on the galactic scale, which would absorb light in characteristic spectroscopic lines for H and He. These spectral lines are not seen, which may be the primary reason that this explanation was dismissed quite early. Furthermore, detailed modeling of the cosmic microwave background (CMB) following the big bang has suggested that most of the primordial mass should *not* be conventional atoms. Most of the astrophysics community has abandoned the concept that conventional matter could account for dark matter.

Hydrogen Snowballs

Alternatively, consider that these H and He atoms are frozen into a large number of small solid bodies, which might form by cohesion and collision, rather than by gravitation. This would *not* show strong spectroscopic lines, and would not radiate electromagnetically, and thus would be virtually invisible. Note that H_2 freezes at 14K, but He remains a liquid with a relatively high vapor pressure down to T=0.

So how cold is this region near galaxies but far from stars? Since distant starlight produces little heating, it is believed that the temperature is limited by the cosmic black body microwave radiation at T = 2.7K. Objects that interact with this microwave radiation would be expected to approach the same temperature. Note that the vapor pressure of solid H_2 at this temperature is extremely small, ~ 10^{-14} atm, so that any solid H_2 body at this temperature is likely to exist for a very long time, as well as capturing any H atoms that happen to impinge on it from the vacuum.

The temperature near the sun or other stars is much warmer, and would likely cause an object of this type to melt quickly, depending on its size. But an object the size of a comet, ~ 1 km, might last a fairly long time. Interestingly, an object on this scale entered the solar system in recent years, named "Oumuamua". A recent paper [5] has noted that the path of this object deviates significantly from a ballistic trajectory, and has suggested that this deviation may be attributed to asymmetric surface boiloff from a solid hydrogen object.

It was also suggested decades ago that solid hydrogen might account for dark matter in galaxies. This article [6] does not seem to have been cited since then. But a simple rough calculation shows that this may be at least plausible.

Consider a 1-km solid hydrogen sphere. Taking a density of 86 kg/m^3, the total mass would be ~ 4 x 10^{10} kg. The entire mass of the Milky Way halo could be constructed from ~ 10^{32} of these giant H_2 snowballs. This seems like an enormous number, but given the very large volume, they would have an average spacing ~ 10^8 km. Such objects would have negligible gravitational interactions between them, would collide very rarely, and would be very difficult to detect.

But the real problem with this approach is that helium is much harder to condense than hydrogen, or anything else. Indeed, the equilibrium vapor pressure of He atoms from liquid He at 2.7K is about 0.16 atm, which is enormous. Uncondensed He gas will show spectroscopic absorption. But if a mechanism can be found to trap most He atoms inside these H_2 snowballs, then that would make the entire concept far more consistent with observations.

Helium Trapping

Although the adhesion of He atoms to other He atoms is very weak, a He atom will adhere much more strongly to any other surface. For example, it is known that a monolayer of He will adhere on a surface of frozen H_2. Can a frozen H_2 snowball provide enough surfaces (including internal surfaces) to trap a substantial portion of the 9% He atoms that may be present?

Consider that a frozen H_2 snowball may initially form by condensation from a combined H_2-He gas. As a new H_2 surface forms, a monolayer of He atoms may adhere to the surface, and then get coated by more H atoms, thus sealing in some of the He atoms. This is not unlike what is known to happen, for example, in sputter deposition of metallic atoms in a dilute Ar atmosphere. A significant fraction of Ar atoms are trapped in the metallic film, even though Ar is a noble gas that does not combine chemically with metal atoms.

The degree of He cryogenic trapping of He in frozen H_2 does not seem to have been evaluated in the literature, but this information could easily be investigated in a small-scale laboratory experiment [7]. Consider a vacuum chamber cooled to 2.7K, where controlled quantities of H_2 and He gas may enter the chamber in appropriate ratios. Some of this may freeze on the walls, and the remainder pumped away. This can be repeated multiple times. At the end, the chamber can be heated up, and the atomic content of the frozen gases measured. How much helium is found trapped in the frozen deposits?

Based on these results, a model can be derived which could be scaled to sizes ~ 1 km corresponding to the proposed galactic H_2/He snowballs. This might show, for example, that most of the He would be trapped inside these objects, permitting only a small fraction to remain as He gas that would leave a spectroscopic signature.

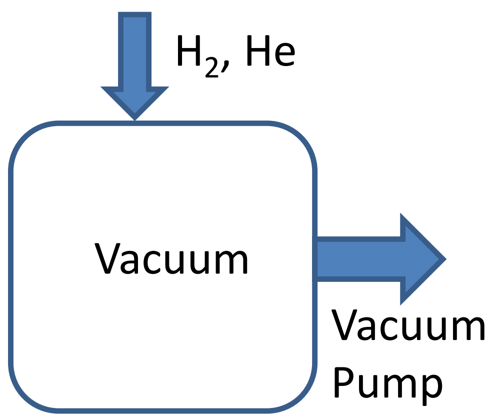

Fig. 1. Configuration for proposed cryogenic laboratory experiment, in which He trapping in frozen H_2 layers may be evaluated.

Conclusions

Conventional models of galaxy formation and composition appear to be incomplete. It is proposed here that galaxies are indeed composed mostly of star-matter (H and He), but that most of this in frozen comet-like objects ~ 1 km in size, which surround the visible galaxies, rather than in stars or interstellar gas. Cryogenic laboratory experiments could verify that most He atoms could be trapped inside frozen H_2 snowballs at T=2.7K.

References

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